THE UNIVERSITY OF TEXAS BULLETIN
No. 3232: August 22, 1932

THE GEOLOGY OF TEXAS

Volume I
Stratigraphy

By

E. H. SELLARDS, W. S. ADKINS, AND F. B. PLUMMER

Bureau of Economic Geology
E. H. Sellards, Director

Tenth Printing 2012

PUBLISHED BY
THE UNIVERSITY OF TEXAS
AUSTIN

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PUBLISHED BY THE UNIVERSITY FOUR TIMES A MONTH AND ENTERED AS SECOND-CLASS MATTER AT THE POSTOFFICE AT AUSTIN, TEXAS, UNDER THE ACT OF AUGUST 24, 1912

The benefits of education and of useful knowledge, generally diffused through a community, are essential to the preservation of a free government.

Sam Houston

Cultivated mind is the guardian genius of Democracy, and while guided and controlled by virtue, the noblest attribute of man. It is the only dictator that freemen acknowledge, and the only security which freemen desire.

Mirabeau B. Lamar

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XI. Geologic map of Texas, scale 1:2,000,000 In pocket

PREFACE

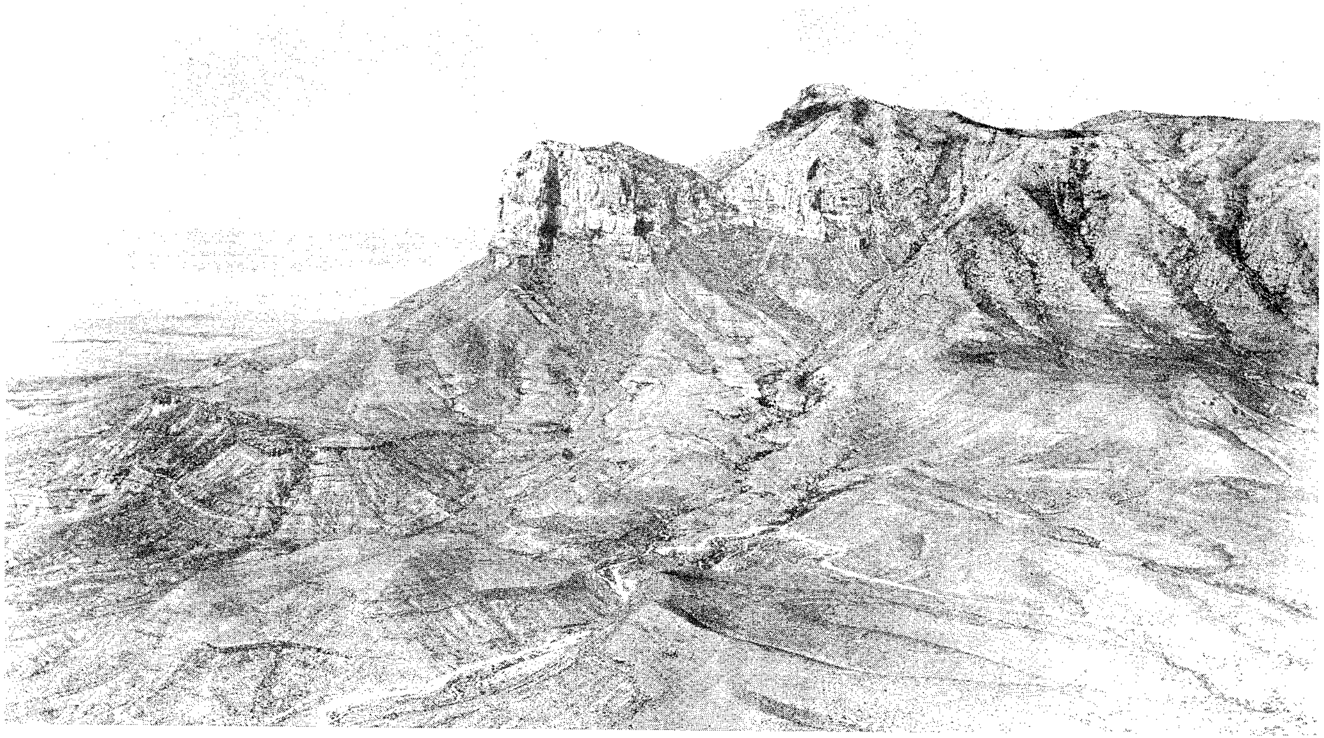
In 1916 the Bureau of Economic Geology issued The University of Texas Bulletin 44, Review of the Geology of Texas, by J. A. Udden, Emil Böse, and C. L. Baker. This publication, accompanied by a geologic map of the state, printed in 1916 and reprinted with some revision in 1919, served a very important purpose in distributing information on the geology of Texas. The present publication, like its predecessor, is written to serve as a general compendium on Texas geology in which is given a generalized account of the geology of the state.

In a publication of this kind the authors become indebted to so many persons and sources of information that it is impossible to make full acknowledgment. A bibliography has been included and the sources of information, in so far as practicable, have been indicated. Partial reference to the literature is given in the text and footnotes. More complete reference will be found under appropriate headings in the subject index which follows the bibliography. Particular acknowledgment is made for the use of manuscripts in advance of publication kindly contributed by several authors as indicated in the text.

The report is written to accompany the new geologic map of the state on the scale 1:500,000 prepared by the United States Geological Survey in coöperation with the Bureau of Economic Geology and other agencies in the state. A smaller map, scale 1:2,000,000, adapted from the larger map, is included with this volume.

The date of publication originally assigned to The University of Texas Bulletin No. 3232 was August, 1932, and this date, accordingly, appears on the title page. However, owing to various delays, printing was not completed and the publication distributed until July, 1933. The geologic map, likewise, was submittted to the engraver July, 1933.

E. H. Sellards, *Director*,
Bureau of Economic Geology.



Southern end of Guadalupe Mountains, Texas, showing Guadalupe Point and El Capitan Peak. Capitan limestone forming the crest of the mountains; Delaware Mountain formation in the foreground. Aerial photo by Thomas F. Fortson, Inc., Dallas, Texas.

THE GEOLOGY OF TEXAS

Volume I
Stratigraphy

By

E. H. SELLARDS, W. S. ADKINS, AND F. B. PLUMMER

Part 1

THE PRE-PALEOZOIC AND PALEOZOIC SYSTEMS IN TEXAS

E. H. SELLARDS

INTRODUCTION

EARLY EXPLORATIONS AND SURVEYS

Geographic and geologic records in Texas begin with the first explorations by the Spanish. In 1520, Pineda coasted from Florida to Vera Cruz and back again and mapped the Gulf coast. Fourteen years later Cabeza de Vaca, after being shipwrecked near Galveston, made a remarkable journey across southern Texas and into Mexico.[1] After another seven years Coronado came into the Texas Panhandle in his search for the seven cities of Cibola.[2] Spanish explorations continued in search of gold and for the defense and protection of Spanish claims. An expedition under De Leon, sent out in 1687, to locate Fort Saint Louis resulted in the mapping of the fords of the rivers and good camping places which later became settlements. The French also shared in the explorations of the country. Saint Denis was sent out by the Governor of Louisiana in 1713 to open up trade with northern Mexico.[3] The cession of Louisiana to Spain

[1]De Vaca's account of his journey, edited by Frederick W. Hodge, is printed in Spanish Explorers in the Southern States, New York, 1907.

[2]Bolton and Marshall, The Colonization of North America, New York, 1921.

Donoghue, David, The Route of the Coronado Expedition in Texas, Southwestern Historical Quarterly, vol. 32, pp. 181–192, 1929.

[3]It will not be possible to mention here more than a few of the many exploratory expeditions into the Texas region. A few references to publications relating to explorations are included in the bibliography. For a more complete reference to explorations in Texas, the reader may consult the following: The Spanish Southwest, 1542–1794, An Annotated Bibliography by Henry R. Wagner, Berkeley, 1924; and Descriptive List of Maps of the Spanish Possessions Within the Present Limits of the United States, 1502–1820, (Woodbury Lowery collection) by Philip Lee Phillips, Government Printing Office, Washington, D. C., 1912.

Probably the first reference to oil in the United States is contained in Spanish Explorers of the Southern United States in the Narrative of the Expedition of Hernando de Soto, p. 263. This observation of an oil scum on the Gulf waters was made in 1543.

Issued July, 1933.

changed somewhat the territory of Spanish interests and led to a series of explorations along the coast and the resultant mapping of harbors and islands. An early map, showing among other things the topographic features of the Colorado River region, was drawn by Nicolas de Lafora, in 1771, after his return from an inspection of the frontiers of New Spain made by the Marquis de Rubí.[4]

Among the earliest published maps touching on the geographic and physical conditions of Texas is one prepared under direction of the Spanish government by the great explorer, traveler, and geologist, Baron von Humboldt. During five years, 1799–1804, in which Humboldt was in the employ of Spain, he visited Spanish America and, although apparently not actually coming into Texas, collected information on all parts of the Spanish provinces and made a map which is indefinite as to Texas, but is nevertheless of value as indicating the extent to which the region was known at that time.[5]

The close of the eighteenth and the early years of the nineteenth centuries witnessed the first American explorations in Texas. Philip Nolan published a description of Texas and a topographic map, issued in New Orleans near the beginning of the nineteenth century. During the years when Texas was a Republic, William Kennedy, an Englishman, visited the country and, upon returning to England, published in 1841 an extended treatise on Texas, a part of which was devoted to the geography, natural history, and topography of the region.[6] This writer gave a careful description of the geology of Texas in so far as it was known at the time, including a carefully compiled topographic map. The publication contains a description of the natural divisions of the Republic, a discussion of the natural history, a detailed description of the more settled coastal plain of Texas, and the first notice of the Cross Timbers belts in the Cretaceous.

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[4]Manuscript map. Original in Madrid, Spain; photostat copy in the Garcia Library, The University of Texas.

[5]Humboldt, Al. de, Atlas Géographique et Physique du Royaume de La Nouvelle Espagne, Paris, 1812.

[6]Kennedy, William, Texas: The Rise, Progress, and Prospects of the Republic of Texas, London, 1841. Reprinted in one volume from the second edition by The Molyneaux Craftsmen, Inc., Fort Worth, Texas, 1925.

GERMAN COLONIZATION

The most extensive and detailed of the early works on Texas geology grew out of the movement for German colonization in Texas. Among these publications were maps published by G. A. Scherpf in 1841 and by Prince Carl Solms-Braunfels in 1846. To this movement must be credited also Ferdinand Roemer's two important works, "Texas" (1849) and "Die Kreidebildungen von Texas" (1852). In these publications Roemer outlined the boundaries, topography, mineral products, botany, zoology, and literature of Texas; described the stratigraphy of "Azoic," Paleozoic, Cretaceous, Tertiary, and Quaternary rocks; described several Paleozoic species from San Saba River, many Cretaceous species, mostly from the basal Fredericksburg group at Fredericksburg, the Washita west of New Braunfels, Aquilla, and other places, and the Upper Cretaceous below New Braunfels. The general boundaries of the Tertiary, Cretaceous, and Paleozoic in central Texas are shown on Roemer's map. The more unsettled center of the state was still exposed to Indian forays; and in west Texas wandering bands of Apaches and Comanches made exploration hazardous except to well-organized parties.

EXPLORATIONS BY THE NATIONAL GOVERNMENT

About 1849 there began a period of reconnaissance and exploration by the national government. Although intended to serve chiefly military purposes, these explorations contributed also to the knowledge of geography and geology.

The first of these many military expeditions[7] to describe specifically geological features in Texas was Marcy's exploration of the Red River in 1852. The areal geology along a line running from Fort Smith, Arkansas, up Red River through Fort Washita and Fort Belknap, was written by G. G. Shumard, the paleontology by B. F. Shumard, the mineralogy by Edward Hitchcock, and a regional geographic map was made by Captain Marcy.

Major W. H. Emory's Report of the Mexican Boundary Survey (1857) described, with many details, the geology, topography, fossils, vegetation, zoology, and other features of the Rio Grande drainage basin. The areal geology was written by Arthur Schott and

[7]Briefly summarized by R. T. Hill, U. S. Geol. Surv. Bull. 45, pp. 18–27, 1887.

C. C. Parry, with contributed papers by James Hall and T. A. Conrad; Conrad and Hall described the fossils. The report contains an accurate map of western Texas and the adjoining regions.

By 1857, therefore, general sections of the Texas geological formations had been made along three roughly parallel lines: in the north, up the Red River valley (Marcy); in the center, along the Colorado and Brazos drainages (Roemer); and in the south, along the Rio Grande (Emory).

STATE AND GOVERNMENT GEOLOGIC SURVEYS

As early as 1857 an attempt was made to develop Texas resources through the establishment of a state geological survey known as the Shumard Survey. This survey terminated in 1861 and, owing to its short duration, no very definite results were obtained. However, several publications of value by B. F. Shumard, and one by G. G. Shumard, subsequently issued, resulted from work done at this time. From 1870 to 1875 a second effort was made to maintain a state geological survey, the Buckley Survey, but no very tangible results were accomplished.

A period of well-directed and well-organized investigation in Texas geology began about 1884 with the initiation of geologic work by the United States Geological Survey. This work led to the preparation of geologic and topographic maps, and the publishing of detailed geologic reports. Among important United States geological publications on Texas of this and later dates are those of Dr. R. T. Hill.

In 1888 the state initiated a third state geological survey. This survey, commonly known as the Dumble Survey, continued until 1894. Two reports of progress, four annual reports, four bulletins, and one special report on lignite, were issued by this survey. The Texas Mineral Survey, under the direction of Dr. W. B. Phillips, established in 1901, continued through 1905. Several bulletins were issued by this survey. The present state organization for investigation of Texas geology and mineral resources, the Bureau of Economic Geology, was inaugurated in 1909. Since its establishment, this Bureau has published numerous reports on the geology of the state. The extent of geologic mapping in the state by this Bureau is indicated in the sketch map on page 20. Maps made by the United States Geological Survey and other organizations are not shown on this sketch, except the state map which has been prepared in coöperation with the National Survey and the geologists and geological societies in the state.

During the past one or two decades, in connection with the development of the petroleum resources of the state, a very active period of investigation of Texas geology has been in progress, supported by private capital. These investigations, carried on by a large number of geologists, have led to some very detailed mapping of both surface and subsurface geology, and to a great development of geophysical investigations.

The accompanying bibliography will serve as a guide to those who desire to follow more closely the history of geologic investigations in Texas. (See Part 3, Bibliography and Subject Index.)

DISTRIBUTION OF LANDS AND SEAS IN GEOLOGIC TIME IN THE TEXAS REGION

In the Texas region, as elsewhere on the continents, the formations available for examination are chiefly those deposited in relatively shallow epicontinental seas, the sediments being derived from nearby lands. A first consideration of Texas stratigraphy, therefore, may very well be a view of the early continental seas and bordering lands of the Texas region. The position of both seas and lands will be found to have shifted in geologic time, and in these introductory pages no more than a very generalized account will be undertaken, the purpose being to present in review the major land and water features of the past which affect Texas stratigraphy.

Sedimentation began on the earth as soon as there were hard rocks on which the elements could act. From this very early time to the present, a great body of sediments has accumulated, a considerable part of which is available for examination and interpretation. For the oldest eras, the Archeozoic and Proterozoic, the information available is so limited that it is difficult to determine the location of land masses. In certain regions, as the Llano uplift, the Van Horn and El Paso regions, deposition is known to have occurred during a part of this time, but the location of the lands from which the sediments came is unknown.

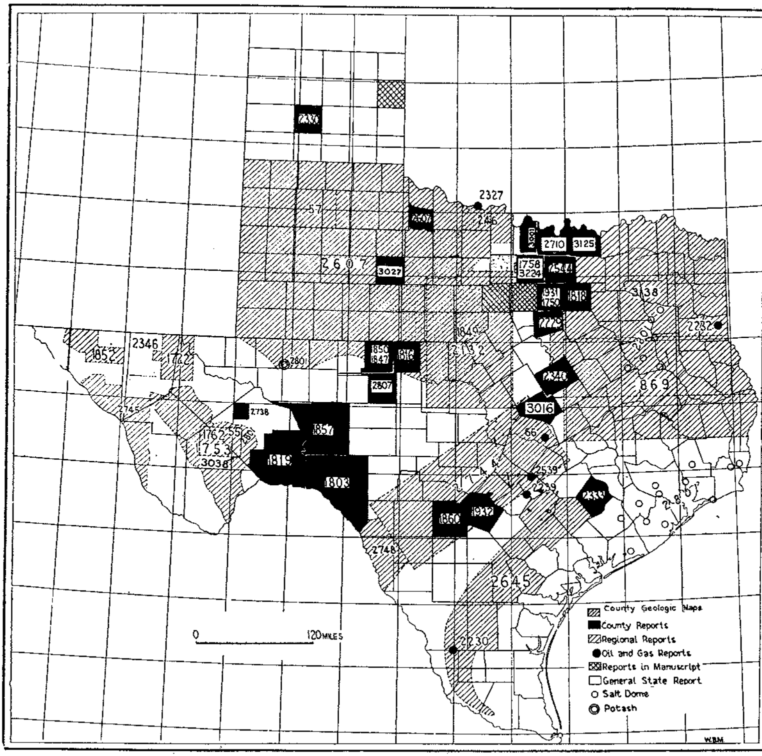

Fig. 1. Sketch map to indicate extent of geologic mapping in Texas by the Bureau of Economic Geology of The University of Texas. Entries on the map refer to bulletins of The University of Texas as follows: No. 55, Richthofenia; 57, Underground Water Supplies of the Llano Estacado; 66, Thrall Oil Field; 246, Clay and Wichita Counties; 1722, Rustler Springs Sulphur Deposits; 1750, Geology of Camp Bowie; 1753, Glass Mountains; 1758, Bridgeport, Wise County; 1762, Permo-Carboniferous Ammonoids; 1803, Val Verde County; 1816, Runnels County; 1818, Dallas County; 1819, Terrell County; 1847, Structure near Robert Lee, Coke County; 1849, Ellenburger Formation; 1850, Coke County; 1852, Diablo Plateau; 1857, Crockett County; 1860, Medina County; 1869, Geology of East Texas; 1931, Tarrant County; 1932, Bexar County; 2132, Stratigraphy of the Pennsylvanian Formations; 2229, Johnson County; 2230, Webb and Zapata Counties; 2232, Panola County; 2239, Rios Well, Luling Field; 2327, Investigations on the Red River; 2330, Potter County; 2333, Colorado County; 2340, McLennan County; 2346, University Land in Culberson County; 2539, Lytton Springs Oil Field; 2544, Denton County; 2607, The San Angelo Formation and the Geology of Foard County; 2645, The Gueydan Formation; 2710, Cooke County; 2738, Fort Stockton Quadrangle; 2744, Balcones Fault Region; 2745, Southwestern Trans-Pecos Texas; 2748, Rio Grande Valley; 2801, Salt Domes and Other Papers; 2807, Tom Green County; 3016, Bell County; 3027, Stonewall County; 3038, Glass Mountains; 3125, Grayson County; 3138, Woodbine sand; 3224, Wise County.

PALEOZOIC LANDS AND SEAS

For the Paleozoic era it is possible to determine to some extent the distribution of land and water, and the larger land masses of this time have received names and, as indicated below, can in a measure be located. The waterways, likewise, are known from the sediments that accumulated and have been preserved in them.

Llanoria.—The present coastal plain of Texas, or a part of it, is believed to have been land during much of Paleozoic time. The drainage at that time flowed westward into seas that occupied much of central Texas. Evidence of such a land area, including southern Arkansas, and a part of Louisiana and Texas, has been given by Branner (145b) and others.[8] To this land, Willis in 1907 applied the term Llano (1761a)[9], a name modified to Llanoria by Dumble (506).[10]

Proof of this land area is found in the great mass of sediments that was removed from it and accumulated in a geosyncline at its west margin. In Arkansas and Oklahoma, Paleozoic sediments were accumulated in the Ouachita geosyncline to a thickness in excess of 25,000 feet (Miser, 115, p. 7). These sediments came from the south (Branner, 145b, p. 368), indicating extensive, and at times elevated, lands in that direction. The Ouachita geosyncline extended southwestward into Texas, as shown by wells drilled near the inner margin of the Gulf Coastal Plain (Miser and Sellards, 1117). These wells entered sediments similar to those of the Arkansas-Oklahoma region. The sediments of this geosyncline could have come only from the east or southeast, as shallow Paleozoic seas lay to the west. These deposits, therefore, indicate a land mass in the coastal plain of Texas and Louisiana.

In the Marathon and Solitario regions of west Texas geosynclinal deposits are brought to the surface by uplifts. The sediments deposited in this geosyncline came from the south or southeast, prob-

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[8]The literature relating to this land mass includes the following references found in the bibliography: Branner, 145b; Chamberlin, 238; Cheney, 246, 247; Dumble, 506; Grabau, 629a; Hilgard, 721b; Miser, 1113; Miser and Sellards, 1117; Powers, 1248; Schuchert, 1382b, 1382c, 1383; Sellards, 1439, 1441: Ulrich, 1674b, 1674c: Van der Gracht, 1677; Willis, 1761a, 1761c, 1761e; Willis and Salisbury, 1761b.

[9]Numbers in the text and footnotes in parenthesis, as (1761a), refer to entries under corresponding numbers in the bibliography.

[10]The term Llanoris has also been used. However, an inquiry made in 1930 indicates preference on the part of geologists most directly concerned for the term Llanoria.

ably from a land mass in northern Mexico (Columbia). The geosyncline bordering Llanoria, trending southwest, curved westward and united with the geosyncline bordering Columbia. On this subject more exact data will doubtless accumulate as well drilling continues. Additional information on the sediments that accumulated in this geosyncline is given subsequently in the description of the Paleozoic of the Llanoria geosyncline.

While the northwestern margin of the land mass Llanoria is thus to some extent located, the southeastern extent is not so well known. Whether the land mass occupied the whole of the present Gulf region, or only a part of the Coastal Plain, or, as is probable, varied in extent in the successive Paleozoic periods, is at this time but imperfectly known. That the land mass was large and was successively re-elevated is evident from the quantity of sediments derived from it during the several Paleozoic periods.

Columbia.—A land area in northern Mexico adjacent to, and probably extending into, Texas has been described by Schuchert under the name Columbia (1382b, p. 470), and by Willis under the name Mexia (1761e, plate facing p. 301). The Marathon and Solitario basins of Texas are within a geosyncline at the north margin of this land mass. Eastward, Columbia is adjacent to, and may have been continuous with, Llanoria.

Siouxia.—The Paleozoic land area Siouxia (also written Siouis), is defined by Schuchert (1385b, p. 1224), as occupying in early Paleozoic time much of the Great Plains area, extending west to Colorado, Wyoming, and New Mexico, south into Texas, and east into Iowa. Near its western margin, mountain ranges described as the Ancestral Rockies were raised in late Paleozoic time.[11] That the land mass Siouxia supplied sediments to the Texas seas cannot at present be shown, and its extension into Texas may be questioned. On the other hand, the land areas, Llanoria and Columbia, supplied a large amount of sediments into the Texas region during Paleozoic time.

Paleozoic Seas.—The region of Paleozoic deposition in Texas was the broad depression between Llanoria on the southeast and Siouxia

[11]Among publications relating to Siouxia and the Ancestral Rockies are the following, listed in the bibliography: Lee, 978, 978a; Melton, 1087a; Schuchert, 1382b, 1383, 1385b; Ver Wiebe, 1694.

on the northwest. In early Paleozoic time, immediately adjacent to Llanoria and its westward extension, Columbia, was the narrow trough already referred to as probably extending entirely across Texas from the Ouachita region of Oklahoma-Arkansas to the Marathon-Solitario region of west Texas. This trough will be referred to as the Llanoria geosyncline. North and west of this trough was a broad depression through central Texas which Schuchert has called the Ouachita embayment (1382g, p. 181). At times the seas were probably entirely withdrawn from both the Ouachita embayment and the Llanoria geosyncline, and at other times flooded extensive areas. An inward migration of folding is recognized (Ulrich, 1674b, p. 435, 597; Cheney, 246), by which, in late Paleozoic, this depressed area was moved westward, receiving thick Pennsylvanian and Permian deposition. This broad depression to the west and north of these land masses is then the principal theater of Paleozoic deposition in Texas.

MESOZOIC LANDS AND SEAS

The Mesozoic witnessed great changes in the position of land masses in Texas. Early Mesozoic (Triassic) was a time of continental elevation in this region and no marine Triassic is known in the state. The non-marine deposits found in west Texas indicate extensive land masses at this time, to the east in Texas and to the west in New Mexico. This condition of continental elevation seems to have extended into Jurassic time since no deposits of early Jurassic age are known in the state.

Since marine deposits are not known to have been laid down in Texas during approximately the first half of the Mesozoic, it is probable that during this time the continent stood at such elevation as to exclude the sea from the Texas region. The Gulf margin of Texas, however, is so deeply buried by later deposits that the presence or absence of early Mesozoic cannot be determined. It is not impossible that early Mesozoic seas encroached on the Gulf margin but no records are at present available.

In late Jurassic time an invading sea extended northward through Mexico into Texas, the deposits from this sea now exposed at the surface being found in Hudspeth County. Whether or not a Jurassic sea also entered Texas on the Gulf margin at this time, is undetermined from lack of records.

Progressive inundation brought the seas during the Cretaceous northwards entirely across Texas. These changes of both lands and seas are more fully discussed in the chapter on Mesozoic stratigraphy. For the purpose of this introductory chapter, it is sufficient to bear in mind that at some time following the close of the Paleozoic, and probably by or before late Jurassic, a fundamental change in land distribution had occurred by which the coastal belt of Texas, which had stood relatively high through Paleozoic, was depressed and gradually became submerged by a sea encroaching from the south and southwest. As a result of this profound change of land level, drainage in the Texas region was reversed. Instead of a northwestward drainage into inland Paleozoic seas, drainage was thereafter southeastward towards the advancing Cretaceous seas. The flooding reached its maximum in early Upper Cretaceous time, largely withdrew at the close of Cretaceous, and was followed by the great Laramide revolution which brought into existence the Rocky Mountain system.

Thus the Mesozoic witnessed a complete change in the position of land masses in the Texas region. The extensive high lands of the eastern part of the state, inherited from Paleozoic time, continued into early Mesozoic, but by depression passed into the low lying coastal belt of late Mesozoic time. On the other hand, the central and western parts of the state, which had been the great theater of Paleozoic deposition, although extensively flooded in late Mesozoic, yet emerged at the close of the era as a great continental land mass. These profound changes in elevation, with the resulting reversal of drainage, give for the last half of Mesozoic and later time an entirely different theater of accumulation of sediments to that of Paleozoic time.

CENOZOIC LANDS AND SEAS

In distribution of land and seas, the Cenozoic records an approach to, and final merging into, modern conditions. The Gulf of Mexico then as now controlled drainage, and the incursions of the sea may be regarded as enlargements of the Gulf of varying extent overlapping onto the adjacent margins. In a large way the Mesozoic and Cenozoic may be looked upon as a unit development in the Texas region, recording depression to such extent as at first to lower a great land mass to submerged condition, and subsequently, in part through fluctuation but in the main through continued subsidence, to bury the land mass by sediments to a depth, at its gulfward side, of many thousand, probably more than twenty thousand feet. By reversal of drainage, much of the rock detrital that had been moved westward during Paleozoic time was returned eastward during late Mesozoic and Cenozoic time. The flow of streams and the quantity and kind of materials carried were affected by fluctuations in elevation, which will be more fully described in the chapters on Mesozoic and Cenozoic stratigraphy. Profound among these changes in elevation were those by which the present Rocky Mountains were made.

The long interval represented by the accumulation of these sediments and by the changes in land distribution witnessed likewise slow but amazing changes in organic life upon the face of the earth. The imperfectly known organisms of the Archeozic and Proterozoic were succeeded by the relatively simple, wholly marine invertebrates of the early Paleozoic, and these in turn are followed by the rich marine and land faunas and floras of the later Paleozoic. Air breathing, as distinct from water breathing; land habitat, as distinct from water habitat; the bony structure of vertebrates; and the vascular structure and seed-bearing habit of plants are among the outstanding advances of the late Paleozoic. Mesozoic time witnessed profound changes, notably in the more complete occupation of the land by reptilian faunas; the diversity of insects, and the resulting development of the flowering plants; the advent of flying reptiles and of birds; and before the close of the era the appearance of the primitive mammalian stock. The Cenozoic leads to the present through the development of a magnificent mammalian fauna; the appearance and dominance of man; and the dwarfing of this great fauna to which unhappy result man on the American as well as on the European continents has so largely contributed.

Summarizing, it may be said that for the long pre-Cambrian but little is known of land distribution, although thick sediments accumulated, now concealed except in limited exposures. In Paleozoic time a land mass giving origin to a great mass of accumulating sediments lay in east Texas, and drainage was westward into the fluctuating seas of central and west Texas. Early Mesozoic was a time of continental emergence, the entire Texas region, so far as known, being land. Drainage at this time was still westward in a part at least of east and central Texas, and was eastward from the Ancestral Rocky Mountains and other land masses. By this drainage continental Triassic deposits were accumulated in a remnant of the Paleozoic basin. By middle or late Mesozoic fundamental changes had occurred, the land to the east was depressed, the drainage reversed, and a vast region inundated by the great flooding of Cretaceous time. Cenozoic was a time of marine deposition on the fluctuating margins of the Gulf of Mexico and of continental deposition and stream terracing inland.

Such is the framework on which the stratigraphic history of Texas is built. This history is more fully given in the chapters which follow.

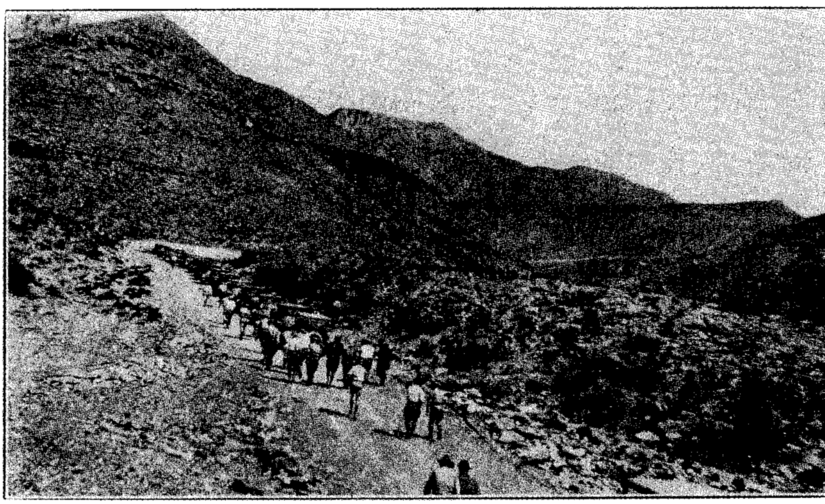

Fig. 2. A geologic excursion into the Delaware mountain region of Texas. Third Texas Field conference, 1927. Geologists of Oklahoma, New Mexico, and Texas. View at the base of Guadalupe Point. Photo by C. N. Gould.

THE PRE-CAMBRIAN SYSTEMS OF TEXAS

(ARCHEOZOIC AND PROTEROZOIC)

The oldest rocks of Texas exposed at the surface are believed to belong to either the Archeozoic or the Proterozoic era. In most parts of the world these very ancient rocks have been greatly altered from their original condition, whatever fossils they may have contained having been for the most part destroyed. Only rarely do these rocks escape such alteration. For this reason it is often difficult to separate the rocks of the Archeozoic from those of the Proterozoic or from later greatly altered rocks. There is some probability that the oldest rocks exposed in Texas are Archeozoic. However, since their age is not definitely known, they are here discussed under the indeterminate heading of pre-Cambrian.

Rocks believed to be of pre-Cambrian age are exposed in Texas in three regions, as follows: the Llano uplift, the Van Horn region, and the Franklin Mountains near El Paso. The lithology of the rocks does not afford sufficient basis for correlation of the pre-Cambrian of these several regions. For this reason the use of separate formation names is required for each of the areas, and no correlation within the pre-Cambrian is attempted. That some of the formations here referred to the pre-Cambrian may in fact be Lower Cambrian is possible. In addition to these areas of exposed rocks, pre-Cambrian is known from well drilling over parts of the state, as described in the section on underground records.

While no fossils have been found in the pre-Cambrian of Texas, except possibly some cryptozoans in the Van Horn region (King, 396b), there is, nevertheless, very good evidence that organisms were present at that time. In the sediments of the Llano uplift, graphite occurs widely, and in places is of sufficient quantity to be produced commercially. Graphite originates, in some instances at least, from carbonaceous materials by metamorphism, and its presence in the rocks may or may not be indicative of life at the time the rocks were accumulating. The iron ore of these formations, found as magnetite and hematite, may likewise be associated in origin with organic processes, although it is not impossible that these minerals have some other origin. The limestones which occur in the formations here referred to the pre-Cambrian may or may not be associated with organic processes.

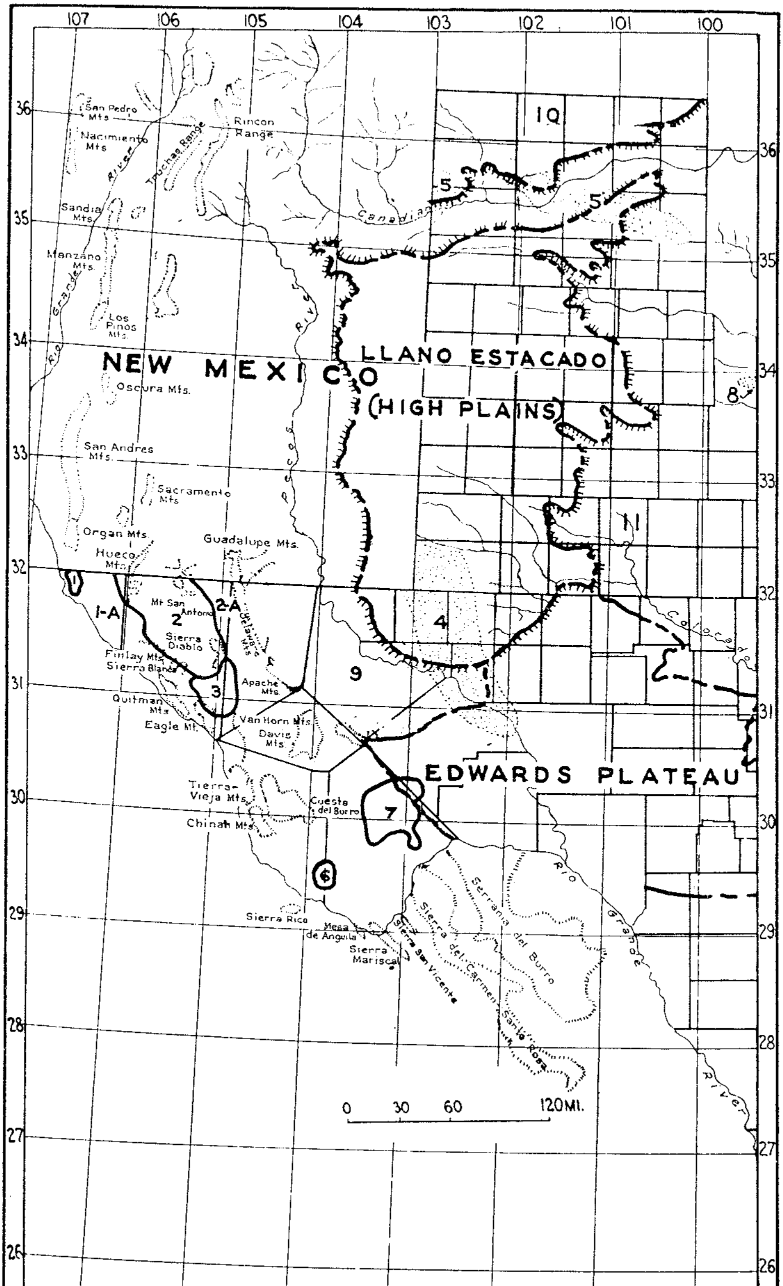

Fig. 3. Index map showing location of some of the regions in Texas west of the 100 meridian referred to in the description of formations. 1, Franklin Mountains; 1a, Hueco bolson; 2, Diablo Plateau; 2a, Salt Flat; 3, Van Horn region; 4, Pecos uplift or Central Basin Platform; 5, Amarillo uplift; 6, Solitario uplift; 7, Marathon uplift; 8, Red River uplift; 9, Toyah basin; 10, High Plains; 11, Osage Plains. The stippling indicates uplifts now concealed by later formations.

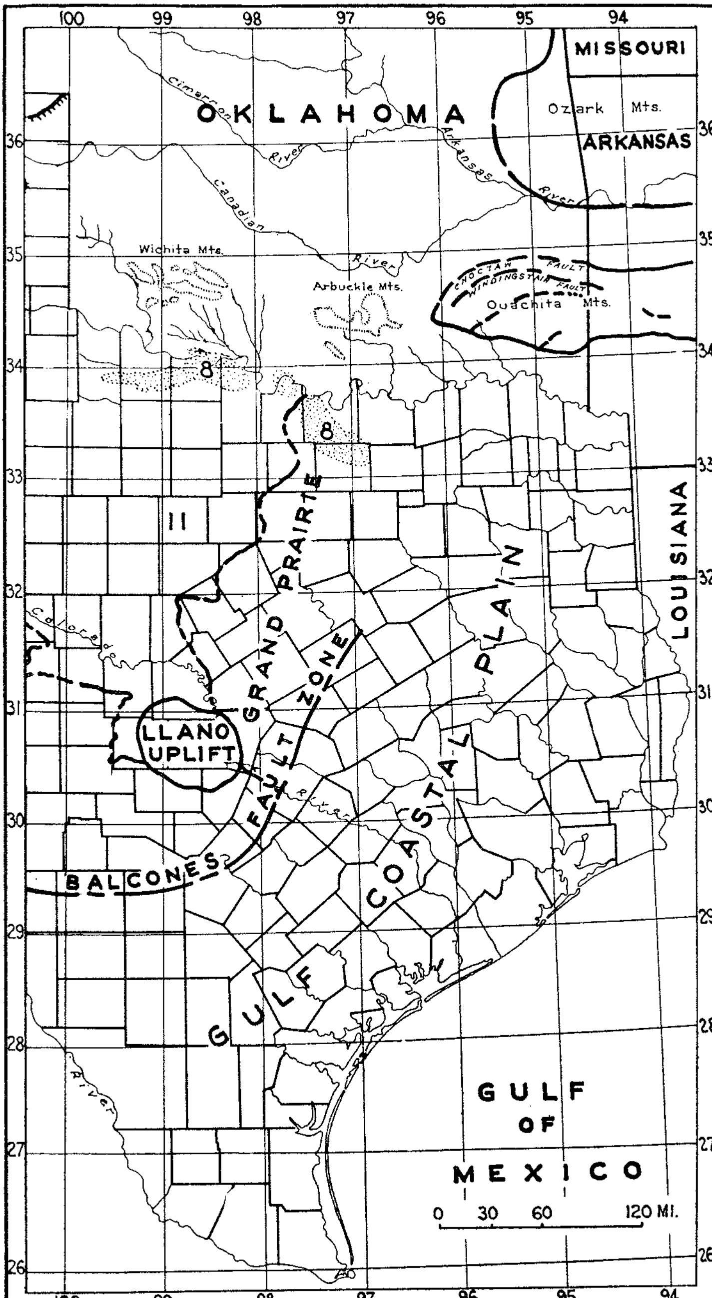

Fig. 4. Index map showing the location of some of the regions in Texas east of the 100 meridian referred to in the description of formations. Legend as in Fig. 3.

The pre-Cambrian formations recognized in surface exposures in the state are as follows:

Llano Region	Van Horn Region	El Paso Region
Granites		
Packsaddle schist	Millican formation	Rhyolite
Valley Spring gneiss	Carrizo Mountain formation	Lanoria quartzite

LLANO REGION OR UPLIFT

The Llano region in central Texas, also known as the Central Mineral region, includes all of Llano County and part of Brown, Mason, McCulloch, San Saba, Lampasas, Blanco, Gillespie, and Kimble counties (fig. 4). Structurally the region is a dome on which the pre-Cambrian, which in the adjacent region is 4,000 or 5,000 feet below sea level, is more than 1,000 feet above sea level, the total doming being 5,000 or 6,000 feet. While the area of exposed Paleozoic and pre-Paleozoic is small, the area affected by the doming is large, a region of 100 miles or more in width being affected. In this great dome the Paleozoic and pre-Paleozoic formations are seen, due to the removal of a Cretaceous blanket that formerly covered them. There is thus found in this region a window of older rock coming up through the Cretaceous.

The Llano Basin.—Although structurally a dome, topographically the area of these exposed pre-Cambrian rocks is now a basin, which may be designated as the Llano basin. This basin is the result of the erosion of the overlying formations from the crest, a rim of Paleozoic and Cretaceous rocks having been left. Projecting ridges of these later formations extend at places into the basin. A prominent ridge capped by Paleozoic, projecting from near Burnet, is known as "Backbone Ridge." Similar, although usually less conspicuous, promontories of Paleozoics project into the basin elsewhere around its margins. Within the basin itself are numerous hills capped with Paleozoic rocks representing outlying remnants of these formations which formerly extended across the dome. One of the largest of these hills in the basin in Llano County is formed by Wiley and Cedar mountains.

Cheney is of the opinion that the Central Mineral region is a part of a structurally ancient feature which he has called the Concho divide, and that the exposures of the pre-Cambrian formations have resulted from the northwestward tilting of this ancient table-land (247c).

The pre-Cambrian of this region, although now highly altered, originally included largely such sediments as sandstones, shales, and a limited amount of limestone. Into these altered sedimentary rocks, igneous rocks, chiefly acidic in character, have been intruded. These intruded rocks appear now largely as granites, although some diorite and other basic rocks are present. Some of the rocks of the pre-Cambrian series are altered by metamorphism to such an extent that it is difficult to determine their origin, whether from igneous or sedimentary materials. In the main, however, the pre-Cambrian of this area represents altered sedimentary rocks.

LLANO SERIES

To the series of altered sedimentary rocks exposed in this uplift, Walcott in 1884 applied the term Llano group (1702). This group, or series, has since been subdivided into two formations, Valley Spring gneiss and Packsaddle schist.[12] These formation names were proposed by Comstock (271), and were subsequently re-defined and applied in their present usage by Paige (1172). The rocks of this series when first described by Walcott were referred by him to the Cambrian. Subsequently, however, they were referred by Paige to the Algonkian (Proterozoic).

In the absence of fossils, which if originally present would have been largely obliterated by metamorphism, the conclusion that the series is of pre-Cambrian age rather than Cambrian rests on the fact that there is evidence, from angular unconformity, erosion, and intrusion of granites, of an extremely long interval of time between the deposition of these sediments and the deposition of the next overlying Upper Cambrian sediments. On the other hand, the assumption that the formations are not as old as Archeozoic (Archean) rests merely on inference derived from the character of the sediments, which include carbonaceous shales and some limestones. Computations of the age from the radioactive minerals, as revised by Arthur Holmes, indicate a probable early Middle pre-Cambrian age for

[12]Throughout this volume formations of a group or series, when listed in the text, are arranged in order beginning with the oldest formation or member. On the other hand, in tables, measured sections, and graphic sections, the oldest formation or member is placed at the bottom of the table or section and the youngest at the top, this being in accordance with established usage.

these minerals which are found in pegmatite veins in the granite (837a, p. 438).[13] The sediments are necessarily older than the granites, although how much older is not determined.[14] The time that has elapsed since the formation of the minerals in the pegmatite dikes as deduced by Holmes from the lead ratios in the radioactive minerals is 1100 million years (837a, p. 351).

VALLEY SPRING GNEISS

The older of these two formations in the classification proposed by Paige is prevailingly a gneiss, which for the most part is light in color, consisting of a predominance of feldspathic and quartzitic minerals. According to Paige, the gneiss originating from sedimentary rocks is with difficulty separable, and in places is inseparable, from that which has been derived from the intruded granite. Quartzites are present, representing altered sandstones. The original limestones, which were present in limited amounts, are now chiefly the calcium silicate, wollastonite. More or less schist is associated with and included in the gneiss.

The separation of this formation from the overlying Packsaddle schist is based in part on the more massive character of the gneiss, and in part upon its greater content of acidic materials. The gneiss, however, not only contains schist, but grades into the schist in such a way as to make definite separation at many localities difficult or impossible. The gneiss is exposed chiefly in the anticlines which here trend northwest. The formation is greatly intruded by granite. Stenzel, who has recently re-studied this formation, is of the opinion that the Valley Spring gneiss is igneous in origin, having been intruded into the Packsaddle schist. Under this interpretation there is but the one sedimentary formation in the pre-Cambrian of this region, the Packsaddle schist next to be described (1525c).

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[13]In this publication references to the literature in the text and footnotes, and in the subject index, include usually only the number assigned to the publication as listed in the accompanying bibliography. The full citation to the publication in question may then be obtained from the bibliography.

[14]Publications listed in the accompanying bibliography relating to the stratigraphy, structure, and minerals of the Llano series include the following: Barrell, 59; Bastin, 77; Becker, 84a; Boltwood, 138a; Buckley, 170, 173; Comstock, 271, 273, 274, 275, 276; Genth, 574; Harrod, 671; Hess, 710, 711; Hidden and Mackintosh, 715; Hidden, 716, 717, 718, 720; Hidden and Hillebrand, 719; Hidden and Warren, 721; Hill, 743; Hillebrand, 828, 829; Iddings, 868; Paige, 1170, 1171, 1172, 1173; Phillips, 1209a; Powers, 1254; Roemer, 1328, 1330, 1331; Schaller, 1367; Stenzel, 1525c; Udden, 1641a; Walcott, 1702, 1702a; B. Willis, 1761c.

Type locality: Valley Spring in Llano County; thickness undetermined.

PACKSADDLE SCHIST

The Packsaddle schist includes a great, although unmeasured, thickness of metamorphosed sediments, originally consisting chiefly of shales with smaller amounts of sandstones and limestones into which were intruded acidic and some basic igneous rocks. The original sediments, having been metamorphosed, became schists, including mica, hornblende, amphibole, and graphite schists, according to the character of the rocks from which they were derived. The sandstones were altered to gneiss or gneissoid schists, and the limestones to marble or wollastonite. Graphite now found in the schist in considerable quantity may have been derived from the organic matter of the sediments.

The schists cleave readily, the direction of cleavage being in agreement, or essentially so, with the original bedding planes. The numerous beds of limestones now changed to marble alternate with the schist and are interbedded with, or parallel to, the cleavage planes in the schist. The sandstones, now quartzitic or gneissoid, are likewise interbedded with the schists. The schists for the most part overlie the gneisses and are found in the synclines, having been removed from the crests of the anticlines except in the southeastern part of the area where exposure of the schists is general.

Type locality: Packsaddle Mountain, Llano County. This formation is extremely thick, measuring not less than several thousand feet.

GRANITE AND OTHER IGNEOUS ROCKS

The pre-Cambrian sedimentary formations have been extensively intruded by igneous rocks, the great body of these intrusives being granites. However, in addition to the granite there are smaller intrusives of more basic rocks including diorite and gabbro. The largest masses of the basic rock intrusives are in the southeastern part of the Llano Quadrangle. Probably derived from these intrusives are the amphibolites, talc, and serpentine, which are found more particularly in the Packsaddle schist. Felsite occurs to a limited extent as dikes in the schist. Paige (1171, p. 21) expresses the opinion that the gabbro-diorite group of rocks is of earlier age than the granites.

Granite intrudes the sedimentaries extensively, occurring as batholiths and as smaller masses, including innumerable dikes, sills, and pegmatites. So extensive are the granite masses that probably between one-third and one-half of the surface exposures within the area are of granite.

The granites present considerable variation, in texture from coarse to fine, and in color from pink or red to gray. The very coarse granites are for the most part red or pink owing to the large potash feldspar crystals. Between these large crystals, and making up the remainder of the rock, is quartz, biotite, and other minerals in smaller amounts. The fine-grained granites vary from pink to gray in color and from fine to medium coarse in texture. They consist of feldspar (microcline, orthoclase, and albite-orthoclase), quartz, biotite, and hornblende. An unusual rock of local occurrence is a quartz-feldspar porphyry. This porphyry is of later age than the granites and occurs as a dike, cutting both the granite and the schist. To this rock Dr. Joseph P. Iddings in 1905 applied the name llanite (1209a). The trade name in common use, however, is opaline granite, quartz phenocrysts in the rock reflecting light in such a way as to resemble opal.

STRUCTURAL CONDITIONS

Attitude of the Strata.—The pre-Cambrian strata in the Central Mineral region, both of the Valley Spring and the Packsaddle formations, dip for the most part at high angles. The rate of dip is determinable, not only from the cleavage planes in the schist, but also from the bands of marble, quartzite, wollastonite, and graphite schists. Measurements made at a number of localities indicate that dips of from 30 to 60 degrees prevail, although dips of both greater and lesser amounts occur.

Regional Structural Features.—The major structural features of the eastern part of the Llano-Burnet region have been described by Paige (1172). In the Llano Quadrangle pronounced folds in the pre-Cambrian rocks trend in a northwest-southeast direction, plunging to the southeast. These folds affect the pre-Cambrian only, not being reflected in the Paleozoic or later rocks. The folds had been truncated by erosion previous to deposition of the Paleozoics. In addition to folds of a northwest-southeast trend, the region is profoundly affected by faults which, although varying in direction, have prevailingly a northeast-southwest trend. These faults affect not only the pre-Cambrian but the Paleozoic as well, and will be more fully described in connection with the Paleozoic systems. The faults, together with the folds, bring about repetitions of the section, increasing the difficulty of estimating the thickness of the pre-Cambrian formations.

PRE-CAMBRIAN HISTORY OF THE REGION

The pre-Cambrian history of the region can in part be determined. Much of the gneisses and schists, as already indicated, is derived from a great series of sediments. That these sediments are of marine origin seems probable, as indicated by the succession of limestones, sandstones, and carbonaceous shales which they contain. Evidence from organisms, however, is wanting, fossils that may have been present having been later destroyed by metamorphism.

After the deposits had become, at least in a measure, indurated, they were extensively intruded by igneous magmas. The earlier and more limited intrusions were probably basic, giving rise on cooling to gabbro, diorites, and other basic rocks. At a later time came much larger intrusions of more acidic magmas, giving rise to the granites. Probably the latest of the intrusives is that from which the dikes of "opaline" porphyry were formed. That these granite intrusives were earlier than the overlying Paleozoic is indicated by the fact that at no place do they cut into the later rocks. Moreover, where the Cambrian rests directly upon the granite, evidence of pre-Cambrian disintegration and decay of the granite may be observed. Reworked granite likewise is found in the Cambrian sediments. The time of intrusion of the igneous rocks, therefore, is subsequent to the formation of the sedimentary series, but previous to the deposition of the overlying Cambrian. The thickness of sediments that originally accumulated was much in excess of that which now remains in this region. This is indicated by the fact that the magmas from which the granites were formed, originally rested (as evidenced by the crystalline character of the rocks) far below the surface. The sediments themselves were sufficiently intruded to undergo re-crystallization and metamorphism. During this time, possibly in connection with the intrusion of the batholiths, pronounced folding was developed, the trend of the folds being northwest-southeast.

Following the intrusion of the igneous rocks and the folding, the region was subjected to extensive erosion. During this period of erosion the uppermost rocks were removed, the folds leveled off, and the granite exposed. Upon these exposed granites and truncated folds the Cambrian sediments were deposited. Since the overlying sediments are of Upper Cambrian age, it is possible that this interval of erosion may have been largely or entirely within Cambrian time.

The history of the region up to the time of the Upper Cambrian, including deposition of sediments, extensive intrusions of igneous rocks, folding and profound erosion, is obviously one of long duration marked by complexity of events. The igneous rock, now exposed at the surface, shows by its coarsely crystalline character that for the most part it is from igneous intrusions once deeply buried under sediments which have since been removed by erosion. This period of great erosion, as well as the diastrophic activity which folded and altered the rocks, took place previous to the deposition of the overlying Upper Cambrian.

TYPICAL EXPOSURES

The locality visited by Walcott, by whom the name of the series was proposed, is on the west side of Packsaddle Mountain about 14 miles southeast of Llano. At this locality on Honey Creek are fine exposures of the Packsaddle schist. These deposits when first examined by Walcott were described by him as exhibiting at Packsaddle Mountain but little evidence of metamorphism, and were then referred to the Cambrian (1702, p. 431).

By following the public road from Honey Creek south and southeast out of the basin, several miles of Packsaddle schist are traversed, in which exposures are frequent and in which the dip in the strata varies in direction from southwest to southeast, and in steepness of dip from 30° to 80°. Although, owing to faulting and folding, the actual thickness of sediments crossed in this section cannot be determined, the exposures afford a conception of the evidently great thickness of the schist series. This road crosses an anticline in the pre-Cambrian which trends northwest-southeast and plunges to the southeast.

The Valley Spring gneiss may be seen a few miles west or southwest of Llano, where it is greatly intruded by granite, or at the type locality about 12 miles northwest of Llano. The very coarse-grained granites are typically developed in the southwestern part of the Llano Quadrangle 15 or 18 miles southwest of Llano. The fine-grained granites which are widely distributed, are extensively quarried near Llano. The porphyry (llanite) is exposed on the Llano-San Saba public road 10 miles north of Llano, at which place the road crosses a dike of this rock.

The Cambrian-pre-Cambrian contact may be well seen on Pedernales River about one mile upstream from McDougall Crossing in Blanco County, and in Burnet County near the public road about one mile east of Kingsland; also near the lead prospects on Beaver and Spring creeks, Burnet County.

VAN HORN REGION

The term Van Horn region is here used to apply to a somewhat indefinitely defined area in the vicinity of Van Horn including parts of Culberson, Hudspeth, and Jeff Davis counties. This region is southeast of the Diablo Plateau and may be regarded as the somewhat broken southeastern extension of this plateau. In the Van Horn region are included pre-Cambrian exposures in the Van Horn, Wylie, and Eagle mountains to the southeast, south, and southwest of Van Horn, and at the south margin of the Diablo Plateau west to near Finlay (region No. 3 of fig. 3, p. 28).

Structurally the Van Horn region is a dome representing the maximum uplift found in Trans-Pecos Texas. The structural conditions in this dome are complicated. The pre-Cambrian rocks were subjected to mountain-making movements in pre-Cambrian time, and doubtless were affected by the late Paleozoic mountain-making disturbances. Again in relatively recent geologic time, probably within the Cenozoic, this region was highly faulted and now includes a great series of tilted blocks. These blocks are at the margin of the great bolson or graben known as Salt Flat, which extends in a north-south direction for more than a hundred miles. At the east side of this bolson are the Guadalupe and Delaware mountains, while at the west are the Diablo Plateau and the fault blocks of the Van Horn region including Baylor, Beach, and Carrizo mountains.

The pre-Cambrian of the Van Horn region includes two formations or series, the Carrizo of Streeruwitz and the Millican, both of which represent almost entirely sedimentary rocks. That the Millican formation is probably of pre-Cambrian age was first suggested by Dumble (491). The reference of the series to the pre-Cambrian is based on the degree of alteration of the rocks, their structural complexity, unconformity with the overlying formations, and other evidence of a long erosion interval between these formations and the next later rocks of the region which are probably of Upper Cambrian age.[15]

CARRIZO MOUNTAIN FORMATION

The term Carrizo has been applied to two Texas formations. Carrizo sandstone was used in a formational sense in the First Report of Progress of the Texas Geological Survey (454, p. 70), applying to an Eocene sandstone exposed in Dimmit County, Texas. Subsequently, in the Second Annual Report of the Texas Geological Survey (458, p. 783), Streeruwitz applied the name Carrizo to an entirely different formation, namely, the pre-Cambrian schists of the Carrizo Mountains. The term Carrizo was used by Streeruwitz in 1889, although apparently not in a formational sense. At a later date Richardson (1314, p. 3) defined more fully the Carrizo formation of the Van Horn region. In conformity with usage adopted by the United States Geological Survey for the state map, and to obviate this conflict in names, the term Carrizo Mountain formation is here used for the schists in the Carrizo Mountains. The rocks involved are varied in character and it is probable that when described in detail they will be regarded as constituting a series rather than a single formation.

The Carrizo Mountain formation consists of quartzites, schists, slates, and some igneous intrusives. The rocks are for the most part of fine texture. The quartzites break with conchoidal fracture and are not foliated. The schists, on the other hand, are foliated and cleave readily. They include mica, quartz-mica, amphibolite, chlorite, epidote, hornblende, and quartz schists. Pegmatite, graphic granite dikes, and quartz veins are present. The slates which are interbedded with the quartzites are of fine texture. These varieties of rocks occur successively in the formation, resulting in alternating

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[15]Publications relating to the pre-Cambrian of the Van Horn region listed in the accompanying bibliography include the following: Baker, 46; Dumble, 454, 458, 459, 491; Osann, 1161; Richardson, 1304, 1305, 1310, 1314; Streeruwitz, 1559, 1560, 1561, 1564, 1566.

bands. The color of the sediments on fresh exposure is prevailingly gray, although varying to dark or black. Some dark chloritic schists in the formation, according to Richardson (1314), are probably derived from sills of basic igneous rocks.

The Carrizo Mountain formation is exposed in the Carrizo Mountains southwest of Van Horn and in the Van Horn Mountains west of Lobo and south of the Southern Pacific Railroad. An exposure of the Carrizo Mountain formation in the northeast front scarp of Eagle Mountains is described by Baker (46, p. 7). The rocks here include quartzites, quartz schists, cherts, and dark intrusives. There are also exposures of this formation at the west margin of Wylie Mountains, at Bass Canyon, and north of Eagle Flat section house, between Allamoore and Sierra Blanca. The rocks consist of a great variety of schists, including pegmatite, granite, and quartz dikes.

Type locality: Carrizo Mountains, Culberson County; thickness undetermined.

MILLICAN FORMATION

The Millican formation, named by Richardson in 1914 (1314, p. 4), consists of sandstone, conglomerate, and limestone. The sandstone is prevailingly red and consists of very fine sand stained by iron oxide. In contrast to the smallness of the grain of the sandstone, the conglomerate is coarse and includes pieces of limestone, sandstone, igneous and other rocks, varying from very small to a foot or more in diameter, usually well cemented in a very mixed matrix of small rock fragments. The conglomerate, according to Richardson, does not occur at a single stratigraphic level but is at various levels in the formation. The limestone, as well as the conglomerate, makes up a subordinate amount of the formation as compared to the sandstone. The limestone is gray and somewhat cherty. Locally, it has been altered to a white marble. Streeruwitz named the sandstone of this formation "Diablo," and Dumble proposed for it the name "Hazel" (1314). The largest body of conglomerate is near the base of the formation and approximates 1,000 feet in thickness.

The Millican formation is exposed north of the Texas and Pacific Railroad and at the southeast side of the Diablo scarp, passing under the Diablo Plateau. Exposures occur in disconnected areas from northwest of Eagle Flat to Allamoore and thence at the base of the escarpment for some miles northeastward. The area of exposure of the Millican does not overlap that of the Carrizo Mountain. The base of neither formation is exposed and both are in angular unconformity with the overlying Paleozoic. The Millican, however, is not so completely metamorphosed as is the Carrizo Mountain, and for that reason is regarded as probably later in age. King has observed also that some fragments of the Carrizo schists are included in the Millican formation (396b).

In most places the two series are separated by several miles of Paleozoic or late Cenozoic deposits. King reports, however, that just north of Eagle Flat section house the two series have been brought into contact by thrust faulting, the Carrizo being here thrust over the Millican, the fault plane dipping south.

Type locality: Millican Ranch, 10 miles northwest of Van Horn; thickness exposed, 2000–3000 feet.

IGNEOUS ROCKS

Igneous rocks are but little developed in the Van Horn region. In the Carrizo Mountain formation, as already mentioned, are some bands of chlorite schist which may be derived from basic igneous sills. Both the Carrizo Mountain and Millican formations are cut by massive diabase dikes and sills.

The sills which give rise to the chlorite schist indicate by the extent to which they are metamorphosed that they were intruded in pre-Cambrian time. The diabase dikes, however, are said by Richardson to be of later origin. With these dikes are associated the silver and copper of the Millican formation.

STRUCTURAL CONDITIONS

Attitude of Strata.—In the Carrizo Mountains the quartzite, schist and slate bands of the Carrizo Mountain formation representing the original strata, dip to the southeast, the amount of dip varying from 25° to 60°. North of the Texas and Pacific Railroad, in the area of exposure of the Millican formation, the strike is prevailingly east-west. However, in the northwestern part of the area of exposure of the Millican formation the strike is northwest-southeast with southwest dip. The dips are determined in the Millican formation chiefly by the position of the limestones and conglomerates, the bedding in the sandstone being obscure. In addition to this prevailing trend in the Millican formation, there are minor folds which affect direction of dip. Near the thrust fault contact of the two series, the rocks of the Millican formation are sharply folded and overturned to the north. Farther to the north away from this contact they flatten and the formation near Sierra Diablo is only gently tilted.

The pre-Cambrian of the Eagle Mountains, according to Baker (46), strikes N. 70° E. and dips steeply S.SE., while that of the Wylie Mountains dips 20° to 30° south. The schists of the Van Horn Mountains dip on the average eastward to southward. Overthrusting of the Carrizo onto the Millican has been described above.

Regional Structural Features.—The Van Horn area is a region of extreme faulting. A late fault system of this region has a north-northwest trend. The salt basin is itself a result of faulting and folding. In addition to the north-south faults are others diverging from this trend, being in places at right angles to it. The result of these main and cross faults is the formation of blocks at the margins of the valley and occasionally within the valley itself. The Carrizo Mountains are a block set off on all sides by faulting or folding. A down block at the north of the exposures of the Carrizo Mountain formation, separating this area from that of the Millican formation, brings the Paleozoic, and locally even the Cretaceous, in contact with pre-Cambrian. The exposed areas of the Carrizo Mountain formation occupy, therefore, up-faulted blocks.

The exposure of the Millican formation, north of the Carrizo Mountains, is affected by faulting, although in a less pronounced degree. Just off the margins of the Diablo Plateau east of the Millican exposures are partly foundered blocks in the valley, such as Baylor and Beach mountains. These blocks, however, expose Paleozoic only, the pre-Cambrian, which underlies the Paleozoics, being submerged. The regional structural features, therefore, affecting formations to as late as the Cretaceous, include block faulting adjacent to a graben.

PRE-CAMBRIAN HISTORY OF THE REGION

As already indicated, the Carrizo Mountain and Millican formations contain sediments including sandstones, silt-stones, shales, conglomerates, and limestones. The alteration processes by which these sediments were changed to quartzites, schists, slate, and marble, operated previous to the deposition of the next latest formations of this region, which are probably Upper Cambrian. To this period also belong the conditions of pressure and stress which resulted in a development of schistosity and slaty cleavage involving the regrouping of the minerals; and the time of folding which in the main produced the high dips of the Carrizo Mountain and the Millican formations. The rate of dip may have been to some extent altered, either increased or decreased, by the extensive block faulting in relatively late geologic time. That the folding was initiated and chiefly developed previous to deposition of the overlying formations is indicated by the pronounced angular unconformity, as well as by the much greater complexity of the pre-Cambrian structural features as compared to those of the later formations. As elsewhere stated, the metamorphism is more pronounced in the Carrizo Mountain formation than in the Millican formation, and to that extent the inference of pre-Cambrian age for the Carrizo Mountain is stronger than for the Millican.

The long period of erosion indicated by the unconformity at the top of this series may be partly or entirely within the Cambrian, the next overlying formations being probably of late Cambrian age.

TYPICAL EXPOSURES

Typical exposures of the Carrizo Mountain formation may be seen generally throughout the Carrizo Mountains south of the Texas and Pacific Railway. The Texas and Pacific Railway from Van Horn west approximately follows a fault at the north side of the mountains and in places passes over exposures of the Carrizo Mountain formation. The new public road, south of the railroad, affords good exposures of the Carrizo Mountain formation. The Millican formation is well exposed and may be readily seen at and near the Hazel and other silver-copper mines 10 to 20 miles northwest of Van Horn, and also at many localities north and northeast of Allamoore. The erosional features of the Millican formation are distinctive. The sandstones, or silt-stone, disintegrate rapidly and form small hills. The surface in the exposed area of this formation can scarcely be said to have a soil, and supports no more than a meager growth of vegetation.

EL PASO REGION

The Franklin Mountains extend from El Paso slightly west of north into New Mexico, where they connect with the Organ and San Andres ranges. Structurally the mountains are a great fault block which dips westward, its east margin being a fault scarp. Immediately east of the mountains is a partially filled bolson or graben. Beyond the valley eastward are the Hueco Mountains, which constitute the west-facing escarpment of the Diablo Plateau (fig. 3, p. 28).

The pre-Cambrian of the Franklin Mountains includes altered sedimentary rocks, the Lanoria quartzite, and, overlying this formation, rhyolitic igneous rock. The exposures of these formations are found in the east-facing scarp. The same formations may be under the scarp at the east side of the valley, but if so are but little exposed. However, King (396b) has recently described red granite exposures at the south end of the Hueco Mountains regarded by him as pre-Cambrian in age. Some of these exposures are noted by Richardson (1304, p. 57), who regarded them as dikes. The exposures are found south and southeast of the entrance to Padre Mine Canyon.[16]

LANORIA FORMATION

The Lanoria formation consists very largely of quartzite with smaller amounts of slaty rock and with some intruded diabase. The quartzite is of fine texture, the quartz grains being embedded in a matrix of silica, sericite, and kaolin. It is hard and is cut by thin sills and dikes of diabase. The contact of the formation with the Cambrian is not seen, as the two formations are separated by rhyolitic igneous rock. The dip of the two series, however, is essentially the same in direction and amount (1312). No fossils have been found, and the formation is referred to the pre-Cambrian because of its position under the Upper Cambrian, this position being comparable to that of the other pre-Cambrian formations previously described.

Type locality: Lanoria settlement, El Paso County; thickness, 1,800 feet exposed, full thickness unknown. The formation was named by Richardson (1312).

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[16]Publications listed in the accompanying bibliography relating to the pre-Cambrian of the El Paso region include the following: Richardson, 1304, 1305, 1307, 1308, 1309, 1310, 1311, 1312, 1313.

IGNEOUS ROCKS

The pre-Cambrian igneous rocks of the Franklin Mountains, aside from diabase sills and dikes, consist of rhyolite porphyry and associated pyroclastic rock. The porphyry is a massive red rock consisting of a fine textured ground-mass in which are phenocrysts of quartz and feldspar. Although prevailingly red, the rock varies to a black ground-mass, in which case the phenocrysts are largely of feldspar. The thickness of the rhyolite is 1500 feet (1312).

At the base of the igneous rocks is an agglomerate of rhyolite, including pieces of rock from the underlying quartzite, indicating an erosional unconformity between the igneous rock and the Lanoria formation. While this agglomerate is not present everywhere, in places it attains a thickness of as much as 400 feet. The overlying formation, the Bliss sandstone, contains inclusions from the rhyolite, indicating that there is also an erosional unconformity between the rhyolite and the Cambrian. According to N. H. Darton, some of the granite of the Franklin Mountains, mapped as post-Paleozoic, is unconformable below the Bliss sandstone, and is of pre-Cambrian age. Other rhyolitic rocks extensively exposed in the Franklin Mountains were intruded subsequent to the Cambrian. Granite, as previously stated, is reported at the south end of the Hueco Mountains.

STRUCTURAL CONDITIONS

Attitude of Strata.—The Lanoria quartzite in the Franklin Mountains dips westward at about the same angle as the Paleozoic rocks, that is, between 20° and 45°. The formation has been little affected by folding, although the rocks are altered from sandstone to quartzite.

Regional Structural Features.—The regional structural features affecting these formations are those of the Franklin Mountains as a whole. The mountain, as already stated, is a great fault block steeply tilted westward and forming a pronounced east-facing scarp. As in the Van Horn region the main trend of the faulting is north-south. In addition, however, there are faults which are transverse or oblique to the main line of faulting, by which the mountain mass is cut into blocks of lesser displacement. The age of this great fault system is relatively late in geologic time, and the faults cut all of the formations of the mountains.

PRE-CAMBRIAN HISTORY OF THE REGION

The pre-Cambrian history of this region includes several recognizable periods. The first is that during which the Lanoria sediments accumulated. At a later time these sediments were intruded by sills and dikes of igneous rock and were uplifted and eroded. Following this period of erosion there occurred lava flows, which now make up the rhyolite. At the base of the lava is an agglomerate, which in places reaches a thickness of 400 feet. The top of the lava in turn was eroded previous to the invasion of the sea and deposition of Cambrian sediments.

TYPICAL EXPOSURES

The Lanoria quartzite and overlying rhyolite are exposed in small areas on the eastern slope of the scarp of the Franklin Mountains. The rhyolite forms the summit and sides of the highest peaks in the mountains. The quartzite, on the other hand, may underlie the Diablo Plateau, representing an extension of the pre-Cambrian of the Van Horn region under somewhat changed lithologic conditions.

UNDERGROUND POSITION OF THE PRE-CAMBRIAN IN TEXAS

The pre-Cambrian is known not only by surface exposures but also, at a number of places, by well cores and cuttings. Wells have been drilled to the pre-Cambrian in counties adjoining or near the Llano uplift, on the Red River uplift, on the Pecos uplift, in the Amarillo region, and on the Diablo Plateau.[17]

LLANO UPLIFT AND ADJACENT REGION

East of the Llano uplift in the old Luling oil field in Caldwell County, wells have reached schists at a depth slightly less than 5,000 feet. In this oil field three wells have been drilled through the Cretaceous and into the underlying rocks. These wells entered schists at depths in feet as follows: Taber farm, 4,796; Tiller farm, 4,807; Kelly farm, 4,728. On the Tiller farm these schists were drilled into to depth 7,504 feet, and on the Kelly farm to 7,859 feet. The rock of the Taber well is a calcite quartz-sericite schist with pink

[17]Publications relating directly or indirectly to the underground position of the pre-Cambrian in Texas listed in the bibliography include the following: Bauer, 78, 79; Hager, 641a; Harrison, 670; Powers, 1254; Pratt, 1264; Sellards, 1423, 1424.

bands due to garnets. The two most abundant minerals are quartz and sericite, which make up about 75 per cent of the rock, sericite predominating. Other minerals are calcite or dolomite, garnet, tremolite or actinolite, and apatite. Essentially similar rock is found in the other two wells. In the Kelly well chlorite schists are found at depth 7,240 feet. In the Tiller well seams, apparently of kaolinite, occur in schists at a depth of 7,169 feet, and a graphitic schist is found at depth 7,483 feet. The schist drilled into in these wells is closely similar to that of the Llano uplift. Additional information on these rocks in Caldwell County is given on page 132.

To the west and south of the Llano region, knowledge of the position of the pre-Cambrian has been somewhat extended by well records in Gillespie and Mason counties. In Gillespie County three wells drilled through the Cretaceous all entered granite at moderate depth, the deepest being at 1,182 feet. This granite is evidently a southward extension of the granites of the Llano uplift exposed in northern Gillespie County. In northwestern Mason County a well has been drilled into the pre-Cambrian at depth of 1,490 feet or less. The rock as indicated by the cuttings is a schist not unlike that exposed in eastern Mason County.

In McCulloch County, northwest of the Llano uplift, two wells have been drilled into the pre-Cambrian. One of these, in the western part of the county, reached schists at depth 2,982 feet. The rock at this locality is a hornblende schist. In the northern part of this county the pre-Cambrian is reached at depth 3,309 feet and is here a granite. Directly north of the Llano uplift in San Saba County granite was encountered at depth 1,655 feet. In Lampasas County three wells have entered granite. From a well on the Wittenberg farm in the western part of the county samples of pink granite were obtained from depth 3,580 feet to 4,180 feet. In Taylor County one well has been drilled into pre-Cambrian sediments reached at a depth of 5,809 feet. In Eastland County a well located north of Cisco entered, at depth 5,425 feet, conglomeratic material from granites or gneiss, and possibly terminated in pre-Cambrian bedrock at depth 5,591 feet.

These records may all be regarded as extending the known position of the pre-Cambrian of the Llano uplift. By interpolating the known thickness of the older Paleozoic formations the depth to this facies of the pre-Cambrian may reasonably be indicated somewhat farther, particularly westward and northward, as has been done on the accompanying map (fig. 5).

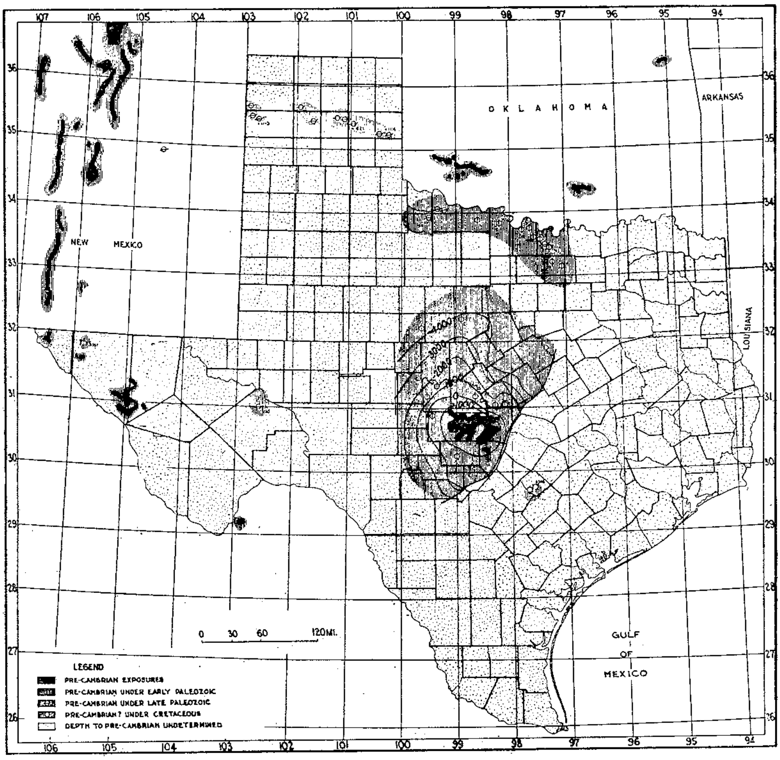

Fig. 5. Map of Texas and parts of adjoining states showing surface exposures and underground position of the pre-Cambrian.

RED RIVER UPLIFT

The Red River uplift, or series of uplifts, consists of buried mountains which affect the structural conditions adjacent to the Red River in north Texas through several counties from Denton and Cooke on the east to Wichita, Wilbarger, and Foard on the west. The uplift has been discovered by drilling, the formations involved being not now exposed. The uplift was first described by Hager in 1919 (641a) and at that time was known to affect Cooke, Montague, Clay, and Wichita counties. Subsequent drilling has shown that it extends southeastward into Denton County and that this, or a similar uplifted area, extends westward through Wilbarger and Foard counties. Whether or not it reaches farther to the west or northwest is not known. The Red River uplift is defined as the uplift, or series of uplifts, extending through several counties adjacent to the Red River in Texas and having an approximately east-west trend (fig. 5, p. 47, and region No. 8 of fig. 4, p. 29).

In these several counties adjacent to the Red River, from Denton and Cooke on the east to Wilbarger and Foard on the west, igneous rocks and schists of the Llano facies have been reached in drilling. The depth varies as does also the character of the rock. At places within this region the pre-Cambrian is within 2,000 feet or less of the surface and elsewhere is reached at a depth in excess of 4,200 feet.

In Denton County gneiss was identified in a well on the Waide farm at dept 1,882 feet. This rock, as determined by J. T. Lonsdale, contains quartz, feldspar, and biotite, with apatite, epidote, titanite, and other minerals. On the Yeatts farm, Denton County, a sample of dark schist was obtained at depth 2,013 feet. In Cooke County, on the Whaley farm, dark green schists were reached at depth 2,312 feet. On the Yosten farm near Muenster at depth 2,750 feet are similar schists, which, according to Lonsdale, contain as predominating minerals quartz, hornblende, and biotite. In Montague County granitic rocks are recorded in two or more wells, and schists in one. The granite of the Lemon well in Montague County at depth 2,707 feet to 2,913 feet as described by T. L. Bailey, is variable, consisting of pink and red granite and greenish-black diabase. In Clay County granite was reached in Byers 41 of The Texas Company at depth 4,240 feet. In Foard County on Mathews' land schists were reached at depth 2,215 feet. A similar schist is reported to have been reached in another well on the same farm at depth 2,465 feet. From the Miller well an arkosic material including igneous pieces was obtained at depth 4,950 feet. In Wichita County a well of the Magnolia Petroleum Company on the Beech lease reached altered rock at 3,000 feet. On the Schakenberg farm a well reached igneous or metamorphic rocks at 3,575 feet. In Wilbarger County on the Stephens ranch igneous rock, identified by F. C. Sealey as diorite, was obtained at 3,007 feet. From the log it appears that similar rock was reached at depth 2,970 feet. On the Zipperle farm in this county gneiss was found at depth 2,881 feet.

History of the Red River Uplift.—Although the Red River uplift is a buried structural feature and can be studied only through well records and samples, not a little of its history may be determined or inferred. The pre-Cambrian rocks are similar to those of the Llano uplift. In both regions the original shales and sandstones were altered to schists and quartzites; both were extensively intruded by igneous rocks, largely acidic, which formed chiefly granites; both regions were intensely eroded in late pre-Cambrian or early Cambrian time. The Upper Cambrian and Lower Ordovician seas crossed at least the eastern part of the Red River uplift. Farther to the west less is known of the early Paleozoic sediments, which are wanting, either through non-deposition or owing to subsequent erosion. The presence of the Bend series over at least a part of the Red River uplift indicates partial, if not complete, submergence during early Pennsylvanian time. The Marble Falls limestone of the Bend series rests disconformably on the older rock. The upper Pennsylvanian, in turn, rests with an angular unconformity on the Marble Falls formation.

The period of intense dynamic activity, which metamorphosed the pre-Cambrian sediments and intruded the granites in both regions, antedates the deposition of the overlying Paleozoic, which is unaltered. The uplift, however, differs from the Llano uplift in that instead of a single great doming it consists of a series of ridges with *en échelon* arrangement. The principal orogenic movement creating this uplift is believed to be of mid-Pennsylvanian age, thus agreeing in time with an uplift in the Llano region.

AMARILLO UPLIFT

The Amarillo uplift as now known extends from Wheeler County, near the Oklahoma-Texas line, westward or slightly north of west, 100 or more miles. Aside from this main anticline are partially isolated domes in Potter, Oldham, and perhaps other counties. This uplift, particularly in its western part, is reflected in the Permian formations at the surface, and drilling for oil and gas was orginially begun on domes on this uplift. As developments progressed, drilling revealed the presence of igneous rocks underneath the oil and gas producing sedimentaries. Frequently also wells have entered or passed through arkosic rocks which probably are not greatly removed from their original source. In these wells not a little difficulty has been experienced in differentiating between granite conglomerate as found in well cuttings and original granite or other igneous rocks (670, 1264).

The well records now available reveal an uplift by which pre-Cambrian rocks were brought near enough to the surface to be within reach of the drill in several counties. This great uplift extends across the Panhandle from Oklahoma into New Mexico. The uplift as a whole is probably a platform of irregular surface from which peaks project. The arkosic materials have accumulated at the sides of such peaks and may in some instances be very local (78, p. 739). The counties, for which records of igneous rock, either in place or as arkosic material are available, are Carson, Collingsworth, Gray, Hartley, Hutchinson, Oldham, Potter, and Wheeler. These counties form a belt extending entirely across the Panhandle. Doubtless additional similar rock will be found in other counties adjoining these (fig. 5, p. 47, and region No. 5 of fig. 3, p. 28).

Several wells in Carson County have entered igneous rock. A well on the McConnell ranch encountered either diorite or diabase containing plagioclase, augite, biotite, and magnetite or ilmenite. Samples of this rock were obtained from depths 2,685 feet,[18] 2,966 feet, 3,005 feet, and 3,050 feet.[19] The rock at 3,060 to 3,084 feet is identified by Bailey as diabase and is regarded by him as coming from a dike. Granite wash is reported from several other wells in the county at depth 2,700 to 3,094 feet. In Gray County a well 7 miles west of Pampa reached igneous rock at depth 2,985 feet. The abundant minerals, as determined by T. L. Bailey, are labradorite and hornblende with some magnetite, the rock being classed as a gabbro or gabbro-diabase. On the Beavers ranch in this county fresh granite is reported at depth 3,305 feet, above which for 500 or 600 feet is granitic reworked material interbedded with shales. In Hutchinson County a well on the McGee ranch is reported in the driller's log to have entered granitic material at depth 3,135 feet. No samples have been seen from the well. Granite

[18]Determination by C. S. Ross, 1924. Letter to Sidney Powers.
[19]Examined by T. L. Bailey and C. S. Ross.

wash is reported in several wells in Oldham County at depth 2,380 to 2,590 feet, and solid granite may have been reached in some of the wells. The Landegrin well in this county was drilled to 5,015 feet without reaching granite wash or pre-Cambrian rock. In Potter County a well drilled by the Emerald Oil Company on the Masterson ranch 20 miles north of Amarillo entered gneiss at depth 2,000 feet and terminated in similar rock at 2,148 feet. Several other wells in the county, after drilling arkosic rock at greater depth, passed through limestones and shales. The log of a well on the George ranch in Wheeler County indicates granitic material, probably conglomerate or arkose, at 2,408 feet and diabase at 2,492 feet. Samples from within the upper interval are seemingly unaltered diabase and granite. Of the rock in the lower interval no samples are at hand. On the Kockelhoffer ranch granitic material is found at depth 2,155 to 2,393 feet. From a well on the Wetzel ranch samples were received from depth 2,248 feet which contained fresh appearing orthoclase, quartz magnetite, and zircon.

Additional records on this uplift are given in the table of wells.

The age of the oldest rock of this uplift can be determined only by inference and analogy. As already stated, the uplift is believed to be connected with, and a part of, the Wichita Mountains of Oklahoma. In the eastern mountains of the Wichita chain, Upper Cambrian and Lower and Middle Ordovician are found exposed and resting unconformably on the older series.[20] Well drilling has demonstrated that the Pennsylvanian is present around these mountains although not exposed.[21] In the belief that the Amarillo uplift is the westward extension of the Wichitas, the rocks at the core of the uplift are referred to the pre-Cambrian.

History of the pre-Cambrian of the Amarillo Region.—Assuming a connection between the Amarillo uplift and the Wichita Mountains, the history of the pre-Cambrian of the two regions may be inferred to be essentially the same. During Upper Cambrian and Lower and Middle Ordovician, the Wichitas proper were covered in part or completely by a shallow foreland sea. The westward limit

[20]Taff, J. A., Preliminary report on the geology of the Arbuckle and Wichita mountains of Indian Territory and Oklahoma, U. S. Geol. Surv., Prof. Paper 31, 1904.

[21]Howell, J. V., Notes on the Pre-Permian Paleozoics of the Wichita Mountain Area, Bull. Amer. Assoc. Petrl. Geol., Vol. 6, pp. 413–425, 1922.

of this sea is unknown, and it has not been determined whether or not it covered the Panhandle region. If the Panhandle region was under sea at this time, the sediments have been removed from at least the higher peaks where Permian or Pennsylvanian now rests on pre-Cambrian. The Pennsylvanian sea, in which sediments were deposited around the Wichitas, extended westward into the Panhandle, as is indicated by the presence of Pennsylvanian at the side of the uplift. The Wichita-Amarillo uplift thus presents a close analogy to the Red River uplift with which it is doubtless closely connected. An early uplift of the Wichitas occurred, according to Tomlinson (1606b), not later than the end of Springer, Lower Pennsylvanian, and a renewed uplift followed the Hoxbar (Canyon). That the Amarillo Mountains and the Red River uplift were made at the same time as the Wichitas, or at approximately the same time, may reasonably be inferred.

PECOS UPLIFT OR CENTRAL BASIN PLATFORM

The Pecos uplift is a buried structural feature affecting formations up to and including the Permian. To some extent it may likewise have affected Triassic and Cretaceous formations, but in the latter the effect, if any, was relatively slight, and the attitude of the surface formations gave no reason to anticipate such an underlying structural feature as drilling disclosed. The Pecos uplift as now known extends from southeastern Pecos County in a northwesterly direction into New Mexico. The uplift has a breadth, as measured in Permian rock, of 30 or 35 miles. On the uplift are superimposed structural features in the Permian, several of which are producing oil. Metamorphic or igneous rocks are known at the present time in one well only, the Shell Company well on The University of Texas lands in Pecos County. In this well igneous or metamorphic rock was reached at depth 4,750 feet. In samples of this series from depth 4,931 to 4,935 feet, Lonsdale has identified the following as abundant minerals: quartz, microcline, albite, hornblende, and biotite; and, in smaller amounts, magnetite, zircon, apatite, and calcite. Much the same minerals, varying in relative amounts, are present in samples at depths 5,001 to 5,004 feet and 5,124 to 5,128 feet. The rock as a whole is granitic and without evidence of metamorphism. The age of this rock is as yet in doubt. From analogy with the Van Horn region to the west and the Llano region to the east, it is regarded as probably pre-Cambrian. This uplift is known also (190,201) as the Central Basin Platform (fig. 5, p. 47, and region No. 4 of fig. 3, p. 28).

DIABLO PLATEAU

The Diablo Plateau is an uplifted large block lying chiefly in Hudspeth County. The block sags in its central area and is structurally higher at its west, east, and southeast margins. At its western margin are the Hueco Mountains bordering the Hueco Bolson. These mountains, according to Baker (MS.), are an asymmetrical anticline, the west flank of which dips very abruptly under the Hueco Bolson. At its east margin is the escarpment of Sierra Diablo bordering Salt Flat. The Finlay dome forms its southwest margin, and at the southeast is the Van Horn dome, now broken into blocks by faulting and deeply dissected by erosion. The Hueco Bolson at the west and the Salt Flat on the east are structural valleys. Fault scarps and abrupt dips separate the sunken valleys from the uplifted blocks. A well on the Diablo Plateau on land of The University of Texas drilled by the California Oil Company reached altered rock at depth 4,725 feet (fig. 5, p. 47, and region No. 2 of fig. 3, p. 28).

ECONOMIC PRODUCTS OF THE PRE-CAMBRIAN IN TEXAS

A highly diversified series of minerals is found in the pre-Cambrian of the Llano region. The mineral products obtained commercially from the Llano series of rocks include granite of several varieties, graphite, lead, manganese, and rare earth minerals. Prospecting has been done for several other minerals of which, however, commercial production has not been obtained. Among these are gold, silver, iron, copper, molybdenite, flourite, zinc, marble, asbestos, serpentine, barite, talc, topaz, and wollastonite (1171). The rare earth minerals were mined for many years at Barringer Hill in Burnet County where a large number of these minerals are found in a large pegmatite dike (711).

The Millican formation of the Van Horn region contains silver and copper minerals, the ore being found in mineralized zones and adjacent to dikes. Several mines in this region have been operated intermittently for many years. Of these, the Hazel Mine northwest of Van Horn has been most extensively worked. Various rock products were formerly made from the minerals of a pegmatite dike in the Carrizo Mountain formation of the Van Horn Mountains, and were marketed under the name of "micolithic" products. Some copper prospects are reported by Baker from the Carrizo Mountain schists (46). Turquoise occurs in the Carrizo Mountain in thin seams along joint planes. The marble of the Millican formation has not been utilized. An outcrop of an iron oxide ore is reported by Streeruwitz (1561).

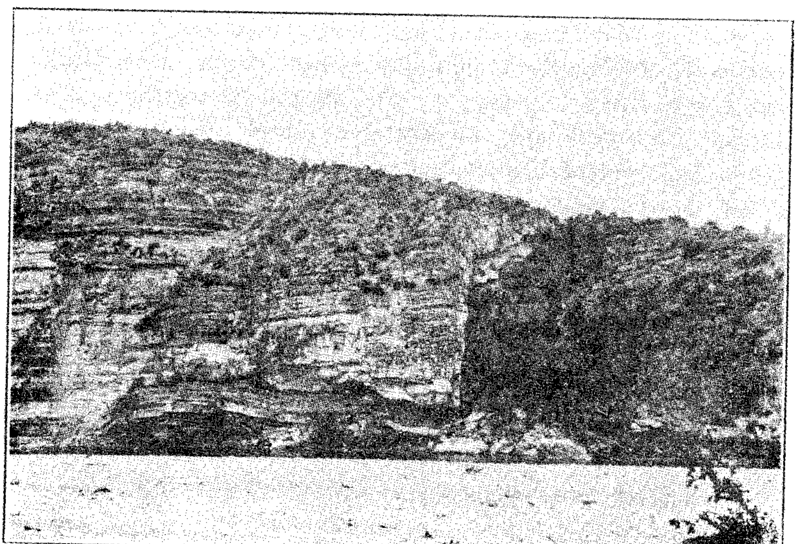

Fig. 6. Faulting in early Paleozoic formations, on James River, fourteen miles southwest of Mason, Texas.

THE PALEOZOIC SYSTEMS

In contrast to the limited exposures of pre-Cambrian, the Paleozoic rocks are extensively exposed in Texas. All of the systems of the Paleozoic are represented, the most widely exposed formations being those of Pennsylvanian and Permian.

CAMBRIAN SYSTEM

Absence of Lower and Middle Cambrian

Neither in surface exposures nor in deep wells has Lower or Middle Cambrian been recognized in Texas. Explorations by drilling are necessarily incomplete, and the observations thus far made may subsequently be modified. It is known, however, that between the pre-Cambrian and the next overlying Paleozoic there is an unconformity of wide extent representing a long interval of time during which the land was being eroded. In Lower Cambrian the sea on the North American continent occupied, so far as known, only the two major troughs or geosynclines, the Cordilleran geosyncline in the western margin of the continent and the Appalachian geosyncline in the eastern part. In Middle Cambrian time a somewhat similar condition persisted and, as now interpreted, no Middle Cambrian deposits are recognized in the Texas-Oklahoma-Missouri region. In the trough bordering Llanoria, early or Middle Cambrian may possibly be discovered but at present are unknown.

Upper Cambrian

Upper Cambrian is recognized in surface exposures in Texas in five areas of the state as follows: the Llano uplift, the Marathon and Solitario uplifts, the Van Horn region, and the Franklin Mountains. Correlation between these widely separated areas is not complete, and separate names are for the most part in use for the several regions. The Cambrian formations recognized in surface exposures in the state are as follows:*

*For the location of these regions in the state see figs. 3 and 4, pp. 28–29.

Llano Uplift	Marathon and Solitario Uplifts	Van Horn Region	El Paso Region
Ellenburger group, basal part (Eminence and Potosi equivalents)			
Fort Sill and Signal Mountain			
Wilberns			
Cap Mountain			
Hickory	Dagger Flat	Van Horn	Bliss

The Upper Cambrian formations of the Llano region in their underground extension are important water-bearing formations. The Hickory sandstone in particular supplies an abundance of water to wells. The Cambrian, particularly the highly glauconitic facies, contains more or less disseminated lead minerals, chiefly the sulphide, galena. Oil and gas have not been obtained from the Cambrian formations. However, there seems no inherent reason why the unmetamorphosed, highly fossiliferous sediments of the Cambrian, such as are extensively spread over most of the region here mapped as having been occupied by a Cambrian sea, may not produce oil under favorable structural conditions.

LLANO REGION

The Cambrian of the Llano region, as now subdivided, includes the following formations, the oldest being named first: Hickory, Cap Mountain, Wilberns, Fort Sill, Signal Mountain and the basal part of the Ellenburger group (Potosi and Eminence equivalents).[22]

The Cambrian and other Paleozoic formations of the Llano uplift lie in nearly horizontal position or with moderate dip. An exception is found, however, in strata around granite knobs found at the margins of the uplift. Around these knobs the Cambrian formations have decided dips up to as much as twelve or sixteen degrees. In such localities the dips are away from the granite knobs. The conditions here are very like those around porphyry

[22]Among publications listed in the accompanying bibliography relating to the Cambrian of the Llano uplift are the following: Comstock, 271, 274; Dake and Bridge, 386b; Deen, 402; Jones, 891; Paige, 1170, 1171, 1172, 1173; Roemer, 1330; Shumard, 1465, 1471, 1473; Ulrich, 1674b; Walcott, 1702, 1703, 1703a–g.

knobs in the Ozarks.[23] In addition, the strata are cut by the northeast-southwest system of faults which affect both the pre-Cambrian and Paleozoics of this region older than the Strawn, resulting in local pronounced dips. Except as locally affected by faulting and by the granite knobs referred to, the strata dip away from the Llano uplift.

Ozarkian and Canadian systems.—In 1911 Dr. E. O. Ulrich proposed a new system, to be known as the Ozarkian, named from the Ozark region of Missouri (1647b). The Ozarkian system, as thus proposed, includes a part of the Cambrian and a part of the Ordovician of the current classification. Under this classification, the Fort Sill, Signal Mountain, Potosi, Eminence, and Gasconade formations are placed in the Ozarkian. The Canadian system proposed at the same time by Ulrich includes the Ordovician from the top of the Gasconade or its equivalent to the base of the St. Peters. In this publication the terms Ozarkian and Canadian are not used and the division between the Cambrian and Ordovician is placed at the top of the Eminence formation or its equivalent.

HICKORY FORMATION

The Hickory formation is prevailingly a conglomerate, or sandstone, which rests on the unevenly eroded surface of the pre-Cambrian schists, gneiss, and granites. Much of the sand is iron stained and in places contains a considerable quantity of iron oxide. Elsewhere it is clean and relatively free of iron. In passing upward it grades into glauconitic sands and limestones of the Cap Mountain formation, the lithologic break between the two formations being not well marked. Near the top some layers of fossiliferous glauconitic limestone alternate with the sandstone. The basal part of the formation varies from place to place in accordance with the character of the underlying pre-Cambrian from which it is derived. Wells drilled into this formation at the margins of the Llano uplift have in most instances obtained an abundance of water. The formation is exposed at many localities at the margins of the Central Mineral region.

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[23]Bridge, Josiah, and Dake, C. L., Initial Dips Peripheral to resurrected Hills, Missouri Bureau of Geology and Mines, 55th Biennial Report, Appendix 1, pp. 1-7, 1929. (Reports issued November, 1928.)

Type locality: Hickory Creek in Llano County; thickness, from a thin stratum to 350 feet or more; correlation, Reagan sandstone of Oklahoma. The formation name was given by Comstock (271).

CAP MOUNTAIN FORMATION

The Cap Mountain formation consists chiefly of limestone, usually glauconitic. In places it becomes a glauconitic marl being but little indurated. In places also, especially near its base, it is a sandy limestone. The change from the underlying Hickory is gradational and a definite contact is difficult to determine. Some of the strata consist very largely of pieces of trilobites. The complete carapace is seldom preserved, notwithstanding that fragments are present in such abundance as to indicate a sea teeming with trilobite life. With the trilobites, and locally making up parts of the stratum, are small brachiopods. The glauconite so abundant in this formation is closely associated with the abundance of organic material. Frequently the glauconite can be seen to lie within the rolled or thickened margins of the trilobite carapaces or spines, and in origin is doubtless associated with the decay of the organic matter. The formation passes by gradation into the overlying Wilberns. The difference between the Cap Mountain and Wilberns is not well marked in the lithology, except that there is less glauconite and more shaly material in the Wilberns. Strata of this formation in which trilobites abound may be seen at Lion Mountain west of Burnet, and at many other localities in the Paleozoic rim of the Llano uplift.

Type locality: Cap Mountain in Llano County; thickness, approximately 90 feet. The formation was named by Paige (1172). It is correlated with the Bonneterre of Missouri and the Eau Claire of Wisconsin.

WILBERNS FORMATION

The Wilberns formation consists of limestone with some shale. Limestone conglomerates are developed locally in the formation. Glauconite is less abundant than in the Cap Mountain. Overlying the Wilberns are the basal formations of the Ellenburger group. The contact between Wilberns and Ellenburger, so far as known, presents no appreciable angularity, although, according to Dake and Bridge, successive formations of the Ellenburger group overlap and rest upon the Wilberns. The lower part of the Wilberns formation includes flaggy limestones, while the shaly phase is best developed in the upper part. The conglomerate lentils in some places consist of flat pieces, often forming edgewise conglomerate. The material of these conglomerates is evidently from the formation itself. This phase of the formation may be seen at exposures on the Llano River and tributaries about ten miles west of Mason. Good exposures of the formation may be seen in the Mason-Brady road south of Camp San Saba.

Type locality: Wilberns Glen on Little Llano River in Llano County; thickness, from a thin stratum to 220 feet. The formation was named by Paige (1172). It is correlated with the Davis of Missouri, Honey Creek of Oklahoma, and Franconian of Wisconsin.

FORT SILL AND SIGNAL MOUNTAIN FORMATIONS

The upper part of the Wilberns as originally defined includes thin-bedded limestones containing an abundance of small round objects identified provisionally as the genus *Girvanella*, probably an alga. At a higher level in the formation are massive, more or less glauconitic limestones. The *Girvanella* zone, according to Ulrich, is within the Fort Sill formation as defined by him from exposures in Oklahoma, and the higher glauconitic limestones are either of this formation or of the overlying Signal Mountain limestone (personal communication). In the mapping of the Llano-Burnet quadrangle by Paige this *Girvanella* zone was usually included with the Wilberns, although at some localities it is placed in the Ellenburger. Good exposures of this part of the formation are found from 2.2 to 3 miles north of Cherokee on the Cherokee-San Saba road. The glauconitic limestone overlying the Fort Still equivalent contains the trilobite *Saukiella* and small gastropods.

Type localities: The type localities of the Fort Sill and Signal Mountain formations are in the Wichita Mountains of Oklahoma. Descriptions of these formations by Ulrich are given by Dake and Bridge (386b).

The fossils obtained from the Cambrian of the Llano region exclusive of the Ellenburger include algae, sponge spicules, cystids, brachiopods, gastropods, and trilobites. Extensive limestone reefs in the Wilberns or Fort Sill formation are thought to have been built up by algae. An abundant fossil in the Fort Sill formation is a small oval object, *Girvanella* sp., probably an alga. Sponge spicules occur at this horizon. Strata of a few inches in thickness in the Cap Mountain or Wilberns formation are in places largely made up of *Pelmatozoa* stems, probably of cystids. Parts other than the stems are rare. The only published reference to cystids apparently is that of Walcott, who lists cystidean plates from Morgans Creek, Burnet County (1703g, p. 213). Trilobites are in places very abundant, strata of some inches in thickness in the Cambrian of the Llano region being made up of fragments of carapaces. Entire specimens, however, are seldom obtained.

The following species of brachiopods, gastropods, and trilobites are listed by Walcott (1703g, pp. 212–213) from the Cambrian of the Llano region. The nomenclature has been revised and brought up to date and the formations which the fossils characterize have been added by J. Bridge and C. E. Resser:

Obolus matinalis	Cap Mountain
Obolus nundina	Wilberns
Obolus sinoe	Wilberns
Obolus tetonensis ninus	Wilberns?
Lingulella acutangula	Wilberns
Lingulella peratenuata	Wilberns
Lingulella texana	Wilberns
Lingulella upis	Wilberns
Lingulepis acuminata	Wilberns
Acrotreta microscopica	Wilberns
Billingsella coloradoensis	Wilberns
Eoorthis iddingsi	Wilberns
Eoorthis indianola	Wilberns
Eoorthis remnicha texana	Wilberns
Eoorthis wichitaensis	Wilberns
Eoorthis wichitaensis laeviuscula	Wilberns
Syntrophia alata	Wilberns
Huenella texana	Wilberns
Huenella texana laeviuscula	Wilberns
"Platyceras" texanum	Wilberns
"Ptychoparia" affinis	Wilberns
"Ptychoparia" burnetensis	Cap Mountain
Wilbernia diademata	Wilberns
Conaspis llanoensis	Cap Mountain?
"Ptychoparia"? metra	Cap Mountain
Pterocephalia occidens	Wilberns
Conaspis patersoni	Wilberns
Conaspis perseus var.	Wilberns
Elvinia romeri	Wilberns
Iddingsia similis	Wilberns
"Ptychoparia" suada	Wilberns
Burnetia urania	Wilberns

Saratogia wisconsinensis	Wilberns
Camaraspis convexa	Cap Mountain?
Dikelocephalus sp.	Wilberns
Wilbernia pero	Wilberns
Irvingella sp.	Wilberns
Irvingella tumifrons	Wilberns
Pterocephalia sancti-sabae	Wilberns
Ptychaspis	Wilberns
"Crepicephalus" texanus	Cap Mountain

ELLENBURGER GROUP, BASAL PART

(POTOSI AND EMINENCE EQUIVALENTS)

The Ellenburger formation was established to include a limestone series exposed in the Central Mineral region of Texas (1172). This series was recognized at the time as being in part Cambrian and in part Ordovician. Recent field work by Dake, Ulrich, and Bridge has shown that the series as a whole can be subdivided on bases both of fauna and lithology. The series includes chiefly limestones and dolomites, some of which are chert bearing, and a very limited amount of thin shales and some sandy strata.

POTOSI EQUIVALENT

The Upper Cambrian and Lower Ordovician formations of the Central Mineral region included in the Ellenburger group are very similar both faunally and lithologically to formations of the same age in the Ozark region of Missouri. The base of the Ellenburger of the northwestern part of the Burnet Quadrangle as described by Paige is marked by massive chert-bearing beds (1172). Much of the chert is drusy and the associated dolomitic limestone is coarsely crystalline. This basal part of the Ellenburger is believed by Dake and Bridge (386b) to represent the Potosi equivalent of the Ozark region. This basal formation of the Ellenburger group is exposed near Tow and on the right bank of the Colorado River three-quarters of a mile above Fall Creek. At this last named locality it contains some fossils, chiefly gastropods and cryptozoans. Among fossils of the Potosi equivalent are the gastropod *Scaevogyra* and fragmentary trilobites.

EMINENCE EQUIVALENT

Above the Potosi in the northeastern part of the Burnet Quadrangle is found finely crystallized cherty dolomite containing, according to Dake and Bridge, faunas of the Eminence formation of Missouri. Similar fossils were obtained from about 3.3 miles north of Cherokee on the Cherokee-San Saba road. At a higher level in the Ellenburger other formations are recognized which are described under Ordovician. The most abundant fossil in the Eminence equivalent is the trilobite *Stenopilus*. *Euptychaspis typicalis* and *Plethopeltis* also are present (Dake and Bridge, 386b).

Type localities: The type localities of the Potosi and Eminence formations are in the Ozark region of Missouri.

EL PASO AND VAN HORN REGIONS

BLISS FORMATION

The Cambrian is represented in the Franklin Mountains by the Bliss sandstone. This formation is prevailingly fine grained, although a conglomerate is usually found at the base. It varies from brown to gray in color. In places it is quartzitic, and elsewhere cross-bedded and less well cemented. The sandstone outcrops in the east facing scarp of the Franklin Mountains and also, to a limited extent, in the Hueco Mountains. In the Franklin Mountains it dips westward.

This sandstone rests with an erosional unconformity on the formations referred to the pre-Cambrian, the Lanoria quartzite and rhyolite. It is in apparent conformity with the overlying Lower Ordovician limestone. A few brachiopods have been found in this formation and are identified by Walcott as *Lingulepis acuminata*, *Lingulella*, and *Obolus materialis* (1312).

The formation is exposed along the eastern front of the Franklin Mountains and, according to Richardson (1312, p. 3), in the central part of the mountains. It is found, according to King (396b), at the base of the south scarp of the Hueco Mountains from four to ten miles southeast of Helms West well and may be seen near the entrance to Padre Mine Canyon. Near here it rests unconformably on red granite.[24]

Type locality: Fort Bliss; thickness, up to 300 feet. The formation was named by Richardson (1312).

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[24]Among publications listed in the accompanying bibliography relating to the Cambrian of the El Paso and Van Horn regions are the following: Baker, 46; Dumble, 491; Richardson, 1304, 1310, 1312, 1313, 1314.

VAN HORN FORMATION

The Van Horn region contains one formation referred provisionally to the Cambrian, the Van Horn sandstone. This sandstone is coarse grained and in part conglomeratic, particularly in its lower part, becoming finer in texture at a higher level. Cross-bedding is present, and the rock is but imperfectly cemented. In coarseness of texture it contrasts with the fine grained underlying pre-Cambrian Millican sandstone. Both sandstones are prevailingly red although the Millican is of deeper color. The Van Horn is a red, arkosic, massively bedded sandstone. From the bottom to the top it contains seams and beds of pebble, cobble, and boulder conglomerate. The fragments are chiefly red granite and red rhyolite porphyry, but there are subordinate fragments of Millican limestone and Carrizo Mountain schist. Four miles west of the Milton ranch, on the south scarp of Sierra Diablo, there are 300 feet of coarse conglomerate at the base with well rounded boulders up to 3 feet across.

No recognizable fossils have been found in the Van Horn sandstone, and it is placed in the Cambrian by reason of its position in the section.[25] It rests unconformably, with gentle dips, on the steeply inclined Millican and Carrizo Mountain formations. In the Van Horn region the Cambrian sandstone is affected by pronounced faulting, but does not show the complicated structural conditions seen in the underlying pre-Cambrian formations. According to King (Guide, 16th International Geological Congress, 396b), it is separated from the Lower Ordovician, El Paso, limestone by an angular unconformity. The formation may be seen in good exposures at the south end of the Baylor Mountains and four miles south of Victoria Peak between the Baylor Mountains and the Diablo Plateau; at the west side of Beach Mountain; and at the foot of the Sierra Diablo north of the Hazel silver mine. Richardson (1314, p. 4) describes the formation as exposed over an area of about ten square miles northwest of Van Horn.

Type locality: "Red Valley" 3 miles northwest of Van Horn; thickness, up to 700 feet. The formation was named by Richardson (1314).

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[25]Streeruwitz is said to have found borings in this sandstone identified by Walcott as *Scolithes linearis* (491, p. 104). According to King these are from an overlying unit which he places in the Ordovician.

MARATHON AND SOLITARIO UPLIFTS

The Marathon uplift is located in west Texas chiefly in the northern part of Brewster County. Originally the uplift was capped by Cretaceous strata, which, however, have been removed by erosion, thus exposing a core of Paleozoic rock. The area of exposed Paleozoics is 35 or 40 miles across and is irregularly circular in outline. Previous to the formation of this great dome, the early Paleozoic rocks had been highly folded, overturned, and in places overthrust. These movements, which have Appalachian trend, affected the Pennsylvanian and older formations, but not, so far as known, the Permian, which was but mildly folded and tilted. The formation of the uplift itself, aside from the thrusting and folding, was not completed until post-Cretaceous time, as shown by the fact that the Cretaceous of the rim rock dips gently away from the uplift, the Laramide and later folding being superimposed upon the already complicated Paleozoic folding.

The Marathon Basin.—The Marathon basin, which occupies the crest of the uplift, has been developed by erosion. In this basin are exposures of Cambrian, Ordovician, Devonian, and Pennsylvanian formations all intensely folded. At the margins of the basin forming the scarps are Permian and Cretaceous formations. The Permian formations, dipping to the northwest, have by erosion formed a pronounced basin-facing scarp. On the opposite side, east and southeast where the bordering formations are Cretaceous in age and of slight (2°–5°) dip, the basin is not limited by a so well marked scarp. To the southwest the basin finds its limits in ranges produced by the Cordilleran folding.[26]

DAGGER FLAT FORMATION

The base of the Paleozoic is not seen in the Marathon uplift. However, in some of the anticlines in the basin, rock as old as Cambrian, Dagger Flat formation, comes to the surface. This formation is exposed in the Marathon and Dagger Flat anticlinoria of the Marathon uplift (936a). The strata at these exposures are much crumpled by intense folding. Much of the formation is sandstone including ledges four or five feet thick passing at a higher

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[26]Publications relating to the Cambrian of the Marathon uplift listed in the accompanying bibliography include the following: Baker and Bowman, 44; King, 936a.

level into flaggy and thinly laminated micaceous sandstone with shale predominating at the top of the formation. The formation is sparingly fossiliferous. The fossils obtained include the brachiopod genera *Lingula* and *Obolus,* and the trilobite *Agnostus.*

In their publication on the Glass Mountains issued 1918, Baker and Bowman (44, p. 81) obtained several fossils from anticlines south of Marathon and east of Peña Colorada Creek. The fossils obtained at these localities include the Cambrian genera, *Lingulella, Acrotreta,* and *Acrocephalites.* King, however, finds that the rocks from which the fossils were obtained at these localities are transported boulders and that they occur in the Woods Hollow formation which is Ordovician. He states also that the fauna of these boulders is of a facies unlike that known in any exposure in the Marathon basin. Certain of the boulders also contain the Upper Ozarkian trilobite *Symphysurina.*

SOLITARIO UPLIFT

The Solitario is a pronounced small uplift located on the border line of Presidio and Brewster counties 10 or 15 miles from the Rio Grande and 40 or 50 miles southwest of the Marathon uplift. This uplift, like the Marathon uplift, was formerly capped by a Cretaceous covering, which has now been largely removed by erosion. Although only a few miles across, the dome involves uplift of several thousand feet.

The Solitario Basin.—The erosional basin resulting from the dissection of the Solitario dome is about four and one-half miles across and is depressed below the average elevation of the surrounding rim from 500 to 1,000 feet. Within this basin are exposed formations ranging in age from Upper Cambrian to Carboniferous. Overlying the Carboniferous, except where removed by erosion, is a great section of Cretaceous. The Paleozoic rocks of this dome are intensely folded, faulted, and in some places overthrust, the trend lines being in general northeast-southwest. The folding giving this trend antedates the Cretaceous and is of the Appalachian trend. The uplift giving rise to the dome is post-Cretaceous and modifies the pre-Cretaceous folding accordingly. The dip in the strata at the margin of the folds is in places as much as 45°.

From the Solitario uplift, 50 miles or more southwest of the Marathon uplift, fossils have been obtained by Sellards and Baker which are identified by Edwin Kirk of the United States Geological Survey as Upper Cambrian. The fossils identified were as follows: *Lingulella* sp., *Obolus* sp., *Agnostus* sp. The formation containing these fossils is probably the same as the Dagger Flat of the Marathon region.

The Dagger Flat formation in the Marathon uplift is exposed in steeply folded anticlines which trend northeast. In the Solitario uplift the structural conditions are complicated, but the trend of the Paleozoic folding is as in the Marathon Region.

Type locality: Dagger Flat northeast of Buttrill ranch. The base of the formation is not exposed and the full thickness is unknown; a maximum of 300 feet is seen. The formation was named by King (936a, p. 1064).

Illustrations of some Cambrian fossils are given in Plate II.

UNDERGROUND POSITION OF THE CAMBRIAN IN TEXAS

The Cambrian has been encountered by well drilling in several counties adjacent to the Llano uplift. At the south of the uplift the Cambrian is found in Gillespie County, where it appears to have a thickness of about 1,000 feet. This depth, however, is based on a single well and may be in error. At the north of the Llano uplift the Cambrian is reached in wells in Brown, Lampasas, McCulloch, Mills, and San Saba counties, where thicknesses up to as much as 600 feet are indicated. By utilizing wells drilled into the Lower Ordovician the approximate position of the Cambrian is determined west of the Llano uplift to Reagan County, and also north as far as Young County.

In northern Texas in the eastern part of the Red River uplift the Cambrian is reached in a number of wells. In Clay County the Cambrian is recognized. Its thickness, however, is not definitely determined. In Montague and Cooke counties it is present, although with undetermined thickness.

In Foard County no Cambrian has been recognized in wells drilled into metamorphic rocks. The Cambrian is likewise absent, so far as known, from the Texas Panhandle.

The table (pp. 192–229) contains a list of wells entering that part of the Cambrian lying underneath the Ellenburger group in Texas.

CAMBRIAN SEAS IN THE TEXAS REGION

Lower and Middle Cambrian.—No proof has been obtained of a Lower or Middle Cambrian in the Texas region, the oldest deposits known both on the surface and underground being of Upper Cambrian age. In the Ouachita geosyncline of Oklahoma and Arkansas the lowest formation exposed is the Collier shale, the age of which is imperfectly known. Ulrich (1674b, p. 676) expresses the view that it may be Lower Cambrian, but Honess (838), finding no diagnostic fossils, considers the age undetermined. Its position under Lower Ordovician places it as probably Cambrian, but a more exact reference cannot now be made. The Ouachita and Marathon areas were probably connected by a geosyncline which is now concealed under the Coastal Plain. This geosyncline was formed as a trough in front of the land mass Llanoria. At no place in this geosyncline has the base of the Paleozoic been seen, and there are as yet no records showing whether or not this geosyncline was invaded by Lower or Middle Cambrian seas. The similar geosyncline formed in front of Appalachia contains Lower Cambrian deposits (1383, p. 187).

Upper Cambrian.—The surface exposures supplemented by the records from well drilling indicate an Upper Cambrian sea which extended across central Texas. Points by which the position of the sea may be approximately located are afforded by well records in Denton, Cooke, and adjoining counties; surface exposures in the Llano, Marathon, and Solitario uplifts, and surface exposures in the Van Horn and Franklin mountains. Initial deposition in this sea as it invaded a previously exposed land surface was chiefly sands, followed over much of the area by glauconitic sand and limestone with some shales.

The westward shore of this sea is possibly indicated by the absence of Cambrian in the Panhandle region of Texas and, so far as the limited records go, in Foard and Pecos counties. On the other hand, the sea may have extended westward across this region, the resulting deposits having been removed by erosion. The location of the Upper Cambrian sea in Texas, as nearly as can now be shown, is given in Figure 7.[27]

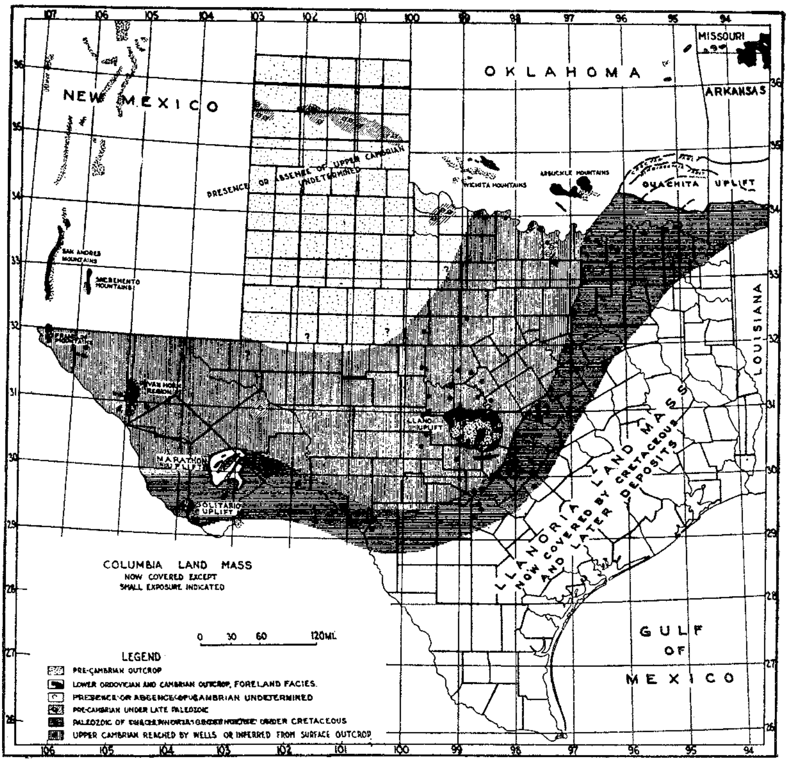

Fig. 7. Map showing probable extent of Upper Cambrian sea in Texas.

RELATION OF THE TEXAS CAMBRIAN TO THAT OF THE ADJOINING STATES

The sea in which the Texas Cambrian sediments accumulated is part of a great Upper Cambrian inundation which spread over a large part of the Mississippi Valley, and continued westward across southern Oklahoma, central Texas, and southern New Mexico and across much of the present Rocky Mountain region. Within this sea in Texas were deposited the formations already described.

[27]Publications relating more particularly to the extent of the Upper Cambrian seas in the Texas region listed in the bibliography include the following: Schuchert, 1382b, 1383; Sellards, 1440, 1443.

In Oklahoma similar deposits accumulated in the Arbuckle-Wichita region. Farther to the northeast, lithologically and faunally related Upper Cambrian deposits are brought to the surface in the Ozark uplift. Similar deposits come to the surface in the Black Hills of South Dakota, in the Big Horn Mountains of Wyoming, and in Colorado, Utah, New Mexico, Arizona, and elsewhere.

The deposits within this great interior sea present characteristics which vary with depositional conditions. Throughout much of the region the Upper Cambrian rests on pre-Cambrian, the Middle and Lower Cambrian being absent. The basal beds are very commonly detrital in nature, consisting of sands and arkosic materials. In a general way these basal deposits of the Upper Cambrian may be correlated, although it cannot safely be assumed that they are in all respects contemporaneous. Among names applied to these sediments in the extensive region covered by the Upper Cambrian sea are Lamotte sandstone in the Ozarks, Reagan sandstone in the Arbuckle-Wichita region of Oklahoma, Hickory sandstone in the Llano uplift of Texas, and Bliss sandstone in the El Paso region of Texas and New Mexico.

In the Texas region, as already stated, the basal sandstones are succeeded by calcareous and glauconitic deposits including limestone. This is true also in the Arbuckle-Wichita region of Oklahoma, the Ozark Mountains of Missouri, and the Black Hills of South Dakota. In Oklahoma, as in Texas and some other localities, the latest Cambrian deposits in this sea include dolomitic limestone. The next succeeding deposits in the same regions were likewise of similar character, so that the exact dividing line between Cambrian and Ordovician is difficult to locate.

ORDOVICIAN SYSTEM

Ordovician formations are exposed at the surface in five areas in Texas as follows: the Llano, Marathon, Solitario, Van Horn, and El Paso regions. The deposits include a shaly sandstone and chert facies in the Marathon and Solitario regions and in the other regions a magnesian limestone facies.

Some of the well-crystallized limestones of the Ellenburger group have been quarried to a limited extent as marbles and for terrazzo material. These limestones underground contain a large supply of water which is usually highly impregnated with hydrogen sulphide gas. Some petroleum has been produced from the limestones of the Ellenburger group at several localities in north-central Texas, and commercial production has been obtained from these formations on the Red River uplift. The deep production in Reagan County, from 8450 to 8772 feet, is from the Ordovician. The maximum depth drilled in this field to the end of 1932 is 9562 feet in Well No. 1-C.

The Ordovician formations recognized in surface exposures in the state are as follows:*

	Llano Region	Van Horn Region	El Paso Region	Marathon Region
Upper Ordovician (Cincinnatian)	Wanting	Montoya	Montoya	Maravillas
Middle Ordovician (Mohawkian)	Wanting	Wanting	Wanting	Woods Hollow Fort Peña
Lower Ordovician (Beekmantown)	Ellenburger group (Cambrian in part)	El Paso	El Paso	Alsate Marathon

LLANO REGION

ELLENBURGER GROUP

The Lower Ordovician is present in the Llano region and is included in and comprises the upper part of the Ellenburger formation as originally defined. However, several distinct units may be recognized in the Ellenburger group, some of which, as already stated, are Cambrian in age. The Lower Ordovician of the Central Mineral region closely resembles that of the Ozark region, and, according to Dake and Bridge, the equivalents of several of the Missouri formations are recognizable in the Ellenburger group (386b).[28]

GASCONADE EQUIVALENT

The equivalent in the Ellenburger group of the Gasconade formation is a crystalline dolomite with more or less chert. This dolomite is divided into an upper and lower member by several beds of dense,

*For the location of these regions in the state see figs. 3 and 4, pp. 28-29.

[28]Publications relating to the Ordovician of the Llano region listed in the accompanying bibliography include the following: Comstock, 271, 274; Dake and Bridge, 386b; Jones, 891; Paige, 1172; Roundy, Girty, and Goldman, 1354; Shumard, 1470; Udden and Waite, 1669; Ulrich, 1674b.

fine-grained, snow-white limestone. Fossils are present although not abundant. This formation may be seen in the bluff on the left side of the Colorado River opposite the mouth of Jim John Creek in the northwestern part of the Burnet Quadrangle. The rock exposed, here about 100 feet above the base of the section, is a dolomitic limestone containing fossils and some chert. The full thickness of the limestone at this locality was not determined but is in excess of 260 feet (386b). The formation is exposed also on the Cherokee-San Saba road from about 5 to 7.4 miles north of Cherokee. A quarry now abandoned has been opened in the limestone member of this formation east of the road, 6.7 miles north of Cherokee. On the Mason-Brady road 0.8 miles north of the San Saba River, a dense limestone, regarded by Dake and Bridge as a middle member of the Gasconade, rests upon the Signal Mountain formation, the intervening formations, Potosi, Eminence, and lower Gasconade being absent at this exposure.

The fossils recognized by Dake and Bridge in the Gasconade equivalent in Texas are *Helicotoma uniangulata* (Hall), *Pelagiella paucivolvata* (Calvin), *Gasconadia putilla* (Sardeson), *Sinuopea humerosa* Ulrich, *Sinuopea,* 3 or 4 undescribed species, *Hypseloconus* sp., *Ozarkina typica* Ulrich and Bridge, *Ozarkina* sp., *Ecyliomphalus gyroceras* (Roemer), undescribed species referable to *Levisoceras, Dakeoceras, Ophileta, Heliocotoma.*

Type locality: The type locality of the Gasconade formation is in the Ozark region of Missouri.

ROUBIDOUX EQUIVALENT

The equivalent in the Ellenburger group of the Roubidoux formation of the Ozark region is a cherty dolomite. On the Cherokee-San Saba road 8.4 and 9.1 miles from Cherokee, fossils characteristic of the Roubidoux formation (386b) are found in abundance. The thickness of the section cannot be measured at this exposure. However, on and near the Llano River, 10 miles southwest of Mason, Dake and Bridge recognized a lower member 100 feet thick consisting of gray cherty dolomite, and an upper member of dense white limestone about 250 feet thick, both containing Roubidoux fossils.

Among fossils reported by Dake and Bridge (386b) from the Roubidoux equivalent in Texas are the following: *Syntrophina* *campbelli* (Walcott), *Roubidouxia* sp. undescribed, *Lecanospira sanctisabae* (Roemer), *Ophileta.* Other gastropods, trilobites, and cephalopods are also present.

Type locality: The type locality of the Roubidoux formation is in the Ozark region of Missouri.

JEFFERSON CITY AND COTTER EQUIVALENTS

The equivalent in the Ellenburger group of the Cotter formation of the Ozark region is chiefly a pinkish-gray crystalline limestone. In an exposure on Honey Creek, 10 miles southeast of Llano, the uppermost 500 feet of the Ellenburger group is limestone of this character. Within 30 or 40 feet of the top of the section is a fossiliferous zone regarded by Dake and Bridge as Cotter in age or younger, and the upper 500 feet of this section is referred by them to Cotter or possibly in part to the underlying Jefferson City. Other localities yielding Jefferson City or Cotter fossils are as follows: 9.7 and 11.4 miles south of Cherokee on the San Saba road; and 1.5 miles south of the Colorado River on the Johnson City road.

The most abundant fossil, coming probably from the Jefferson City equivalent, is the sponge, *Calathium.* From higher in the section, probably the Cotter equivalent, Dake and Bridge obtained the following: *Orospira* cf. *bigranosa* Ulrich, *Ceratopea,* 2 species, *Ophileta* cf. *canadaensis* (Billings).

Type localities: The type localities of the Jefferson City and Cotter formations are in the Ozark region of Missouri and Arkansas.

These several units, the Gasconade, Roubidoux, Jefferson City, Cotter, and perhaps others, although recognized as present in the Ellenburger group, have as yet been but imperfectly delimited, and the surface distribution of each cannot now be given.

The Ellenburger group as a whole, including both the Cambrian and Ordovician formations, on the surface and underground, is widespread in Texas. Its thickness ranges from a thin stratum to 2,000 feet. This great irregularity is due in part to erosion, the formation having in places been removed. An unevenness in thickness occurs likewise through absence of some of the formations of the group. Thus Dake and Bridge find the Cambrian formations of the Ellenburger (Potosi and Eminence equivalents) present in the northwestern part of the Burnet Quadrangle but absent farther west at

Camp San Saba, the overlying upper Gasconade there resting on the Signal Mountain formation. This absence of the Potosi and Eminence equivalents is interpreted by them as evidence of overlap, although it may, of course, also represent an erosion interval between the Eminence and Gasconade.

Owing to the great economic importance of recognizing the Ellenburger in drilling, this group of formations has been extensively studied from well cuttings, and its place underground has been determined over a large area in the central part of the state. The limestones and dolomites of this group are separable from other formations in this part of the section by their lithologic characteristics, thus facilitating their identification in wells. The minute texture of the dolomitic limestones as seen in thin section is distinctive (1669). The insoluble residues afford criteria by which not only the group but the several formations may be more or less readily recognized. Megafossils are present at several horizons, as indicated in the preceding description of formations.

The outcropping belt of the Ellenburger formations encircle the Llano uplift and some formations of the group evidently formerly extended across the uplift. In its present structural relations it dips away in all directions from this uplift.

The maximum thickness of the group as revealed by well drilling is found in eastern Brown, eastern McCulloch, Mills, and western Lampasas counties. This area is between the Lampasas and Bend arches. The present great thickness of the Ellenburger group in this region may be due to non-erosion in pre-Bend time, or may be due to non-deposition on the Bend and Lampasas arches if they were positive elements as early as Ordovician time, which is possible. In these counties, Ellenburger thicknesses are found as follows: southeastern Brown County, Cress well, 1,346 feet; southeastern McCulloch County, Beasley well, 1,235 feet; Mills County, Harrison well, 1,525 feet, and western Lampasas County, Wittenburg well, 1,977 feet. Much thinner Ellenburger is found in the western part of these counties and farther west, as follows: western Brown County, Fuller well, 1,074 feet; western McCulloch County, Zella well, 875 feet, and White well, 952 feet; and Taylor County, Webb well, 561 feet. On the Lassiter farm in Palo Pinto County a well was drilled

1,600 feet into the Ellenburger without reaching the bottom of the formation.

On the Red River uplift, thicknesses of the Ellenburger are recorded varying from a thin stratum to 1,000 feet. Thus, in the Whaley well of McElreath and Suggett and in the Donald well, Gulf Production Company, in Cooke County, the Pennsylvanian rests directly on pre-Cambrian, the early Paleozoic being absent. This is true also of Matthews 1 and 3 of the Shell Company in Foard County. In the Daugherty well, Benson Brothers, Cooke County, the thickness of the Ellenburger is 961 feet.

VAN HORN AND EL PASO REGIONS

EL PASO FORMATION

The Lower Ordovician is represented in the Van Horn and El Paso regions by a magnesian limestone, the El Paso formation. In the Van Horn region this formation consists of gray magnesian limestones with some chert and, near the base, lenses of sandstone. It is exposed in Beach and Baylor mountains. In the El Paso region the formation, consisting of magnesian limestone and some chert, is exposed in the Franklin and Hueco mountains. In the Van Horn region, according to Richardson (1314), the formation is sparingly fossiliferous throughout, the fossils being of Beekmantown (Lower Ordovician) age. The remainder contains a few Lower Ordovician fossils. The El Paso limestone is mottled and well bedded.

In some of the original descriptions there was included with the Van Horn formation a series of quartzose sandstones and grits, which grade into the El Paso limestone above, and which contain, to near their base, Ordovician fossils. It was in these beds that Streeruwitz reported worm borings. The quartzose sandstones rest with a clean-cut contact on the Van Horn arkoses, and in view of their Ordovician fossils and their relations to the limestone above, they are now placed as the basal member of the El Paso limestone.[29]

The more common fossils of the El Paso formation are: a sponge, *Calathium* sp.; gastropods including *Ophilita* sp., *Maclurea* sp.; and an orthoceroid related to *Piloceras* or *Cameroceras* (1312).

[29]Publications relating to the Ordovician of the Van Horn and El Paso regions listed in the accompanying bibliography include the following: Baker, 46; King, 936b; Richardson, 1304, 1310, 1312, 1314; Streeruwitz, 1561, 1566.

Type locality: Franklin Mountains in the El Paso region; thickness, 1,000 feet. The formation was named by Richardson (1304).

MONTOYA FORMATION

The Montoya formation found in both the Van Horn and El Paso regions is similar in character to the El Paso limestone. In the El Paso region it is seemingly conformable with the El Paso formation and is separable only on the evidence of the fossils. In the Van Horn region sandstone is found locally at the base of the Montoya, varying in thickness up to 100 feet. Exposures are found at the southern end of the Franklin Mountains and generally as a narrow band in the upper part of the east-facing scarp of the mountains. In the Hueco Mountains the formation may be seen in Long Canyon about 4 miles east of Helms West well (King, 396b), and 9 miles southeast of Hueco Tanks (1312, p. 4). In the Van Horn region it may be seen at the southeast side of Baylor Mountain and capping Beach Mountain. In addition, King has observed the limestones in the east scarp of northern Sierra Diablo between Marble and Apache canyons (936b, p. 96). In the lower part of the formation fossils are abundant, representing, according to Ulrich and Kirk, a Cincinnatian fauna. The fossils include several well known Upper Ordovician brachiopods, the sponge *Receptaculites,* and various corals, such as *Halysites.*

The Montoya formation is predominantly thickly bedded, and crops out in bold ledges, such as those on the crest of the Franklin Mountains at its southern end. Moreover, the formation is characteristically very cherty, with the cherts occurring as long lenticles in the limestone.

The best exposure of the Montoya limestone in the region is at the south end of the Franklin Mountains at the high point on the El Paso scenic drive. Excavation for the road has revealed its basal contact and to the west several hundred feet of its lower beds.

Type locality: Franklin Mountains, east of Montoya station, 10 miles north of El Paso; thickness, 250 feet. The formation was named by Richardson (1312).

MARATHON AND SOLITARIO REGIONS

The Ordovician of the Marathon region includes extensive deposits of shales, sandstones, limestones, and cherts. King has recently divided the Ordovician of the Marathon region into five formations as follows: Marathon, Alsate, Fort Peña, Woods Hollow, and Maravillas (936a).[30]

MARATHON FORMATION

The Marathon formation consists of flaggy beds of limestone, prevailingly gray or black in color and usually dense in texture. Shale partings are interbedded with the limestone and greenish clay strata are present. Some sandstone and conglomerate are found in the formation and also a limited amount of chert. The formation is exposed on the surface at the town of Marathon, and at the northeast end of Dagger Flat anticlinorium. Good exposures are seen also 3 miles west of old Fort Peña Colorada and on Alsate Creek. The relative amount of limestone in the formation increases northward, and to one of the limestone members, approximating 75 feet in thickness near the middle of the formation, King has applied the term Monument Spring dolomite (936a, p. 1068). This member, in which Kirk found a resemblance both in lithology and fauna to the El Paso limestone, thins and disappears southward.

The fauna of the Marathon formation includes many graptolites, among which are *Tetragraptus, Phyllograptus, Didymograptus, Goniograptus, Loganograptus,* and *Dictyonema.* Brachiopods, pteropods, trilobites, and sponges are present. According to identifications made by Kirk. the fauna indicates Deepkill (Beekmantown) age.

A small collection of graptolites made in the central part of the Solitario uplift by Sellards and Baker in March, 1931, was found by Ruedemann to contain *Phyllograptus ilicifolius, Tetragraptus fruticosus,* and *Didymograptus bifidus.* These indicate, according to Ruedemann, middle Deepkill (Beekmantown). The approximate equivalent of the Marathon formation, therefore, is found in the

[30]Publications relating to the Ordovician of the Marathon and Solitario regions listed in the accompanying bibliography include the following: Marathon: Baker, 44; King and Bowman, 936, 936a; Solitario: Powers, 1249; Sellards, Adkins, and Arick, 1436; Udden, 1626.

Solitario uplift. The limestone facies, however, is less well developed there.

Type locality: Marathon; thickness, 500 to 1,000 feet. The formation was named by King (936a).

ALSATE FORMATION

The Alsate formation is chiefly a shale with varying amounts of limestone. It is well exposed on Alsate Creek a few miles south-southwest of Marathon, and in the Marathon and Dagger Flat anticlinoria. In the northern area of its exposures it is largely shale with some sandstone and conglomerate. Southward it contains numerous thin limestone strata, and in the Dagger Creek anticlinorium, where it is 125 feet or more thick, contains limestone ledges similar to those of the overlying Fort Peña formation.

Graptolites are present in this formation, including *Oncograptus, Didymograptus, Tetragraptus, Phyllograptus.* In the formation is found also the gastropod *Maclurea,* a small *Orthis,* and a few trilobites. The fauna, according to Kirk, indicates high Beekmantown.

Type locality: Alsate Creek, 2½ miles west of Fort Peña Colorada; thickness, 25 to 125 feet. The formation was named by King (936a).

FORT PEÑA FORMATION

The Fort Peña formation consists of thick bedded limestones and cherts with some thin partings of shale. The chert layers are usually thin, although in some localities they reach a thickness of 3 or 4 feet. At the base is a conglomerate consisting of pieces of chert, limestone, and sandstone.

Fossils are not abundant in this formation. However, a small fauna obtained by King indicates the Middle Ordovician age of the formation. The genera listed by him are *Climacograptus, Diplograptus, Didymograptus, Tetragraptus, Ceraurus, Bucania, Orthis,* and other brachiopods.

Graptolites obtained from the Solitario were identified by Ruedemann as including *Diplograptus (Glyptograptus) angustifolius* Hall of Normanskill (Chazy) age. It would seem, therefore, that the approximate equivalent of the Fort Peña formation is found in the Solitario uplift.

Type locality: ridge north of Fort Peña Colorada; thickness, 125 to 200 feet. The formation was named by King (936a).

WOODS HOLLOW FORMATION

The lower part of the Woods Hollow formation consists, according to King, of flaggy thinly laminated gray or yellowish sandy limestone, or limy sandstone with shale partings, and grades upward into greenish clay shale with a few interbedded limestone layers. Some beds of nodular limestone are present which contain comminuted remains of various fossils.

Exposures of this formation are found in the Marathon region between Woods Hollow and Little Woods Hollow Creek on the former Louis Granger ranch. Other exposures are seen near Peña Blanca Spring and Garden Springs. An abundant fauna is found in this formation including graptolites, bryozoa, trilobites, brachiopods, and bivalves. This fauna indicates Middle Ordovician age, approximately Trenton.

Collections made from the Solitario by Sellards and Baker in 1931 were identified by Kirk as containing the following fossils: *Trematis, Orthis, Ceraurus, Hebertella.* These, in the opinion of Kirk, indicate the Woods Hollow formation.

Type locality: Woods Hollow Mountain; thickness, 470 feet. The formation was named by King (936a).

The sediments making up the four formations last described, which are of a considerable thickness, were placed originally by Baker and Bowman in the Marathon series. Formation names were not assigned at that time to the subdivisions of this series. From fossils then obtained, however, it was recognized that the Marathon series included formations of both lower and upper Ordovician age (44).

MARAVILLAS FORMATION

The lower part of the Maravillas formation consists of thick ledges of dark-gray limestone with interbedded thin layers of dark chert and thin dark bituminous limestones. Some thin conglomerate beds are present. Southwest of Marathon, near Monument Springs and Rock House Gap (Payne Ranch), these conglomerates, containing cobbles and boulders, reach a thickness of from 10 to 20 feet.

The upper part of the formation consists very largely of thin-bedded black chert. Thin layers of bituminous limestone and shale are found in this part of the formation between the chert strata. One of these shale strata has a thickness of about 5 feet. At its base where conglomerate beds are present this formation, according to Baker and Bowman, rests unconformably on the older beds. A pronounced erosional break separates it from the overlying Caballos novaculite. The formation is extensively exposed in the Marathon area. Among easily accessible exposures are those at Fort Peña south of Marathon.

The Maravillas formation is abundantly fossiliferous, particularly in its lower part. The fauna obtained by Baker and Bowman, which includes graptolites, bryozoa, brachiopods, corals, and trilobites, was identified by E. O. Ulrich and was at that time regarded as being in part Trenton and in part Richmond in age. A re-study of this and related faunas from the western United States has led Kirk to regard these faunas as representing Cincinnatian only. Accordingly, the Maravillas is now regarded as being entirely Upper Ordovician. Kirk regards this formation as the approximate equivalent of the Montoya formation. The fossils of this formation have been listed by Baker and Bowman (44, p. 89).

The Maravillas formation is present in the Solitario uplift, where, as in the Marathon area, it forms prominent cliffs. In the eastern part of the basin this formation is exposed in several northeast trending anticlines. Near the northeast and the southwest margins of the basin the Maravillas occurs in large fault blocks. The thickness of the formation has not been measured at this locality, but it is obviously several hundred feet thick.

Type locality: Maravillas gap, 20 miles south of Marathon; thickness, 100 to 400 feet. The formation was named by Baker and Bowman (44).

Overlying the Maravillas chert in the Solitario uplift is a green shale, the maximum observed thickness of which does not exceed 25 or 50 feet. This shale, lying between these heavy cherts and the Devonian novaculite, is but imperfectly exposed and as a rule is seen only as a grass covered slope between these two formations. The best exposures seen were in fault blocks in the southwest and northeast parts of the basin. A similar shale of lesser thickness is locally present in the Marathon uplift, where it is occasionally present between the Maravillas chert and the Caballos novaculite (44, 936a).

Illustrations of some of the fossils of the Ordovician systems are given in Plates III and IV.

UNDERGROUND POSITION OF THE ORDOVICIAN IN TEXAS

Lower Ordovician.—Through the aid of well drilling, the position of the Lower Ordovician underground is located over an extensive region in central Texas and thence north to the Oklahoma line. From its outcropping belt in the Llano uplift the Ellenburger limestone dips away in all directions. To the east and southeast its extent is limited, since it is not present in wells drilled in Caldwell County. To the southwest and west it has been found to be present where wells have penetrated the overlying formations. To the north and northeast of the Llano uplift the formation is entered by numerous wells as far north as Young County, and is again brought within reach of the drill on the Red River uplift in Denton, Cooke, and Montague counties. It is absent, so far as records have shown, from the crest of the highs in the Red River uplift, in the Panhandle region, and in Foard and Pecos counties. On the other hand, it is possibly present at the sides of these uplifts, and, if so, its former extent entirely across western Texas is thus indicated.

The counties in which wells have been drilled into or through the Ellenburger group in central Texas are as follows: Brown, Callahan, Coleman, Comanche, Concho, Cooke, Coryell, Denton, Eastland, Edwards, Erath, Hood, Irion, Jack, Kimble, Kendall, Lampasas, McCulloch, Menard, Mills, Palo Pinto, Reagan, Runnels, San Saba, Shackelford, Stephens, Throckmorton, Sutton, Wichita?, Wilbarger?, Young, Crockett.

In Grayson County in northern Texas, well drilling has revealed Ordovician shales and cherts of the Ouachita facies (1117). In Reagan and Crockett counties deep drilling has revealed the presence of Middle Ordovician, Simpson or Chazy series, underlying the Permian basin.* These sediments include shales, sandstone, and

*A well entering the Ellenburger in Crockett County (Stanolind Oil Company No. 1 Todd), not indicated in fig. 8, p. 81, was completed in December, 1932, while this report was in press. (Identification of samples by H. A. Hemphill.)

limestones (1428). The Upper Ordovician has not been found in drilling.[31]

ORDOVICIAN SEAS IN THE TEXAS REGION

Lower Ordovician.—From surface exposures and well records it is possible to locate an extensive sea in Lower Ordovician time, reaching, as did the Upper Cambrian sea, entirely across Texas from northeast to southwest. Two facies of deposition are present, geosynclinal at the southeastern margin of the sea, and foreland over a larger region. In the foreland facies deposition during Lower Ordovician time consisted largely of magnesian limestone,

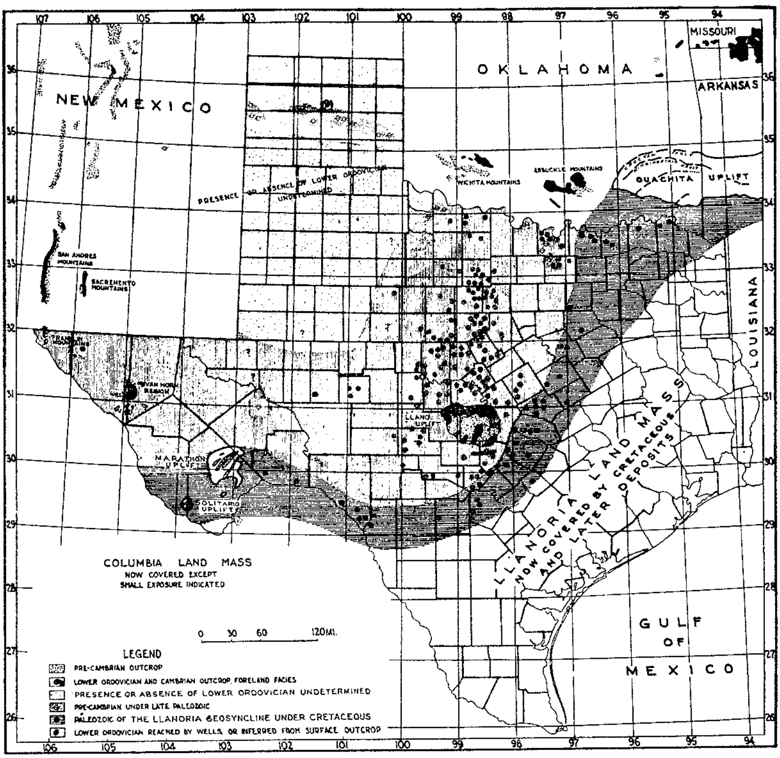

Fig. 8. Map showing probable extent of Lower Ordovician sea in Texas.

[31]Publications relating to the underground position of the Ordovician in Texas listed in the accompanying bibliography include the following: Cheney, 246, 247; Harlton, 653; Lowman, 1020, 1021; Miser and Sellards, 1117; Sellards, 1403, 1428, 1441.

including the upper part of the Ellenburger group of the Llano uplift and the El Paso limestone of the Van Horn and El Paso regions. Geosynclinal deposits of Lower Ordovician time are exposed in the Marathon and Solitario regions, where they consist of shales, cherts, non-magnesian limestones, and some sandstone. In addition, wells in northeastern Texas, Red River, Lamar, Grayson, and Fannin counties, have entered shale and quartzite believed to be of Ordovician and Cambrian age representing the southwestern extension of the Ouachita geosyncline (1117, 1441). The continuation of the geosyncline southwestward to the Marathon region is indicated by well records. The geosyncline lies in the Coastal Plain near its inner margin, and is concealed by Cretaceous sediments. In view of the extensive inundation of the foreland and the presence of Lower Ordovician seas at the east and west ends of the geosyncline, it is assumed that Lower Ordovician seas extended entirely through the geosyncline bordering Llanoria. The Lower Ordovician sea thus spread extensively across central Texas. Although absent from the crest of the uplifts in the Amarillo region and in Foard County, the Lower Ordovician may be present off these highs as is possibly indicated by wells in Foard and Wheeler counties.

The position of the Lower Ordovician sea in Texas is indicated in Figure 8, page 81.

Middle Ordovician.—Middle Ordovician is exposed in the Marathon and Solitario regions, and is found in wells in Reagan County at a depth of from 8,200 to 8,500 feet.* Aside from these three localities the extent of the Middle Ordovician sea in Texas is as yet undetermined. The exposures of older rocks in the Llano region fail to reveal the presence of Middle Ordovician, and this appears to be true also of the Van Horn and El Paso regions. Moreover, there is, as yet, no conclusive evidence of the presence of Middle Ordovician between the Reagan County locality and the north boundary of Texas. The widespread distribution of Middle Ordovician in Oklahoma would cause one to expect an extension of this sea across Texas, but this inference is at present unproven. Reworked Simpson fossils are reported to have been found in Pennsylvanian formations in a well on the Elva Ranch in Hutchinson County.

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*While this report was being printed Simpson was encountered in the Stanolind Oil Company No. 1 Todd well in Crockett County at a depth of 7006 to 7247 feet. (Letter from A. L. Ackers, December 20, 1932.)

Upper Ordovician.—Upper Ordovician deposits are found extensively in Oklahoma and are present in the Van Horn, El Paso, and New Mexico regions. The presence of Upper Ordovician (Richmond) is reported in Reagan County (653) and in Young County (247), although in both instances on evidence not in all respects satisfactory. In addition to its demonstrated presence in west Texas, it is not improbable that the Upper Ordovician sea invaded an extensive area through central Texas, but such invasion is scarcely demonstrated at the present time.

Upper Ordivician is well represented in the Marathon and Solitario regions of west Texas and in the Ouachita region of Oklahoma and Arkansas. Moreover, the extension of the sea of this time into the geosyncline in Texas is demonstrated by the presence of graptolites of this period from a well in Grayson County (1117). In view of these facts, it would appear that the Upper Ordovician sea occupied the geosyncline bordering Llanoria.

RELATION OF THE TEXAS ORDOVICIAN TO THAT OF THE ADJOINING STATES

The sea that extended across Texas in Lower Ordovician time connected through southern Oklahoma with the larger flooded area of the Mississippi Valley, and through southern New Mexico with the southern Pacific coast region. Accordingly, deposits similar in character and more or less nearly contemporaneous in age are found in these states. In Oklahoma these sediments are included in the Arbuckle formation of the early literature. To the westward the El Paso limestone of western Texas extends into New Mexico.

Although disconnectedly exposed, the Lower Ordovician of Texas in the Llano, Van Horn, and El Paso regions (Ellenburger and El Paso formations), as well as that entered by wells on the Red River uplift, is believed to correlate with the main part of the Arbuckle series of Oklahoma and with the Beekmantown of the northeastern part of the United States.

The Ordovician reached by deep wells in the Permian basin in Reagan and Crockett counties is of the age of the Chazyan and Beekmantown of the eastern United States (1428). The Montoya formation has been determined by Ulrich and Kirk as having a Cincinnatian fauna.

SILURIAN SYSTEM

The Silurian, as here used, includes the formations from the close of the Richmond to the close of the Cayugan. Three series are included in the Silurian system as follows: Alexandrian, Niagaran, and Cayugan. As thus defined, the Silurian is but scantily represented in surface exposures in Texas and as yet is but little known underground. The one Silurian formation recognized in surface exposures in Texas is the Fusselman limestone of the El Paso and Van Horn regions. In addition Silurian deposits are believed to have extended from the Ouachita region of Oklahoma into the Llanoria geosyncline in Texas.*

The Lower Silurian, Alexandrian, has not been recognized in surface exposures in Texas. Deposits of this age are reported to have been found underlying the Permian basin in Reagan County (653, p. 617; 1019, p. 618). These observations, however, have not been subsequently confirmed. To what extent, if at all, the Lower Silurian underlies the Permian basin is as yet unknown. Of Upper Silurian, Cayugan, likewise no record has yet been found in Texas.[32]

EL PASO AND VAN HORN REGIONS

FUSSELMAN FORMATION

Silurian rocks are exposed in the Franklin, Hueco, and Diablo mountains of the El Paso and Van Horn regions and have been described as the Fusselman formation. This formation is prevailingly a massive light-colored magnesian limestone. It is exposed in the northern part of the Franklin Mountains where it caps the highest peaks. It occurs also farther south within two miles of Fort Bliss. Exposures may be seen about 7 miles south of Hueco Tanks in Hueco Mountains. According to Richardson, small reworked pebbles resembling the Montoya formation are found in the Fusselman limestone in exposures north of El Paso indicating an erosional unconformity. Recently King (936b) has recognized this formation in outcrops at the east margin of the Sierra Diablo, where it is preserved in minor synclines in the Baylor Mountains

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*For the location of these regions see fig. 3, p. 28, and fig. 10, p. 128.

[32]Publications relating to the Silurian in Texas listed in the accompanying bibliography include the following: Darton, 395; King, 936b; Richardson, 1312.

and in the northern part of the Diablo scarp between Marble and Apache canyons. The formation here is 300 or 400 feet thick and as in the Franklin Mountains consists of white dolomitic limestone with few fossils.

Fossils in the Fusselman formation are not abundant but are found at a few localities. Among the fossils obtained are *Pentamerus*, *Amplexus*, and *Favosites*, the species present indicating, according to Ulrich, an Upper Niagaran age.

Type locality: Fusselman Canyon in the Franklin Mountains; thickness, approximately 1000 feet. The formation was named by Richardson (1312).

UNDERGROUND POSITION OF THE SILURIAN IN TEXAS

Relatively little drilling having been done in the parts of west Texas in which Silurian is known to be present, no information has as yet been obtained as to its underground distribution. Among wells in the Llanoria geosyncline considered as probably entering Silurian are the Slayden well in Bell County, the Pucek well in Falls County, and the Elsner well in Hays County, all of which contain altered shale or phyllite resembling the Missouri Mountain slate (see table of wells, pp. 188, 189).

SILURIAN SEAS IN THE TEXAS REGION

Lower Silurian.—In the region of the Llano uplift Silurian is absent both in surface exposures and, so far as determined, in wells. From the crest of the Red River uplift in Cooke, Montague, and adjoining counties the Silurian is likewise absent as shown by well drilling. This is apparently true also of wells drilled in the Amarillo region and in Wilbarger and Foard counties. That the Silurian, although absent from the crest of these highs, may be present on the flank and in the synclines is, of course, possible, although at present there is no definite evidence of a Lower Silurian sea in the Texas region.

Middle Silurian.—The Fusselman limestone is proof of a Middle Silurian sea in the El Paso and Van Horn regions of Texas. How widely these deposits may have originally extended can only be conjectured. These older Paleozoics are known in the state largely on structural highs which bring them to or near the surface. The

Silurian if originally present on such uplifts has, with the exception of the El Paso and Van Horn regions, been removed by erosion. To what extent such formations persist in the basins now covered by later deposits can be determined only by drilling.

That a Silurian sea invaded the geosyncline in front of Llanoria is shown by the presence of formations of this period in the Ouachita Mountains of Arkansas and Oklahoma where the Blalock sandstone and Missouri Mountain slate probably represent this system. From cores obtained from wells it is considered probable that the Silurian of the Ouachita Mountains area continues southwestward underlying the Cretaceous at the inner margin of the Gulf Coastal Plain to or beyond Blanco County in the central part of the state (1117, 1441).

RELATION OF THE TEXAS SILURIAN TO THAT OF ADJOINING STATES

The Middle Silurian of the El Paso and Van Horn regions, Fusselman formation, extends northward and westward into New Mexico (Darton, 395). Deposits of equivalent age, although differing lithologically, are found in the Hunton series of Oklahoma.

How far eastward in Texas this sea extended is unknown, no Silurian deposits having been found in the Marathon, Solitario, or Llano uplifts. However, in view of the fact that Silurian seas spread across southern Oklahoma and are believed to have reached into Texas in the trough in front of Llanoria, it would not be unexpected to find that a part or all of central Texas was inundated during Silurian time. At present, however, there is no record of such seas in the foreland facies in central Texas.

DEVONIAN SYSTEM

Devonian deposits attain a considerable development in the Marathon and Solitario regions of Texas and are present in the Franklin Mountains of the El Paso region and in the Diablo Plateau of the Van Horn region. Devonian of the geosynclinal facies is probably present also in the Llanoria geosyncline.[33]

[33]Publications relating to the Devonian in Texas include the following: Baker and Bowman, 44; Darton, 396; King, 932, 936, 936a, 936b; Udden, Baker, and Böse, 1652.

MARATHON AND SOLITARIO REGIONS

CABALLOS FORMATION

The Devonian of the Marathon region has been described by Baker and Bowman (44) and by King (936a). Originally two formation names were proposed, the Caballos novaculite and the Santiago chert (1652, pp. 39–41). Subsequently, however (44, p. 93), but one formation was recognized, the Caballos. The formation consists almost entirely of novaculite and chert, the two varieties differing but little in composition. The novaculite is the more resistant to erosion, and being white in color and capping many of the ridges, it is the most conspicuous formation in the Marathon basin. The chert is vari-colored, being green and black. The only fossils found in the formation are linguloids in some of the limestones, and radiolaria, which are best preserved in the chert.

King (936a) has noted variation in facies in this formation, the novaculite which predominates in the southeastern area giving place in part northwesterly to bedded chert with shale partings and some limestone. This author divides the formation into five (unnamed) members as follows: lower chert, lower novaculite, middle chert, upper novaculite, and upper chert. Of the two novaculite members, the lower is thickest in the northern part of the area and the upper in the southern part.

A similar formation is found in the Solitario uplift, where it is conspicuous by its white color and cliff exposures.

Because of the position of the Caballos in the section of its lithologic resemblance, this formation is correlated with the novaculite of the Ouachita Mountains of Oklahoma and Arkansas. The Arkansas novaculite in turn is considered to be Devonian of Oriskany or Onondaga age, that is the upper part of the lower Devonian or lower part of middle Devonian.

Fossils are rare in the Arkansas novaculite. Honess in his detailed study of this formation in Oklahoma found but one recognizable fossil, *Leptocoelia flabellites,* characteristic of the Oriskany or Onondaga (838, p. 117). The fossil was found near the top of the lower division of the novaculite in Oklahoma.

From the middle and upper parts of this formation in Arkansas, Miser and Purdue (1114, p. 58) obtained fossil wood, conodonts, linguloids, and *Sporangites*. These fossils, according to Ulrich, indicate that the middle and perhaps upper parts of the formation are of the age of the Woodford chert and Chattanooga shale.

The Caballos formation contains radiolaria, and in the northwestern part of the basin, where thin limestones come into the section, contains linguloid brachiopods (936a, p. 1078).

Type locality: Caballos Mountain, 14 miles southeast of Marathon; thickness, variable from 200 up to 600 feet. The formation was named by Baker and Bowman (44).

EL PASO AND VAN HORN REGIONS

PERCHA FORMATION

The Devonian of the Franklin Mountains, according to Darton (396, p. 116), is chiefly shale resting upon the Fusselman limestone (Silurian) and overlain by Mississippian or Pennsylvanian. Only limited exposures occur. The shale is lithologically similar to, and probably is to be correlated with, the Percha shale of New Mexico.

The fossils found in these shales are *Orbiculoidea* sp., *Lingula* sp., and fragments of a large pelecypod. The section published by Darton indicates 174 feet of shales and limestone exposed at the locality measured. The one exposure of this formation in Texas described by Darton is on the west slope of the Franklin Mountains, 12 miles north of El Paso and 5½ miles east and 1½ miles north of Canutillo station.

Rocks regarded as possibly of Devonian age have recently been found by King in the eastern margin of the Sierra Diablo. At this locality the supposed Devonian rocks consist of 100 feet or more of black or brown bituminous shale and shaly limestone, including lenses and thin beds of white, buff, or dull green chert. The shale resembles that of the Percha formation and the chert suggests the Caballos formation. Similar shales with chert are found in the Hueco Mountains (932, p. 910).

Type locality: The type locality of this formation is on Percha Creek, near Kingston, New Mexico.

UNDERGROUND POSITION OF THE DEVONIAN IN TEXAS

Notwithstanding that numerous wells have been drilled over a large area in central Texas reaching to formations older than the Devonian, deposits of this age have not been definitely recognized in the foreland facies of sediments in central Texas. It is true that Harlton and Lowman report Devonian in deep wells in the Big Lake oil field in Reagan County (653, 1019). However, these reports have not been satisfactorily confirmed. On the other hand, considering the fact that Devonian, represented by the Percha formation, extends into Texas from the New Mexico region, it would not be unexpected if Devonian should be found to be present underlying some parts of the foreland region of Texas.

Several wells located near the inner margin of the Gulf Coastal Plain have drilled into sediments similar to and probably identical with the Devonian of the Ouachita region of Oklahoma. Among wells entering sediments of this kind are the Bailey and Slayden wells in Bell County and probably the Walsh well in Williamson County (see tabulated data on wells, pp. 187, 191), all of which entered novaculite.

DEVONIAN SEAS IN THE TEXAS REGIONS

So far as known the earliest Devonian, Helderbergian, is unrepresented in Texas. The succeeding stage, Oriskany, or the still later stage, Onondaga, is probably represented by the Caballos novaculite and a part of the upper Devonian by the Percha shale.

The Caballos novaculite, containing radiolaria, is of marine origin, and if rightly placed as of Lower or Middle Devonian age, indicates a sea of that time occupying the Marathon geosyncline. The close lithologic resemblance of these deposits to those formed probably contemporaneously in the Ouachita geosyncline of Oklahoma and Arkansas together with supporting evidence from wells in the intervening area suggest the probability of a Devonian sea which occupied a geosyncline lying in front of the land mass Llanoria and extending from the Ouachita region of Oklahoma to the Marathon region of Texas.

In late Devonian time the sea in which the Percha formation was deposited extended into Texas, as shown by the deposits found in the Franklin Mountains and in the east scarp of the Diablo Plateau.

How far to the eastward in Texas this late Devonian sea extended is yet to be determined.

RELATION OF THE TEXAS DEVONIAN TO THAT OF THE ADJOINING STATES

The Caballos formation appears to have, on the basis of lithology, a definite relationship to the Arkansas novaculite with which it is possibly continuous underground. The Devonian of the Franklin Mountains finds its relationship and probable continuity with the Percha shale of New Mexico.

MISSISSIPPIAN SYSTEM

The formations now very generally referred to the Mississippian and Pennsylvanian systems formerly constituted a single system, the Carboniferous, and this term is still used by European geologists and by the United States Geological Survey. In the present publication, the Mississippian and Pennsylvanian are ranked as systems. The term Carboniferous is, however, here used in referring to formations that are not definitely determined as to age, and are either Mississippian or Pennsylvanian or both. The term Mississippian was proposed as a series name by Alexander Winchell in 1869 and is approximately equivalent to Lower Carboniferous or sub-Carboniferous of earlier usage or of present European usage. The Pennsylvanian was proposed as a series name by H. S. Williams in 1891 and is the equivalent of the Upper Carboniferous of earlier usage. Both series were raised to the rank of systems by T. C. Chamberlain.

Mississipian rocks are exposed in Texas in the Llano uplift and in the Hueco Mountains at the northwest margin of the Diablo Plateau. The Tesnus formation of the Marathon region, discussed under Pennsylvanian, may be in part Mississippian, the age of this formation being at present undetermined. The Mississippian limestones and shales underground in north central Texas are the source of some, although not a large quantity of, oil and gas.

The earliest definite recognition of the Mississippian in Texas was by Girty who in 1912 referred the Barnett shale to this system, and in 1926, with Roundy and Goldman, described the Boone-age limestone of San Saba County. Beede in 1918 described the Mississippian of the Hueco Mountains. Tarr in 1890 obtained a goniatite, probably from the Barnett, which Hyatt identified as a Lower Carboniferous form. Tarr appears to have referred the entire Bend group to the sub-Carboniferous (1584, p. 202).

In the following table the approximate position of the Texas formations in the system is indicated.

Series	Group	Llano Region	Hueco Mountains	Marathon-Solitario Regions
Tennesseian	Chester	Barnett formation	Helms (in part)	Tesnus (in part)
	Iowa	Not known	Not known	Not known
Waverlian	Osage	Chappel formation	Not known	Not known
	Kinderhook	Not known	Not known	Not known
	Chattanooga	Not known	Not known	Not known

LLANO REGION

In the Llano uplift both Upper and Lower Mississippian are in part represented, the Lower by a thin limestone of Boone or Osage age, here named the Chappel formation, and the Upper by limestones and shales of Chester age, the Barnett formation. These formations are affected by the post-Lower Pennsylvanian faulting of this region but otherwise present no complicated structural features. They dip away from the Llano uplift at a low angle, usually between 1 and 2 degrees, although higher dips occur locally.[34]

OSAGE GROUP

CHAPPEL FORMATION

The presence of deposits in Texas of Boone or Osage age was made known in 1926 by Roundy, Girty, and Goldman (1354). The deposits referred to this series consist of a limestone, the known maximum thickness of which in surface exposures is only a few feet. As yet this limestone is known only in a few small exposures on the north and west sides of the Llano uplift. The limestone of this formation is hard, medium dark in color, and abounds in

[34]Publications listed in the accompanying bibliography relating to the Mississippian of the Llano region include the following: Cummins, 339; Girty, 592; Girty and Moore, 593; Goldman, 601; Moore, 1131; Paige, 1172; Plummer and Moore, 1228; Roundy, Girty, and Goldman, 1354; Smith, 1496; Tarr, 1584; Udden, 1652.

crinoid fragments. It rests disconformably upon Lower Ordovician, Ellenburger, and is overlain, disconformably, by the Barnett shale. The lowermost part of this formation contains, according to Goldman, as inclusions small pellets of the Ellenburger. Moreover, the rock has in places become firmly united by cementation to the Ellenburger, so that no parting plane now exists, and the exact dividing line between the formations is difficult to determine in the field, or even by aid of sections in the laboratory. In the main, however, the two formations are easily separable both by lithology and by fossils. Previous to the work of Roundy, Girty, and Goldman, the thin Boone-age limestone was either entirely disregarded or was included either with the Marble Falls or with the Ellenburger.

The fauna of the Boone limestone of Texas as determined by Girty and Roundy is described in Professional Paper 146 of the United States Geological Survey. The megafauna including brachiopods and other fossils, according to Girty, contains largely new species and is in many respects peculiar. Twelve new species are described by Girty, eleven species are recognized as having affinity with species found elsewhere, and the remaining forms are not specifically identified (1354). Of the microfauna, one species of Ostracoda occurring in this limestone is found also in the Barnett shale and in the Fayetteville formation of Arkansas, two species are described as new, and two are regarded as doubtfully identical with species found elsewhere. On the basis of this fauna, this limestone is referred by these writers to the Boone or Osage group.

Type locality: three miles southeast of San Saba; thickness, a few feet at the outcrop, underground north and west of the Llano uplift, absent or ranging from a thin stratum to 150 feet.

CHESTER GROUP

BARNETT FORMATION

Overlying the Chappel formation or, in its absence, resting on older deposits, is the Barnett formation consisting largely of shale with a few feet of limestone at the top. In the shale are indurated layers usually from a few to several inches thick, often lense-like in occurrence. The shale is very bituminous and is dark with usually a brownish tinge. It is fissile and in places contains plant fragments which were so much disintegrated previous to fossilization as to be unidentifiable. This formation is exposed as a narrow belt around the north margin of the Llano uplift and is in places wanting. Thus in the Llano and Burnet quadrangles the Marble Falls limestone rests directly upon the Ellenburger. At the south of the Llano uplift on the Pedernales River in Blanco County a similar section is found, the Barnett being absent. Exposures and well records in the western part of Blanco County on the Pedernales River and in the Gillespie County indicate the absence of both Mississippian and Pennsylvanian, the Cretaceous there resting upon Ordovician or older formations. In Kimble County at the west side of the Llano uplift, a thin Barnett is believed to be present at least locally, being exposed on the Pfluger ranch, 6 miles east-southeast of London. South of the Central Mineral region, Barnett shale apparently is present in a well on the Kassen farm in Kendall County, but elsewhere so far as known is absent. North of the Central Mineral region this formation is very generally present underlying the Marble Falls limestone. It thickens northward becoming 200 or more feet thick in Palo Pinto and adjoining counties.

The probable age of the Barnett has given rise to much discussion, the question at issue being whether it is late Mississippian or early Pennsylvanian. As early as 1912, Girty, recognizing three divisions in the Bend, referred the lowermost division to the Mississippian (1172, p. 8). Again in 1919 (592), he emphasized the existence of an unconformity between the lower shale of the Bend series and the Marble Falls limestone, the lower shale (Barnett) being Mississippian. Moore (1131, p. 153) although regarding final correlation of the Barnett as unsettled, concurs tentatively in referring the formation to the Mississippian.

Among fossils of the Barnett indicating Mississippian age are the brachiopod, *Leiorhynchus,* the goniatite, *Glyphioceras,* and the bivalve, *Caneyella,* and other types indicating a close relationship with the lower part of the Caney shale of Oklahoma. The microfauna includes *Ammodiscus,* ostracods, and conodonts (1354). The faunas of both the Barnett and (lower) Caney, according to Girty, are strikingly similar to the Moorfield of Arkansas and the Mayes of northeastern Oklahoma, both of which are Mississippian.

The Barnett rests unconformably upon the Chappel or, where that formation is absent, upon Lower Ordovician, Ellenburger. Between the Barnett and the overlying Marble Falls, according to Goldman, is a disconformity marked by glauconite and phosphate. Girty likewise maintains that a pronounced change in fauna occurs at this line and identifies the unconformity with that which is widespread in the Mississippi Valley separating the Mississippian and Pennsylvanian systems (592, 1354). This formation was first recognized as a distinct unit by Udden, Böse, and Baker (1652, p. 42) by whom it was described as the Lower Bend shale. Subsequently the shale as a member of the Bend series was named and briefly described, including faunal lists, by Plummer and Moore (1228). The limits of the formation were subsequently extended by Girty (592) to include a few feet of the overlying limestone. The Barnett formation has a moderate dip away from the Llano uplift and away from the crest of the Bend Arch.

Type locality: Barnett Spring, San Saba County; thickness, 30 to 50 feet at the outcrop, 100 to 200 feet underground to the north.

HUECO MOUNTAINS

The Hueco Mountains are at the northwest margin of the Diablo Plateau.[35]

HELMS GROUP

The Helms group, as described by Beede (91), consists of thin-bedded often shaly limestone of prevailingly yellow, drab, or buff color. Chert occurs locally in concretions, layers, and masses. Some sandstone is present and the limestone strata are very commonly separated by marl or shale layers. Shales which in some localities amount to 100 feet or more in thickness underlie the limestones.

The strata are in places fossiliferous. The fauna has not been fully described but includes brachiopods, *Pentremites*, crinoids, cephalopods, trilobites, and the Upper Mississippian genus *Archimedes*. Weller, who examined a collection made by Beede, identified the fossils as of Chester age (91).

The Helms group rests unconformably upon the Silurian, Fusselman formation, and is separated by a disconformity from the overlying Pennsylvanian, Magdalena group. Additional information on the Helms group has been given by Philip and Robert King (932, p. 910) who recognize three divisions in the group of which the uppermost only contains the Chester fossils. The lowermost member,

[35]Among publications listed in the bibliography relating to the Mississippian of the Hueco and Franklin Mountains are the following: Beede, 89, 91; King and King, 932.

as reported by Darton, is Devonian (396). The Helms group probably occurs in the Franklin Mountains (932).

From the Hueco Mountains in which the sediments are exposed, the rocks of the formation dip in general northeastward into or under the Diablo Plateau. There are, however, pronounced local differences in the direction and amount of dip due to folding and faulting.

Type locality: southern Hueco Mountains; thickness, between 400 and 600 feet. The formation was named in 1920 by J. W. Beede (91).

MARATHON AND SOLITARIO REGIONS

In the Marathon and Solitario regions a great hiatus occurs following the Devonian and in these areas no Mississippian, so far as yet known, is present unless possibly either the uppermost part of the Caballos formation or the lower part of the Tesnus formation belongs in this system. The Tesnus formation is described under Pennsylvanian and the Caballos under Devonian.

The Stanley and Jackfork formations of the Ouachita Mountains of Oklahoma are believed to extend southwestward into Texas. These formations, however, are not exposed at the surface in Texas being concealed by Cretaceous and later formations. They are described with the other formations of the Llanoria geosyncline.

UNDERGROUND POSITION OF THE MISSISSIPPIAN IN TEXAS

Mississippian sediments of foreland facies in Texas are thin, a large part of the system being unrepresented. This observation holds for the underground development so far as known, as well as for the very limited regions of surface exposures. The Chattanooga group is unknown in the state both on the surface and underground although the Shreiner well in Edwards County is reported to contain *Sporangites* of a type known only in the Chattanooga shale. This seemingly isolated occurrence of the Chattanooga shale in the Texas region unfortunately lacks more definite confirmation. Deposits of Kinderhook age are unknown, and of the Osage group there is known at present only the one thin limestone described above under the name of Chappel formation. It is extremely difficult to make a positive identification of this limestone in well samples, the rock being finely broken by the drill. However, considerable study has been given to this problem by several of the geologists connected with oil companies in the state and a Mississippian limestone has been more or less definitely recognized underground over a large area north, west and southwest of the Llano uplift. Among the counties in which it is recognized are Callahan, Coleman, Eastland, Edwards, Shackelford, Stephens, Throckmorton, and Young (see tabulated data on wells, pp. 197–229). Limestones of this age may also be present in some of the deep wells in Reagan County although this inference at present lacks confirmation.

The Barnett shale which overlies the Chappel formation is not only more fully exposed on the surface but is also more fully recognized underground. This formation, exposed around the north margin of the Llano uplift, passes underground and is very generally recognized underlying the Pennsylvanian northward to Young County. Westward the formation is less well known although it is apparently present in Taylor County. South of the Central Mineral region the Barnett is definitely recognized in one well only on the Kassen farm in Kendall County. The counties in the state in which the Barnett has been recognized underground are Brown, Callahan, Coleman, Comanche, Eastland, western Erath, Kendall, Lampasas, McCulloch, Mills, Palo Pinto, San Saba, Shackelford, Stephens, Taylor, and Young (see list of wells, pp. 192–229).

Owing to the lack of extensive drilling the extent of the Helms group of west Texas underground is undetermined.

MISSISSIPPIAN SEAS IN THE TEXAS REGION

The central Texas region was invaded at least twice by marine waters during Mississippian time. The deposits left by each of these invasions are relatively thin nowhere exceeding, so far as known, 200 or 300 feet. A possible spread of the Chattanooga sea into Texas on which the evidence is inconclusive has already been mentioned. The earliest definitely established Mississippian sediments are those of the Chappel formation of the Osage group found at the surface in the northwest margin of the Llano uplift and more or less definitely known underground in eight or more counties southwest, west, and north of the Llano uplift extending north as much as 200 miles. These records indicate that a sea of approximately mid-Mississippian time spread widely over central Texas. From the crest of the pronounced highs such as the Red River, Amarillo, and Pecos uplifts, these deposits are wanting. They may, however, occur at the sides or in the basins entirely across western Texas although this inference is unproven at present.

Another great invasion of the Texas region occurred in late Mississippian, Chester epoch. Here again the resulting deposits, the Barnett formation of central Texas, are relatively thin. The wide extent of this late Mississippian sea is indicated by the wide distribution of the resulting deposits over a greater part of central Texas as previously described. That these sediments are now locally absent both at the surface and underground in the structurally high areas, as in the Red River uplift, is in all probability due to pre-Pennsylvanian erosion. A late Mississippian sea spread across extreme west Texas, as is shown by the presence of the Helms group of Chester age. That this sea connected across the intervening area with the Barnett sea cannot at present be asserted, nor can the northwestward limits of this sea in the Panhandle region now be determined. These deposits are absent on the Amarillo and Pecos uplifts, but this may be due to erosion.

The extent to which the Mississippian seas invaded the Llanoria geosyncline is imperfectly determined. In the Marathon and Solitario regions, as already noted, much or possibly all of the Mississippian is wanting. The Ouachita Mountain region of Oklahoma and Arkansas contain the great Stanley-Jackfork series which is placed by some as late Mississippian. This series, as previously stated, extends into Texas. Hence late Mississippian, if these formations are such, is represented in Llanoria geosyncline. Unless the uppermost part of the Arkansas and Caballos novaculites proves to be Mississippian, no evidence exists of early or middle Mississippian in this geosyncline.

RELATION OF THE TEXAS MISSISSIPPIAN TO THAT OF THE ADJOINING STATES

The Barnett is considered as of the age of a part of the Caney shale of Oklahoma. The continuity of the deposits is now interrupted across the Red River uplift, but this interruption is probably due to pre-Bend erosion. The facies of deposition in the Texas Mississippian formations is in general that of the Oklahoma and Missouri

Paleozoic, and it therefore seems most likely that the seas in which these deposits were formed were connected with the Mississippi embayment through these states.

PENNSYLVANIAN SYSTEM

The entire Pennsylvanian system is well represented in Texas. Rocks of this age are exposed in a great belt extending through north-central Texas from the Red River southward to the Llano uplift, and thence westward and southwestward until concealed by the overlying Permian or Cretaceous. In the Marathon and Solitario uplifts, formations of this system again come to the surface. A third region of disconnected exposures is that of the Diablo, Hueco, and Franklin mountains. The formations of these several regions will be separately discussed.

Rocks of this system are found underground in north-central Texas west and east of the belt of surface outcrop and also southwest of the Llano uplift. The Pennsylvanian of north-central Texas is connected underground with that of Trans-Pecos Texas and, with the exception of some of the most pronounced highs, underlies much, if not all, of the great Permian basin. The sediments occur under varying facies. In extreme north Texas and the adjacent part of Oklahoma the uppermost part of the Pennsylvanian is of the red bed facies. Southward the red beds grade into normal marine limestones and shales. The sandstones and limestones of this system have afforded storage for a very large quantity of oil and gas, which is being produced in north-central Texas.

The occurrence of Pennsylvanian in Texas seems to have been first recorded in 1852 by Roemer (1331), who included it under the general term of Carboniferous. In 1853 Shumard noted the existence of the Carboniferous of north-central Texas and adjoining parts of Oklahoma (1476a). The next important advance in a knowledge of the Pennsylvanian of Texas came with the work of the Dumble Geological Survey from 1888 to 1894. During this time Dumble and his associates established the main subdivisions of the Pennsylvanian of north-central Texas and some of those of Trans-Pecos Texas. In recent years the literature on this system has been greatly augmented by the work of many geologists.

The fossils of the Pennsylvanian system in Texas include, in the normal marine facies, large invertebrate faunas which as yet have been described in part only. The ammonoids as a rule serve as excellent stratigraphic fossils. The species of this group found in the Upper Mississippian, Pennsylvanian, and Permian of north-central Texas are described by Plummer and Scott in a monograph now in manuscript (1234f). In the partially marine strata is a rich fossil plant flora, only a small part of which has been described.

The Pennsylvanian series, groups, or formations recognized in the state are as follows:*

North-central Texas and Llano uplift	Hueco Mountains	Diablo Mountains	Marathon uplift	Solitario uplift
Pueblo Harpersville Thrifty Graham Caddo Creek Brad Graford Palo Pinto			Gaptank	Wanting
Mineral Wells Millsap Lake	Magdalena	Magdalena	Haymond	Wanting
Smithwick Marble Falls	Bend	Bend	Dimple Tesnus	Wanting Tesnus

LLANO REGION

In the Llano region no very pronounced break marks the dividing line between the Mississippian and Pennsylvanian, and there has been some difference of opinion as to where the line actually falls. In this publication the Marble Falls, which is separated by a disconformity from the underlying Mississippian (Barnett), is regarded as the basal Pennsylvanian formation.

The Lower Pennsylvanian formations exposed in the Llano uplift are the Marble Falls and Smithwick, which form the Bend group. These formations are conformable with each other, but are disconformable with the underlying Barnett, and are separated from the

*For location of the regions referred to see figs. 3 and 4, pp. 28–29.

overlying Strawn in and around the Llano uplift by an erosional unconformity. In regional structure they dip gently away from the Llano uplift. The Bend was named by Dumble in 1890 (458, p. lxv) and was more fully defined by Cummins in 1891 (342, p. 372).[36]

BEND GROUP

MARBLE FALLS FORMATION

The Marble Falls formation, in its surface exposures, is chiefly a limestone with no more than a small percentage of shale occurring as thin strata between limestones. Underground to the north and west, these conditions change notably, the Marble Falls containing increased percentage of shales and to the northwest possibly becoming largely a shale. The limestone is prevailingly dark in color although light colored strata are found also. Fossils are fairly abundant, and in thin section it is seen that the rock in some strata consists largely of fossil fragments among which are many sponge spicules.

This formation is extensively exposed around the Llano uplift, particularly at the east, north, and west sides. It is absent at the southeast side at Johnson City and Fredericksburg, but probably extended formerly entirely across the uplift. It disconformably overlies the Barnett, and in many places, as at the type locality and generally in the southeastern and southern parts of the Central Mineral region, transgresses across the Barnett by overlap and rests on older formations.

The formation contains a large invertebrate fauna (1228). An ammonite zone containing *Gastrioceras kingi*, *G. compressum*, and other ammonites occurs near the top of the formation (1234f). Other common fossils are *Chaetetes milleporaceus* and *Campophyllum torquium* (592, p. 72). Fossil plants are found in this formation on Lynch Creek, near the Colorado River in Lampasas County. The most abundant fossil at this locality is a species of *Megalopteris*.

Type locality: Marble Falls in Llano County; thickness, 350 to 600 feet. The formation was named in 1889 by Hill (743).

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[36]Among publications listed in the accompanying bibliography relating to the Bend of the Llano region are: Cummins, 342; Dumble, 458; Girty, 592; Girty and Moore, 593; Hill, 743; Moore, 1130, 1131, 1137; Paige, 1172; Plummer and Moore, 1228.

SMITHWICK FORMATION

The Smithwick formation at the surface is prevailingly a black shale. Some indurated, more or less calcareous, strata are present, and underground to the north of the Central Mineral region some limestone members are found in the formation. The shale is dense, finely laminated, and fissile, breaking into "splinters." Some sandy layers are found in the upper part of the formation. Fossils are moderately abundant, including a varied invertebrate fauna and some plants preserved as impressions. This formation lies at the surface over a limited area at the north and west sides of the Llano uplift and passes underground to the north and west. It differs in thickness from 300 feet at the surface to a maximum of about 600 feet underground north of the Central Mineral region.

About 50 feet below the top of this formation is an ammonite zone containing *Gastrioceras compressus, G. branneri, Pronorites arkansasensis*, and other fossils (1234f).

Type locality: The type locality of this formation is at Smithwick, east of Marble Falls. The exposures at this place, however, are of sandy shales and coarse sandstones with indeterminate plant fragments, the exposures suggesting Strawn rather than Smithwick. If these exposures at the type locality prove to be Strawn, the name Smithwick, well established in the literature, will doubtless be retained. Under these conditions, Bend post office on the Colorado River may be given as a suitable type locality, the formation being there well exposed throughout most of its entire thickness. The formation was named by Paige in 1912 (1172).

OSAGE PLAINS REGION OF NORTH-CENTRAL TEXAS

The term Osage Plains region of north-central Texas is here applied to a large area extending from the foot of the High Plains east to the Cretaceous exposures, north to the Red River and south to the Llano uplift. This region is the Texas part of the Osage Plains as defined by Fenneman (538). With the exception of Cretaceous remnants, the surface formations on these plains are almost entirely of Pennsylvanian and Permian age. Near the western margin, at the foot of the High Plains, some Triassic is present, and, at the margins of the Llano uplift, formations older than Pennsylvanian are exposed. The regional dip in these formations is W-NW and amounts to from 30 to 50 feet per mile. Locally the dip is reduced or accentuated by mild structural features, including terraces, westward plunging noses, and small anticlines and synclines. While Lower Pennsylvanian formations underlie much or all of this region, they are exposed only in the Llano uplift and have been described under that heading.

The Upper Pennsylvanian is exposed in the eastern part of this large region in the Colorado and Brazos river valleys. The Callahan divide, capped by a Cretaceous remnant, separates these two areas of Pennsylvanian, and it is not always possible to trace members across or under this "divide." For this reason the terminology differs somewhat in the Colorado and Brazos areas.[37]

The Upper Pennsylvanian of north-central Texas includes three groups, the Strawn, Canyon, and Cisco, each subdivided into several formations and members. Following is a list of the formation and member names applied to the Upper Pennsylvanian of this region. The names are listed in stratigraphic order, or as nearly so as possible, beginning with the youngest. For each member name there is given by whom and when named, type locality if known, and reference to the publication in which the name was proposed or first used. Names abandoned on account of being synonyms or preoccupied are in italics. Many of the member names were used in private reports before they appeared in published reports. The references here given are to published reports. The type localities for the member names proposed by Drake in 1893 (449) are not separately given since all are on, or near, the Colorado River along which the section was made. For the Putnam and Moran formations heretofore placed in the Pennsylvanian, see under Permian.

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[37]Publications listed in the accompanying bibliography relating to the Pennsylvanian of north-central Texas include the following: Adams, 5; Bay, 81, 82; Bullard and Cuyler, 176; Cheney, 246, 247; Cummins, 339, 342, 346; Cushman and Waters, 371, 380; Drake, 449; Dumble, 458; Harlton, 650, 651, 652; Moore, 1136, 1137, 1138; F. B. Plummer, 1227, 1234a, 1234f; Plummer and Moore, 1228; H. J. Plummer, 1236; Romer, 1351; Shumard, 1465; Scott and Plummer, 1396, 1397, 1398; Scott and Armstrong, 1398b; Taff, 1577; Tarr, 1582, 1583, 1584; David White, 1749c; Maynard White, 1753a; University of Texas, geologic maps, 1853.

Tabulated list of formation and member names applied in the Upper Pennsylvanian of north-central Texas.

Cisco Group

Pueblo Formation*

Camp Colorado limestone, Drake, 1893; (449).

Nimrod limestone, Wender and Fisher, 1929; near Nimrod, Eastland County; (1853, Eastland County).

Eolian limestone, Plummer and Moore, 1921; near Eolian, Stephens County; (1228, p. 172).

Stockwether limestone, Drake, 1893; (449).

Coon Mountain sandstone, Drake, 1893; (449).

Camp Creek shale, Drake, 1893; (449).

Harpersville Formation

Saddle Creek limestone, Drake, 1893; (449).

Belknap limestone, Plummer and Moore, 1921; Fort Belknap, Young County; (1228, p. 162).

Waldrip limestone, Tarr, 1889; (1584, p. 207).

Crystal Falls limestone, Plummer and Moore, 1921; near Crystal Falls, Stephens County; (1228, p. 162).

Thrifty Formation

Breckenridge limestone, Plummer, 1919; Stephens County; top of Thrifty formation; (1227, p. 144).

Chaffin limestone, Drake, 1893; Colorado River valley; (449).

Parks Mountain sandstone, Drake, 1893; (449).

Lohn shale, Drake, 1893; near Lohn, McCulloch County; (449).

Specks Mountain limestone, Drake, 1893; (449).

Blach Ranch limestone, Plummer and Moore, 1921; east of Breckenridge, Stephens County; (1228, p. 154).

Ivan limestone, Plummer and Moore, 1921; Ivan, Stephens County; (1228, p. 154).

Avis sandstone, Plummer and Moore, 1921; Avis, Jack County; base of Thrifty formation in Brazos Valley region; (1228, p. 154).

Graham Formation

Wayland shale, Plummer and Moore, 1921; near Wayland, Stephens County; (1228, p. 130).

Gunsight limestone, Plummer, 1919; near Gunsight, Stephens County; (1227, p. 144).

Trickham shale, Drake, 1893; near bottom of Thrifty in Colorado River valley; (449), (1228).

*This formation and the Saddle Creek limestone of the Harpersville formation may prove to be Permian.

Bluff Creek shale, Drake, 1893; (449).

South Bend shale, 1921; South Bend, Young County; (1228, p. 129); name preoccupied, see Necessity shale.

Necessity shale, Plummer; (1234e). Replacing South Bend shale.

Bunger limestone, 1919; Bunger, Young County; (1227, p. 143).

North Leon limestone, Reeves, 1922; north fork, Leon River, Eastland County; 75 feet below Bunger limestone; (1296, p. 117).

Gonzales limestone, Ross, 1921; Gonzales Creek, Eastland County; (1352, p. 307).

Canyon Group

Caddo Creek Formation

Home Creek limestone, Drake, 1893; (449).

Eastland limestone, Plummer, 1919; (1227, p. 142). Same as Home Creek limestone.

Jacksboro limestone, Plummer, 1919; Jacksboro, Jack County; (1227, p. 143).

Finis shale, Plummer and Moore, 1921; Finis, Jack County; (1228, p. 127).

Hog Creek shale, Drake, 1893; (449).

Cundiff limestone, Armstrong, 1929; Cundiff, Jack County; (1853).

Cherry limestone, Plummer, 1919; (1227, p. 142).

Brad Formation

Ranger limestone, Plummer, 1919; Ranger, Eastland County; (1227, p. 142).

Placid shale, Plummer and Moore, 1921; Placid, McCulloch County; (1228, p. 110).

Graford Formation

Clear Creek limestone, Drake, 1893 (449). Preoccupied by Clear Creek limestone of the Devonian of Illinois proposed by Worthen in 1866. It may be replaced by Merriman, a term applied originally to a part of the Clear Creek.

Merriman limestone, Reeves, 1922; Merriman Church, south of Ranger, Eastland County; 84 feet below base of Ranger limestone; (1296, p. 120). Representing upper part of the Clear Creek limestone.

Cedarton shale, Drake, 1893; Cedarton, Brown County; (449).

Seaman Ranch beds, Plummer and Moore, 1921; Seaman Ranch, Palo Pinto County; (1228, p. 111).

Adams Branch limestone, Drake, 1893; (449).

Staff limestone, Wender and Fisher, 1930; Staff, Eastland County; (1853, Eastland County). Same as Adams Branch limestone.

Wiles limestone, Bradish and Fisher, 1929; Wiles, Stephens County; (1853).

Brownwood shale, Drake, 1893; Brownwood, Brown County; (449).

Milburn shale, Tarr, 1889; Milburn, McCulloch County; (1584, p. 205).

Rochelle conglomerate, Tarr, 1889; near Rochelle, McCulloch County; (1584, p. 205).

Oran sandstone, Plummer and Moore, 1921; Oran, Palo Pinto County; (1228, p. 97).

Wizard Wells limestone, 1930; same as Devils Den limestone; (1398).
Devils Den limestone, Böse, 1917; Jim Ned Hill, west part of Wise County; (132, p. 17).
Jasper Creek beds, Scott and Armstrong, 1932; Jasper Creek, Wise County; (1398b).
Chico Ridge limestone, Scott and Armstrong, 1932; south of Chico, Wise County; (1398b).
Rock Hill limestone, Böse, 1917; west of Bridgeport, Wise County; (132, p. 16).
Lake Bridgeport shale, Scott and Armstrong, 1932; Lake Bridgeport, Wise County; (1398b).
Bridgeport limestone, Böse, 1917; name preoccupied, having been used in 1873 for Silurian bed in Ohio; replaced by Willow Point limestone.

Palo Pinto Formation

Willow Point limestone, Armstrong, 1929; Willow Point, southwestern part of Wise County; (1853).
Bridgeport coal, Cummins, 1891; Bridgeport, Wise County; (342, p. 437).
Balsora limestone, Scott and Armstrong, 1932; 1 mile west of Balsora, Wise County; (1398b).
Sanders Bridge limestone, Scott and Armstrong, 1932; Boone Creek, 3¼ miles northwest of Booneville, Wise County; (1398b).
Boone Creek limestone, Armstrong, 1929; Boone Creek, Jack County; (1853).
Martin Lake limestone, Scott and Armstrong, 1932; Martin Lake, 2 miles south of Bridgeport, Wise County; (1398b).
Hudson Bridge limestone, Scott and Armstrong, 1932; 3 miles southeast of Bridgeport, Wise County; (1398b).

Strawn Group

Capps limestone, Plummer and Moore, 1921; 5 miles east of Brownwood, Brown County; (1228, p. 97).
Ricker bed, Drake, 1893; (449).
Gordon, Plummer, 1919; Gordon, Palo Pinto County; (1227, p. 138). Preoccupied by Gordon of Dumble.
Antelope Creek sandstone, Drake, 1893; (449).
Indian Creek bed, Drake, 1893; (449).
Comanche Creek shale, Drake, 1893; (449).
Wilbarger Creek sandstone, Drake, 1893; (449).
Buffalo Creek shale, Drake, 1893; (449).
Rough Creek sandstone, Drake, 1893; (449).
Hanna Valley shale, Drake, 1893; (449).
Cottonwood Creek bed, Drake, 1893; (449).
Spring Creek shale and sandstone, Drake, 1893; (449).
Brown Creek sandstone, Drake, 1893; (449).
Big Valley bed, Drake, 1893; (449).
Bull Creek sandstone, Drake, 1893; (449).
Horse Creek shale, Drake, 1893; (449).
Fox Ford bed, Drake, 1893; (449).

Shadrick Mill sandstone, Drake, 1893; (449).
Elliot Creek shale, Drake, 1893; (449).
Burnt Branch bed, Drake, 1893; (449).
Lynch Creek shale and sandstone, Drake, 1893; (449).

Mineral Wells Formation

Keechi Creek limestone and shale, Plummer and Moore, 1921; Palo Pinto County; (1228, p. 78).
Turkey Creek sandstone, Plummer and Moore, 1921; Palo Pinto County; (1228, p. 77).
Salesville shale, Plummer and Moore, 1921; Salesville, Palo Pinto County; (1228, p. 77).
Dog Bend limestone, Plummer, 1929; (1853).
Lake Pinto sandstone, Plummer and Moore, 1921; Lake Pinto, Palo Pinto County; (1228, p. 77).
Village Bend limestone, Plummer, 1929; (1853).
East Mountain shale, 1921; near Mineral Wells, Palo Pinto County; (1228, p. 77).
Hog Mountain sandstone, Plummer, 1929; (1853).

Garner Formation

Brazos sandstone, Plummer, 1919; (1227, p. 138).
Brazos River sandstone; same as Brazos sandstone.
Mingus shale, Plummer and Moore, 1921; Palo Pinto County; (1228, p. 76).
Thurber coal, Plummer and Moore, 1921; Thurber, Erath County; (1228, p. 76).
Goen limestone, Plummer, 1929; (1853).
Santo limestone, Plummer, 1929; (1853).
Barton Creek limestone, 1929; name preoccupied, having been applied in the Cretaceous of Texas by Hill.

Millsap Lake Formation

Grindstone Creek member, Scott and Armstrong, 1932; (1398c) .
Lazy Bend member, Scott and Armstrong, 1932; Lazy Bend on Brazos River; (1398c).
Brannon limestone, Scott and Armstrong, 1932; (1398c).
Steussy shales, Scott and Armstrong, 1932; (1398c).
Meek Bend limestone, Scott and Armstrong, 1932; (1398c).
Hill Creek beds, Scott and Armstrong, 1932; (1398c).
Dennis Bridge limestone, Scott and Armstrong, 1932; (1398c).
Kickapoo Falls limestone, Plummer, 1919; (1227, p. 138).
Dickerson member, Scott and Armstrong, 1932; (1398c).

STRAWN GROUP

The Strawn sediments are exposed in two detached areas in the extreme eastern part of the Osage Plains region in the Brazos and Colorado river valleys. The Brazos River valley exposures include an area elongated northeast-southwest through Parker, Palo Pinto, and Erath counties. The Colorado River exposures occupy a smaller area along the Colorado River in San Saba, Mills, southern Brown, and western Lampasas counties. In the Brazos River valley the group has heretofore been subdivided into the Millsap and Mineral Wells formations and in the Colorado River valley into many units.

The term Strawn was proposed in 1890 by Dumble (458, p. lxvi) and was more fully defined by Cummins in 1891 (342, p. 374).

MILLSAP LAKE FORMATION

The Millsap division of the Pennsylvanian was proposed by Cummins in 1891 (342, p. 372). Subsequently the term Millsap was dropped and the sediments of this division included in the Strawn. In 1921, Millsap was revived and used as a formation name in Texas (1228, p. 69). In the meantime, however, Millsap had been applied to a formation of Mississippian age in Colorado. To obviate the dual usage of the word Millsap, Scott and Armstrong (1398c, MS.) used the term Millsap Lake for the Texas formation, which usage is here adopted.

The Millsap Lake formation has a limited exposure in the Brazos River valley, where it occurs as an inlier exposed as the result of the removal of overlying formations. To the northwest it dips under the later Pennsylvanian. In all other directions, east, northeast, south, and southeast, it passes under the Cretaceous. At the top it is conformable with the overlying Pennsylvanian formations. The base of the formation is not exposed, but is possibly unconformable with the Smithwick. This, however, cannot be verified from lack of exposures. Two small exposures seen in Comanche County may represent this formation (1228, p. 70).

The formation is largely shales with some conglomerates and thin sandstones. Limestones are present but are thin and usually lenticular in character. The members are, in descending order, Grindstone Creek beds, Brannon limestone, Steussy shales, Meek Bend limestone, Hill Creek beds, Dennis Bridge limestone, Kickapoo Falls limestone, Lazy Bend beds, and Dickerson beds (1398c). The part of the formation exposed measures 1600 feet. Fossils, including fusulinids, brachiopods, corals, bryozoa, bivalves, and gastropods, are locally abundant, being found chiefly in the lentils of limestone.

Type locality: Millsap Lake, Parker County; maximum thickness, 3000 feet or more.

GARNER FORMATION

The Garner formation has been proposed by Scott and Armstrong (1398c) to include the lower part of the Mineral Wells formation of Plummer and Moore. To this formation are referred the Thurber coal, Mingus shale, and Brazos sandstone. The formation as thus defined consists of a coal seam, shales, sandstone, and conglomerates. Some thin limestones are present, one of which is near the middle of the Mingus member.

The Thurber coal with some associated thin limestones and shales marks the beginning of the formation. Next overlying this member is the Mingus member consisting of 250 or 300 feet of sandy shale. The Brazos sandstone and conglomerate next above the Mingus shale is 25 or 30 feet thick and forms a conspicuous escarpment.

Type locality: Garner in Parker County; thickness, from 400 to 500 feet.

MINERAL WELLS FORMATION

The Mineral Wells formation as restricted by Scott and Armstrong consists chiefly of shales, sandstones, and conglomerates. The shales predominate, occurring in beds of 200 or more feet thick. Some thin lenticular limestones are present. The formation includes the following members: East Mountain shale, Lake Pinto sandstone, Salesville shale, Turkey Creek sandstone, and Keechi Creek limestone and shale. The several members thicken to the northeast.

The East Mountain shale, about 300 feet thick, includes a thin limestone near the top and is in places highly fossiliferous. The Lake Pinto massive sandstone which caps the escarpment at Mineral Wells is 20 or 25 feet thick. The Salesville shale overlying the Lake Pinto sandstone is about 150 feet thick. It is overlain by the Turkey Creek sandstone, which is 10 or 15 feet thick. The top member of the formation, the Keechi Creek sandstone and shale, is exposed in the escarpment formed by the Palo Pinto limestone. This member is from 100 to 150 feet thick. Locally fossils are abundant and the formation contains a large and varied invertebrate fauna.

The Garner and Mineral Wells formations differ from the underlying Millsap Lake formation in that they contain a much larger amount of sandstone and conglomerate. These deposits indicate stronger stream activity than in Millsap Lake time and also more diversified conditions since coal beds and thin, somewhat persistent, limestones are present.

Type locality: East Mountain near Mineral Wells in Palo Pinto County; thickness, from 750 to 1800 feet.

In the Colorado River valley the Strawn group consists largely of alternating beds of sandstone and shale. The entire group represents near-shore deposits, the sediments having come, not from the nearby Central Mineral region, but from a land mass to the east or northeast now concealed. The combined thickness of these units is 3500 or 4000 feet. The beds overlap to the west so that the actual thickness of the Strawn is much less than that, probably not in excess of 1200 feet at any one locality. Drake (449) described and assigned names to these successive beds, recognizing the following units: Lynch Creek, Burnt Branch, Elliott Creek, Shadrick Mill, Bed No. 8, Fox Ford, Horse Creek, Bull Creek, Big Valley, Brown Creek, Spring Creek, Cottonwood Creek, Hanna Valley, Rough Creek, Buffalo Creek, Wilbarger Creek, Comanche Creek, Indian Creek, Antelope Creek, and Ricker. The Capps limestone is now regarded as within the Strawn group. This limestone, represented by a coral reef, is well exposed in the old public road, 5 miles east of Brownwood.

The Cretaceous covering of the Callahan divide prevents tracing the connection of the Strawn of the Brazos and the Colorado river valleys, and, owing to the variable character of the deposits, it has not been found possible to make direct correlation of the strata of the two areas. The Strawn of the Colorado River valley contains much coarser sediments and fewer fossils than does that of the Brazos River valley. However, underneath the Cretaceous in Wise County the Strawn again assumes a near-shore facies containing several coal beds and lenses of sand and sandy shale (1398b).

CANYON GROUP

The Canyon group in north-central Texas differs from the Strawn group in that it contains thick limestone beds alternating with shales and contains relatively little sandstone. The source of sediments was from the east, and the exposures of Jack and Wise counties indicate an approach to the shore line, the deposits there having an abundance of conglomerates, many and irregular sands, clays, and several coal beds (1398b). The group, as now subdivided, includes four formations, as follows: Palo Pinto, Graford, Brad, and Caddo Creek. The total thickness of the group in the Colorado River valley is about 750 feet, and in the Brazos River valley 950 or 1000 feet (1853), and in Wise County 1500 feet.

The term Canyon was proposed in 1891 by Cummins (342, p. 374). The group was subdivided and the formation names here used were proposed by Plummer and Moore in 1921 (1228, p. 90). This group occupies a belt from 10 to 20 miles wide extending from Wise County southwest to McCulloch County. The Brazos area is separated from the Colorado area by the Callahan divide. In the southern region there is evidence of disturbance at the close of the Strawn, some conglomerates being found in the basal Canyon. Within the Canyon there are no marked unconformities, and its relation to the overlying Cisco, Graham formation, is that of apparent conformity. According to Plummer and Scott the *Uddenites* fauna described originally from the Glass Mountains region is present in the Canyon and lower Cisco.

PALO PINTO FORMATION

The Canyon group was initiated in the Brazos River valley by a heavy, massive, escarpment-forming limestone, the Palo Pinto formation, which rests with apparent conformity on the Strawn, indicating, however, a pronounced change in depositional conditions. This limestone, which attains a maximum thickness of about 100 feet, thins and breaks into several divisions to the northeast (1398b). A thin limestone lying about 100 feet above the Capps limestone in Brown County may represent this formation.*

In Wise County, where the formation is about 350 feet thick, six limestone members are recognized as follows: Hudson Bridge, Martin Lake, Boone Creek, Sanders Bridge, Balsora, and Willow Point.

*M. G. Cheney, letter of December 14, 1932.

These limestones are separated by shales and sandstones and one bed of coal, mined at Bridgeport (1398b).

Type locality: The type locality is at the town of Palo Pinto in Palo Pinto County; thickness, 50 to 100 feet.

GRAFORD FORMATION

The Graford formation consists of shales, limestones, and some sandstones. The Wiles limestone occurring within this formation in Eastland County is regarded by some geologists as equivalent to the limestone that is mapped as Adams Branch in Brown County and by others as about 100 feet below the Adams Branch limestone.

The top of the Graford as defined at the type locality apparently falls within the Merriman (Clear Creek) limestone equivalent and not at the Adams Branch limestone as given in the original description (1228, p. 95). In order to adjust the limits of these formations it is proposed to extend the Graford to include all of the Merriman limestone equivalent and to modify the definition of the Graford and Brad formations accordingly. This usage would restrict the Brad formation to the Placid shale and the Ranger limestone and extend the Graford formation in the Colorado River valley to include the Cedarton shale and Merriman (Clear Creek) limestone.

A conglomerate known as the Rochelle conglomerate occurs locally in the Colorado River valley near the base of the Brownwood shale. This conglomerate, which consists largely of angular or but slightly rounded cherts, is exposed, according to Bay (82), at the following localities: on the San Saba road 4 miles east of Rochelle; on the old Rochelle-Brady road 5 miles southwest of Rochelle; 3½ miles southeast of Rochelle; on the old Brownwood road 1 mile from the Rochelle-San Saba highway; and at the McCulloch-San Saba county line 3 miles southeast of Cowboy.

In Wise County the following members have been named: Lake Bridgeport shales, Rock Hill limestone, Jasper Creek shales, Chico Ridge limestone, and Devils Den limestone. The Chico Ridge is a local reef-like limestone, equivalent to the Jasper Creek shales. The Adams Branch limestone is not present in Wise County, and the division line between the Graford and Brad formations can be only approximately determined (1398b).

An ammonite fauna, obtained from the Brownwood shale member, chiefly from a clay pit at Bridgeport, contains, among others, *Gastrioceras illinoisense, G. subglobosum,* and *Prouddenites primus* (1234f).

Type locality: The type locality is at Graford in Palo Pinto County; thickness, 450 feet in the Colorado River valley, 550 feet in the Brazos River valley (1853), and more than 800 feet in Wise County.

BRAD FORMATION

The Brad formation consists chiefly of shales and limestones. The members now recognized are the Placid shale and Ranger limestone. In the Brazos River valley the members originally recognized were the Seaman Ranch beds and the Ranger limestone (1228, p. 109). In Wise County the Adams Branch limestone is wanting, and in this county the shales and sandstones from the Devils Den limestone to the Ranger limestone have been named the Ventioner beds (1398b). The Ranger limestone may be followed northeast into Wise County, where it passes under the Cretaceous.

Type locality: The type locality is at Brad in Palo Pinto County; thickness, 125 to 200 feet.

CADDO CREEK FORMATION

The Caddo Creek formation consists of the Hog Creek shale, overlain by the Home Creek limestone. In the Brazos River valley some sandstones are present. The shale both in the Brazos and Colorado river valleys is relatively unfossiliferous. The Home Creek limestone member is variable in thickness and in Jack County includes the Jacksboro limestone which, according to Bullard and Cuyler (176, p. 61), has been traced northward into Montague County, where, as a thin stratum, it passes under the Cretaceous about 2 miles south of Fruitland. The Cundiff limestone in this formation in Jack and Wise counties, consisting of three ledges, is possibly of algal origin. Ammonites obtained from the Hog Creek shale include *Uddenites, Gastrioceras hyattianum, G. modestum, G. subglobosum,* and others (1234f). The Finis shale, which with the Jacksboro limestone was formerly referred to the Graham formation, is now placed in the Caddo Creek formation (1853, Jack County).

Type locality: The type locality is Caddo Creek near Caddo in Stephens County; thickness, Colorado River valley, 125 feet; Jack County, 350 feet; Wise County, 400 feet.

CISCO GROUP

The Cisco, the uppermost group of formations in the Pennsylvanian of the central Texas region, includes shales, sandstones, conglomerates, limestones, and coal beds. Eastward the sands and conglomerates increase in thickness, while westward conglomerates and coals disappear and a greater regularity in deposition prevails, the source of sediments having been from the east. The surface exposures of the formations of this group occupy a belt from 20 to 40 miles wide extending south-southwest from the Red River to the Cretaceous overlap in McCulloch County. The group continues underground across the Permian basin. Its relation to the underlying Canyon, and to the overlying Permian, is that of apparent conformity. Within the group, between the Graham and Thrifty formations, is an erosional unconformity which in some localities cuts out the Wayland shale, the uppermost member of the Graham formation. In the northern part of the state a facies change occurs in the Cisco group. The limestones disappear, the marine deposits giving place to a non-marine or partially marine facies. This group contains a large invertebrate fauna and some fossil plants.

The term Cisco was proposed in 1890 by Dumble (458, p. lxvii) and was later more fully defined by Cummins (342, p. 374). In 1921 Plummer and Moore subdivided the group into the following formations: Graham, Thrifty, Harpersville, Pueblo, Moran, and Putnam (1228). This classification is here followed except that, for reasons subsequently given, the Putnam and Moran formations are referred to the Wichita group of the Permian. The Cisco group, as thus restricted, has a thickness in the Colorado River valley of 820 feet and in the Brazos River valley of 1180 feet.*

GRAHAM FORMATION

The Graham formation at the base of the Cisco group is best developed in the Brazos River valley, where it has been subdivided into several members as follows: Gonzales limestone shale and sandstone; Bunger limestone; Necessity shale and sandstone; Gunsight

*These thicknesses are based on measurements supplied by M. G. Cheney (letter of January 17 1933).

limestone; and Wayland shale. Formerly the Jacksboro limestone and Finis shale of Jack County were placed in this formation but they are now recognized as part of the Home Creek limestone of the Caddo Creek formation. To the southwest the formation thins, the lower members, according to Plummer and Moore, being lost by overlap. The members recognized in the Colorado River valley are the Bluff Creek shale, Gunsight limestone, and Wayland shale. The uppermost member, the Wayland shale, is notably fossiliferous. An erosional unconformity is found at the top of the formation by which the Wayland shale is cut out locally. Some geologists prefer making the division line between the Canyon and Cisco at this break in sedimentation—a position supported also by a break in the micro-fauna—thus placing the Graham formation in the Canyon group (652, p. 139). The formation is traced northward into Montague County (176, p. 63). The limestones thin northward and have largely disappeared where the formation passes under the Cretaceous in Montague County (176, p. 63). A chert conglomerate is found in this formation at its type locality and at several other localities.

A large ammonite fauna obtained from the Necessity shale at several localities includes *Uddenites, Gastrioceras modestum, Schistoceras hyatti, Shumardites simondsi,* and *Goniloboceras welleri* (1234f).

Type locality: The type locality is at Graham in Young County; thickness, 160 feet in the Colorado River valley, and 350 or 450 feet in the Brazos River valley.

THRIFTY FORMATION

Resting upon the erosional unconformity at the top of the Wayland shale is the Thrifty formation, the basal member of which is a sandstone or, locally, a conglomerate. The formation is of about the same thickness throughout its extent from the Colorado River valley to the Brazos River valley. Coal beds found in this formation in the Colorado River valley were named the Chaffin beds by Drake (449). In Montague County the limestones are wanting, the formation consisting of sandstones and shales (176). The members of the Thrifty formation, some of which have not received names, are as follows: Avis sandstone; shale and sandstone; Ivan limestone; shale and sandstone; Blach Ranch limestone; shale; and

Breckenridge limestone. The Breckenridge limestone has been followed to the northern part of Jack County, where it gives place to sandstone and shale.

Type locality: The type locality is at Thrifty in Brown County; thickness, 200 to 230 feet.

HARPERSVILLE FORMATION

The Harpersville formation, resting upon the Thrifty, consists of a sandstone at the base, followed by shales, including coal beds and some limestones and sandstones. The coal beds mined at Newcastle are in this formation. North of Young County the limestones of the formation give place to sandstones. In the Brazos River valley the following members are recognized: sandstone and shale; Crystal Falls limestone; shale, sandstone, limestone, and coal beds; Belknap limestone; shale, and sandstone; and Saddle Creek limestone. The fauna of the Saddle Creek limestone is believed by Roth to be equivalent to that of the Neva limestone of Oklahoma and Kansas although the genus *Schwagerina* was not found in the Saddle Creek limestone (1353b). Some of the limestones of this formation continue northward through Jack County, but are replaced in Montague County by sandstones and shales.

Type locality: The type locality is at Harpersville in Stephens County; thickness, 240 to 300 feet.

PUEBLO FORMATION

The Pueblo formation consists of shales in which are included some sandstone and a massive limestone. The members recognized are as follows: Camp Creek shale; Stockwether limestone; shale; and Camp Colorado limestone. North of Throckmorton County the limestones disappear and the formation limits are difficult to determine.

Type locality: The type locality is Pueblo in Callahan County; thickness, 190 to 230 feet.

HUECO MOUNTAINS

Both Upper and Lower Pennsylvanian are present in the Hueco Mountains at the northwest corner of the Diablo Plateau.[38]

[38]Among publications listed in the accompanying bibliography relating to this area are the following: Beede, 89, 91; King and King, 932; R. E. King, 940; Richardson, 1312.

BEND AND MAGDALENA GROUPS

In the Hueco Mountains are 1200 feet of beds of Pennsylvanian age, which are of very similar character to those of the Magdalena group of New Mexico, and are apparently of about the same age. Following Beede's usage (91, p. 10) the name is therefore applied in this area. The basal beds of the section may be as old as the Bend group of central Texas, but this correlation has not been proven. The lower half of the section consists of thick-bedded limestones, which are crowded with masses of the coral *Chaetetes milleporaceus,* and in which are also found *Spirifer rockymontanus.* Near the middle occurs *Fusulina meeki, Fusulina euthysepta,* and *Chonetes mesolobus.* The upper part of the group consists of thin and thick bedded limestones, separated by beds of marl. These contain various species of *Triticites,* and numerous Upper Pennsylvanian brachiopods, including *Enteletes* near the top. The group apparently contains equivalents of part of the Strawn, Canyon, and Cisco groups of central Texas. Near Powwow Canyon, a few miles south of Hueco Tanks, the group is overlain unconformably by conglomerates and red beds of the Powwow member at the base of the Permian.

Exposures of these strata may be seen on the west face of Rancheria Mountain[39] and elsewhere in the Hueco Mountains region.

Similar limestones are found in the Franklin Mountains north of El Paso, where fossils like those in the lower part of the group in the Hueco Mountains have been collected (932, p. 911).

DIABLO MOUNTAINS

The Diablo Mountains form the east margin of the Diablo Plateau. The principal cliff-forming rock of this escarpment is the Permian limestone. Underlying the Permian with an angular unconformity are various earlier Paleozoic formations, including the Magdalena, Bend, and older formations.[40]

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[39]Rancheria Mountain may be reached as follows: Follow the El Paso-Carlsbad road from El Paso about 31 miles, turn south on dim ranch road. (This road is about 1½ miles east of the Weed, N. M., road.) Follow the ranch road in a southerly direction about 5 miles to the west end of Rancheria Mountain.

[40]Among publications listed in the bibliography relating to the Pennsylvanian of this region are the following: Arick, 33a; Beede, 91; King and King, 932; R. E. King, 940.

BEND GROUP

The known exposures of Bend in the Diablo Mountains are found in several small draws at the foot of the escarpment about 1 mile north of the entrance to Marble Canyon and some 33 or 34 miles north of Van Horn.[41] The exposures of Bend include both shale and limestone. The shale is in part non-resistant, breaking down upon exposure, but in some strata it is well indurated and much like the Smithwick shales seen at Bend on the Colorado River and elsewhere. The limestone which underlies the shale is much like the Marble Falls. This locality has been described by Arick, who found at one exposure 20 feet of limestone and about 50 feet of shale. Fossils found in ironstone concretions in the shale have been identified by Plummer as Smithwick (33a, p. 486).

MAGDALENA GROUP

In the east scarp of the Diablo Plateau about 1 mile south of Marble Canyon (30 or 31 miles north of Van Horn) exposures of the Magdalena group underlie the Permian limestone with angular unconformity (33a, p. 485, and 932, p. 911). These deposits are seen in the scarp from place to place for several miles. The thickness of the formation at this locality has not been determined.

MARATHON AND SOLITARIO REGIONS

The Pennsylvanian of the Marathon region, including possibly some Mississippian, has been subdivided into four formations, as follows: Tesnus, Dimple, Haymond, and Gaptank. To the Gaptank apparently must be added a part of the Wolfcamp as heretofore defined. These formations, consisting of shales, sandstones, and limestones, attain a thickness of 10,000 or more feet. Structurally these deposits up to and including the Gaptank partake of the intense folding of the Marathon region. The structural conditions are therefore complicated, including steep often overturned folds,

[41]This locality is reached by leaving the Van Horn-Carlsbad road at the road dip approximately ⅛ mile south of the entrance to Figure 2 Ranch and following a dim trail making about S. 60° W. to its end, 1.1 miles. From the end of the trail, go on foot to the escarpment in the direction N. 60° W. Exposures will be found in draws near the foot of the escarpment. The strata, consisting of limestones and shales, dip to the southwest and are overlain by Upper Pennsylvanian formations, the basal strata of which consist of sandstones and purple shales.

and thrust faults. As previously stated, the trend of folds in this region is northeast-southwest. In the Solitario region, of these formations only the Tesnus is exposed.[42]

TESNUS FORMATION

The Tesnus formation, exposed in the Marathon and Solitario regions, consists largely of shales and sandstones, including arkose and graywacke. The sandstones are mostly fine-grained and greenish in color weathering to a rusty-brown, although some light colored sandstones are present. The green color is due to a chloritic matrix in which the small sand grains are imbedded. The Rough Creek shale member at the base of the formation (44, p. 101) includes 865 feet of dark green and black shale. Sandstones, shales, and some conglomerates overlie the Rough Creek member. Near the top, in the northeastern part of the basin, the formation is marked by a shale member 100 feet or more thick (936, p. 32). The Tesnus is separated from the underlying Caballos by an erosional unconformity and grades into the overlying Dimple limestone.

This formation is extensively developed in the southeastern part of the Marathon basin and is found also in the synclines over much of the central part of the basin. Its greatest thickness, 7000 feet (1435, p. 12), is attained in the southeastern part of the basin. It thins to the northwest, the source of sediments being from the southeast. It occupies much of the southwestern part of the Solitario basin and is found also in limited exposures in the eastern and northeastern parts.

Good exposures of this formation may be seen on the Marathon-Sanderson road from 14 to 18 miles from Marathon, where it occupies the crests of anticlines. The gradation from the uppermost Tesnus shale to the Dimple limestone may be seen near the west end of the road cut, 14 miles east of Marathon.

Fossils are rare in the Tesnus. A few plants have been found near the top of the formation which, although poorly preserved, suggest Pennsylvanian rather than Mississippian. A similar conclusion is indicated by a few foraminifera obtained from near the top of the formation (936, p. 36).

[42]Publications relating to the Pennsylvanian of the Marathon region listed in the accompanying bibliography include the following: Baker and Bowman, 44; Keyte, Blanchard, and Baldwin, 924; P. B. King, 927, 928, 936, 936a; King and King, 930, 932; R. E. King, 940; Sellards 1435; Udden, 1643.

Type locality: Tesnus station in the eastern part of the Marathon basin; thickness, 3000 to 7000 feet. The formation was named by Baker in 1916 (1652, p. 46) and was more fully described by Baker and Bowman in 1917 (44, p. 101), and by King in 1931 (936).*

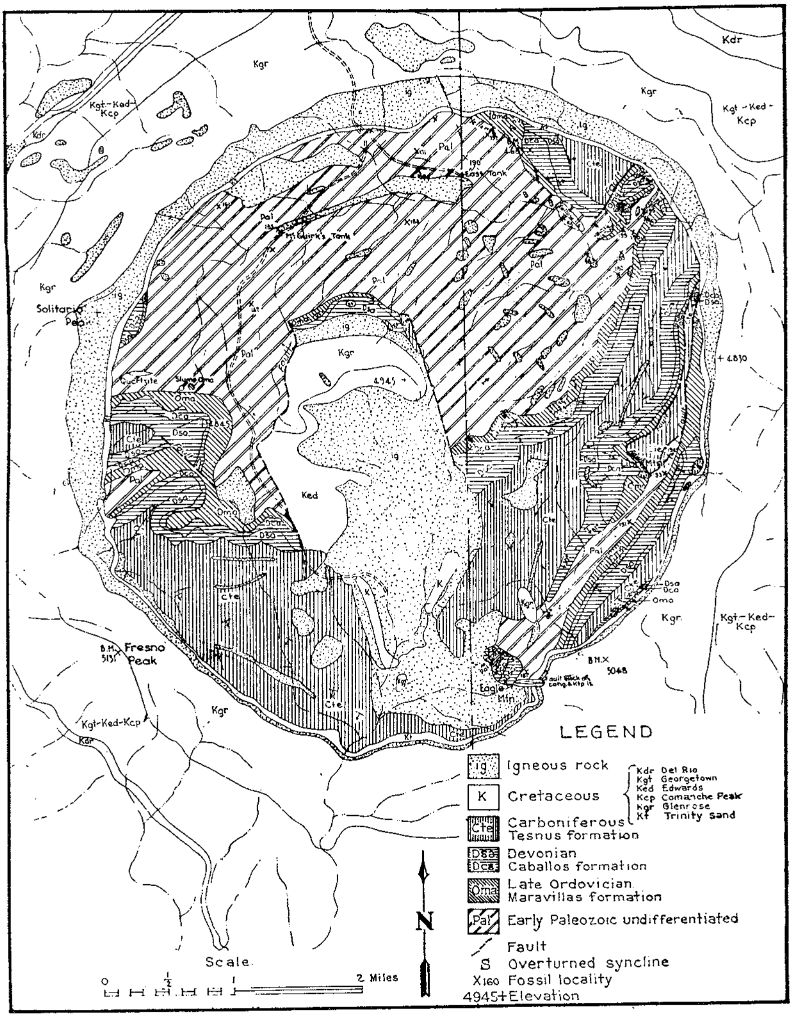

Fig. 9. Geologic map of the Solitario uplift of Presidio and Brewster counties, Texas.

*The term Rough Creek, applied to the basal members of this formation, is preoccupied, having been applied by Drake in 1893 to a member in the Strawn formation. (449).

DIMPLE FORMATION

The Dimple formation consists chiefly of relatively thin-bedded limestone, much of which is chert-bearing. Interbedded with the limestone are some shales, thin conglomerates, and chert pebbles. The limestone shades from gray to black. The formation is conformable with both the Tesnus below and the Haymond above. At its base in the eastern part of the Marathon basin is a transition zone of 60 feet, and at the top it grades into the Haymond by a transition zone of about 200 feet (936, p. 36).

Although fossil fragments are abundant, making up a considerable part of the limestone, identifiable fossils are rare. Those that have been found, both megascopic and microscopic, including brachiopods, corals, bryozoa, and a few foraminifera, are suggestive of an early Pennsylvanian age. The possible Bend age of this formation is suggested both by the lithology and by such fossils as have been obtained from it (936, p. 39; 1669, p. 7). Definite proof of this correlation, however, is lacking. Fusulinids are not among the fossils obtained from this formation.

The Dimple formation is exposed at many localities in the Marathon basin, usually in ridges trending northeast. A complete section may be seen in the cut on the Marathon-Sanderson road, 14 miles east of Marathon.

Type locality: The Dimple Hills, northeast of Marathon; thickness, 1100 feet. The formation was named by Udden in 1916 (1652, p. 46); the first detailed description was by Baker in 1917 (44, p. 105).

HAYMOND FORMATION

The Haymond formation is lithologically much like the Tesnus, consisting largely of fine sandstones and shales with some arkoses and conglomerates. It is exposed extensively in the eastern and northeastern parts of the Marathon basin from the Southern Pacific Railroad north to within 1 mile or less of Gap Tank.

Fossils are rare in the Haymond.

An unusual feature of the Haymond is the occurrence of large erratic boulders in the upper part of the formation. These boulders differ in size, the largest being 130 feet long and 25 feet thick. They represent several formations, some of which are not now exposed in this region. Paleozoic formations represented by these boulders are the Dimple (limestone), Tesnus (quartzite), Caballos (novaculite), Maravillas (chert). Numerous small quartzitic, graphitic, and metamorphic boulders are probably derived from pre-Cambrian rocks not now exposed. Such boulders and associated conglomerates are known at three localities in the eastern and northeastern parts of the basin, the best exposures being found west of Housetop Mountain. The mode of transportation of these boulders has not been in all respects satisfactorily determined. Some of those who have examined the erratics regard them as blocks transported incident to thrusting, while others feel that some other mode of transportation must be considered.[43]

Type localities: synclines north of Haymond station; thickness, 1800 feet or more. The formation was named by Baker (44, p. 107; 1652, p. 46).

GAPTANK FORMATION

The Gaptank formation consists largely of shales, sandstones, and limestones with some conglomerates. The limestones are gray and yellow and include both thin and massively bedded strata. Udden has suggested that it may be necessary to divide the formation into two units (1643, p. 38), upper and lower, the massive limestones being found mostly in the upper member.

The lower member has about 50 feet of limestone at the base, followed by shale and sandstones, which, according to King, contains five conglomerates ranging in thickness from 15 to 50 feet. These conglomerates include rock from the Dimple, Caballos, Maravillas, and other older Paleozoic formations. The upper member has five massive limestone strata ranging from 40 to 75 feet in thickness interbedded with shales and sandstones.

This formation is exposed in the northern and western parts of the Marathon basin near Gap Tank on the north and Dugout Creek on the west. An isolated exposure is found on Black Peak, north of Doubtful Canyon in the Del Norte Mountains. At this locality the Pennsylvanian is exposed, due to a post-Cretaceous thrust fault.

[43]To reach the locality of exposures of these boulders, follow the Marathon-Sanderson road 19.8 miles east of Marathon and turn south on ranch road, following this road 2 miles to a windmill. Some large novaculite and limestone boulders will be found northwest of the windmill, and to the southwest the boulder horizon shows more or less continuously for several miles.

King finds no obvious unconformity between the Haymond and Gaptank. If not the whole formation, the lower member at least is involved in the strong folding and overthrusting of this region.

In contrast to the underlying relatively non-fossiliferous Pennsylvanian formations, the Gaptank is in some horizons highly fossiliferous both in the limestones and in the more or less calcareous shales and sandstones. The fossils include brachiopods, bryozoa, ammonites, fusulinids, and others. Fossils are found in the basal limestones, the coral *Chaetetes milleporaceous* being particularly abundant. Calcareous sandstones, 400 and 700 feet above the base, also contain fossils. The upper part of the formation is less abundantly fossiliferous.

For reason given under discussion of the Wolfcamp formation, the Uddenites and overlying limestone members of the Wolfcamp are included with the Gaptank.

Type locality: Gap Tank on the Marathon-Fort Stockton road, 23 miles north of Marathon; thickness, 1800 feet (lower member, 1000; upper, 800 feet). The formation was named in 1916 by Udden (1652, p. 47) and more fully described by him in 1917 (1643, p. 38).

UNDERGROUND POSITION OF THE PENNSYLVANIAN IN TEXAS

Lower Pennsylvanian.—On the Colorado River, the Lower Pennsylvanian formations (Bend group) exposed in Burnet and Llano counties dip eastward and are quickly lost or changed in facies as they pass into the Llanoria geosyncline (see p. 127). Farther to the south at Johnson City in Blanco County they are absent, as already stated, both at the surface and underground. South of the Llano uplift at Fredericksburg in Gillespie County, these formations are likewise absent, the Cretaceous there resting upon the pre-Cambrian, Cambrian, or Ordovician. In Kendall, Kerr, and Bandera counties, however, the Lower Pennsylvanian has been encountered in several wells, indicating that the Lower Pennsylvanian probably originally extended over this entire region and was removed at some localities by pre-Cretaceous erosion. In southern Kendall County the Llanoria geosynclinal sediments again immediately underlie the Cretaceous. At the southwest and west sides of the uplift the Lower Pennsylvanian has been recognized in wells as far as Real, Edwards, Sutton, and Schleicher counties, and less definitely in eastern

Crockett County. At Big Lake in Reagan County and on the Central Platform in Pecos County these formations are absent. Whether the absence of the Lower Pennsylvanian in these two counties is due to local uplift and erosion or is due to its not having been deposited in this part of the state is at present undetermined.[44]

A large area northwest and north of the Llano uplift is underlain by Lower Pennsylvanian. The Bend is believed to have been entered in wells in Irion County, as well as in Taylor, Callahan, Throckmorton, Archer, and Jack counties, and in all of the counties between these and the Llano uplift. Westward from these counties, drilling has as a rule not penetrated deep enough to test the presence or absence of the Lower Pennsylvanian except at Big Lake in Reagan County where the Bend is absent on the uplift. No Lower Pennsylvanian has been proved to be present on or around the Amarillo uplift. It is absent likewise, so far as known, from some parts of the Red River uplift, not having been found in Foard, Wilbarger, or Clay counties. It is, however, present as a remnant in the eastern part of this uplift in Wichita, Cooke and Denton counties.* The thickness of the Bend group underground is variable. The greatest thickness is found in the basin area intermediate between the Red River and Llano uplifts, the maximum being about 1200 feet. On the uplifts, except on the Bend arch, the Bend, due to erosion previous to Upper Pennsylvanian deposition, ranges from a few feet to several hundred feet, the uppermost formation, the Smithwick, being usually absent. The tabulated data on wells may be consulted for additional information on the distribution of these formations underground.

Upper Pennsylvanian.—The Upper Pennsylvanian of the Brazos Valley is exposed as an inlier, bordered on the east and south by Cretaceous and on the north and west by Permian formations. The Upper Pennsylvanian dips to the northwest and only the lowermost formation, the Millsap Lake, on the Brazos River, continues east under the Cretaceous. In the Llanoria geosyncline, which passes through

[44]Publications relating to Pennsylvanian underground in Texas listed in the accompanying bibliography include the following: Cheney, 246; Glenn, 594; Goldman, 598, 599; Miser, 1116; Miser and Sellards, 1117; Scott and Armstrong, 1398b; Sellards, 1441; Udden, 1635; Waite and Udden, 1701.

*The Bend evidently covered most or all of the Red River uplift and was removed by erosion in pre-Upper Pennsylvanian time. Remnants of the Bend may therefore be found in any one of these counties, particularly at the sides of the uplift.

Hill and adjoining counties, the Pennsylvanian, where present under the Cretaceous, is of changed facies.

In the Colorado River valley the conditions are somewhat different to those of the Brazos River valley. The east and south margins of the Upper Pennsylvanian are in part exposed; to the northeast and southwest these formations pass under Cretaceous and to the northwest under Permian. In this western direction the later Upper Pennsylvanian formations have been reached in wells as far to the west as the foot of the High Plains, and with little doubt the late Pennsylvanian formations pass under the High Plains of the Panhandle region and unite with the Pennsylvanian of New Mexico. From the extreme highs, however, such as the tops of the Amarillo Mountains, the Pennsylvanian is absent, the Permian there resting on the pre-Cambrian. The Pennsylvanian, however, is present at the sides of these mountains.

The lower division of the Upper Pennsylvanian, the Strawn group, has been found to thin very rapidly westward and to thicken eastward. The earliest formation, the Millsap Lake, thickens rapidly eastward. Wells in Bosque and Johnson counties, and in western Hill County, entering this formation immediately under the Cretaceous, have drilled 3500 or more feet into it without finding evidence of formation change. Fossils are rare, and it cannot be definitely asserted that this entire thickness of sediments is to be referred to the Upper Pennsylvanian, the provisional reference being made on lithology. From its surface exposures the formation thins underground westward. In Wise County, northeast of the belt of surface exposures, the Strawn reaches a thickness of 4300 feet (1398b). The Mineral Wells formation likewise thins westward.

In the Colorado River valley the Strawn beds, there subdivided into many members, thin rapidly westward. The source of sediments was a land mass lying to the east. It is assumed by some that, while a low-lying land mass approximately in the position of the Bend arch was being gradually submerged, the Strawn sediments overlapped onto this land, which was completely submerged by the end of the Strawn stage.

The Canyon sediments likewise thicken and assume a shoreline phase eastward, although the shoreline facies of this and the overlying Cisco group has largely been lost by erosion. The eastern shoreline obviously was not stationary through Upper Pennsylvanian time but moved progressively westward, thus bringing into the Cisco group, at least of north-central Texas, a larger amount of conglomerate, coal, and other near-shore sediments than is found in the underlying Canyon.

Southwest of the Llano uplift in Kerr, Real, Edwards, and other counties, is found, under the Cretaceous and overlying the Bend, a thickness of several thousand feet of Upper Pennsylvanian shales and sandstones. The age of these deposits is probably Strawn and later. Upper Pennsylvanian is probably continuous from this region westward across the Pecos Valley to the Marathon region of west Texas.

Drilling in the mountainous region of Trans-Pecos Texas affords as yet no more than limited information on the Pennsylvanian underground.

PENNSYLVANIAN SEAS IN THE TEXAS REGION

The Pennsylvanian seas, as shown by the deposits which accumulated in them, were spread extensively across the Texas region. A Lower Pennsylvanian sea extended from an Oklahoma connection in the region of Denton, Cooke, and Montague counties southwestward through north-central Texas, crossing the present Llano uplift, and thence westward, connecting with the west Texas sea of the same time in which were deposited the Lower Pennsylvanian sediments of the Diablo, Hueco, and Franklin mountains. The northwestern shoreline of this sea is imperfectly determined. Lower Pennsylvanian, Bend group, was either not deposited or was subsequently eroded from the Amarillo uplift and from the western part of the Red River uplift. Such deposits are absent likewise on the Reagan County dome (Big Lake oil field) and on the Pecos uplift in Pecos County. However, its absence at these localities may be due to erosion, and it may be found that the Lower Pennsylvanian sea extended northwestward across the Panhandle region of Texas.

The Llanoria geosyncline was probably fully occupied by a Lower Pennsylvanian sea. This conclusion is supported by the presence in the Marathon basin of the great uninterrupted series of Pennsylvanian sediments, representing deposition from earliest Pennsylvanian or late Mississippian to late Pennsylvanian time. What is possibly the equivalent of the oldest of these deposits is found in the Stanley-Jackfork series of the Ouachita Mountains of Oklahoma. Although concealed in the intermediate region by Cretaceous formations, similar shales and sandstones are shown by well drilling to be present in the geosyncline, indicating that the entire geosyncline was receiving sediments in late Mississippian or early Pennsylvanian time (fig. 10, p. 128).

A pronounced break between Lower and Upper Pennsylvanian occurs over much of the Texas region, indicating that the Lower Pennsylvanian seas were in part, if not entirely, withdrawn, this withdrawal being followed by an erosion interval previous to the spread of the Upper Pennsylvanian seas. Evidence of the interval of erosion is found at several localities. On the Red River uplift the Bend group persists as a remnant only, being in places entirely removed and elsewhere remaining in varying amounts. It is overlain unconformably by Upper Pennsylvanian. A similar condition may be seen in surface exposures in the Llano uplift, the Cretaceous and Upper Pennsylvanian covering having been largely removed. The exposures of this uplift show that the Lower Pennsylvanian was eroded and mildly warped previous to the incursion of the Upper Pennsylvanian sea. Again in extreme west Texas in the Hueco Mountains a similar break in deposition is recorded by the angular unconformity which separates the Bend and Strawn groups. In the great Llanoria geosyncline, on the other hand, the seas may have remained continuously until finally excluded by mountain-making at the close of Lower Pennsylvanian or in Upper Pennsylvanian time.

Following this great withdrawal at the close of Lower Pennsylvanian time, the return of the sea into the Texas region in Upper Pennsylvanian time was gradual. An early basin of deposition, which has been called the Strawn basin, centered in the Bosque County region where, as previously stated, is now found, underlying the Cretaceous, a maximum thickness of the early Strawn sediments. Shoreline deposits of this basin are found at the south on the Colorado River and at the northeast in Wise County. It seems not improbable that a similar basin of about the same age, known as the Kerr basin, developed in the same way southwest of the Llano uplift in the Kerr County region, where Upper Pennsylvanian shales, now covered by Cretaceous, likewise accumulated to a great thickness. These regions are adjacent to the Llanoria geosyncline and both may be regarded as extensions from it. Cheney and Harris have suggested that these basins of deposition were connected in Strawn time around the southeast side of the present Llano uplift (247c). This hypothesis, attractive as it is, meets with the objection that the Strawn sediments of the Colorado River region are of very nearshore facies, indicating a shoreline seemingly not so remote as this hypothesis would require.

The sea in north-central Texas extended progressively westward during Strawn time. The relatively wide distribution of this sea is shown by the occurrence of Strawn-age sediments in north-central Texas, in the Marathon region, and in the Diablo and Hueco mountains of west Texas.

In Middle and late Upper Pennsylvanian time, Canyon and Cisco epochs, the sea spread much more widely across northwestern Texas, reaching the Rocky Mountains region.

RELATION OF THE TEXAS PENNSYLVANIAN TO THAT OF ADJOINING STATES

The Texas early Pennsylvanian of the trough facies, as the Tesnus of the Marathon region, is much like the Stanley-Jackfork series of Oklahoma. That it is of the same age, however, has not been demonstrated, notwithstanding that both were deposited in the same geosyncline. The Bend seas are traced to the north state line and a possible continuance into Oklahoma is found in the seas in which the Springer, Upper Caney, and Wapanucka formations were deposited.

The Upper Pennsylvanian finds its direct connection northward with the great series of Upper Pennsylvanian of the Mid-Continent basin extending northward through Oklahoma, Kansas, and Nebraska.

PALEOZOIC OF THE LLANORIA GEOSYNCLINE

It has been shown in recent years that the Paleozoic of the Ouachita Mountains of Oklahoma extends southwestward into Texas, where it is concealed under a Cretaceous covering. In 1918 and 1919 Udden made observations on the rocks under the Cretaceous in two wells in the Balcones fault zone in Williamson and Bexar counties, Texas. The altered condition of these rocks suggested to him profound movements in the Balcones region in pre-Cretaceous time, and enabled him to determine the sediments affected as pre-Paleozoic or altered Paleozoic (1649, p. 1085; 1651, p. 129). Additional wells were subsequently drilled in the Balcones zone and

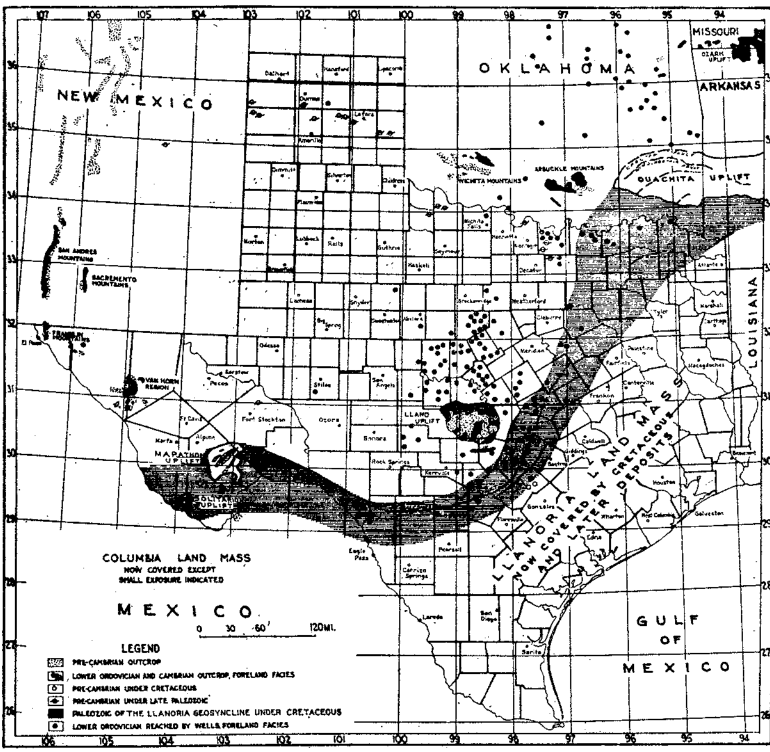

Fig. 10. Paleozoic of the Llanoria geosyncline in Texas.

description of samples published from time to time (Adkins, 11; Adkins and Arick, 16; Sellards, 1402). In January, 1929, Sellards mapped the probable continuation of sediments of the Ouachita facies southwestward in the general region of the Balcones fault zone to central Texas, and suggested their relationship to similar sediments in the Marathon region (1423, p. 3, and map). In June and in August, 1929, Cheney postulated the extension of the Ouachita basin of Oklahoma southwestward into Texas and suggested its possible connection with the Marathon basin (246, p. 570; 247, p. 14). The evidence of the extension of these sediments south and southwest, then available from well records, was given by Miser in October and December, 1929 (1115, p. 9; 1116, p. 215), and by Sellards in December, 1929 (1433, p. 232). This evidence is more fully presented in two papers published in July, 1931 (Miser and Sellards, 1117; and Sellards, 1441). The probable position of the hinterland, Llanoria, and of a part of the now closely folded region in front of it, was indicated by King in January, 1931 (936, p. 113). A map by Sellards showing the approximate location of the trough through Texas was issued in February, 1931 (1439). In September, 1931, appeared an extended discussion of this and related subjects by Van der Gracht (1677), who had arrived independently at conclusions similar to those expressed in some of the publications listed above which he had not seen until his own paper was in press.[45]

Names suggested for this great structural feature are: Ouachita geosyncline for that part which includes the Ouachita Mountains of Oklahoma and Arkansas; Ouachita synclinorium for the entire basin in Arkansas, Oklahoma, and in Texas as far south as Georgetown in the central part of the state (Cheney, 246, p. 583, map); Marathon geosyncline for the Marathon region (King, 936, p. 114); Ouachita embayment for the Ouachita Mountains area and the entire foreland of the Texas region (Schuchert, 1382g, p. 181). In this publication the term Llanoria geosyncline is used for the comparatively narrow trough that extended through Texas from the Marathon region to the Ouachita region. The terms Ouachita geosyncline, Marathon geosyncline, and Ouachita embayment are used as originally applied.

The belt in Texas underlain by these formations, as shown by drilling, lies near the inner margin of the Gulf Coastal Plain, the trough which received these sediments having been formed immediately in front of the old land mass Llanoria. Well samples, cores, and cuttings, have been obtained from a considerable number of wells entering these sediments, but from only a few have fossils

[45]Letter of April, 1931.

of stratigraphic value been obtained. These fossils, chiefly graptolites, supplementing evidence derived from the character of the deposits, make it possible to demonstrate the Paleozoic age of the formations concerned, and to follow this belt, although concealed by overlying Cretaceous, for approximately 600 miles, from exposures in the Ouachita Mountains region of Oklahoma to similar exposures in the Marathon and Solitario regions near the Mexican border in Trans-Pecos Texas. The counties through which this belt is known to pass in Texas, named in order from northeast to south and southwest, are: northern Red River, northern Lamar, northern Fannin, central and southern Grayson, western Dallas, western Ellis, eastern Hill, eastern McLennan, western Falls, central Bell, central and western Williamson, western Travis, eastern Hays, western Caldwell, eastern Comal, northern Bexar, southern Medina, southern Kendall, central Kinney, southern Val Verde, southern Terrell, southern Brewster, and southern Presidio.

The formations that lie within this geosyncline, exposed in the Marathon and Solitario uplifts, have already been described (pp. 64, 117). They include formations of Upper Cambrian, Ordovician, Devonian, and Carboniferous age. The similar formations exposed in the Ouachita Mountains of Oklahoma and Arkansas have been described in several publications. Although, owing to the few fossils obtained, it has often been difficult to identify formations with certainty, it is probable that in the Llanoria geosyncline, concealed by the Cretaceous, formations are present representing Cambrian, Ordovician, Silurian, Devonian, and Carboniferous. Rocks, on the basis of lithology, probably representing the Cambrian or Ordovician, have been found under the Cretaceous in Red River and Lamar counties. Shales and cherts obtained from the Wall well in Grayson County were found to contain Ordovician fossils, and are believed to represent the Big Fork chert and Stringtown shales of the Ouachita section (1117, p. 817). Graptolites of Ordovician or Silurian age have been obtained also from Bell County (1441, p. 827). Novaculite, probably an extension of the Arkansas novaculite of Devonian age, is believed to be present in Bell County. Rocks agreeing in lithology with the Missouri Mountain slate have been found in wells in Bell, Falls, and Hays counties (1441, 827), and probably in Grayson County (1117, p. 805). The Stanley and

Jackfork formations of the Ouachita region, late Mississippian or early Pennsylvanian, have been recognized provisionally in almost all of the counties through which this belt passes, from the Red River to the Colorado River. It is believed therefore that, within this geosyncline, all or nearly all the formations known in the Ouachita Mountains of Oklahoma and Arkansas are represented. Their most typical representation is found in that part of the geosyncline extending from Oklahoma southward to the central part of Texas. The part of the geosyncline west of Medina County is less well known. It is probable that the sediments in that part of the trough find their closest relationship with those of the Marathon and Solitario regions.[46] As previously stated, the source of the sediments is from the Llanoria land mass lying to the east or south of the geosyncline.

Although concealed by a Cretaceous covering, the western margin of rock of the Ouachita facies is known within narrow limits. The Choctaw fault, which marks the western limits of these sediments in surface exposures in the Ouachita Mountains, passes under the Cretaceous covering near Atoka, Oklahoma. From this locality a line may be drawn continuing southwestward towards Texas, west of which wells enter rocks of the Arbuckle foreland facies and east of which wells enter rocks of the Ouachita facies under the Cretaceous (1117, p. 808). This line, continued into Texas through Grayson County, likewise limits the Ouachita facies. The Wall well, having Big Fork chert and Stringtown shale immediately under the

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[46]The principal publications relating to the land mass Llanoria are cited in footnote 8, page 21. Among publications relating more directly to the sediments derived from this land mass and accumulated in the geosyncline at its margin are the following: *Oklahoma:* Honess, C. W., Geology of Atoka, Pushmataha, McCurtain, Bryan, and Choctaw Counties, Oklahoma, Okla. Geol. Surv., Bull. 40-R, pp. 18–20, 1927; Miser, H. D., and Purdue, A. H., Geology of the DeQueen and Caddo Gap Quadrangles, Arkansas, U. S. Geol. Surv., Bull. 808, pp. 137–138, 184–185, 1929; Purdue, A. H., and Miser, H. D., U. S. Geol. Surv., Geol. Atlas, Hot Springs Folio 215, 1923; Honess, C. W., Geology of the Southern Ouachita Mountains of Oklahoma, Okla. Geol. Surv., Bull. 32, 1923; Miser, H. D., Geologic map of Oklahoma, U. S. Geol. Surv., 1926; Miser, H. D., Structure of the Ouachita Mountains of Oklahoma and Arkansas, Okla. Geol. Surv., Bull. 58, 1929 (abst., Geol. Soc. Amer., V. 39, p. 180, 1928); Ulrich, E. O., Fossiliferous Boulders in the Ouachita 'Caney' Shale and the Age of the Shale Containing Them, Okla. Geol. Surv., Bull. 45, 1927; Powers, Sidney, "Age of Folding of the Oklahoma Mountains," Geol. Soc. Amer., V. 39, pp. 1031–1079, 1928; Moore, R. C., Framework of Southeastern North America, Geol. Soc. Amer., V. 39, p. 181, 1928 (abst.); Branner, G. C., Geologic map of Arkansas, Arkansas Geol. Surv., 1929. *Texas* (listed in bibliography): Adkins, 11; Adkins and Arick, 16; Baker and Bowman, 44; Cheney, 246, 247; Hopkins, 844; King, 936; King and King, 930, 932; Miser, 1116; Miser and Sellards, 1117; Plummer, 1234a; Sellards, 1402, 1423, 1429, 1430, 1435, 1439, 1441, 1444a; Udden, 1649, 1651.

Cretaceous, is near but east of the line. West of the line in this county under the Cretaceous are Pennsylvanian deposits of undetermined thickness. Continuing southwest the line of separation under the Cretaceous between the rock of geosynclinal and foreland facies is fairly definitely placed, particularly in McLennan, Bell, Williamson, Blanco, and Kendall counties. From Kendall County the line swings more to the west and is less definitely placed. A northward salient is indicated by wells in Val Verde and Terrell counties. After curving northward in these counties, the line limiting the belt of rock of geosynclinal facies reaches the Marathon area which is a part of this salient.

While the west and north boundaries of these formations are thus fairly well known from the Ouachitas to the Marathon Mountains, the east or south margins are almost unknown. At one locality only in Texas is the east margin probably known. Wells drilled on the Tabor, Tiller, and Kelley farms in the Luling oil field of Caldwell County, Texas, reached highly altered rocks immediately under the Cretaceous, believed to represent the Llano series of pre-Cambrian age (1433, p. 820). This locality, accordingly, seems to be east of the trough in which these Paleozoic sediments accumulated. If so, the Llanoria geosyncline has a width in this part of the state of about 40 miles (see map, fig. 10, p. 128). In Mexico, near Boquillas, south of the Marathon region, is an exposure of schists under Cretaceous which may indicate the south limit of the geosyncline in that region.

The following description of a core from the Tabor well (depth 4796 feet) by T. L. Bailey will serve to indicate the character of the rock below the Cretaceous in Caldwell County.

The sample consists of about two inches of a one and one-half inch core of fine-grained, well metamorphosed, light pearly-gray, calcite-quartz-sericite schist with pink and dark gray bands or streaks, the pink being due to garnets. The rock has a very bright sheen due to the abundance of sericite mica and the foliae are sharply bent into small undulations in many places. In thin section the rock is seen to have a minutely fibrous as well as foliated schistose texture. The two principal minerals in the rock are quartz and sericite. The quartz occurs in very small, elongated, lenticular grains with the bent or wavy mica flakes filling in the spaces between them. Thus in a section cut parallel to the schistosity but at right angles to the foliation much of the rock has a distinct plaited appearance when seen under high power magnification with the nicols crossed to bring out crystalline structure and orientation of its component minerals. The quartz and sericite comprise about 75 per cent of the rock. The grains usually exceed one-twentieth of a mm. in length. The commonest accessory mineral noted in this rock is abundant, dark red, submetallic, minute, dodecahedral or rounded crystals of garnet. There appears to be some hematite in the rock also. Extremely minute, but abundant, needles of what appears to be a colorless amphibole, probably tremolite or actinolite, are shot all through the rock. These needles have various orientations but the majority are roughly parallel to the schistosity. Minute, slender, blunt-ended prisms of apatite are very common. These minute prisms and needles can scarcely be seen under less magnification than 150 diameters, but can be easily distinguished when magnified 300 diameters. Sericite is the most abundant mineral of the two. In certain portions the rock is almost entirely composed of sericite and in other portions, of about half sericite and half quartz. Dolomite comprises about 20 per cent of the rock. This occurs in elongated, somewhat irregular, lenticular aggregates of colorless dolomite or possibly calcite. The carbonate effervesces like dolomite. From its texture and mineral composition this rock, before metamorphism, was evidently a calcareous, somewhat ferruginous, shale containing a large number of silt or very fine quartz sand grains. This sample is probably from the Packsaddle schist or its equivalent.

The following comments on samples of this rock are by V. E. Barnes:

Tiller wells No. 1 and 2: The schistosity in the core from Tiller No. 1 dips about 15 degrees and is parallel to the bedding. The bedding is marked by an alternation of white sandy layers with dark shaly layers. In the core from Tiller No. 2 the schistosity has the same dip, but is crossed by the bedding at a high and irregular angle. The mineral composition of this rock appears to be mostly sericite and chlorite with a small amount of quartz. Much of the material that apparently is either rutile or zircon is present. The degree of metamorphism is rather advanced, suggesting these rocks may be pre-Cambrian in age.

Kelley well No. 1: The sample studied from this well is a core of green schist, the cleavage of which dips at an angle of 16 degrees. This dip is rather flat and is suggestive of "load cleavage." The attitude of the cleavage to the bedding could not be determined. The rock is composed of chlorite and some sericite and quartz. Many slender needles are present of a geniculate twinned mineral, with high index and birefringence, that is probably either rutile or zircon. Augen are present as very small islands around which shear planes have veered. The schistosity has evidently formed by a combination of minute attrition of the original mineral content and re-crystallization of the materials present.

One very peculiar augen-like, or possibly better described as metacryst-appearing, object is composed of calcite, pyrite, and chlorite bordered on two sides by quartz in which are parallel inclusions of chlorite perpendicular to the general schistosity of the rock. The schistosity bends about this object, suggesting that it is an augen. The mineral composition is neither compatable with an original rock or a metacryst. Apparently, however, it is of a metacrystic origin with some shearing after its development, thus bending the cleavage about it.

This core is of a very highly metamorphosed rock and is suggestive of the schists found in the Central Mineral region. The age is probably pre-Cambrian.

Little is known as to the thickness of sediments in the Llanoria geosyncline. In the Ouachita Mountains in Oklahoma, sediments of this facies reach a thickness of some 25,000 feet, and in the Marathon region of Texas of probably 20,000 feet. So great a thickness, of course, cannot be seen in any one section, but is the sum total derived from various exposures. The substratum on which these sediments rest has not been seen in either the Ouachita or Marathon regions and has not been reached by wells, unless possibly the Wardlaw well in Kinney County, to which reference has been made. The depth to which wells have been drilled into these sediments in the several counties is from a few hundred to about 3000 feet. If, as seems probable, the sediments encountered in drilling are in the form of thrust sheets, it is not unlikely that these sheets at some localities may be relatively thin and may have been thrust across other deposits of the foreland facies. This is possibly the condition in Kinney County.

The sediments in this geosyncline are usually more or less altered, often crumpled, minutely folded, slickensided, and faulted. In cores it is often seen that shales have been pressed into sandstones. The dip, as occasionally determinable from cores, is often, although not always, steep. In some of the wells from which samples have been examined there is evidence of a reversed position of sediments, as Silurian overlying Devonian (1441, p. 827). These conditions are believed to indicate that the sediments of this geosyncline, where concealed by Cretaceous, are folded, faulted, overthrust, and overturned, as they are in the Ouachita and Marathon exposures.

Cores from several of these wells have recently been examined by V. E. Barnes, who reports, with respect to the degree of metamorphism on samples from several wells, as follows:

Mellon Oil Company's No. 1 Bailey, Bell County: Many thin sections are available of material from this well from depths of 1920 to 3660 feet. Some of the shale fragments are composed of non-oriented minerals. In others considerable oriented sericite and chlorite are present. Slickensides are abundant in many of the samples, with the development of platy minerals parallel to the slippage planes. Between the depths of 3640 and 3650 feet, several round bodies, with evenly spaced inward-extending but slightly developed partitions, were noticed. These are undoubtedly organic and have been described provisionally as radiolarians by Adkins in University of Texas Bulletin 3016. In addition to those already described, several rounded bodies were observed in material from between the 2640 and 2655 foot level. The metamorphism exhibited in these rocks is slight, and their age is undoubtedly Paleozoic.

Ben Williams Oil Company's No. 1 Warwick, Bell County: The rocks examined are quartzites and phyllites. The quartzites are composed of rounded grains, apparently cemented rather tightly by silica. Some shearing has caused many of the grains to be broken. The phyllites are shales that have had the minerals re-oriented in such a manner that rotation between cross nicols causes them to extinguish as a unit. Rearrangement of this magnitude is easily accomplished in a shale and does not necessarily indicate a great amount of movement. No organic fragments were recognized.

Hillsboro City Well, Hill County: The cuttings from this well are of quartzite and phyllite. The quartzite is composed of quartz with some feldspar and has suffered some granulation, with a few sections showing a mosaic-like interlocking of grains. The phyllites have been formed by the recrystallization of the materials present, for the most part, into sericite oriented in one direction. The less resistant rocks of this series show considerable recrystallization.

Waco Oil and Refining Company's No. 1 Harrington, McLennan County: Many veinlets of calcite and quartz penetrate quartzite in the one sample examined from this well. The quartzite is composed of grains of quartz that have been largely recrystallized and much broken. The metamorphism is rather advanced.

Concord's No. 1 Dillahunty, Red River County: The thin piece of core available from this well shows crinkly cleavage that is almost horizontal. The chief mineral apparently is chlorite, with some sericite and quartz. The quartz is in bands of elongated mosaic-like grains exhibiting wavy extinction. Some needle-like crystals of zircon or rutile have developed. The metamorphism exhibited by this core is rather advanced.

Griffith's No. 1 Evans, Travis County: Cores from this well show cleavage dipping at about 70 degrees. A section parallel to the cleavage shows almost a total absence of metamorphism. Several organic remains, probably of plants, were observed. A thin section across the cleavage shows that schistosity has developed parallel and close to the widely spaced cleavage planes. Metamorphism is very slight.

Miller and Mayfield's No. 1 Miller, Williamson County: This rock is little more than a shale and has changed only along shear planes into parallelly-oriented minerals. The metamorphism is very slight.

The degree of metamorphism of the older rocks encountered in wells near the Balcones fault zone varies between wide limits. The very much metamorphosed rocks of Caldwell County, such as those of the Kelly, Tabor, and Tiller wells, that have such flatly dipping cleavage, probably belong to some pre-Cambrian series of rocks.

The rest of the rocks studied, when listed by localities in the approximate order of decreasing metamorphism, are as follows: Red River County, McLennan County, Hill County, Bell County, Travis County, and Williamson County. The Bell, Travis, and Williamson county rocks are very slightly metamorphosed and contain organic remains in many samples. The rocks from Red River, McLennan, and Hill counties have been subjected to more change than the group just mentioned.

The Wardlaw well in western Kinney County, after passing through 1675 feet of rock of geosynclinal facies under the Cretaceous, appears to have entered magnesian limestones such as characterize a foreland facies. This well is thought to have penetrated the thrust sheet and reached the underlying foreland facies across which the sheet had been thrust. This interpretation cannot, however, be regarded as established.

The Llanoria geosyncline apparently ceased to receive sediments near mid-Pennsylvanian time. In the Ouachita region no sediments remain of age later than the Lower Pennsylvanian. In the Marathon region of Texas the Haymond formation, which may be of Strawn age, lies within the geosyncline. If Upper Pennsylvanian sediments are present in the geosyncline in the intervening area where the records are from well samples only, they are non-fossiliferous and have not been detected. It seems probable that a general uplift of the Llanoria region near mid-Pennsylvanian time shifted the basins of accumulation westward, so that in early Strawn time the principal basins of accumulation in front of Llanoria were west of the Llanoria geosyncline and included the Strawn and Kerr basins previously described (pp. 124, 125).

The folding of the sediments in the geosyncline was probably progressive. In the Marathon region there was a period of intense folding and thrusting late enough to involve at least the lower Gaptank. The pronounced folding of the region, however, was completed before Permian time. In the Ouachita region, according to Miser, the intense folding can be placed as probably later than Allegheny, mid-Pennsylvanian time, and as pre-Cretaceous (1115, p. 27). In the intervening area between these outcrops, the only definite information available is that the folding is pre-Cretaceous and the sediments of the geosyncline are probably thrust across sediments of Strawn age. Future well drilling may prove that they are also thrust across Canyon or later sediments, but such evidence is not at present available.

The structural trends in these sediments are in direct opposition to those in the sediments of the foreland. The geosyncline trends southwest, and thus is at right angles to the Red River uplift which trends southeast. The conditions in these two pronounced structural features at their intersection in eastern Denton or western Collin County is unknown, but it is possible that the rocks of the Ouachita facies are there thrust across rocks of the foreland facies of the Red River uplift. The Llano uplift of central Texas is not within this geosyncline, but is a feature of the foreland within the Ouachita embayment as defined by Schuchert.

The Balcones fault zone of Texas lies wholly within the Llanoria geosyncline and agrees in trend with the Choctaw and other faults of the Ouachita Mountains. The two series of faults, however, are of wholly different character. The faults of the Ouachita region are overthrust from the southeast, the thrusting having occurred in Paleozoic time. The Balcones fault zone, on the contrary, has normal or gravity faults with accompanying downblocks or grabens, the major downthrow being to the east. These faults cut formations as late as Eocene. Nevertheless there may be a causal relation between these faults notwithstanding their different character and age. It is fully demonstrated that the Paleozoic formations of the Ouachita series of Oklahoma extend southwestward into Texas and are there found underlying the Cretaceous and occupying approximately the Balcones fault zone across the state, turning westward at San Antonio towards the Marathon and Solitario regions. The formations in the Marathon and Solitario uplifts are intensely folded and overthrust, much as are those in the Ouachita Mountains. It is to be inferred, therefore, that these formations are likewise folded and faulted in the intervening area where they are covered by Cretaceous. This inference is supported and in a measure established by the following observations: The cores taken in wells in this zone indicate at several localities steeply dipping and closely folded rocks; the wells after passing through the Cretaceous in this zone enter various Paleozoic formations with no indicated regularity in regional distribution. The conclusion, therefore, is that the Balcones zone of Texas is underlain by a highly broken and faulted series of Paleozoic formations resembling in lithology those of the Ouachita Mountains of Oklahoma on the one hand and of the Marathon region on the other and being in fact a connecting belt between these two regions and having suffered similar deformation. To the east of this zone we must assume the existence during Paleozoic time of a land mass from which the great body of sediments of this series came. To the west, as shown by the sediments that accumulated, were the shallow foreland seas in which were deposited limestones, shales, and some sands.

In the post-Mississippian history of this region the following events may be determined: Following the Stanley-Jackfork deposition and within Paleozoic time, northward and westward thrusting resulted in close folding and overthrusting. As a result of this diastrophism the thick sedimentary series which had accumulated in the trough in front of the land mass was intensely folded, crumpled, and thrust. The width of the geosyncline was reduced, the reduced width being compensated probably by increased elevation. It is not improbable that more than one period of folding and thrusting may have occurred, as seems to have been the case in the Marathon region and possibly also in Oklahoma. In any case the result was the obliteration of the geosyncline in front of the land mass and the continuous westward migration of the shore line through late Paleozoic time.

Another great event in the history of this region is the change during perhaps mid-Mesozoic time in relative land elevation by which the great basin of Paleozoic deposition of central and west Texas became elevated, and, on the other hand, the previously high land of southeast Texas became depressed, thus reversing drainage and initiating the conditions by which the Gulf of Mexico became a great basin of deposition, a condition that has continued to the present time.

The reversal in relative elevation progressed to the extent of complete submergence of the Texas region during Cretaceous and was followed by moderate uplift in the central Texas region. The changes during Tertiary time include down-warping near the Gulf coast and moderate uplift inland. Under these conditions of strain the Balcones zone of faulting was formed.

In these changes in elevation forces were acting on three rock series of varying power of resistance, as follows: (a) The basement rocks, including schists or granites or both, which made up the Llanoria land mass at the east; (b) the Paleozoic rocks of the foreland, consisting of limestones, shales, and some sands, the whole series being relatively thin and resting upon basement rocks; (c) intermediate between these two types a relatively narrow belt of rocks which had accumulated to a great thickness in the trough immediately in front of the Llanoria land mass consisting very largely of shales, sandstones, and thin-bedded cherts. These rocks had already been intensely folded, faulted, and broken by the previous westward thrusting.

The major faulting in connection with this warping occurred in the narrow belt of sediments of the geosynclinal facies because these sediments were weaker both by reason of previous faulting and because of the character of the rocks. The faulting having thus been initiated in the underlying rocks of this character necessarily affected the overlying Cretaceous and Eocene. It follows, therefore, that the agreement in location and trend of the Balcones zone of faulting with the buried Paleozoics of the Ouachita facies is not accidental but is causal. In south-central Texas, igneous rocks were extensively extruded and intruded in and near the Balcones zone and chiefly within the belt of rocks of the Ouachita facies. The intrusion of these igneous rocks at these localities is possibly likewise because of the presence of the geosynclinal facies of the Paleozoics (1444a, p. 745).

Additional information on the Paleozoic of the Llanoria geosyncline is given subsequently in the tables of well records.

Van der Gracht has compared the structural conditions in this region to the northern front of the Variscan Mountain system of southern England, Wales, northern France, Belgium, Holland, and Westphalia, and to the much later Alps and Carpathians. The Carboniferous deposits of the Ouachita Mountains, Stanley and Jackfork formations, he compared to the Flysch facies of the Alps;

and the thick Upper Pennsylvanian deposits of Oklahoma and Texas, to the Molasse.[47]

PENNSYLVANIAN-PERMIAN CONTACT

In the mid-continent region, the Pennsylvanian-Permian contact in Kansas, Oklahoma, and Texas has been variously placed by different writers. In Texas the contact was placed by Drake in 1893 at the base of the Coleman Junction limestone (449). Subsequently Plummer and Moore selected the top of this limestone as the dividing line between the two systems (1228, p. 190). On evidence furnished by sediments and fauna, Wrather in 1917 proposed that the contact be placed at the base of "yellow-weathering limestones found in the hills about 2 miles west of Moran in Shackelford County" (1801, p. 94). King (940, p. 22) maintains that the contact should be placed much lower than the Coleman Junction limestone. Roth, in a recent note (1353c), proposes that the Permian in Texas should be lowered to include the Crystal Falls limestone member of the Harpersville formation, some 700 feet below the Coleman Junction limestone. For reasons subsequently given, the contact is here placed at the base of the Moran formation, 300 or 350 feet below the Coleman Junction limestone. In Oklahoma and Kansas the contact has been placed at the Wreford, Cottonwood, Neva, Americus, and Hart limestones, the Asher sandstone, and the Elmdale shales.[48]

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[47]The term Flysch, applied originally to Alpine deposits of Cretaceous and Oligocene age, is applied by Van der Gracht as a general term to sediments deposited during the late stages of a geosyncline. "This formation," he says, "can be conceived as rapidly filling the foredeep, which was being depressed in front of an advancing major crustal thrust block and migrating with it." The Molasse is the detritus worn from elevated ranges during and immediately after a major diastrophism, deposited in a later foredeep, considerably in front of the preceding Flysch geosyncline. It may be deformed and overthrust by the final last advance of the thrust sheets (Nappe or Decke). Remnants of the thrust sheets, remaining as outliers in front of the main sheet, are known as Klippen. The substratum underlying the thrust sheets is the autochtone, and the overthrust complex, the allochtone. The hinterland is the region, usually, but not necessarily, mountainous, from which the sediments of the geosyncline were derived, and is bordered by the geosyncline which receives the sediments. The foreland is the relatively broad expanse separated from the hinterland by the geosyncline. The sediments in the foreland are usually thinner than those of the geosyncline, and of different facies, contain a larger element of chemical or organic rocks, such as limestones and dolomites. As a rule life was more abundant in the foreland than in the geosyncline, and the sediments are often fossiliferous.

[48]Prosser, C. S., Jour. of Geol., Vol. 10, p. 718, 1902; Haworth, E., Kansas Univ. Geol. Surv., Vol. 9, p. 69, 1908; Gould, C. N., Ohern, D. W., and Hutchison, L. L., State Univ. of Oklahoma, Research Bull. No. 3, 1910; Beede, J. W., Oklahoma Geol. Surv., Bull. 21, pp. 21–23, 1914; King (940, p. 22); Moore (1833b, chart); Birk, R. R., Bull. Am. Assoc. Petr. Geol., Vol. 9, p. 989, 1925.

The actual stratigraphic relations of these several members in Texas, Oklahoma, and Kansas has not been satisfactorily determined. The Coleman Junction limestone in Texas grades into sandstones near Megargel in Archer County.[49] From this locality sandstones representing the approximate horizon of the Coleman Junction limestone have been followed through Archer, Clay, and Montague counties (see map, fig. 11*).

The limestones of the normal marine section in northern Oklahoma and Kansas near the Permian-Pennsylvanian contact, when traced southward, grade into sandstones and are lost in the red bed facies. From the Oklahoma state geologic map, it appears that the Cushing limestone horizon, traced southward, is found, in Pottawatomie County, to underlie the Asher sandstone.[50] This sandstone has been traced by Birk from Byars near its type locality in Pottawatomie County around the Arbuckle uplift and into Carter County, Oklahoma.[51] The horizon, however, has not been traced to the Texas state line but has been shown to lie several hundred or possibly 1000 feet below the Cornish and Ryan sandstones which are reported to come to the Red River approximately opposite the Clay-Montague county line (1606, p. 60).

The Cushing limestone (also known as Red Eagle) is within the Elmdale formation, and hence is stratigraphically below the Neva, Cottonwood, and Wreford limestones and from 45 to 80 feet above the Americus (Foraker) limestone. The Neva limestone, which can be followed southward in Oklahoma through Osage, Pawnee, and Payne counties, is 50 or 100 feet above the Cushing limestone. The Cottonwood limestone, which can be followed through Osage and Pawnee counties, is about 140 feet above the Cushing. The

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[49]According to C. O. Nickell (MS.) the northernmost exposure of the Coleman Junction in limestone facies is found 4 miles east of Megargel.

*The sources chiefly responsible for the lines shown on this map are as follows: A, various sources; B, V. E. Timms, Shell Petroleum Corporation; and C. O. Nickell; C, D, E, and G, chiefly from the Gulf Production Company. Line D near the Red River in the vicinity of the Nocona oil field is purely conjectural, no continuous line of exposures having been mapped. It was assumed that the line would swing northward as a result of the structural high in the Nocona oil field. F, Continental Oil Company; H, I, J, K, and L, from map of Jack County issued by Bureau of Economic Geology, 1929.

[50]Geologic map of Oklahoma by H. D. Miser, U. S. Geol. Surv., 1926. Robert H. Dott estimates the interval between the Cushing limestone and the Asher sandstone as 150 feet. (Letter of December 8, 1932.)

[51]Birk, R. R., The extension of a portion of the Pontotoc series around the western end of the Arbuckle Mountains, Bull. Am. Assoc. Petr. Geol., Vol. 9, pp. 983–989, 1925.

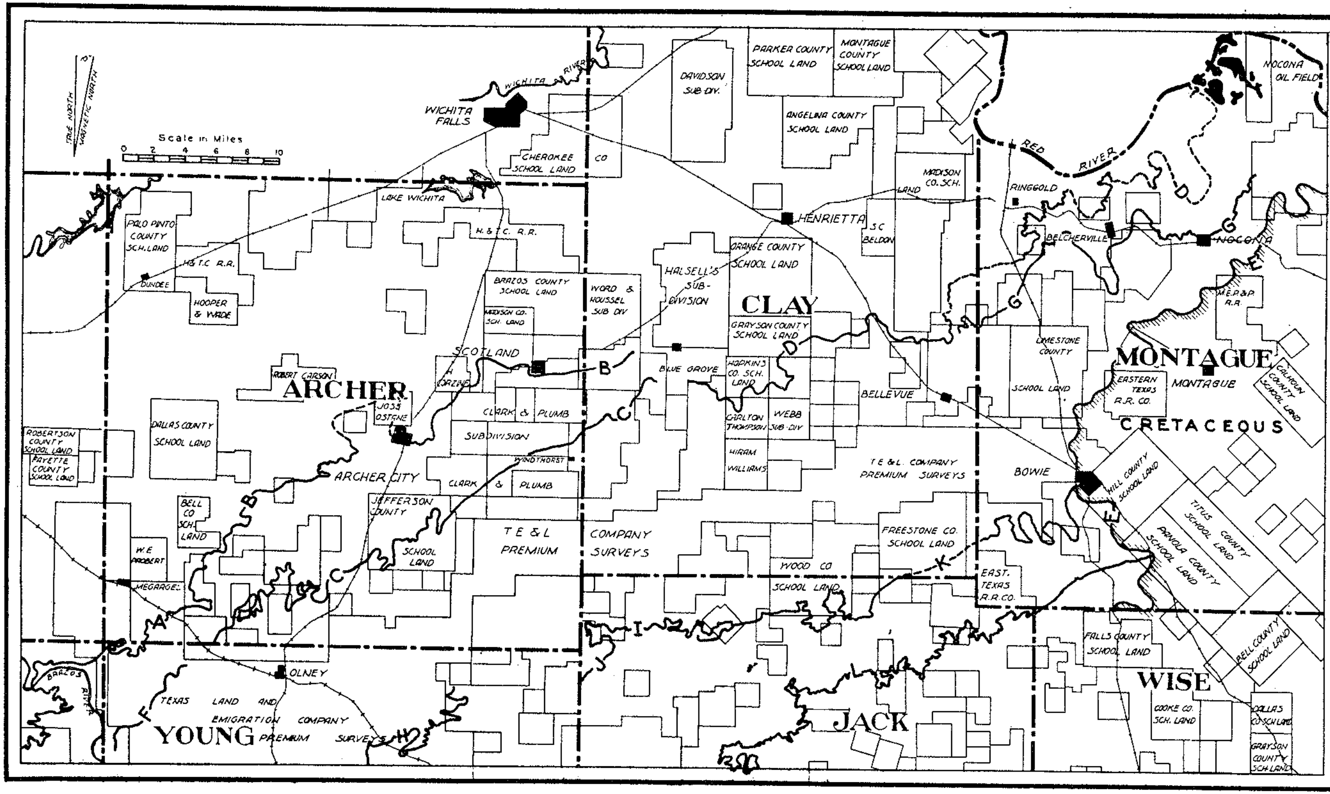

Fig. 11. For explanation see opposite page.

Wreford limestone in Osage County, Oklahoma, lies 350 or 400 feet above the Red Eagle.[52] Next above the Wreford is the Fort Riley limestone. Measured intervals cannot be strictly applied in determining equivalency since members may transgress to higher or lower levels, or the intervals may otherwise vary.

Since the individual formations and members have not been traced through the red bed facies, the Pennsylvanian-Permian contact must be determined independently by paleontology in the Oklahoma, Kansas, and Texas regions, as well as in Trans-Pecos Texas. According to Beede the most pronounced paleontologic change in the section in northern Oklahoma and Kansas is found at the horizon of the Elmdale shales and Neva limestone, and on this evidence he proposed that the base of the Permian be placed "not higher than the top of the Neva nor lower than the base of the Elmdale." The fusulinid genus *Schwagerina* is present in the Neva in Kansas and Oklahoma but has not been found in the Elmdale.

White finds that the Neva limestone includes a flora not older than the Permian as recognized in Europe (1751a). The Elmdale flora, on the other hand, although containing some Permian species, he regards as Pennsylvanian. On the evidence given by Beede and White, Schuchert (1385, p. 827) draws the Pennsylvanian-Permian contact at the base of the Neva limestone. King (940, p. 22), finding *Triticites ventricosus* abundant in both the Uddenites zone of Trans-Pecos Texas and the Elmdale formation of Kansas, regards these two zones as equivalent and places both in the Permian, extending the Permian to include the Americus (Foraker) limestone below the Elmdale formation, where a Permian element is first found in the flora and fauna. Moore has likewise placed the contact at the

[52]Oklahoma Geol. Surv., Bull. 40-T, p. 220, 1928.

Fig. 11. Approximate mapping of the Coleman Junction limestone horizon through Archer, Clay, and Montague counties, Texas. A, the Coleman Junction limestone in Throckmorton, Young, and southwestern Archer counties; B, sandstone believed by some to represent the Coleman Junction horizon and by others to represent a horizon slightly above the Coleman Junction; C, sandstone somewhat below the Coleman Junction horizon; D, sandstone in Montague County believed to be close to the Coleman Junction horizon; E, Paleozoic-Cretaceous contact in Montague County; F, line indicating trend of sandstone horizons in northwestern Young County; G, sandstone horizon through Montague County; H, the Saddle Creek limestone horizon in northeastern Young County; I, J, K, sandstone horizons believed to be somewhat below the Saddle Creek limestone horizon in northwestern Jack County; L, the Gunsight limestone horizon in Jack County.

base of the Americus limestone (1833b, chart). For reasons given elsewhere, the Uddenites zone is here placed in the Pennsylvanian.

In the Oklahoma-Kansas section the genus *Schwagerina* has not been found lower in the section than the Neva limestone. In the Glass Mountains the earliest appearance of this genus seems to be above the Uddenites zone of the Wolfcamp formation.[53] This fossil has been found by Henderson in the north-central Texas region in the Moran formation.* There are evident difficulties in fixing a contact line between Pennsylvanian and Permian in regions where no great break occurs in the section. Nevertheless, on the evidence now at hand, the most logical placing of this contact is above the Uddenites member of the Wolfcamp formation in the Glass Mountains, and at the base of the Moran formation in north-central Texas.

Roth reports finding what he regards as a Neva fauna, but without *Schwagerina*, as low as the Saddle Creek limestone at the top of the Harpersville formation of north-central Texas (1353b). It is therefore possible that the contact may come below the Moran, but conclusive evidence bringing it below that level in Texas has not been found.†

Hyatt identified the nautiloid *Stenopoceras dumblei* from the top of the Wichita (Albany) group in Texas (346, p. 223; 863, p. 347; 864, p. 446) and from the Fort Riley limestone in Kansas. In Osage County, Oklahoma, this limestone is 20 or 30 feet above the Wreford. This fossil may indicate an actual or approximate equivalency of the Fort Riley limestone with the top of the Wichita group (1385, p. 829).

The Pennsylvanian-Permian contact in the Glass Mountains is discussed under the Wolfcamp formation.

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[53]In University of Texas Bulletin 3211, White records *Schwagerina* collected by Upson from the "Lower Wolfcamp," but the exact relation to the section, whether in the Uddenites zone or not, is not made clear.

*These fossils are founds in clay and marl exposures on the public road and railroad in Callahan County from 2¾ to 3 miles west of Dothan. The horizon is 70 feet below the Sedwick limestone and is at or near the Horse Creek limestone.

†In his paper (1353b) Roth placed these fossils in the Crystals Falls limstone. The locality which he gives, however, (letter of Jan. 11, 1933) .8 mile north of the Coleman-Brownwood road, 2.8 miles west of the east line of Coleman County, indicates a thin limestone about 20 feet below the Saddle Creek limestone.

PERMIAN SYSTEM

Rocks of Permian age are found in Texas in several widely separated areas. Perhaps the most nearly complete marine Permian section in America is that of the Glass Mountains in Trans-Pecos Texas. Other regions in the state in which Permian rocks are exposed are as follows: the Guadalupe-Delaware-Apache mountains; the Diablo Plateau and associated mountains; the west side of the Franklin Mountains; the Sierra Madera and the Chinati mountains; and the Osage Plains region of north-central Texas. In addition, rocks of this system are found underground throughout the great Permian basin extending from the Pecos Valley northward into New Mexico, Oklahoma, and Kansas. These deposits at the surface and underground include varying facies, among which are normal marine limestones, sandstones, and shales; massive dolomites, often occurring in great reefs; non-marine or partially marine red beds; beds of gypsum at the surface and anhydrite underground; and, underground, various salts of which common salt, halite, is the chief constituent, although other salts, particularly of potash, are also present. The Permian basin containing these anhydrite, salt, and red bed deposits connects the Permian of the Trans-Pecos region with that of north-central Texas. This basin spoons out southward in Texas and at one locality in the bed of the Pecos River in the northwestern part of Val Verde County, the Lower Permian or uppermost Pennsylvanian is exposed on the south margin of the basin. Elsewhere the Permian of the southeast margin of the basin is concealed by Cretaceous deposits.

From the dolomites, limestones, and sandstones of this system is obtained much of the oil of the Permian basin. The silver of the Shafter region is obtained from a Permian limestone, the Cibolo formation. No potash is being produced at present in Texas, although in the New Mexico part of the Permian basin one mine is now in operation. The gypsum deposits are being utilized and salt has been produced to some extent.

Studies in the Texas region have contributed largely towards establishing the Permian system in the United States. In 1857 Hall described *Composita mexicana* which had been collected from Trans-Pecos Texas by the Emory Boundary Survey (643). In 1858 Marcou described one species from the Delaware Mountains, *Productus* *delawarii,* referred to the Lower Carboniferous (1041, p. 45). In 1858 and 1859 B. F. Shumard described fossils which had been collected by G. G. Shumard from the Delaware and Guadalupe mountains (1458, 1461). These were correctly assigned to the Permian, and, although this reference was subsequently contested, the Permian age of the formations was ultimately established by Girty's study of the Guadalupian fauna (590).

From the red bed facies of Wichita County, Cummins and others obtained vertebrate fossils which Cope described in several papers, the first one being published in 1878. A large series of publications issued during the past half century, based on vertebrates, invertebrates, and plant fossils from the Texas Permian, has greatly enriched knowledge of the Permian system.

The Permian formations recognized in surface exposures in the state are as follows:

Glass Mountains	Guadalupe-Delaware-Apache Mountains	Diablo Plateau	Chinati Mountains	North-Central Texas
Bissett	Rustler			
	Castile			Quartermaster†
				Cloud Chief†
Capitan*	Capitan			Whitehorse†
Word	Delaware Mountain	Delaware Mountain	Cibolo	
Leonard*	Leonard	Leonard	Alta	Blaine
Hess*		Hess		San Angelo
				Choza
				Vale
				Arroyo
Wolfcamp		Wolfcamp	Cieneguita	Lueders
				Clyde
				Belle Plains
				Admiral
				Putnam
				Moran

GLASS MOUNTAINS

Structually the Glass Mountains are a monocline of chiefly late Paleozoic formations, sloping to the northwest and forming the northwest flank of the Marathon uplift. Towards the uplift the

*Those followed by asterisk are found also in the Sierra Madera.

†Included in Peacock in Stonewall County.

late Paleozoic formations, chiefly Permian, terminate abruptly in a southeast facing scarp, and the mountains, so-called, include the scarp and northwestward slope of the monocline. Their width is 12 or 15 miles and their length, approximately in the direction of strike, is 30 or 40 miles. For the greater part of this distance they form the northwest margin of the Marathon basin. At the base of the scarp are Pennsylvanian and, in places, some older formations. However, the greater part of both the scarp and the slope of the mountains is of Permian rocks. Some igneous rock is present locally, and Cretaceous remains as a remnant on the northwest slope. Some of the Permian formations are exposed also in the Del Norte Mountains, which form a part of the west rim of the Marathon basin, and in the Sierra Madera, a small dome east of the Glass Mountains.

The strike of the Permian formations of the Glass Mountains is northeast and the dip northwest. The amount of dip ranges from 1 to 20 degrees. In addition to the monoclinal dip, the strata are in places mildly folded. They are also cut by numerous small post-Cretaceous normal faults which trend approximately with the dip. The structural conditions are thus relatively not complicated. Unconformities are, however, present as well as several conglomerates. The facies of deposition, on the other hand, is remarkably varied and changeable, a fact which has added materially to the difficulties of determining formation limits and equivalencies. The Permian section here is about 7000 feet thick. The Del Norte Mountains are in the belt of Rocky Mountain folding and the Permian in this range is affected by post-Cretaceous thrusting and folding, and by igneous intrusions.

Aside from a lead-silver prospect near Altuda, these Permian formations have yielded no products of economic value. However, their underground connection (often in changed facies), with the petroleum-producing formations of the Permian basin gives to them an exceptional interest economically as well as in their stratigraphic relations.

The information now available on the Glass Mountains has been accumulated through the observations of many geologists. Hill, in 1900, described the Glass Mountains and recognized the Paleozoic age of the strata (800, p. 4). From notes made in 1904 Udden, in

1907, described the section near Altuda and compared the rocks with those of similar age at Shafter, both being referred to the Upper Carboniferous (1626, p. 20). In 1914 and 1915 Udden and associates made the first detailed study of the section and at that time subdivided this great series of Permian sediments into formations and assigned formation names. Recent highly valuable studies of this region have been made by P. B. King and R. E. King and others. The following formation names are here used for this series: Wolfcamp, Hess, Leonard, Word, Captain, and Bissett.[54]

WOLFCAMP FORMATION

The Wolfcamp formation as originally defined by Udden and Böse consists of shales and limestones with some sandstone and conglomerate. At the base at the type locality is about 100 feet of shale, the Uddenites member, containing a fauna which has come to be known as the *Uddenites* fauna from the presence of the ammonite genus *Uddenites.* Above the shale is a gray limestone member 50 feet thick, followed by thin-bedded limestones and shales, approximately 550 feet thick. The gray limestone contains but few fossils, and the Permian genus *Schwagerina,* so far as definitely determined, appears first in the upper member. Keyte and others have maintained that the Uddenites member is Pennsylvanian in age and a part of the Gaptank formation (924, p. 175). J. P. Smith, who has studied the ammonites of this member, regards them as older and more primitive than any Permian [ammonoids] previously known and distinctly younger and more specialized than any known Coal Measures fauna (1498). Recently Plummer and Scott have found that the *Uddenites* fauna is present in the lower part of the Cisco group (1398, p. 355). In the limestone above the Uddenites member they find the Pennsylvanian ammonite *Schistoceras hyatti* Smith. In the present publication the Pennsylvanian-Permian line, in agreement with this new evidence, is drawn above the Uddenites and limestone members, these members being referred to the Gaptank formation. The Wolfcamp formation, thus restricted, consists of about 550 feet of thin-bedded limestones and shales.

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[54]Publications relating to the Permian of the Glass Mountains region listed in the accompanying bibliography include the following: Baker and Bowman, 44; Beede, 95; Böse, 130, 131; Keyte, Blanchard, and Baldwin, 924; Keyte, 925; P. B. King, 927, 928, 936; King and King, 930, 932; R. E. King, 940; Schuchert, 1382a, 1384, 1385; Smith, 1498; Udden, 1626, 1643, 1668; Willis, 1764.

Keyte, Blanchard, and Baldwin believe that an unconformity occurs at the top of the limestone above the Uddenites member (924). P. B. King and R. E. King, on the contrary, do not recognize such unconformity. The Wolfcamp is unconformably overlain by the Hess and is exposed in the scarp at the east foot of the Glass Mountains from Dugout Mountain, south of the Southern Pacific Railroad, to Gap Tank.

Among fossils of the Wolfcamp formation as here restricted are the following (940, p. 7):*

Schwagerina	Avonia boulei
Perrinites cumminsi	Marginifera capaci
Prothalassoceras welleri	Aulosteges wolfcampensis
Orthotetella wolfcampensis	Teguliferina bösei
Derbya buchi	Parakeyserlingina fredericksi
Productus gratiosus occidentalis	Camarophoria thevenini
Productus semistriatus	Spirifer condor
Productus wolfcampensis	Martinia wolfcampensis

Type locality: Wolf Camp, 12 miles northeast of Marathon; thickness, 600 feet.

HESS FORMATION

The first publication in which the Glass Mountains formations were defined was issued in 1916, at which time the Leonard formation was described as the basal formation of the Permian in the Glass Mountains (1652, p. 51). A year later in special reports on the Glass Mountains the Wolfcamp and Hess formations were introduced. To the Hess were assigned sediments, chiefly in the eastern part of the Glass Mountains, which previously had been included in the Leonard (1643, p. 43). At the same time the Wolfcamp was differentiated from the sediments previously referred to the Gaptank (131, p. 16).

Recently King (936f) has come to the conclusion that Hess and Leonard represent the same formation under changed facies. The

*In The University of Texas Bulletin 3211, explanation of Figures 10–12, Plate VIII, *Schwagerina fusulinoides* is given as from the upper Gaptank. This, however, is an error as the specimens in question, as shown on page 21 of the same publication, are from an ant hill, and the formation from which they came is not known. In the same publication this species and *S. uddeni* as well as *Triticites longissimoideus* are recorded as coming from the lower Wolfcamp formation at the type locality. These records are likewise the result of an error in labeling. The specimens in question came from the basal 5 feet of bed 13, sec. 24, described in Univ. of Texas Bull. 3038, p. 55. (Letter of M. E. Upson to M. P. White, August, 1932.) The horizon of bed 13 of this section is in the upper member of the Wolfcamp formation.

eastern exposures of the Hess, under this interpretation, are lagoonal deposits, and the westward exposures of the Leonard are the open sea sediments. Intermediate between the two, at and near Leonard Mountain, is a reef facies through which the formations intergrade. As a matter of convenience the two formation names are here retained, although it is probable that they represent deposits of about the same time interval under open sea, reef, and lagoonal facies.

The Hess formation consists of limestone, shale, sandstone, and conglomerate. It overlies the Wolfcamp with an angular unconformity. At the base of the formation in the eastern part of the Glass Mountains is a persistent thin conglomerate made up of limestone and chert. An east and west facies are recognized. In the east facies the limestones are mostly thin-bedded and change laterally into vari-colored shales, marls, and sandstones. The west facies is a reef-like limestone.

The Hess, which in the northeastern Glass Mountains is 2100 feet or more thick, thins to the southwest to about 100 feet. Conversely, the Leonard as originally defined, which in the southwestern part of the Glass Mountains is 1800 feet or more thick, thins northeastward.

Among the fossils of this formation are the following (940, p. 9):

Rhipidomella hessensis
Enteletes dumblei
Streptorhynchus lamellatus
S.? undulatus
Meekella attenuata
Geyerella americana
Chonetes hessensis
Productus ivesi
Striatifera pinniformis
Marginifera whitei
Scacchinella gigantea
Aulosteges medlicottianus
Prorichthofenia likharewi
Prorichthofenia teguliferoides
Lyttonia nobilis americanus
Pugnoides elegans
P. texanus
P. transversus
Camarophoria venusta
Spirifer huecoensis
Squamularia guadalupensis
Spiriferina angulata
Hustedia hessensis
Composita mexicana
C. subtilita
Perrinites compressus

Type locality: Hess ranch in the Glass Mountains; thickness, 2150 feet. The formation was named in 1917 by Udden (1643, p. 43).

LEONARD FORMATION

The Leonard formation likewise presents an east and west facies consisting of limestone, shale, and some conglomeratic limestone.

It is thickest in the western exposures, 1800 feet or more, and there consists of thin-bedded limestones and siliceous shales. The shales contain radiolaria and sponge spicules and the limestones contain a varied marine invertebrate fauna. In its eastern exposures the formation thins to 300 feet or less and consists of limestone and dolomite with included sand and pebbles. In the Glass Mountains section it is apparently conformable with the overlying Word formation. The 2000 or more feet of limestones and shales included in the Leonard and Hess formations make up much of the east front of the Glass Mountains.

Both the Leonard and Hess formations contain invertebrate fossils. The Leonard, representing an open sea facies, is somewhat more fossiliferous than is either the reef or lagoonal facies of the Hess. Some of the Hess fossils have been given in the preceding list. The following are from the Leonard (940, p. 9):

Enteletes plummeri
Meekella difficilis
M. globosa
Chonetes subliratus
C. permianus
Productus ivesi
P. leonardensis
P. occidentalis
P. schucherti
Linoproductus waagenianus
Marginifera cristobalensis
M. manzanica
M. reticulata
M. reticulata angusta
M. sublaevis
Aulosteges magnicostatus
A. medlicottianus
A. subcostatus
A. trigonalis
Prorichthofenia likharewi
P. uddeni
Lyttonia nobilis americanus
Pugnoides bidentata
Camarophoria venusta
Uncinuloides guadalupensis
Spirifer marcoui infraplica
S. costella
S. mexicanus latus
S. pseudocameratus
Squamularia guadalupensis
Martinia rhomboidalis
Spiriferina hilli
Hustedia meekana
H. mormoni papillata
Composita mira
C. subtillita
Perrinites vidriensis

Type locality: The type locality of the Leonard formation is in the east scarp of Leonard Mountain, a part of the east scarp of Glass Mountains.

WORD FORMATION

The Word formation in the Glass Mountains (Delaware Mountain formation in part) consists in its lower part of shales with interbedded thin limestones and fine-grained sandstones. The upper part is sandy, often finely bedded, and grades from sandy limestone to calcareous sandstone. In the western exposures a cherty limestone

100 to 340 feet thick, is found at the base, overlain by siliceous shale and sandstone. Above the shale is a sandstone 300 to 500 feet thick and at the top of the formation pink and yellow dolomites. At its southernmost exposure in the Del Norte Mountains the formation consists largely of conglomerates and sandstones. In the eastern part of the Glass Mountains the formation thins and contains much dolomite, and at the northeasternmost exposure consists of 300 feet of cherty dolomite.

This formation in the Glass Mountains is apparently conformable with the underlying Leonard and overlying Capitan. It is exposed in a narrow belt extending northeast across the Glass Mountains. In the western part of the mountains the outcrops are on the slope in front of the great cliffs of the Vidrio member of the Capitan formation. In the eastern part of the mountains it outcrops back of the prominent front scarp formed by the Hess limestones. It is also exposed in the Del Norte Mountains to the southwest and in the Sierra Madera uplift to the northeast, as well as in the Guadalupe, Delaware, and Diablo mountains.

In his original description of the Glass Mountain region, Udden named these sediments the Word formation from the Word ranch in the Glass Mountains. However, the close relationship of the Word and Delaware Mountain formations, recognized at the time the formation was described (1643, p. 50) and more fully confirmed later, caused him to propose in 1927 that the two be united and the term Word be dropped as a formation name (1668, p. 159). There are some differences in lithology since the Word, as typically developed, is chiefly limestone, while the Delaware Mountain at its type locality is largely sand. However, southward in the Delaware Mountains, the Delaware Mountain formation grades into limestone. There may be some differences also in the sediments included, since at its type locality the Delaware Mountain formation is unconformable on the Leonard, while at the type locality of the Word no break has been detected. The Word may therefore be retained as a convenient term for a facies of the Delaware Mountain formation.

The Word facies contains many invertebrate fossils, among which fusulinids, brachiopods, and ammonites are numerous. In the Glass Mountains three faunas representing the lower, middle, and upper parts of the formation have been recognized by King (940, p. 10).

The upper member is correlated with the dark limestone at the top of the formation at its type locality at Guadalupe Point. These faunas are in part as follows:

Lower Part
- Chonetes subliratus
- Productus indicus
- Linoproductus waagenianus
- Avonia subhorrida rugatula
- Camarophoria venusta
- Hustedia meekana
- Composita mira

Middle Part
- Enteletes dumblei
- Meekella attenuata
- Meekella skenoides
- Productus multistriatus
- Avonia signata
- A. walcottiana
- Marginifera opimus
- M. popei
- M. wordensis
- Aulosteges guadalupensis
- A. tuberculatus
- Prorichthofenia permiana
- Lyttonia nobilis americanus
- Waagenoceras dieneri
- Gastrioceras roadense
- Pugnoides swallowiana
- Rhynchopora taylori
- Camarophoria venusta
- Spirifer pseudocameratus
- S. sulcifer
- Squamularia guadalupensis
- Spiriferina laxa
- Punctospirifer billingsii
- Hustedia meekana
- Composita emarginata affinis
- Composita mira
- Dielasma spatulatum
- Dielasmina schucherti minor
- Medlicottia burkhardti
- Stacheoceras bowmani

Upper Part
- Meekella attenuata
- Derbya crenulata
- Chonetes quadratus
- Productus arcticus
- P. guadalupensis
- Linoproductus nasutus
- L. phosphaticus
- Waagenoconcha montpelierensis
- Avonia signata
- Marginifera opimus
- Marginifera popei
- M. texana
- Spirifer sulcifer
- Spiriferina laxa
- Punctospirifer billingsii
- Hustedia meekana
- Composita emarginata affinis

Type locality: The type locality of the Word formation is at Word Ranch in the Glass Mountains; thickness, 300 to 1500 feet.

CAPITAN FORMATION

Overlying the Word formation is some 2800 feet of limestone in which Udden recognized three units, which he named Vidrio, Gilliam, and Tessey. The Vidrio consists of 1400 feet of massive dolomitic limestone containing few fossils. This limestone occupies the crest of the scarp in the western part of the Glass Mountains from Altuda to Hess Canyon. The Gilliam consists of 500 feet of stratified thin-bedded dolomitic limestone including one thin sandstone. It is exposed on the north and northwest slopes of the mountain. The Tessey includes 900 feet of massive dolomitic limestone overlying the Gilliam and exposed on the northwest slope of the mountain. Udden expressed the opinion that the Vidrio, Gilliam, and Tessey were the equivalent of the Capitan of the Guadalupe Mountains (1643, p. 54). Additional studies by P. B. King and R. E. King have confirmed Udden's view as to the equivalency of these three units with the Capitan. It was shown by them also that the units represented changing and intergrading facies of the one formation. Accordingly they proposed that the formation be recognized as the Capitan, of which the Vidrio, Gilliam, and Tessey are members. They found also that, while the three members can be distinguished in the eastern part of the Glass Mountains, to the west beyond Gilliland Canyon they merge and cannot be distinguished. On the other hand, a new member, the Altuda, comes into the lower part of the formation. This member consists of thin-bedded dolomitic limestone, sandy limestone, and siliceous shale. It thus follows that while the formation in the western as in the eastern exposures may show three divisions, a massive dolomite below; thin-bedded strata, largely dolomitic, in the middle; and massive dolomite above, yet these divisions are not stratigraphically equivalent, the western section representing only the equivalency of the Vidrio and Gilliam, the Tessey being absent.

The Capitan rests with apparent conformity on the Word formation and is overlain unconformably by the Bissett, or in the absence of the Bissett, by the Cretaceous.

Being chiefly a reef facies of dolomitic limestone, the Capitan is less abundantly fossiliferous than some of the other formations of this region. Some of the fossils in the formation in the Glass Mountains are: reef forming algae (?), *Fusulina elongata, Squamularia guadalupensis, Martinia subquadrata, Composita emarginata affinis, Pleurophorous* sp.

Type locality: El Capitan Peak at the south end of the Guadalupe Mountains; thickness in the Glass Mountains about 3000 feet. The formation was named in 1904 by Richardson (1304, p. 41).

BISSETT FORMATION

The Bissett is a non-marine formation consisting of conglomerate, red shales, sandstone, and local limestone and marl deposits. The conglomerate, which varies in thickness from 10 to 500 feet, includes boulders from various underlying formations but chiefly from the Capitan on which it rests. In the region of Bissett Mountain the basal part of the formation is made up of red shales with some interbedded conglomerate, above which are heavy conglomerates. At some other localities marl beds are interbedded with and overlain by conglomerate. These marl beds contain fossil plants and a few invertebrates. One vertebrate bone likewise has been reported. The fossil plants found in the Hess Canyon exposures north of Warren ranch have not been fully studied but appear to indicate late Paleozoic, and on this evidence the formation is referred tentatively to the Permian. The following plants from this formation have been identified by David White: *Cordaites, Poacordaites, Brachyphyllum, Paleotaxites, Pachypteris, Walchia, Cladophlebis,* and Gymnosperm seeds. The one bone fragment reported from this formation is said by Case to suggest Triassic rather than Permian and to represent possibly the genus *Desmatosuchus.*[55]

The formation is seen in disconnected outcrops on the northwest slope of the Glass Mountains from near the Southern Pacific Railroad to 4 miles northeast of the Sibley ranch house, a distance of about 25 miles. It rests unconformably, but without appreciable angularity, on the underlying Permian, although as interpreted by King it overlaps from the Tessey member of the Capitan formation on which it rests in the eastern exposures onto the Gilliam member in the western exposures. The overlying Cretaceous rests with angular unconformity on the Bissett.

Type locality: Bissett Mountain, 6 miles north-northeast of Altuda; thickness, 720 feet. The formation was named in 1927 by P. B. King (928).

SIERRA MADERA DOME

The Sierra Madera dome is of small area but of pronounced uplift, bringing Permian to the surface through Cretaceous. It is located about 8 miles northeast of the eastern exposures of the Glass Mountains and 25 miles south of Fort Stockton in the Fort Stockton

[55]E. C. Case, letter to Sidney Powers, January 23, 1932. The Bissett, according to Case, is apparently in about the position of the La Plata of southwestern Colorado, which is not far from the Shinarump.

Additional and somewhat better preserved plants were obtained by E. H. Sellards and L. W. Konz from this formation in March, 1931. These have recently been examined by David White who writes of them as follows: "They seem to confirm identification of *Cordaites*. At the same time, the new material looks somewhat Mesozoic, especially the stem with the distant cycadlike leaflets. I am not prepared to say that it is Mesozoic, but the case requires careful deliberation. The additional specimens furnish better specific characters than the first lot, but they add almost nothing to the total number of the species, which is possibly too small to settle beyond question the age of the Bissett." Letter of September 29, 1932.

plateau subdivision of the Edwards Plateau region. The dome is about three miles across and its crest now stands some 600 feet above the surrounding Cretaceous covered plain. The Paleozoic formations exposed in this dome, ranging from the Hess to the Capitan, are essentially extensions of the Glass Mountains series and are described under that heading.

At the center of the dome, according to King (936, p. 123), are dolomites of the Hess and Leonard formations, around which is a belt of exposures of the Word (Delaware Mountain) formation, and, on the flanks, exposures of the dolomitic phase of the Capitan formation. The dips in these formations vary from 45 to 90 degrees and at the south side of the dome the strata are overturned. The dome is not symmetrical, since in addition to local overturning there are small anticlines and synclines on the flanks and some faulting in the dome. The dips flatten to 15 degrees in places before the Permian is lost under the surrounding Cretaceous. In the Cretaceous, dips are seen around the northeast side of the dome of from 2 to 10 degrees. The time of the intense folding was obviously post-Permian and apparently pre-Cretaceous. A slight additional folding in post-Cretaceous is, however, evident by the abnormal dips in the Cretaceous at the northeast side of the dome.

GUADALUPE, DELAWARE, AND APACHE MOUNTAINS

The Guadalupe, Delaware, and Apache mountains form an approximately continuous range trending south-southeast from New Mexico into Texas. Structurally this range is an east dipping monocline. The west margin is a fault scarp facing the Salt Flat graben. By eastward dip the strata pass underground and into the Permian basin. The Apache Mountains are detached from the Delaware Mountains by the Seven Heart Gap fault zone which trends southeast.[56] The Guadalupe Mountains trend northeast.

In the scarp at the west side of the Delaware Mountains, the Leonard and Delaware Mountain formations are exposed. Eastward from the scarp, following the dip of the monocline, the Castile and

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[56]Publications relating to the Guadalupe, Delaware, and Apache mountains listed in the accompanying bibliography include the following: Baker, 51; Beede, 86, 94; Blanchard and Davis, 122; Crandall, 332; Darton and Reeside, 394; Darton, 394a, 395; Girty, 589, 590, 591; Keyte, 925; King and King, 932; R. E. King, 940; Lloyd, 1002; Richardson, 1304, 1310, 1314; Schuchert, 1384, 1385; B. F. Shumard, 1458, 1459, 1461; G. G. Shumard, 1477; Tarr, 1586, 1588; Willis, 1762, 1764.

Rustler formations come into the section. In addition to the Leonard and Delaware Mountain formations exposed in the scarp, the Guadalupe Mountains are capped by a great reef limestone, the Capitan formation. A similar limestone is exposed in the Apache Mountains. At the southern end of the Guadalupe Mountains, Guadalupe Point rises boldly, and in part vertically, from the Salt Flat. El Capitan Peak, north of the point, rises to elevation given by the United States Geological Survey as 8700 feet, this being the highest recorded point in Texas (frontispiece).

LEONARD FORMATION

The Leonard formation in the Delaware and Guadalupe Mountains is represented by a dark limestone which has been named the Bone Springs member (122, p. 962, and 332, p. 930), also called Bone Canyon member (940, p. 14). This limestone, referred to by Girty as the basal black limestone (590, p. 10), is about 1000 feet thick and contains a fauna essentially identical with that of the Leonard of the Glass Mountains (940, p. 11). Among the species represented are *Productus leonardensis, Marginifera cristobalensis, Pugnoides texanus, P. bidentatus, Composita mexicana,* and *Peritochia erebus, Paraceltites elegans, Agathiceras texanum,* and *Perrinites* sp.

This limestone is exposed along the base of the escarpment of the Guadalupe and Delaware mountains as far south as Seven Heart Gap. The type locality of this member is at Bone Springs Canyon on the west side of Guadalupe Mountain.

On the west side of the Guadalupe Mountains a few miles north of Bone Springs Canyon the Bone Springs member is overlain by a white limestone which is there several hundred feet thick. Among the few fossils found in this limestone is *Aulosteges magnicostatus,* a Leonard species. From its position in the section, its lithology, and limited fauna, this limestone is correlated by King (940, p. 11) with the Victoria Peak member of the Leonard, the type locality of which is at Victoria Peak in the Diablo Mountains. At Bone Springs Canyon this member is absent, although a conglomerate at the base of the Delaware formation, according to King, contains boulders from it.

DELAWARE MOUNTAIN FORMATION

The upper part of the scarp at the west margin of the Delaware Mountains as far south as Seven Heart Gap is of the Delaware Mountain formation. At Guadalupe Point, the southern extremity of the Guadalupe Mountains, this formation includes about 2000 feet, chiefly of sandstones, in which are some dark limestones. The uppermost of these limestones has been referred to by Girty and others as the upper dark limestone (590, p. 11). To the north of this locality, west of Guadalupe Point, the formation thins to about 100 feet at the New Mexico-Texas state line. The upper dark limestone member of the type section, which here underlies the Capitan limestone, is regarded by King as the equivalent of the upper limestone of the Word (Delaware Mountain) formation in the Glass Mountains. Among fossils common to the two limestones are the following: *Derbya elevata, Chonetes hillanus, Marginifera popei, M. optimus, Spirifer sulcifer, S. laxa, Composita,* and *Emarginata affinis.*

As originally proposed by Richardson, the Delaware Mountain formation included all of the strata exposed at Guadalupe Point up to the Capitan limestone (1304, p. 38), and in the Delaware Mountains up to the Castile gypsum. The Delaware Mountains, however, are given as the type locality. The Capitan overlies strata of the Delaware Mountain formation at Guadalupe Point, as described by Richardson. However, observations elsewhere show that the Capitan is a great reef, or series of reefs, occurring in and mostly towards the upper part of the Delaware Mountain formation. The gradation from reef, through fore-reef, into the Delaware Mountain limestones and sandstones may be seen at the mouth of McKittrick Canyon and elsewhere.

The fauna of the Delaware Mountain formation, according to Girty, who gives extensive lists, is characterized by a relative abundance of pelecypods and gastropods, with fewer brachiopods than in the Capitan (590, p. 23). At the base of the formation there is an unconformity as shown by a conglomerate at the Bone Springs Canyon exposure. This conglomerate is recognized also in the section made by Beede on the Delaware Plateau about 25 miles southeast of Guadalupe Point (94, p. 9).

Type locality: Delaware Mountains; thickness, 2100 feet.

CAPITAN FORMATION

Overlying the Delaware Mountain formation at Guadalupe Point in an almost vertical cliff, including El Capitan Peak, there is about 2000 feet of dolomitic limestone which Richardson named Capitan (1304, p. 41). From this limestone and the underlying Delaware Mountain formation was obtained the fine Permian fauna which Girty has so fully described in his monograph, The Guadalupian Fauna (590). This great mass of limestone is a reef which extends from Guadalupe Point in Texas northeastward to Carlsbad, New Mexico. It is 2000 feet thick and 5 miles wide and is exposed for a distance of 70 miles. This reef and those of about the same age in the Apache and Glass mountains are the largest reefs in North America and are surpassed in size only by the great Triassic reefs of the southern Tyrol.

To determine the equivalency of this reef in the nearby strata has proved difficult, resulting in divergent views and much discussion. An early interpretation was that the Capitan reef limestone is equivalent to the Castile gypsum, but this has been shown not to be true as the gypsum overlies the Capitan (394, p. 417). A dark limestone, exposed in McKittrick Canyon on the east side of the Guadalupe Mountains, named Frijole limestone, was formerly assumed to be the equivalent of the dark limestone member at the top of the Delaware Mountain formation at Guadalupe Point. Lloyd in 1929 (1002, p. 650) maintained that the Frijole limestone was the equivalent of the upper 1000 feet or thereabouts of the Capitan reef and that this limestone interfingered with steeply dipping foreset beds from the Capitan. At about the same time Blanchard and Davis (122, p. 979) reported having traced this dark limestone southwestward from McKittrick Canyon to Guadalupe Canyon. It was impossible to trace it farther because of change of facies, but at that locality the Frijole limestone equivalent was above 1000 feet of Capitan limestone. It was thus shown that the Frijole cannot be the same as the dark limestone at the top of the Delaware Mountain formation at the type locality.

The interval between the upper dark limestone at the top of the Delaware Mountain at the type locality and the Frijole limestone has not been determined on account of lack of continuous exposures.

The sands of this interval, according to the observations of several geologists, pass by abrupt gradation westward into the Capitan limestone. Blanchard and Davis believe that much, and possibly all, of the Capitan at the type locality is the equivalent of this interval from the top of this dark limestone to and including the Frijole limestone (122, p. 979).

The entire list of fossils from this formation is too extensive to be included here, but may be consulted in Girty's monograph (590). Except for ammonites, the common groups of Permian invertebrates are represented. Among the brachiopods are the following (940, p. 13):

Streptorhynchus gregarium	Prorichthofenia permiana
Geyerella americana	Pugnoides elegans
Chonetes hillanus	Camarophoria? indentata
Productus capitanensis	C.? longaeve
P.? pileolus	Uncinuloides guadalupensis
P.? limbatus	Spirifer mexicanus
Avonia latidorsata	S. sulcifer
Linoproductus waagenianus	Squamularia guadalupensis
Marginifera popei	Martinia rhomboidalis
Striatifera pinniformis	Spiriferina laxa
Leiorhynchus bisculatus	Punctospirifer billingsii
Lyttonia nobilis americanus	Composita emarginata

To the northwest, the reef facies of the Capitan gives place to lagoonal deposits. Several units are recognized. At the top is the Seven Rivers gypsum, below which is the Queen sand zone. The lower members of the section have been compared to the Chupadera formation of New Mexico. The Carlsbad limestone of New Mexico, about 300 feet thick, is probably the equivalent of the uppermost part of the Capitan. In the Delaware Mountain group three facies are thus recognized, as follows: lagoonal facies, found chiefly in New Mexico; a reef facies, the Capitan limestone; and a normal marine facies, the Delaware Mountain formation. These several units are partially equivalent in time but it is convenient to retain the several formation names.

Type locality: Guadalupe Point in the Guadalupe Mountains; thickness, 2000 feet.

CASTILE FORMATION

The Castile formation, which comes into the section on the east-sloping monocline of the Delaware Mountains a few miles east of the scarp, consists largely of gypsum in its surface exposures, and of gypsum, salt, and red beds underground in the Permian basin. The outcropping belt, 15 to 30 miles wide, extends approximately north-south through Culberson County between the Delaware Mountains and the Rustler Hills. No fossils have been obtained from this formation.

Underground in the Delaware basin, this formation may be divided into two units. The lower, about 1500 feet thick, consists chiefly of anhydrite with some shale, limestone, and salt. The upper part of the formation, about 800 feet thick at the outcrop, thickens underground and contains anhydrite, salt, red shale, sandstone, and some dolomitic limestone. The principal salt bed of the Delaware basin, which may extend eastward across the basin to Howard County correlated with either the lower Quartermaster or the upper Cloud Chief, is in this part of the Castile. The lower member of the formation, on the other hand, is confined to the Delaware basin (201).

Type locality: Castile Springs in northern Culberson County; thickness, in surface exposure, 800 feet; underground, 4000 feet. The formation was named in 1904 by Richardson (1304, p. 43).

RUSTLER FORMATION

The Rustler formation at the top of the Permian of the Delaware Mountain region consists very largely of white or gray dolomitic limestone exposed in the Rustler Hills. In the northern part of this area a thin conglomeratic sandstone with some clay underlies the limestone which, however, is absent in the southern exposures where the dolomite rests upon the gypsum of the Castile formation. The formation is apparently unconformable on the Castile. Eastward it may be traced underground above the rapidly thickening Castile across the Delaware basin, continuing as far eastward possibly as Midland County, where it underlies sands referred to the Quartermaster (201, p. 981). The Rustler limestone is in some localities very oolitic.

Almost no fossils have been recorded from this formation. Richardson obtained only indefinite invertebrates resembling *Myalina* or *Mytilus* and some plant fragments.

Type locality: Rustler Hills of eastern Culberson County; thickness, 200 to 375 feet. The formation was named in 1904 by Richardson (1304, p. 44).

DIABLO PLATEAU

At the east margin of the Diablo Plateau in the Sierra Diablo, Permian formations are exposed as follows: Wolfcamp, Hess, Leonard, and Delaware Mountain. The Wolfcamp, which rests on Pennsylvanian with an angular unconformity, is 175 feet thick and has an abundant invertebrate fauna. The Hess and Leonard formations, including the Bone Springs and Victoria Peak members, overlie the Wolfcamp. These formations have a total thickness in the Diablo east scarp of approximately 2200 feet, of which 400 feet is Hess, 800 feet Bone Springs member of the Leonard, and 1000 feet Victoria Peak member of the Leonard. The Bone Springs black limestone, in part at least, grades laterally into the Victoria Peak white limestone so that the actual thickness of the formation is somewhat less than the combined thickness of the members. On the west side of Salt or Crow Flat, opposite Guadalupe Mountains, there is a rapid change northward from limestones to dolomite and gypsum (the Chupadera facies of New Mexico). The Delaware Mountain formation comes into the section at the northern end of the scarp, about 500 feet of this formation being exposed (940, p. 15).

Rocks of probably similar age, but of different facies and fauna, underlie the plateau, the few fossils found being those of the Gym formation of New Mexico.

At the northwest margin of the plateau in the Hueco Mountains the Permian consists largely of dolomitic limestone containing the fauna of the Gym formation. King recognizes three members (unnamed) which differ faunally. The lower member, gray limestone, containing an abundance of *Schwagerina*, is considered by him as of about Wolfcamp age. The middle member, dark limestone, is 250 feet thick. The upper member, 800 feet thick, including 150 feet of red beds, does not contain *Schwagerina*. The middle and upper members are regarded as of Hess age. The lower and middle members are recognized also on the west flank of the Franklin Mountains.[57]

[57]Publications relating to the Permian of the Diablo Plateau listed in the accompanying bibliography include the following: Arick, 33a; Baker, 46, 51; Beede, 89, 91; Blanchard and Davis, 122; Keyte, 925; King and King, 932; R. E. King, 940; Richardson, 1304, 1305, 1310, 1312, 1313, 1314; Schuchert, 1384, 1385.

The Permian of the Diablo region rests unconformably on various older formations. In the Hueco and Franklin mountains it rests on Pennsylvanian. This is true also of a part of the northern Diablo Mountains, although, owing to truncated folds, various formations down to Ordovician are here in contact with the Permian. Farther south along the Diablo east scarp, the Permian overlaps on to pre-Cambrian, being in contact with both the Millican and the Carrizo Mountain formations. The Permian seas in this region thus invaded a folded and eroded land surface.

The Permian of this region is involved in the late block-faulting by which has been produced the outstanding present structural and topographic features. The tilting of blocks incident to their faulting has resulted in some high dips, and in the Hueco Mountains there is some folding. In the main, however, the Permian of this region does not present complicated structural conditions.

The Finlay dome is near the southwest margin of the Diablo Plateau. This dome has Cretaceous rock at the sides and a core of Permian rocks. The oldest formations exposed are of Hess and Leonard age and include limestone and some shale, the shale and some of the limestone being fossiliferous. Unconformably above these limestones, according to Baker, are conglomerates, limestone, and sandstones, containing *Fusulina elongata* and *Lyttonia.* Farther south in the Malone Mountains are exposures of Permian limestone and gypsum, probably of about the same age as the formations of the Finlay dome (940, p. 17).

Near Dahlberg in the Carrizo Mountains, southwest of Van Horn, is found about 400 feet of Permian limestone containing a Gym fauna. In the Wylie Mountains, southeast of Van Horn, about 1400 feet of limestone of similar facies is exposed. In both exposures the Permian rests on pre-Cambrian. Permian limestones are exposed in the Eagle and Van Horn mountains (46, p. 9).

CHINATI MOUNTAINS

The Chinati Mountains in Presidio County, about 40 miles southwest of Marfa, are essentially a dissected plateau of lava. This plateau has been lifted by intrusives, partly buried by extrusives, and the margins cut into by erosion sufficiently to expose Permian and Cretaceous formations. The Permian, thickness about 6000 feet, is seen in an outcropping belt between 1 and 2 miles wide around the south, east, and north sides of the east end of the plateau and in Pinto Canyon at the northwest side. The attitude of the strata is affected by intrusives, and locally they are steeply dipping. Aside from high dips around these intrusives the strata present no highly complicated structural features.

The geology of this region was first described in 1904 by Udden (1623), who recognized and named three Paleozoic formations as follows: Cieneguita, Alta, and Cibolo, constituting the Chinati series. At that time these formations were tentatively referred to the Pennsylvanian with the suggestion that the uppermost part might be Permian. In 1929 Baker obtained sufficient fossils to refer the entire series to the Permian (53), representing the equivalency of the Glass Mountains section from the Wolfcamp to or above the Word. The silver of the Shafter mines is from the limestones of this series.[58]

CIENEGUITA FORMATION

The Cieneguita formation consists of shales, limestones, and conglomerates. The shale contains some strata of chert.[59] An unusual feature of the formation is the inclusion of quartz, limestone and other fragments and pebbles in a calcareous matrix of fine texture. Some limestone pebbles of these conglomerates are as much as three inches across and many of them are faceted. Large granitic boulders are found in some of the conglomerates. The base of the formation is not exposed. However, the presence of the granitic boulders would seem to indicate that basement rocks may not be far below the surface. *Schwagerina* occurs throughout this formation (53).

Type locality: about 3 miles north of Cibolo ranch and south of Ojo Bonito, east side of Chinati Mountains; thickness, 1000 feet.

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[58]Publications listed in the accompanying bibliography relating to the Permian of the Chinati Mountains include the following: Baker, 53; Howbert, 849; Keyte, 925; R. E. King, 940; Udden, 1623.

[59]The term Cieneguita was applied to a Cretaceous formation in Mexico in 1895 (Castillo y Aguilera, Fauna fosil de la Sierra de Catorce, San Luis Potosí, Mex. Com., B. 1, 1895). However, the United States Geological Survey does not regard a name as preoccupied by reason of its having been used outside of the United States; accordingly, the use of the name is continued in Texas.

ALTA FORMATION

The Alta formation consists of sandy and clayey beds with little or no limestones or other calcareous deposits. The lower part of the formation contains chiefly dark shale, 2000 feet, while in the upper part are lighter colored, more or less sandy, shales, and sandstones of fine texture, 1550 feet. The formation is apparently conformable with the overlying and underlying formations. Among the fossils from the lower shale member are *Productus ivesi* and *Perrinites vidriensis*, indicating Leonard age.

Type locality: about 3 miles north of Cibolo ranch at the east side of Chinati Mountains; thickness, 3550 feet.

CIBOLO FORMATION

The Cibolo formation consists largely of limestones. At the base is a marly shale, 100 feet thick, containing lenses of siliceous and organic sand. This marly shale is followed by massive limestones, 133 feet; thin-bedded limestone and sandstone containing sponge spicules, 85 feet; thin-bedded limestone with platy cherts, 450 feet; and yellow massive dolomite limestone, 650 feet. The formation is overlain by Cretaceous and igneous rocks.

According to King the fossils of this formation indicate its correlation with the Word (Delaware Mountain). Among those obtained are *Waagenoceras, Medlicottia, Agathiceras girtyi, Adrianites marathonensis,* and *Stacheoceras gilliamense* (940, p. 17).

Type locality: east bluff of Sierra Alta Creek near Cibolo ranch, 3 miles north of Shafter; thickness, 1450 feet.

OSAGE PLAINS REGION OF NORTH-CENTRAL TEXAS

The western one-half or more of the Osage Plains region of north-central Texas has Permian at the surface. The formations dip west-northwest at a low angle, usually less than 1 degree, and are conformable with the underlying Pennsylvanian. Their outcropping margins accordingly form narrow belts trending approximately north-south, the indurated strata, sandstones, limestones, and gypsum beds forming east-facing escarpments. The subdivisions recognized are the Wichita, Clear Fork, and Double Mountain groups, each of which is subdivided into several formations and members. The total thickness of the Permian in this region is 4000 or 5000 feet.

On the Red River at the north line of the state, the entire Permian is of the red bed facies, consisting of red and gray or blue shales and sandstones, including, in the Double Mountain group, dolomites and gypsum. Southward from the Red River a facies change occurs by which the Wichita group changes to blue shales and limestones. A similar change occurs underground to the west, the red bed facies changing to the "Big Lime" of the Panhandle region. In the red bed facies on the Red River, the Wichita contains land plants and vertebrate fossils but relatively few marine fossils. South of the Brazos River, where normal marine conditions prevail, marine invertebrate fossils abound. In the next group, Clear Fork, the change to the south from the red bed facies is less obvious. However, thin limestones and dolomites come into the section southward, and underground in the southern part of the basin this group changes to shales and limestones. In the uppermost group, Double Mountain, the red bed facies continues throughout the exposed belt in north-central Texas, the group including, in addition to red and gray clays and sandstones, dolomites and gypsum beds. However, underground to the southwest, the lower part of this group, the Blaine formation, as now interpreted, grades to massive limestones. In the Glass Mountains in Trans-Pecos Texas the entire Permian, with the exception of the uppermost part, is of the non-red bed facies, consisting of marine limestones, shales, conglomerates, and sandstones.[60]

Following is a list of formation and member names applied to the Permian strata of north-central Texas. The names are listed in stratigraphic order or as nearly so as possible, beginning with the youngest. For each member name there is given by whom and where named, type locality if known, place in the formation, and reference to the publication in which the name was proposed or

[60]Publications listed in the accompanying bibliography relating to the Permian of the north-central Texas region include the following: Adams, 5; Beede, 85, 88, 90, 93; Beede and Waite, 87; Beede and Bentley, 92; Beede and Christner, 96, 97; Broili, 156; Case, 202, 207, 216, 220, 227; Cope, 291, 292, 293, 294, 296, 306; Cummins, 340, 342, 349, 350; Drake, 449; Dumble, 458; Gordon, 608, 609, 610, 611; Gould, 615, 618, 621, 622; Gould and Lewis, 623; Gould and Willis, 625; Henderson, 704; Hubbard and Thompson, 854; Lloyd and Thompson, 1001; Marcou, 1048; Patton, 1180, 1185; Plummer and Moore, 1228; Romer, 1351; Udden and Phillips, 1632; Univ. of Texas, maps, 1853; Willis, 1764; Williston, 1774, 1779, 1784; Wrather, 1801.

first used. Names abandoned on account of being synonyms or preoccupied are in italics. Many of these member names were used in private reports before they were used in published reports. The references here are to published reports only. The type localities for the several members named proposed by Drake in 1893 (449) are not separately given, since all are on or near the Colorado River, along which the section was made.

List of Permian Formation and Member Names Applied in North-Central Texas

Double Mountain Group

Quartermaster Formation

Alibates dolomite, Gould, 1907; Alibates Creek, Potter County, upper part of the Quartermaster formation; (615, p. 17).

Saddlehorse gypsum, Gould, 1907; bluffs of Canadian River in Texas; 60 to 80 feet above base of Quartermaster formation; (615, p. 16).

Cloud Chief-Whitehorse or Peacock formation.

Sweetwater dolomite; (1001, p. 953). Name preoccupied, having been applied by Endlich in 1897 to Tertiary deposits in Wyoming.

Claytonville dolomite, Cheney, 1929; 2 miles west of Sweetwater; about 50 feet below the base of the Quartermaster in Fisher County (Morley); (247, p. 26). Replaces the name Sweetwater which is preoccupied.

Claytonville gypsum, Morley, 1929; Fisher County, about 300 feet under the Claytonville (Sweetwater) dolomite; (1853, Fisher County). Name preoccupied by Claytonville dolomite.

Lake Trammel sandstone, Wrather, 1917; part or all of Whitehorse sandstone (1801, p. 950).

Memphis sandstone, Lloyd and Thompson, 1929; buttes near Memphis, Hall County; 250 feet above the base of the Whitehorse sandstone; (1001, p. 953). The name Memphis sandstone has been abandoned by the United States Geological Survey and the name Dosier sandstone substituted for it.

Croton gypsum, Storm, 1929; Stonewall County; about 75 feet below the Quartermaster in Stonewall County; (1853, Stonewall County). Same as Eskota gypsum.

Eskota gypsum, Lloyd and Thompson, 1929; northern Nolan County; 120 feet above the Childress dolomite and gypsum; (1001, p. 953).

Ward gypsum, Storm, 1929; Stonewall County; about 300 feet below the Croton gypsum and about 100 feet above the Childress (Wagon Yard) gypsum; (1853). This may be the Eskota gypsum. The name Ward is preoccupied, having been used for an Ordovician limestone in Tennessee.

Royston gypsum. See Royston formation, p. 177.

Oriana gypsum, Patton, 1930 (ms. 1927); near Oriana, Stonewall County; about 100 feet above the Swenson gypsum; (1185, p. 47). The relation of this gypsum to the Croton gypsum has not been determined. The two may be the same.

Swenson gypsum, Patton, 1930 (ms. 1927); near Swenson, Stonewall County; at base of the Peacock formation; (1185, p. 46). The Swenson gypsum is apparently the same as the Childress dolomite and gypsum.

Blaine Formation

Childress dolomite and gypsum, Lloyd and Thompson, 1929; Childress, Childress County; (1001, p. 952). Top member of the Blaine about 150 feet above the Guthrie (Aspermont) dolomite in Childress County (Lloyd and Thompson).

Ideal gypsum, same as Childress.

Wagon Yard gypsum, Storm, 1929; Stonewall County; about 300 feet above the Guthrie (Aspermont) dolomite; (1853). This is apparently the same as the Childress dolomite and gypsum. Although proposed at about the same time, the term Childress is in more common use.

Guthrie dolomite, Cheney, 1929; Guthrie, King County; top of main gypsum series of the Blaine as defined by Lloyd and Thompson; (247, p. 25, and 1001, p. 951).

Aspermont dolomite, Morley, 1929. Same as the Guthrie which was proposed at about the same time. The Guthrie has been more commonly used.

Acme dolomite, Lloyd and Thompson, 1929; Acme, Hardeman County; 100 or 200 feet below the Guthrie dolomite. The Acme dolomite is probably the same as the McCaulley.

McCaulley dolomite, Cheney, 1929; McCaulley, Fisher County; (247, p. 26). Believed to be the same as the Acme dolomite. The term Acme is in more general usage than McCaulley.

Mangum dolomite, Gould, 1905; Mangum, Greer County, Oklahoma; 150 or 200 feet above base of the Blaine formation; (1001, p. 951).

Groesbeck dolomite, Cragin, 1897; in the Blaine (329a).

Collingsworth gypsum, Gould, 1905; Collingsworth County, Texas; upper gypsum of Blaine formation (614a, p. 70).

Quanah gypsum, Cragin, 1897; near base of Blaine (392a).

San Angelo Formation

Blowout Mountain sandstone (1801). See San Angelo formation.

Clear Fork Group

Choza Formation

Merkel dolomite, Wrather, 1917; Merkel, Taylor County; near top of Clear Fork group; (1801, p. 97).

Wichita conglomerate, Case, 1907; (207).

Vale Formation

Bullwagon dolomite, Wrather, 1917; Bullwagon Creek, Taylor County; at top of the Vale formation, about 340 feet above the base of the Clear Fork group; (1801, p. 97).

Buffalo Hill sandstone, Wrather, 1917; Buffalo Hills, Taylor County; near the base of the Clear Fork group; (1801, p. 100).

Tye formation. See Vale formation.

Abilene formation. See Arroyo formation.

Arroyo Formation

Standpipe limestone, Cheney, 1929; top of Standpipe hill, Abilene, Taylor County; top of the Arroyo formation; (247, p. 27).

Lytle limestone, Lloyd and Thompson, 1929; near Abilene, Taylor County; (1001, p. 949).

Rainy limestone, Cheney, 1929; Rainy Creek, 6 miles east of Abilene, Taylor County; (247, p. 26).

Wichita Group

Lueders Formation

Lake Kemp limestone, Garrett, Lloyd and Laskey, 1930; east end of Lake Kemp, Baylor County; top of Lueders formation; (1853, Baylor County).

Maybelle limestone, Romer, 1928; east of Lake Kemp, Baylor County; (1351, p. 74).

Paint Rock beds, Drake, 1893; Paint Rock, Concho County; basal part of Lueders formation as defined in the present publication; (499).

Clyde Formation

Talpa limestone, Drake, 1893; Talpa, Coleman County; top of Clyde formation; (449).

Grape Creek shale and limestone, Drake, 1893; lower part of Clyde formation; (449).

Fulda sandstone, Case, 1907; Fulda, Baylor County; (207).

Belle Plains Formation

Bluff Bone bed, Udden, 1912; Bluff Creek, south of Electra, Wichita County; upper part of the Wichita group; (1632, p. 36).

Beaverburk limestone, Udden, 1912; Beaver Creek, Wichita County; upper part of Wichita group; (1632, p. 31).

Bead Mountain limestone, Drake, 1893; top of Belle Plains formation in Colorado River valley; (449).

Valera shale, Drake, 1893; (449).

Jagger Bend limestone, Drake, 1893; Jagger Bend, Colorado River; (449).

Admiral Formation

Elm Creek limestone, Drake, 1893; top of Admiral formation; (449).
Coleman limestone and shale, Drake, 1893; Coleman County; (449).
Indian Creek limestone, Drake, 1893; name preoccupied, see under Strawn; (449).
Hordes Creek limestone, Drake, 1893; (449).
Lost Creek shale, Drake, 1893; (449).

Putnam Formation

Coleman Junction limestone, Drake, 1893; (449).
Santa Anna Branch beds, Drake, 1893; (449).
Putnam limestone, 1929; name preoccupied by Putnam formation; (1853, map of Shackelford County).
Putnam sandstone, 1929; name preoccupied by Putnam formation; (1853, map of Shackelford County).

Moran Formation

Sedwick limestone, Bradish and Fisher, 1929; Stephens County; (1853).
Santa Anna shale, Drake, 1893; (449).
Horse Creek limestone, Drake, 1893; preoccupied, see under Strawn; (449).
Dothan limestone, Plummer, 1919; near Dothan, Eastland County; (1227, p. 145).
Watts Creek shale, Drake, 1893; (449).

WICHITA GROUP

Cummins in 1890 established the Wichita beds which represent the lowest division of the Permian in the Wichita region of north Texas (340, p. 187). In the same publication Dumble described briefly the Coleman-Albany group, said to overlie the Cisco and to represent the latest series of the Coal Measures (458, p. lxvii). This group, with the name abbreviated to Albany division but still retained in the Coal Measures, was more fully described by Cummins in 1891 (342, p. 375). Cummins at that time regarded the Albany beds south of the Brazos River as wedging in between the Cisco and Wichita groups and recording an erosion interval between the Cisco and Wichita north of the Brazos (342, pp. 397, 401). In 1892 Jules Marcou expressed the view that the Albany was Permian (1048, p. 369). In a manuscript prepared probably in 1893 for the Fifth Annual Report of the Texas Geological Survey, but not published, Cummins recognized the Albany as a part of the Permian representing the southward extension of the Wichita group under changed facies.[61] A paper citing Marcou's opinion and verifying the equivalency of the Wichita and Albany was published by Cummins in 1897 (349). The term Wichita group, as here used, is equivalent to the Wichita-Albany of Cummins.

A very remarkable reptilian fauna has been obtained from the Wichita and Clear Fork. The vertebrate fossils of the Wichita group in the red bed facies are listed, and localities discussed, by Romer (1351). The invertebrates of the normal marine facies include a large fauna. A list of species from the Admiral formation is given by Plummer and Moore (1228, p. 194), and the common species of the overlying formation are mentioned by Beede in his section on the Colorado River (87). The plants of this group have been listed by White (610).

The Wichita group is apparently conformable both with the underlying Pennsylvanian and the overlying Clear Fork. No pronounced unconformities have been found within the group. For reasons already given, the Pennsylvanian-Permian contact is here placed at the base of the Moran formation and this formation, together with the overlying Putnam formation, is therefore transferred to the Wichita group.

The Wichita group has been variously subdivided. In this publication six formations are recognized, as follows: Moran, Putnam, Admiral, Belle Plains, Clyde, and Lueders, each consisting of several members. These formations occupy a belt extending from the Red River in a south-southwesterly direction to the Cretaceous overlap south of the Colorado River, through Montague, Clay, Wichita, Archer, Baylor, Young, Throckmorton, Haskell, Shackelford, Jones, Callahan, Taylor, Coleman, Runnels, and Concho counties.

The contact of the Wichita group with the Clear Fork at the top of the Lueders formation has been followed from the Colorado River into Wilbarger County. On the Red River this contact is difficult to determine but is probably near the Wichita-Wilbarger county line. The group as thus defined is 1500 or 1600 feet thick.

MORAN FORMATION

The members of the Moran formation recognized by Plummer and Moore are as follows: in the Colorado River valley, Watts

[61]This manuscript has been deposited by C. L. Baker in the Bureau of Economic Geology.

Creek shale, Horse Creek limestone, Santa Anna shale, and Sedwick limestone;* in the Brazos River valley, sandy shale, Dothan limestone, shale with sandstone, and Sedwick limestone. Recently Henderson has shown that the fusulinid *Schwagerina* is present in this formation. Because of the presence of this fossil the Pennsylvanian-Permian contact is here drawn at the base of the Moran formation, and the Moran and Putnam formations are transferred to the Wichita group of the Permian. The Pennsylvanian-Permian contact may lie in the Harpersville formation, as proposed by Roth (1353b). However, the evidence for placing it lower than the Moran formation is not at present conclusive.

Type locality: The type locality of this formation is at Moran in Shackelford County; thickness in the Colorado River valley, 200 feet, and in the Brazos River valley, 350 feet. The formation was named by Plummer (1227, p. 143).

PUTNAM FORMATION

The Putnam formation, as originally defined, consisted of a shale with some sandstone overlain by a limestone. Two members were recognized, the Santa Anna Branch shale and the Coleman Junction limestone. In the Colorado River valley the limestone forms a prominent escarpment but thins and disappears to the north. The Coleman Junction limestone at the top of the formation, followed northward into Archer County, grades into sandstone. Its approximate horizon, however, has been followed through Archer County and for some miles into Clay County.

Type locality: The type locality is at Putnam, Callahan County; thickness in the Colorado River valley, 140 feet, and in the Brazos River valley, 190 feet. The formation was named by Plummer and Moore in 1921 (1228, p. 183).

ADMIRAL FORMATION

The Admiral formation consists of a series of shales with some limestones, and, at the top, a limestone, the Elm Creek, from 20 to 50 feet thick. The escarpment formed by the limestone is prominent from the Colorado River north through Throckmorton County. Farther to the north, however, the limestones grade into shales.

*The Dothan limestone is also present under the Horse Creek limestone in Coleman County.

In the Colorado River valley, Drake recognized the following members now placed in this formation: Lost Creek shale, Hordes Creek limestone, Indian Creek shale, limestone and marly clay, Coleman limestone and shale, and Elm Creek limestone. The Indian Creek shale contains an abundant ammonoid fauna of the *Perrinites bösei* zone. The term Indian Creek, however, is preoccupied, having been previously applied by Drake to a member in the Strawn.

Type locality: Admiral in Callahan County; thickness, 300 to 350 feet. The formation was named by Plummer and Moore (1228, p. 192).

BELLE PLAINS FORMATION

The Belle Plains formation consists of shale, calcareous marl, and limestone. Thin limestones occur locally throughout the formation, and at the top there are somewhat heavier limestones, the Bead Mountain and the Beaverburk. These limestones, particularly the top ones, make small escarpments. From the Colorado River the Bead Mountain limestone may be followed north through Throckmorton and Baylor counties, beyond which it grades into the red beds section of the Wichita region. The Beaverburk limestone, named by Udden and Phillips (1632, p. 31), has been traced north to Burk in Wichita County. From near the top of this formation, at the old military crossing on the Wichita River in Baylor County, Cummins in 1889 obtained a collection of fossils from which C. A. White described four species of ammonites.

In the Colorado River valley the formation includes the following beds named by Drake: shale, Jagger Bend limestone, Valera shale, and Bead Mountain limestone. Beede, however, from the fossils, favors associating the lower members of this formation up to and including the Jagger Bend with the Elm Creek member of the Admiral formation (1228, p. 198).

Type locality: Belle Plains in Callahan County; thickness, 200 to 300 feet. The formation was named by Plummer and Moore (1228, p. 195).

CLYDE FORMATION

The Clyde formation includes shales, marly beds, and buff limestones. In the Colorado River valley it was defined as including members as follows: shale, Grape Creek shale and limestone, and Talpa limestone.

Type locality: Clyde in Callahan County; thickness, 200 to 475 feet. The formation was named by Plummer and Moore (1228, p. 197).

LUEDERS FORMATION

The Lueders, here regarded as the top formation of the Wichita group, consists of limestones and shales. The limestone of this formation is quarried at Ballinger, Runnels County, and at Lueders, Jones County. The Maybelle and Lake Kemp limestones are members of this formation. The limestones are relatively fossiliferous, large bivalves being abundant at Ballinger. The limestones of this formation can be followed north into Wilbarger County, beyond which the formation grades into the red bed facies of the Red River region. With the Lueders formation is here included on the Colorado River the Paint Rock bed of Drake.

Type locality: Lueders in Jones County; thickness, 65 to 275 feet. The formation was named in 1917 by Wrather (1801, p. 94).

CLEAR FORK GROUP

The Clear Fork group was named by Cummins in 1890 (340, p. 188), and was more fully defined in 1891 (342, p. 401), at which time the contact between the Albany (then regarded as of Coal Measures age) and the Clear Fork was placed by Cummins as approximately at the divide between the Clear Fork of the Brazos and its tributary, California Creek.* Thus placed, the uppermost limestone of the Albany is at the top of the Lueders formation (1853, Shackelford County) and is now known as the Lake Kemp limestone (1853, Throckmorton County). The Clear Fork is 1200 or 1500 feet thick and as now subdivided includes the Arroyo, Vale, and Choza formations.

The vertebrate fossils of the Clear Fork group in north Texas are listed by Romer (1351). Some plants have been obtained which are listed by White (610). Only a small marine invertebrate fauna is known from this group (87 and 92).

Underground to the west the Clear Fork equivalent probably lies next above the "Big Lime" of the Panhandle section and includes the so-called "Red Cave" and a part of the salt beds of that section

*Cummins (342), map following p. 552.

(1764, p. 1007). In the southern part of the Permian basin the equivalent of this group, according to present interpretations, is within the black shale series below the "Big Lime" of the Reagan County section.

The Clear Fork group is conformable with the underlying Wichita but is separated by an erosional unconformity from the overlying Double Mountain. No unconformities are known to occur within the group. As the formations dip westward, their outcropping margins form narrow belts trending approximately north-south. The width of the several formation belts is, of course, proportional to the thickness of the formations. The group as a whole occupies an outcrop zone 30 to 35 miles wide, from the Red River southwestward through Wilbarger, Foard, Baylor, Knox, Haskell, Jones, Taylor, Runnels, and Tom Green counties to the Cretaceous overlap.

ARROYO FORMATION

The Arroyo formation consists of shales, limestones, marls, and gypsum. At the type locality the limestones are thin, usually 1 to 3 feet, the greater part of the formation being shale. In Runnels County there is one persistent gypsum bed in the lower part of the formation. Of several thin limestones three have been named as members, the Rainey, Lytle, and Standpipe limestones. The type locality of each is in Taylor County. This formation, which was tentatively placed by Beede at the top of the Wichita group, is here considered as the basal formation of the Clear Fork, which recent county mapping seems to show more nearly conforms with the original limits of that group as defined by Cummins. A few invertebrate fossils are found in Runnels County in the limestones of this formation. Ammonites have been obtained from the Lytle limestone near the top of this formation 1 mile east of Abilene, representing the *Perrinites kempae* zone (1234f).

Type locality: Los Arroyos, near Ballinger, in Runnels County; thickness, 260 feet. The formation name was given in 1918 by Beede (87, p. 45), replacing the preoccupied name Abilene previously proposed by Wrather (1801).

VALE FORMATION

The Vale formation as originally defined consists of shale and sandy shale and some sandstone. The original definition is here modified by including in this formation a thin overlying dolomite member named by Wrather the Bullwagon dolomite (1801). In Taylor County this dolomite is 5 feet thick and consists of two strata separated by a clay parting. On the Colorado River an apparently equivalent member consisting of thin dolomites and shales is 36 feet thick. In Tom Green County it is 44 feet thick, of which more than half, about 25 feet, is dolomite (704, p. 15). A few fossils, chiefly bivalves, are found in the dolomite. Thickening of the dolomite member is accompanied by thinning of the underlying shale, which is about 340 feet thick in Taylor County, 154 feet in Runnels County, and 50 feet in Tom Green County.

Type locality: Vale post office (now abandoned) on the Ballinger-Maverick road at the east side of Valley Creek, Runnels County; thickness, 100 to 340 feet. The formation was named by Beede (87, p. 47), replacing the preoccupied name Tye previously proposed by Wrather (1801).

CHOZA FORMATION

The Choza formation consists of red shales with some thin dolomites. The most persistent of the dolomites is the Merkel member named by Wrather (1801). The other dolomites give place northward to shales. On the Colorado River the Merkel dolomite is within about 270 feet of the top of the formation. In Taylor County this interval overlying the dolomite has been reduced to about 25 feet, and in Stonewall County the Merkel member is either cut out by the erosional unconformity which separates this formation from that next above, or, like other dolomites of this formation, terminates northward by lithologic change (1185, p. 17). Ammonites have been obtained from about 167 feet above the base of this formation on the Colorado River.

Type locality: Choza Mountain near Tennyson, Coke County; thickness, 870 feet. The formation was named by Beede (87, p. 49).

DOUBLE MOUNTAIN GROUP

The Double Mountain group, as established in 1890 by Cummins (340, p. 188), is the uppermost group of the Permian of the north-central Texas region. This group is separated from the underlying Clear Fork by a pronounced erosional unconformity. The sediments are largely sands, sandstone, shale, and gypsum. Much difficulty has been found in making suitable subdivisions in this group, and the formations now recognized are provisional and will doubtless be in part modified or added to. It has been found possible to apply formation names used in Oklahoma to some extent but not fully. The total thickness of the Double Mountain group is from 1500 to 2000 feet.

The formations of this group recognized in Stonewall County, Texas, are: San Angelo, Blaine, and Peacock. An alternate subdivision of the group in Texas recognizes the following formations: San Angelo, Blaine, Whitehorse, Cloud Chief, and Quartermaster (1001).

The term Royston formation was applied by Cheney in 1929 to about 100 feet of shale, gypsum, and thin dolomite exposed at Royston in Fisher County. This unit is probably the basal part of the Peacock formation as defined by Patton and is probably chiefly within the Whitehorse as mapped by Lloyd and Thompson (247, p. 26).

The outcropping belt of this group is broad at the north, extending from a few miles west of Vernon in Wilbarger County, where the San Angelo formation crosses the Red River, to Potter County in the Panhandle region. In its southward extension the outcropping belt narrows by the eastward extension of the High Plains and the Triassic formations and is terminated at the south in Tom Green County by the overlap of the Cretaceous.

Relatively few fossils have been obtained from the Double Mountain group. Some ammonites have been found in the Blaine formation in Stonewall and Hardeman counties. The Whitehorse formation has yielded fossils in Oklahoma and Texas described by Beede (85).

The Double Mountain group extends to the west underground across the Panhandle region. The formations and horizons recognized are the "Big Lime" (Wichita), "Red Cave," and "Salt Series"

(Clear Fork plus San Angelo and probably Chickasha), Blaine, Whitehorse-Cloud Chief, and Quartermaster. Of these formations the Cloud Chief and Quartermaster outcrop at the surface as far west as Potter County (1764, p. 1005). To the southwest underground in the Permian basin, the Blaine formation is thought to grade into limestones.

SAN ANGELO FORMATION

The San Angelo formation consists of chert conglomerate, sandstones, and some shales. The conglomerate is best developed in the region of San Angelo and on the Colorado River. Northward the conglomerate gives place to finer materials. Sands and sandstones, however, persist as an important part of the formation to the Red River, as well as in the equivalent of this formation, the Duncan of Oklahoma and the possibly equivalent upper Harper of Kansas.

According to Beede, the southern part of the formation as exposed in Texas constitutes a large delta, centering near Tennyson in Coke County. From this locality the formation is less conglomeratic, not only along the strike north and south, but also down the dip west or northwest. The siliceous conglomerate phase reaches to the southern part of Stonewall County and is succeeded farther north in this county by a conglomerate dolomite and other similar rock fragments (1185, p. 21).

Type locality: San Angelo in Tom Green County; thickness, 60 to 250 feet. The formation was named in 1891 by Lersch (984, p. 77).

BLAINE FORMATION

The Blaine formation, as the term is now used in Texas, includes more than does the Blaine of the type locality in Oklahoma. Not only is the underlying Chickasha, or a part of it, merged with the Blaine in Texas usage, but the overlying Dog Creek of Oklahoma is included in part or entirely.

The formation as thus defined consists of red and gray shales, massive gypsum, dolomite, and some sandstone. The gypsum beds are lenticular and range in thickness from a few inches to as much as 30 feet. The dolomite beds in some localities contain poorly preserved bivalves. The following dolomite horizons in this formation have received names: Mangum, Acme, Guthrie, and Childress (1001, p. 951). The Guthrie is possibly the same as the Aspermont named by Morley in 1929. The Blaine outcrops in a belt which narrows from about 40 miles on the Red River to 15 miles or less at Sweetwater.

An ammonite fauna has been obtained from the Acme dolomite member near Acme in Hardeman County (see p. 181).

Type locality: Blaine County, Oklahoma; thickness, 550 to 900 feet. The formation was named in 1902 by Gould and more fully described by him in Oklahoma in 1924 (618, p. 331). It was redefined, as here used, in 1929 by Lloyd and Thompson (1001, p. 950).

WHITEHORSE-CLOUD CHIEF-QUARTERMASTER FORMATIONS

The difficulty of making exact correlation with the formations recognized in the Upper Permian of Oklahoma led Patton in 1930 to propose a new name, Peacock formation, for all that part of the Permian above the Blaine exposed in Stonewall County, Texas. These sediments as here exposed, 700 or 750 feet in thickness, consist of thin beds of dolomite, red shales, thin gypsum beds, and fine-grained sandstone. The amount of sandstone increases towards the top of the formation. At the base of the formation is a gypsum bed named the Swenson member by Patton; about 100 feet above the base is the Oriana gypsum member (1185).

An ammonite fauna has been obtained from this formation at the falls on Salt Croton Creek, Stonewall County (see p. 181).

In 1929 Lloyd and Thompson recognized in Texas the Whitehorse-Cloud Chief and Quartermaster formations of Oklahoma (1001), representing approximately the equivalent of the Peacock formation as later proposed by Patton. To the Whitehorse is referred, on the Red River, red friable sandstone, sandy shale, and some gypsum. The Whitehorse-Cloud Chief as thus defined outcrops in north Texas from Chillicothe almost to the west line of Hall County, about 40 miles, and narrows southward. The Whitehorse is recognized west of Aspermont in Stonewall County and south of Sweetwater (Lake Trammel sandstone of Wrather). The overlying heavy gypsum beds are regarded as occurring within the Cloud Chief equivalent.

The Eskota gypsum, Dozier sandstone, and Claytonville[62] dolomite are members in the Whitehorse-Cloud Chief interval. The Quartermaster formation in Texas, according to these authors, is from 200 to 300 feet thick and consists of well bedded red sands and sandy and gypsiferous shales. It is traced southward to Kent County (1001, p. 953), beyond which it is overlapped and concealed by the Triassic.

Type locality: The type locality of the Peacock formation is at Peacock in Stonewall County. The type localities of the Whitehorse, Cloud Chief, and Quartermaster formations are in Oklahoma.

UNDERGROUND POSITION OF THE PERMIAN IN TEXAS

The highly diversified character of the Permian sediments and the remarkably rapid lateral change of facies has made the tracing of the formations underground unusually difficult. As has been indicated, the Permian outcrops at both the west and east sides of the Permian basin. In the basin it is covered by Triassic, Cretaceous, and Cenozoic formations. The problem of correlating across the basin has been attacked by following formations from either side towards the middle of the basin and thus obtaining correlations across the basin, supplementing correlations made directly from fossils obtained from the surface exposures. A large number of geologists have contributed toward making these correlations, and the results, although not yet complete, nevertheless record an important advance in a difficult undertaking.[63]

The first correlations of formations on the opposite sides of the basin were made by the aid of fossils from the surface exposures. Ammonites have been obtained from several localities in the Wichita group of north-central Texas. From 4 miles south of Dundee, Archer County, in the Belle Plains formation, Wrather obtained *Paralegoceras baylorense, Perrinites cumminsi, Stacheoceras walcotti,* and *Medlicottia copei.* Böse was of the opinion that these were approximately of Hess age (131). However, King (940), on the basis of

[62]The term Sweetwater applied to this dolomite has been found to be preoccupied (247, p. 26). A small collection of invertebrates, obtained from the Dozier (Memphis) sandstone, is listed by Gould (614b, p. 23).

[63]Publications listed in the accompanying bibliography relating to the underground position of the Permian in Texas include the following: Ackers, 1; Baker, 51; Bauer, 78; Bybee, Boehms, Butcher, Hemphill, and Green, 190a; Cartwright, 201; Edwards, 517; Gould and Willis, 625; Hoots, 841; Lang, 975; Sellards and Patton, 1414; Sellards and Williams, 1421; Sellards, Bybee, and Hemphill, 1428; Willis, 1764.

more complete fossil collections from the Glass Mountains, regards them as probably of upper Wolfcamp age. The vertebrates and plants found in the Wichita are not directly comparable since neither has been obtained from the Wolfcamp.

From the Clear Fork group in Runnels County on the Colorado River, 3 miles east of the west county line, Beede obtained a few fossils from the Bullwagon dolomite member of the Vale formation. Aside from some pelecypods and gastropods, the fossils from this locality are *Perrinites* n. sp., *Medlicottia* n. sp. (aff. *M. orbinyana* Vern.), and *Gastrioceras* n. sp. These few fossils afford no very definite correlation with the Glass Mountains section.

In the Blaine formation of the Double Mountain group ammonites have been obtained at the falls of the Salt Croton Creek in Stonewall County, where the following were obtained: *Perrinites hillí, Stacheoceras* sp., and *Medlicottia* sp.* Some ammonites have been obtained also from the Mangum dolomite member of the Blaine formation from near Quanah in Hardeman County. From this locality Böse lists *Perrinites* and *Gastrioceras*. These fossils, particularly *Perrinites gouldi* Plummer (MS.), which is very close to *P. vidriensis*, are believed to indicate that the Leonard is of Blaine age.

In 1910 and again in 1926, on evidence furnished by invertebrate fossils, Beede suggested that the Queen sand in the Captain formation correlates with the Whitehorse formation (86 and 96).

In tracing formations by means of well records it has been necessary to rely largely on lithologic characters since index fossils are even more rarely found than on the surface exposures. Eastward from the Guadalupe Mountains the Bone Springs member of the Leonard formation quickly drops in the Delaware basin below the depth of drilling. The Capitan formation, as previously stated, grades eastward into the Frijole limestone member and into sands, and in the Delaware basin is not separable from the Delaware Mountain formation. These two formations, constituting the Guadalupe Mountain group, consisting of fine sands and some dark limestones, are readily traced eastward across the Delaware basin. At the margin of the Central Platform, east of the Delaware basin, conditions with respect to these formations become obscure. Cartwright maintains that the Capitan equivalent again assumes a reef

*These fossils are from the Guthrie (Aspermont) dolomite near the top of the Blaine formation.

facies at the west margin of the Central Platform and changes eastward on this platform to a lagoonal facies. East of the platform in the main Permian basin, the Delaware Mountain formation consists of anhydrite, salt, and red beds, and is thought to tie in at eastern exposures with the Whitehorse formation (201). The Castile gypsum, which at the surface is 800 or 1000 feet thick, increases in the Delaware basin to 4000 feet and is divisible into two units, lower and upper. The lower Castile probably pinches out against the Central Platform, while the upper member apparently passes across this barrier and includes the principal salt beds in the main Permian basin. The exact equivalency of the upper Castile on the eastern side of the basin is in doubt, but it is possibly either Quartermaster or Cloud Chief. The Rustler formation at the top of the Permian of the Delaware Mountains may be traced eastward with no important change, other than thinning, as far as Winkler County and possibly Midland County, where it is lost, being there possibly within or below the Quartermaster formation. A section across the southern part of the Permian basin is given in Figure 12. For a detailed section on large scale see Bybee, Hemphill, and Boehms (190b).

This interpretation of equivalencies across the basin is supported by the observations of Bybee and associates, who have followed a horizon considered to be the Queen sand zone from two wells in New Mexico in a southeasterly direction to Crockett County, Texas. The Queen sand, which is the equivalent of a part of the Capitan, and, according to these writers, the same as the Yates sand of the Yates field in Pecos County, is placed near the top of the Delaware Mountain formation ("Delaware sands"), which in turn is regarded as a part of the Whitehorse of the eastern section (190a). This correlation agrees with that made by Beede from surface exposures in 1910 and 1926 (86 and 96).

Underneath the "Big Lime" in the southern part of the Permian basin is a great series of black shales and limestones. These have been drilled through near the center of the basin in Reagan County where they are 4200 feet or more thick. The genus *Schwagerina* is found in these shales and limestones within about 500 feet of the base. The presence of this fossil and associated *Fusulina* species indicates that 3700 feet or more of this black shale is Permian (1428,

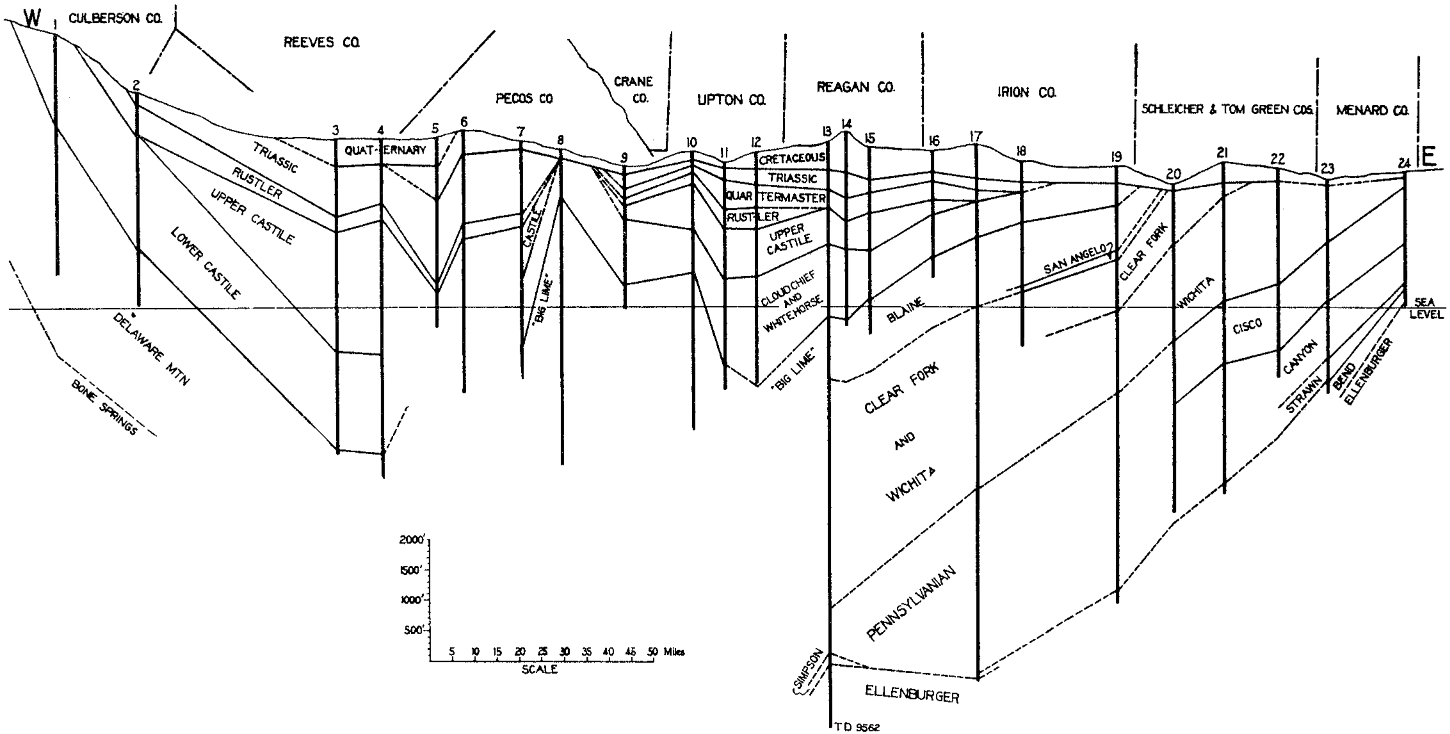

Fig. 12. Geologic section across the southern Permian basin of Texas, adapted from section made by H. P. Bybee, H. A. Hemphill, and E. F. Boehms. The wells utilized in constructing the section and indicated in the sketch are as follows: 1, California Co., Gresham and Hunter 1; 2, Gresham and Hunter, Fee 1; 3, Southern Crude Oil Purchasing Co., Kloh 1; 4, Penn Oil Co., Bowles 1; 5, World Oil Co., Kloh 1; 6, Phillips Petroleum Co., Pryor 1; 7, Pinal Dome Company, Devlin 1; 8, Roxana-Kirby, Univ. 1; 9, Marland Oil Co., Blakesley 1; 10, Marland Oil Co., Burleson 3; 11, Virginia-Tex Co., Univ. 1; 12, Kirkwood Oil Co., Rankin 1; 13, Big Lake Oil Co., Univ. 1-C; 14, Grayson et al, Univ. 1; 15, Simon and Hoffman, Univ. 1; 16, Empire Oil and Gas Co., Sawyer 1; 17, P. H. Williams, Ash 1; 18, Virginia-Tex Co., Noelke 1; 19, Sun Oil Co., William 1, and lower section of Stanolind Oil and Gas Co., Williams 1; 20, Phillips Petroleum Co., Gulden 1; 21, Delmar Oil Co., O'Harrow 1; 22, Paragon Oil Co., Boyd 1; 23, Cromwell et al, Winslow 2; 24, Barnett et al, Drake 1. Well No. 8 terminates in rocks probably of pre-Cambrian

p. 156). If the correlations given above are correct, namely that the Blaine and San Angelo formations find their equivalency in the "Big Lime" and sandy zone at its base, it follows that the upper 3700 feet or more of the black shale series represents the Clear Fork and Wichita groups.

The equivalencies in the basin of Permian formations outcropping at the east margin have already been in part indicated. A sand which may be approximately the equivalent of the Quartermaster lies at the top of the Permian in the basin. Although outcropping under the Triassic at the east margin as far south as Kent County, it does not outcrop as a sand at the west margin of the basin. The Rustler limestone, at the top of the Permian in surface exposures on the west side of the basin, may lie underground in or just below this formation. The principal salt of the southern part of the main basin, and in the Delaware basin, is either in this formation or in the Cloud Chief. The considerable interval occupied by the combined Cloud Chief and Whitehorse formations, not separable in Texas either on the surface or underground, as already stated probably includes in the basin the approximate equivalent of the Guadalupe Mountain group, the Queen sand zone (Yates sand zone in the basin) being correlated with the Whitehorse sandstone. In the basin this interval includes anhydrite, sand, and, locally, reef dolomitic limestone on the west margin of the Central Platform.

The Blaine formation, believed because of evidence furnished by fossils to be the equivalent of the Leonard, is interpreted as grading underground into heavy limestone, the "Big Lime" of the central part of the main basin. The San Angelo at the base of the Double Mountain group at the east side of the basin has been followed underground, and is correlated with a sandy zone near the base of the "Big Lime" at Big Lake in Reagan County. It may correlate with the conglomerate at the base of the Hess formation in the Glass Mountains, thus indicating that this break in sedimentation, so pronounced at the east side of the basin in Texas and Oklahoma, likewise affected the Glass Mountains region where it is marked, locally at least, by an angular unconformity.

In the High Plains or Panhandle region the principal salt-forming conditions occurred earlier than in the Pecos or southern end of the basin. The "Big Lime" of that area is in the Wichita group and the principal salt beds are below the Blaine. Thus the "Big Lime," some red beds, and the principal salt beds occupy approximately the interval of the black shales of the southern basin section. The salt beds of Oklahoma and Kansas are of still earlier age, occurring in the Wellington of possibly upper Wichita age (625 and 1764). These observations are consistent with the view now generally accepted of a gradually desiccated southward-retreating inland sea in Permian time.

PERMIAN SEAS OF THE TEXAS REGION

The Permian seas occupied a wide area in the Texas region extending from Mexico and the southwestern part of the state, including the Chinati, Glass, and Diablo mountains, northeastward into the adjoining states of Oklahoma and Kansas. To the northwest this sea likewise reached beyond the boundaries of Texas, and, at the time of its maximum extent, spread widely across New Mexico, Arizona, and northward, at many places invading areas that had been land during a part or all of Pennsylvanian time. No pronounced break occurs at the southeast margin of this sea through Texas, Oklahoma, and Kansas, thus indicating that the sea was an inheritance from Pennsylvanian time.

This main basin of Permian deposition extends for approximately 1000 miles through Texas and adjoining states. A close inspection of the deposits shows that it was not, throughout, a basin of uniform duration or conditions of deposition. The sea occupying this basin passed from the open water, marine condition of Pennsylvanian and earliest Permian time, through successive stages with many fluctuations, to ultimate complete desiccation. Under these conditions were deposited the several kinds of sediments varying from strictly marine, clastic, and organic rocks, various chemical precipitates, to, lastly, continental deposits. In general the sea withdrew to the southwest, and desiccation thus affected the northern part of the basin earlier than the southern part.

Salt-forming conditions began in Kansas as early as the equivalent of the Wichita epoch. At a later time, probably upper Clear Fork and early Double Mountain time, salt-forming conditions had extended southward to the northern Panhandle region. In still later time, probably in middle or early upper Double Mountain time salt-forming conditions were reached in the southern part of the basin. At the extreme southwest margin of the basin the seas continued longest, and here, in the Glass-Apache-Delaware-Guadalupe mountains, marine fossils are present through 6000 or 7000 feet of sediments.

RELATION OF TEXAS PERMIAN TO THAT OF THE ADJOINING STATES

The relation of the Texas Permian to that of the adjoining states has already been indicated. The open-sea, marine facies of the lowest Permian, Wichita group, gives place northward in Texas to a red bed facies on the Red River at the north state line. This facies continues northward approximately halfway through Oklahoma, where there is again a gradation, in part at least, to normal marine conditions in northern Oklahoma and Kansas. The Kansas formations of the latter part of this stage, however, contain salt deposits. The remainder of the Permian formations, the Clear Fork and Double Mountain groups, continue the red bed facies into Oklahoma and Kansas. The southward extension of the Permian in Mexico is not well known. King has shown, however, that at Las Delicias in Coahuila there is a thick mid-Permian limestone series (940, p. 18).

CLOSE OF THE PALEOZOIC

With the desiccation of the Permian seas and the final filling of the great Permian basin, the Paleozoic records in Texas are closed. The latest Paleozoic containing identifiable marine fossils is the Capitan formation. Later than the Capitan are the Castile and Rustler formations and, if relations are correctly understood, a part or all of the Quartermaster. These formations, however, contain no fossils of stratigraphic value. The Bissett formation, if correctly referred to the Permian, likewise represents a stage later than the Capitan, probably representing non-marine deposition.

Following the close of the Permian, the Texas area, so far as the records show, was a land region throughout Triassic time and was flooded in part in Jurassic time. In Cretaceous time occurred another great inundation over a greatly changed land mass. The Mesozoic and Cenozoic eras are discussed in Parts 2 and 3 of this volume.

STRATIGRAPHIC DATA FROM WELLS

WELLS ENTERING PALEOZOIC OF THE LLANORIA GEOSYNCLINE

Abbreviations used in the table headings for wells entering Paleozoic of the Llanoria geosyncline are as follows: TD, total depth; Elev, elevation; Pal, depth to Paleozoic; and Rock, kind of rock encountered. In the column recording elevations, A is used to indicate elevation by aneroid barometer, and T, elevation taken from topographic map. All elevations given are to be regarded as approximate only. Samples from the wells here listed, with a few exceptions, are contained in the collection of the Bureau of Economic Geology.

The formations overlying the Paleozoic in all of the wells in this first table are of Cretaceous age. In those wells located west of the Balcones fault zone, the Comanche Cretaceous only is present, while wells east of this zone pass through a part or all of the Gulf series which overlies the Comanche series.

BELL COUNTY[64]

Name and location of Well	TD	Elev	Pal	Rock
Bacon 2, Nolan Bell Co.; 3.9 mi. W of Nolanville	1820	820A	896	Black shale
Bailey 1, Mellon Oil Co.; Evitts Surv.; 7. mi. S, 4 E of Killeen	3790	700A	798	Slaty shale and novaculite
Ferguson 1, Winans & Forbes; James Bowers Surv.; 7 mi. NW of Belton	1780	550T	821±	Black shale, gray quartzitic sandstone
D. W. Hair 1, Rio Grande Oil Co.; 2¼ mi. NW of Belton	2002	625T	1157±	Black shale, gray quartzitic sandstone
Holcomb 1, Bell County Oil Co.; Walker Surv.; 3 mi. W of Belton	1640	760A	1107	Quartzitic sandstone
Slayden 2, Eclipse Oil Co.; 7 mi. S of Killeen	1216	900A		Fractured shale[65]

[64]Several other wells in western Bell County were drilled through the Cretaceous. See Univ. of Texas Bull. 3016, p. 86, 1930.

[65]Exact depth to Paleozoic not determined. Samples examined at depths ranging from 695 to 1050 feet.

Name and location of Well	TD	Elev	Pal	Rock
Warrick 1, Bell Williams Oil Co.; Ingram Surv.; 6.7 mi. NW of Jarrell	1373	864A		Hard shale and quartzitic sandstone[66]
Warrick 1, J. B. Hartman; Webb Surv.; 6.8 mi. NW of Jarrell	2772	944A	973	Hard shale
BLANCO COUNTY				
Specht 1, Hicks et al; T. M. Fowler Surv. 27; 22 mi. S of Johnson City	1635	1330	1470±	Altered shale[67]
BEXAR COUNTY				
Camp Bullis, U. S. Gov't.	1910	1050T	1799	Altered shale
Leon Springs, U. S. Gov't.	2500	1156T	1046	Altered shale
Pepper 1, Gas Ridge Snyd.; 14 mi. W of San Antonio	3783	950T	2864	Altered shale
CALDWELL COUNTY				
Schawe 1, Gulf Coast Drilling Co.; Maxwell	3445	604	3415	Shale
DALLAS COUNTY				
Seaton 1, McNeil & Mathews; 2 mi. NE of Britton	2660		2435[68]	Black shale
ELLIS COUNTY				
Hale 1, Triangle Corp.; 1 mi. S of Avalon	3190	455	3060[69]	Slickensided shale and quartzitic sandstone
FALLS COUNTY				
F. Pucek 1, Humble Oil & Rfg. Co.; L. Thuner Surv.; 4 mi. from W and 6½ from S county line	3576		3535	Phyllite
FANNIN COUNTY				
Lane 1, Elkay Oil & Gas Co.; James Bourland Surv.; 2 mi. NW of Ector	3134		2380	Black shale and sandstone
Martin 1 (Joe Horne), Doyle and Jondeau; R. P. Mayo Subd.; 7 mi. NE of Paris	2958	532	2860	Gray indurated shale
R. E. Morgan 1, Ed. V. Parsons; J. C. Inglish Surv.; 3 mi. E and 1 N of Savoy	3048	666	2280±	Hard sandstone and shale

[66]Exact depth to Paleozoic not determined. Samples examined at depths ranging from 1190 to 1373 feet.

[67]Exact depth to Paleozoic not determined. Samples examined at depth 1635 feet.

[68]Exact depth to Paleozoic not determined. Cores examined at depths 2435 and 2655 feet. The top of the Paleozoic may be near 690 feet.

[69]Exact depth to Paleozoic not determined. Cores examined at depths 3060 and 3155–3190 feet.

GRAYSON COUNTY†

Name and location of Well	TD	Elev	Pal	Rock
Butcher 1, Peters Oils Inc.; P. Boon Surv.; 3 mi. E of Denison	4003		1511	Black shale and sandstone
Easton 1, Westover Oil Co.; Surv. 443; 9 mi. NW of Denison	1070		830±	Hard sandstone
Munson 1, Peters Oils Inc.; Ramon Rubio Surv.; 2½ mi. N of Denison	3640	650T	2370±	Black shale and sandstone
Williams 1, Verne and Dumas; 3.9 mi. NE of Van Alstyne	4250	790	3425?	
Wall 1, Simpson-Fells Co.; Reeves Surv.; 8 mi. W by N of Denison	2515	734	963±	
HAYS COUNTY				
Elsner 1, E. A. Buckman; Fowler Surv.; 3 mi. S of Dripping Springs	2454	1075T	688±	Black shale
Heidenreich 1, Harley & Whitington; 3 mi. SE of Kyle	2767		2750[70]	Dark schistose shale
HILL COUNTY				
Hillsboro City Well 1	2136	635	1900±	Quartzite
Hillsboro City Well 2	2152	634	1792±	Quartzitic sandstone
Hillsboro City Well 3	1838	625	1794±	Shale and quartzitic sandstone
Weatherbee 1, Hill-Texas Co.; W. O. Merriwether Surv.; 3½ mi. E of Hillsboro	4000	800	2275±	Black shale and quartzitic sandstone
KENDALL COUNTY				
Boerne City Well; 1 mi. W of Boerne	1118		925±	Schistose shale
Bowles 1, Permian Oil Co.; 6 mi. NE of Boerne	1550	1410	1195±	
Kunz 1, Abercrombie & Harrison, J. W. Cormack Surv.; 7 mi. E, 1 N of Boerne	2250	1352	1895±	Schistose shale‡
KINNEY COUNTY				
Wardlaw 1, Magnolia Petroleum Co.; M. Valdez League; 16 mi. W of Brackett	5280	988	3450	Altered shale and limestone[71]

[70]Exact depth to Paleozoic not determined. Travis Peak core seen at depth 2626 and Paleozoic cores at 2750 and 2767 feet.

[71]After passing through more or less altered rock from 3450 to near 5050 this well entered unaltered limestone of Ellenburger facies in which it terminated at 5280 feet.

†For other wells in Grayson County drilled into the Paleozoic, see Bull. Amer. Pet. Geol., vol. 15, p. 815.

‡Relatively unaltered Paleozoic entered at about 800 feet.

Name and location of Well	TD	Elev	Pal	Rock
Weatherbee 1, Haveline Oil Co.; I.&G.N.Ry.Co. Surv., Blk. 5, Sec. 21; 14 mi. NE of Del Rio	4398+	1187		Altered shale
LAMAR COUNTY				
Ford 1, Bailey Dev. Co.; Doss Surv.; 9 mi. N, 8 mi. W of Paris	1930	565	1880	Quartzite
MEDINA COUNTY				
Rothe 1, California-Medina Assoc.; Medina Co. School Lands, Sec. 1012; 8 mi. NW of D'Hanis	3705		2616±	Black shale[72]
Zerr 1, Switzer et al; I. I. Casenova Surv. 459; 5 mi. W-NW of Hondo	3635			Black shale[73]
McLENNAN COUNTY				
Harrington 1, Waco Oil & Rfg. Co.; Moore Surv.; 4½ mi. N of Waco	3600	500T	2600	Quartzitic sandstone and black shale
Stuart 1, St. Louis Oil Pool; Johnston Surv.; 2¾ mi. S, ½ mi. E of McGregor	3512	750T	1235±	Black hard shale, limestone and chert
RED RIVER COUNTY				
Dillahunty 1, Concord Oil Co. (Pearsons et al); I. Moore Surv.; 3 mi. from W county line, 6 mi. S of Red River	2545	482	2137[74]	Schistose sandy shale
Lady Alice 1, Johnston Petr. Synd.; Gamble Surv.; at Silver City, 18 mi. N of Clarksville	4470		1763	Hard shale
TERRELL COUNTY				
Cowden 1, Williams et al; T.C.Ry. Co., Blk. D-10, Sec. 71; 5½ mi. E, 10 mi. S of Sanderson	3150	2430		Schistose shale[75]
Folsom, S. W. Texas Oil & Gas Assoc.; E.L.&R.R.Ry.Co. Surv., Blk. D-7, Sec. 148; 8 mi. S of Watkins	3580	1850T	1970†	Schistose shale

[72]Exact depth to Paleozoic not determined. Core examined at 3556–58 feet.

[73]Exact depth to Paleozoic not determined. Sample examined at 3635 feet.

[74]Exact depth to Paleozoic not determined. Samples examined at depths 2137 and 2500 feet.

[75]Exact depth to Paleozoic undetermined. Samples examined at 3150 feet. Log reports quartz and calcite veins in more or less altered shale from 2685 to the bottom of well.

†Exact depth to Paleozoic not determined. Schistose shale is found at depth 2795 feet and below.

TRAVIS COUNTY

Name and location of Well	TD	Elev	Pal	Rock
Blunn Creek well, City of Austin; South Austin	2246	538	2200±[76]	Indurated black shale and quartzite
Evans 1, Griffith et al.; 9 mi. SW of Leander	983	1024A	620	Shale and quartzite
Reimer 1, E. D. Summerow; J. C. Little Surv.; 23 mi. W ,6 mi. N of Austin	1274	800T	266	Black shale
Romberg 1, Cypress Creek Drilling Assoc.; J. M. Miller Surv.; 25 mi. W, 8 mi. N of Austin	1560	800T		Black shale[77]
VAL VERDE COUNTY				
Harrison 1, Plateau Oil Co.; I.& G.N.Ry.Co. Surv., Blk. 3, Sec. 14; 9 mi. E, ½ mi. N of Del Rio	3507	1109	3148	Talcose shale
Holman 1, Williams Drilling Co.; G.H.&S.A.Ry.Co. Surv.; Blk. N, Sec. 5; 10 mi. W, 11 mi. N of Del Rio	2935	1300		Hard black shale and calcite
Russell & Weathersbee 1, East Del Rio Oil Co.; I. Mitchell Surv. 183; 1 mi. E of Del Rio	3350	951	2800	Altered shale
Stevenson 1, Transcontinental Oil Co.; I.&G.N.Ry.Co. Surv., Blk. 4, Sec. 8; 4 mi. N of Del Rio	4412	1050	2423	Schistose shale
WILLIAMSON COUNTY				
Conway 1, Donnelly et al.; Burleson Surv.; 7 mi. SW of Liberty Hill	1133	950T	695	Black shale and siliceous limestone
Georgetown City Well	1807	442	1260[78]	Schistose shale
Miller 1, Miller & Mayfield; 3 mi. E of Liberty Hill†	1910	1000T	696	Shale

[76]The exact depth to Paleozoic is undetermined. A core taken at 2189 was of basal Cretaceous conglomerate. One of the pebbles of the conglomerate was of chert similar to that of the Maravillas formation of the Marathon region or the Big Fork chert of the Ouachita region. Fragments of novaculite are likewise present in this basal conglomerate. Cuttings at and below 2200 consist chiefly of more or less altered brown shale interpreted as probably the oxidized and somewhat decayed top of the pre-Cretaceous deposits. A core taken at depth 2246 consisted of black, indurated, much squeezed shale and black quartzite cut by calcite veins.

[77]No samples received above 834 feet. Cretaceous-Paleozoic contact probably nearly as in Reimer 1.

[78]Exact base of Cretaceous difficult to determine. See J. A. Udden, "Observations on Two Deep Borings Near the Balcones Faults," Bull. Amer. Assoc. Petrol. Geol., Vol. 3, pp. 124–131, 1919. Depth of 1260 feet is here used as the probable base because water is reported to have been obtained to that depth. The base of the Cretaceous may be at 1036 feet or above, or may be somewhat below 1260 feet. The well was drilled by standard tools and, in the absence of cores, determination of the formations is particularly difficult.

†An offset to this well drilled by H. A. McLeon had reached a depth of about 1600 feet at the end of November, 1932. Casing was set to shut off water at depth 890 and to prevent caving at

Name and location of Well	TD	Elev	Pal	Rock
Walsh 1, Palm Valley Oil Co.; 5½ mi. W of Round Rock	1230	839T	1230±	Novaculite

WELLS ENTERING PRE-PENNSYLVANIAN FORMATIONS, FORELAND FACIES

Abbreviations used in the table headings for wells entering the pre-Pennsylvanian formations, foreland facies, are as follows: TD, total depth; Elev, elevation; Miss, Mississippian; Ord, Lower Ordovician; Camb, Cambrian; p-Camb, pre-Cambrian; and Abst, absent. A star (*) in the table indicates that the formation referred to was not reached. Neither Silurian nor Devonian is represented, so far as known, in any of the wells here listed except in the one well in Hudspeth County. These systems, accordingly, are not listed in the table headings. The Mississippian shown in the table, when not otherwise indicated, is the Barnett formation. All elevations given are to be regarded as approximate only.

ARCHER COUNTY

The formations in this county overlying those here recorded include Lower Permian and Upper and Lower Pennsylvanian. The Barnett shale, Mississippian, is probably present but has not been definitely identified.

Name and location of well	TD	Elev	Miss	Ord	Camb	p-Camb
Gose 60, Continental Oil Co.; A.T.N.C. lands, Bl. 8; 7 mi. W, 9½ N Archer City	5280	1060	?	5060	*	*
Wilson 1, Lease 5-A, Lindsey Deep Oil Dev. Co.; A.T.N.C. lands, Sec. 75; 5½ mi. N, 1 E Archer City	5748	981		5340	*	*

BLANCO COUNTY

The formations in Blanco County overlying those here described are of Comanche age. In the northern part of the county Lower Pennsylvanian comes into the section under the Cretaceous. The Mississippian is not known to be present in this county. The southeastern part of the county contains sediments of the Llanoria geosyncline facies and the wells of that part of the county are described under that heading.

Name and location of well	TD	Elev	Miss	Ord	Camb	p-Camb
Bruckner, Winans and Forbes; Z. Hemphill Surv.; 1 mi. S Johnson City	360		Abst	240	*	*
Glasscock 1, R. A. Rodson et al; McDonald Surv., 6.8 mi. S Johnson City	968	1300T	Abst	704	*	*
Leeder 1, Lile and Adams; N. Mixon Surv., 2¼ mi. N, 3 W Blanco	530			405	*	*

1420. Samples submitted at depths between 1500 and 1580 feet were black slickensided shale and dark quartzitic sandstone.

BROWN COUNTY

The formations in Brown County overlying those here recorded are Cretaceous, locally present, and Upper and Lower Pennsylvanian.

Name and location of well	TD	Elev	Miss	Ord	Camb	p-Camb
Abney 1, Graham, Ludlow and Thomas; Kerr County School Land Surv. 272; 6 mi. S, 2 E Brownwood	2610	1504	1502?	1510	*	*
Alvis 1, Oil States Petroleum Co.; H.T.&B.Ry.Co. Surv. 37; 12½ mi. N, 1 W Bangs	3160	1575	2925	3035	*	*
Anderson 1, Honea et al; S. Durr Surv. 161; 11 mi. S Brownwood	1425	1440A	1321	1380	*	*
Anderson 1, E. M. Treat et al; S. Durr Surv. 161; 11 mi. S Brownwood	1385	1425	1296	1365	*	*
Andrews 1, Pippin Oil Co.; H. H. Hall Surv. 49; ½ mi. S, ¾ E Brownwood	2401	1316	1575	1675	*	*
Armstrong 1, Prairfie Oil and Gas Co.; H.&G.N.Ry.Co. Surv., Bl. 1; 2 mi. NE Cross Cut	3480	1656	3315	3430	*	*
Baugh 1, Bartles and Dumenil and Texas Co.; Osborn Dalton Surv. 26; 7½ mi. N, 1½ E Brownwood	3400	1395	2155	2278	*	*
Baugh 1, The Texas Co.; J. Deason Surv.; 11 mi. N-NW Brownwood	3055	1435T	2404	2490	*	*
Bettis 1, Arkansas Fuel and Gas Co.; G. W. Webster Surv. 179; 12 mi. S Brownwood	1439	1460T		1320	*	*
Boysen 1, Hart et al; E.T.Ry.Co. Surv. 7; 3 mi. SE Bangs	1957	1598A		1936	*	*
Brooke 1, Superior Oil and Gas Co. and Geo. Lamb; J. Padillo Surv. 645; 2 mi. SW Byrd's store	3585	1527	2715	2826	*	*
Brooke and Smith 2, McClung et al; J. Thom Surv. 53; 2 mi. NW Brownwood	1885	1438	1785	1880	*	*
Burns 1, Gilman, Crabtree and Simmons; G. C. Baker Surv. 7; 12 mi. N, 6 E Brownwood	3260	1777		3003	*	*
Byler 16, Shoup et al; T.&N.O. Ry.Co. Surv. 43; 6 mi. NW Bangs	2619	1549		2600	*	*
Cabler 1, C. E. Bonwell; F. Wardzeuski Surv. 324; 1 mi. NE Zephyr	1785	1498		1768	*	*
Calvert 1, Ben O. Madison; R. Hall Surv. 38; 8 mi. SE Brownwood	1421	1315		1400	*	*
Capps 1, Texas Eastern Oil Co.; Patrick Sullivan Surv. 17; 2. mi NE Brownwood	1900	1377	1720	1845	*	*

Name and location of well	TD	Elev	Miss	Ord	Camb	p-Camb
Capps 3, Texas Eastern Oil Co.; P. Sullivan Surv. 17; 1 mi. NE Brownwood	2080	1380		1845	*	*
Cason 1, Denny et al; W. G. Wilson Surv. 64; 6 mi. NW Brownwood	2475	1547		2220	*	*
Collier A-1, Lloyd Oil Corp.; Wm. A. Smith Surv. 139; 4 mi. NE Winchell	1481	1407	1306	1362	*	*
Coyle 1, Lucky Six Oil Co.; M. W. Shannon Surv. 26; 4 mi. W Brownwood	2050	1607A	1802	1842	*	*
Cross 1, A. A. Peard; E. D. Prewett Surv. 13; south county line	2803	1417	Abst?	1270	2470?	*
Davis 1, Carter et al; Jas. Bird Surv. 102; 5 mi. S, 1 W Bangs	2218	1553	1902	1991	*	*
DeBusk 1, Honea and Evans; J. Padillo Surv. 645; 2 mi. SW Byrd's store	2806	1470T	2705	2806	*	*
DeBusk 1, Phillips Petroleum Co.; E. Bell Surv. 648; 6 mi. from W, 10 from N county line	3115	1512		3110	*	*
Dixon 1, Glenn and McLaughlin Co.; Wm. Harrel Surv. 174; 1 mi. W Indian Creek	1518	1332A	1370	1410	*	*
Durham-Ratliff 1, C. W. Crader et al; J. H. Roberts Surv. 333; 9 mi S-SE Brownwood	1601	1490A	1445	1558	*	*
Evans 1, J. L. Gray; H. D. Yates Surv. 37; 8 mi. SE Brownwood	2004	1291		1364	*	*
Evans 1, Phillips and Van Bebber; C. S. Gorbett Surv., Sec. 16, 7½ mi. NE Brownwood	2353	1522		2086	*	*
Ford 1, Liberty Oil Co.; E.T.Ry. Co. Surv., Sec. 3; ½ mi. S May	3122	1652		3107	*	*
Fourth and First National Bank 1, Bourn et al; N. Reed Surv. 131; 4 mi. E. Winchell	1410	1325T	1120	1140	*	*
M. E. Fry 1, Baker and Hodges, D. Y. Pyron Surv. 8; 10 mi. SE Brownwood	1271	1285	1195	1265	*	*
Fuller 1, Empire Oil & Gas Co.; C. B. Jenning Surv. 353; 2¼ mi. W, 1¼ N Bangs	3708	1563	2235	2345	3203?	*
Gaines 1, Sinclair-Gulf Oil Co.; N. Jordan Surv. 12; 12 mi. N, 4 W Brownwood	2778	1520	2596	2760	*	*
Gehrke (W. P. Logan) 1, Cleone Oil Co.; Kerr County School Lands Surv. 277; 3 mi. S Brownwood	2105	1387	1470	1575	*	*
Gordon 1, Lockhart and Co., A. Marshall Surv. 605; 3 mi. W, slightly N Brownwood	1960	1499		1914	*	*

Name and location of well	TD	Elev	Miss	Ord	Camb	p-Camb
Geo. T. Graham 1, Producers and Refiners; J. Brown Surv. 137; 3⅔ mi. N Byrd's store	3210	1548	2909	3000	*	*
Grantham 1, Brownwood Production and Refining Co. and Gladys Belle Oil Co.; M. Little Surv. 39; 6 mi. NW Brownwood	2240	1542A	2150	2202	*	*
Greeley 1, Collins et al; J. W. and R. Leavett Surv. 157; 5 mi. NW Indian Creek	1465	1396A		1404	*	*
Hall 1, Gulf Production Co.; F. Hunt Surv. 9; 5 mi. W Brownwood	2182	1606T	2085	2140	*	*
Harris 1, Pennant Oil Co.; J. Sanders Surv. 162; 4 mi. from N, ½ from W county line	3450	1575		3335 ?	*	*
Helms 1, Lamb-Slick et al; A. White Surv. 161; 6 mi. SW Cross Cut	3242	1568	3050	3170	*	*
Hester 1, Long Oil and Gas Co.; H.T.&B.Ry.Co.Surv., Sec. 58; 10½ mi. N, 3½ E. Brownwood	2650	1550T	2515	2625	*	*
Honnel (Daniels) 1, McGee and Pollard; J. Kellogg Surv. 34; 1 mi. W Elkins	1400	1340A	1218	1283	*	*
Irby 1, McCamey et al; S.A.& M.G.Ry.Co. Surv.; near N county line, 3½ mi. from E county line	3569	1672	3380	3445	*	*
Jones 1, Y. C. Oil Co. et al; H. Kaber Surv. 19; 2 mi. NE Brownwood	2545	1367	1715	1795	*	*
Lehman 1, Kingwood Oil Co.; H. T.&B.Ry.Co. Surv. 15; 9 mi. NW Brownwood	2587	1590		2560	*	*
Looper 1, Bailey et al; J. Padillo Surv. 646; 3½ mi. SW Byrd's store	2922	1523		2910	*	*
Low 1, D. R. Bailey et al; J. M. Baker Surv.; 8½ mi. N, 1 W Bangs	2790	1572	2650	2755	*	*
Lowe 1, J. W. Collins; R. Ross Surv. 44; 3 mi. S, 1½ E Brownwood	1590	1375T	1487	1570	*	*
McHam 1, Hart Petroleum Co.; J. Duckworth Surv., Bl. 56; 4½ mi. NE Brownwood	2075	1448	1940	2060	*	*
MacMullen 1, Calcasieu Oil Co. Inc., C. West Surv. 291; 7 mi. S, 1½ W Brownwood	1568	1545	1513	1564	*	*
Martin 1, Creits et al; T. S. Goodrum Surv.; 8 mi. S Brownwood	1450	1446	1255	1299	*	*

Name and location of well	TD	Elev	Miss	Ord	Camb	p-Camb
Matlock 1, Pecan Bayou Oil Co.; Brown County School Land Surv. 360; 3½ mi. E Brownwood	2757	1417		1850	*	*
Nash 1-A, Olvey and Robins; C. E.P.L.M.Ry.Co. Surv.; 4 mi. NE Indian Creek	1520	1480A		1432	*	*
Parker 1, C. E. Bonwell and Mrs. Hazel Holloway; Brown County School Lands Surv. 361; 6 mi. E. Brownwood	2520?	1376T	1820	1890	*	*
Ratliff 1, Warren Devel. and Hanna Bros.; P. McAnally Surv. 35; 9 mi. SE Brownwood	1350	1400A		1243	*	*
Sewell 1, E. J. McJunken et al; T.T.Ry.Co. Surv. 3; 5½ mi. N, 3½ W Brownwood	2505	1500T		2230	*	*
Shelton 2, H. J. Uhl; D. S. Camp Surv.; 3 mi. SW Brownwood	1885	1480A	1745	1777	*	*
Shore 24, L. H. Wentz; Charles Betts Surv. 625, 17 mi. from N, 1 from W county line	2682	1460	2575	2670	*	*
Simmons 1, Panuco Exp. Co.; W. Deavenport Surv.; 7 mi. S Brownwood	1534	1522		1504	*	*
Smith-Scott 1, Pippin Oil Co.; M. Huling Surv.; SW limits Brownwood	1918	1427		1800	*	*
Suddeth 1, Sen-Tex; B.B.B.&C. Surv. 17, Bl. 3; 3 mi. from N, 2 from E county line	3506	1704	3145	3292	*	*
Taber 1, Tippit et al; C. G. Fenner Surv.; 4½ mi. N Brownwood	2180	1350T	1895	2060	*	*
Taylor 2, Anchor Oil Co.; T. J. Majors Surv. 507; 3 mi. NW Brownwood	2056	1504	1924	1990	*	*
Turner 1, Prairie Oil and Gas Co.; Mahala Duncan Surv.; 4 mi. N, 2 E Grosvenor	3270	1546	2935	3050	*	*
Weeden 1, Partridge Oil and Gas Co.; H.T.&B.Ry.Co. Surv. 51; 10½ mi. N, 5 W Brownwood	2760	1492	2545	2657	*	*
Wheeler 1, Transcontinental Oil Co.; J. J. Lively Surv., Sec. 91; 3½ mi. NW May	3360	1572		3350	*	*
Windham 1, Honea et al; E. M. Tanner Surv. 130; ¼ mi. NE Byrd's store	2850	1430T	2705?	2845	*	*
Wortham 1, Honea et al; J. Duckworth Surv., Subd. 23; 4 mi. E, 3 N Brownwood	2240	1465	2000	2107	*	*
Wright 1, Irwin et al; Kerr County School Lands Surv., Bl. 88; 3 mi. SE Brownwood	2170	1415		1705	*	*

BURNET COUNTY

The formations in Burnet County overlying those here recorded are Cretaceous and Upper and Lower Pennsylvanian. In the southern part of the county the Lower Ordovician, Cambrian, and pre-Cambrian formations are exposed.

Name and location of well	TD	Elev	Miss	Ord	Camb	p-Camb
Taylor 1, Twin City Oil Co.;T.& N.O.Ry.Co. Surv., Sec. 7; 3 mi. E Victor Lake	2300		550	575	*	*

CALDWELL COUNTY

The formations in Caldwell County overlying those here recorded are Lower Eocene (central and eastern parts of the county) and Upper and Lower Cretaceous. In the western part of the county Paleozoic formations underlie the Cretaceous (see preceding list of wells in the Llanoria geosyncline). From the character of the rock, the three wells here listed are believed to have probably entered pre-Cambrian under the Cretaceous.

Name and location of well	TD	Elev	Miss	Ord	Camb	p-Camb
Kelley 1, United North and South Oil Co.; Reavill Surv.; Luling oil field	7859	449	Abst	Abst	Abst	4728
Tabor 8, United North and South Oil Co.; Luling oil field	4854	488	Abst	Abst	Abst	4796
Tiller 1, United North and South Oil Co.; Luling oil field	7504	438	Abst	Abst	Abst	4807

CALLAHAN COUNTY

The formations in Callahan County overlying those here recorded are Cretaceous, locally present, and Upper and Lower Pennsylvanian.

Name and location of well	TD	Elev	Miss	Ord	Camb	p-Camb
Childs 1, F. E. Henderson et al; J. Sayers Surv.; 10 mi. S, 3 E Putnam	4030	1846		3890	*	*
Hall 1, Humble Oil and Refining Co.; R. A. Pace Surv., Sec. 232; 2½ mi. from S, 14 from W county line	3870	1660	3748[79]	3730	*	*
Harris 1, Greenlee et al; Dyson Surv.; 3 mi. NE Cross Plains; 2 mi. from E, 5 from S county line	3880	1800		3780	*	*
Johnson 1, Empire Gas and Fuel Co.; G.H.&H.Ry.Co. Surv., Sec. 146; 3 mi. from S, 8 from W county line	4140	1832	3905	4055	*	*
Ruddloff 1, Roxana Petroleum Corp.; Comal County School Lands, Sec. 53; 1 mi. from S, 6 from E county line	3612	1646		3570	*	*
Sealev and Smith, Empire and Johnson; G.H.&.H.Ry.Co. Surv., Sec. 151; 4 mi. from S, 9 from W county line	4174	1830		4076	*	*

[79]Mississippian below Barnett, commonly referred to as "pink Crinoidal" limestone, possibly the Chappel formation.

Name and location of well	TD	Elev	Miss	Ord	Camb	p-Camb
Vestal 1, New South Oil Assn.; J. Dyson Surv.; 1½ mi. E, 1½ N Cross Plains	3755	1786		3735	*	*
Windham 1, Mid-Tex Oil and Gas Co.; Geo. Hancock Surv., Sec. 370; 3 mi. NE of Olpin	4438	1859		4232	*	*

CARSON COUNTY

The formations in Carson County overlying those here recorded are of Cenozoic, Triassic, and Permian age. In the wells here recorded in this and other counties in the Panhandle region the intervening systems from Pennsylvanian to Cambrian inclusive are absent. These wells, however, are located on the Amarillo uplift. Off of this uplift and at its sides Pennsylvanian and possibly older formations are present.

Name and location of well	TD	Elev	Miss	Ord	Camb	p-Camb
Lane 1, Empire Gas and Fuel Co.; I.&G.N.Ry.Co. Surv., Bl. 4, Sec. 72; 6 mi. from N, 8 from E county line	2980	3188	Abst	Abst	Abst	2550
McConnell 1, Tipton and Waggoner Refining Co.; I.&G.N.Ry. Co. Surv., Bl. 3, Sec. 201; 2 mi. from E, 9 from N county line	3084	3302	Abst	Abst	Abst	2685
Thompson 1, Shamrock Oil Co.; I.&G.N.Ry. Surv., Bl. 7, Sec. 15; 10 mi. from E, 14 from N county line	3404	3383	Abst	Abst	Abst	3045

CLAY COUNTY

The formations in Clay County overlying those here recorded are of Lower Permian and Upper Pennsylvanian age. In the one well that has penetrated to the pre-Cambrian the Lower Pennsylvanian and Mississippian and probably Ordovician are absent. This well, however, is located on the Red River uplift and the absence of the Lower Pennsylvanian, Mississippian, and Ordovician is probably due to erosion in post-Lower Pennsylvanian time and previous to the deposition of the oldest Upper Pennsylvanian (Cisco or Canyon) present at this locality.

Name and location of well	TD	Elev	Miss	Ord	Camb	p-Camb
Byers 41, The Texas Co.; Gaston Surv., Bl. 19, Byers Subd.; 2½ mi. E Petrolia	4289	978	Abst	Abst	3440	4240

COLEMAN COUNTY

The formations in Coleman County overlying those here recorded are of Permian and Upper and Lower Pennsylvanian age. Cretaceous deposits persist locally as outliers. Permian is present in the western half of the county.

Name and location of well	TD	Elev	Miss	Ord	Camb	p-Camb
Adams 1, Arizona Oil Co.; A. Wickson Surv. 168; 2 mi. NW Burkett	3511	1581	3320	3425	*	*
Burke 1, Pippin Oil Co.; A. Williams Surv. 655; 4 mi. E Santa Anna	2679	1596	2575	2664	*	*

Name and location of well	TD	Elev	Miss	Ord	Camb	p-Camb
Busch 1, Roberts et al; H.E.&W. T.Ry.Co. Surv.; ¾ mi. SE Whon	1635	1411		1618	*	*
Campbell 2, Gladys Bell Oil Co.; H.T.&B.Ry.Co. Surv., Bl. 2, Sec. 60; 1 mi. S, 2½ E Santa Anna	2750	1643		2724	*	*
Cox 1, Halbert-Neeley et al; M. Dirks Surv. 203; 25 mi. S, 4 W Coleman	2490	1515		2190	*	*
Dibrell 2, Thomas et al and Sims; H.T.&B.Ry.Co. Surv. 16; 1½ mi. NE Camp Colorado	3500	1580	3040	3114	*	*
Dibrell 1, Wise Oil Corp.; H. Kigan Surv. 498; 1½ mi. SE Camp Colorado	2920	1482	2800	2900	*	*
Featherstone, Manhattan Oil Co.; G.H.&H.Ry.Co. Surv., Bl. 2, Sec. 52; 4 mi. from N, 8½ from W county line	4331	1940	4209	4220	*	*
Floyd 1, Humphrey and Dozier; Coleman County School Lands, Bl. 90, Sec. 23; 2 mi. E Rockwood	1845	1432	1756	1805	*	*
Goodgion 1, Andrew Urban; E. Williams Surv., Bl. 2; 2 mi. N Trickham	2160	1435	1918	2010	*	*
Guthrie 1, Producers Oil Co.; Bonds and Sanders Surv. 78; 1½ mi. S, ½ W Trickham	1975	1392	1698	1780	*	*
Guthrie 1, The Sun Co.; H.E.& W.T.Ry.Co. Surv. 112; 7 mi. S, 3 W Trickham	2267	1492	1803	1860	*	*
Halbert 1, Milham Corp.; S. J. Martin Surv. 162; 2½ mi. E Camp Colorado	3025	1550	2910	2985	*	*
Harris 1, Slick Oil Co.; H. Starnes Surv. 63; 2½ mi. S, 1½ E Santa Anna	3264	1583	2540	2605	*	*
Hubbard 1 (Ray Copeland); Capital City Oil Co.; W. Coale Surv. 718; 3½ mi. NE Coleman	3604	1683	3290	3407	*	*
Jennings 4, Derby Oil Co.; A. S. Lipscomb Surv. 94; 5 mi. N Trickam	2435	1506	2100	2165	*	*
Johnson 1, T. B. Slick and Snyder Oil Co.; H.T.&B.Ry.Co. Surv. 21; 3¾ mi. NE Camp Colorado	3310	1649A	3130	3227	*	*
Miller 1, Moutray Oil Co.; W. C. Perry Surv.; 4 mi. N, 9 W Goldbusk	3627	1687		3355	*	*
Miller 1, Syndicate Oil Corp.; Fort Bend County School Lands Surv., Sec. 37; 4 mi. from W, 3 from S county line	3075	1562		2885	*	*

Name and location of well	TD	Elev	Miss	Ord	Camb	p-Camb
Miller 1, Tidal Oil Co. (System); Fort Bend County School Lands Surv., Subd. 8-A; 4 mi. SE Leaday	3175	1565		2830	*	*
Morris 4, Eastland Oil Co.; Wm. Webber Surv. 772; 6 mi. E Coleman (in Eastland pool)	3318	1595	3212	3245	*	*
Morris 1, Independent-Phillips et al; T. J. Frizell Surv.; 4 mi. NW Coleman	3685	1780	3520	3595	*	*
Morris 2, Midwest Exploration Co.; A. Newschaffer Surv., Bl. 750; 8 mi. N Coleman	3667	1622	3430	3580	*	*
Morris 3, Magnolia Petroleum Co. and Elizabeth Oil Co.; David Breeding Surv.; 9 mi. N, 2 E Coleman	3438	1582	3350	3432	*	*
Morris 4, Magnolia Petroleum Co. and Elizabeth Oil Co.; David Breeding Surv.; 9½ mi. N, 2 E Coleman	3978	1583	3270	3417	*	*
Morris 5, Magnolia Petroleum Co. and Elizabeth Oil Co.; David Breeding Surv.; 9 mi. N, 2 E Coleman	3430	1578	3330	3418	*	*
Neff 1, Sinclair-Gulf Oil Co.; G. Eubanks Surv. 173; 11 mi. N, 7 E Coleman	3425	1593	3245	3325	*	*
O'Hair 1, Root and Ferl; Casper Simon Surv.; 4 mi. NE Coleman	3347	1642	3210	3285	*	*
Overall 1. Anzac-Continental; G. H.&H.Ry.Co. Surv., Bl. 1, Sec. 10; 6 mi. S, 2 W Coleman	3240	1674	3010	3145	*	*
Overall 1, Flanigan; W. Woolsey Surv., Sec. 294; 3½ mi. S, 2 W Coleman	3535	1791	3340	3456	*	*
Padgett 1, Sinclair-Gulf Oil Co.; Brazoria County School Lands Surv. 226; 2 mi. from W and S county line	3580	1596		3445	*	*
Pitts 1, Samuels; J. Johnson Surv., Sec. 5; 3 mi. W Coleman	3503	1790		3480	*	*
Richardson 1, Schemel et al; L. F. Pease Surv., Bl. 268; 1½ mi. S Whon	1659	1410T	1543	1583	*	*
Sealy-Hutchins 1, Sinclair-Gulf Oil Co.; G.H.&H.Ry.Co. Surv. 23; 9 mi. N, 2 W Coleman	3920	1882	3795	3885	*	*
Sealy and Smith 1, Magnolia Petroleum Co. and Elizabeth Oil Co.; G.H.&H.Ry.Co. Surv., Bl. 2, Sec. 9; 7 mi. N, 1½ E Coleman	3610	1714		3530	*	*
Sealy-Smith 4, Roth and Farout; G.H.&H.Ry.Co. Surv., Bl. 1, Sec. 19; 1¼ mi. N. Valera	3642	1830	3500	3570	*	*

Name and location of well	TD	Elev	Miss	Ord	Camb	p-Camb
Slate 1, Magnolia Petroleum Co. and Elizabeth Oil Co.; J. Kaufman Surv. 237; 20 mi. S, 2 W Coleman	3130	1442		2304	*	*
Starr 1, Roth and Farout; Burnet County School Lands, Bl. 86; 1 mi. W Valera	4303	1917	3625	3680	*	*
Wallace 2, Robertson and Son; Wm. Farris Surv. 279; 7 mi. S Santa Anna	2612	1541	2408	2533	*	*

COMANCHE COUNTY

The formations in Comanche County overlying those here recorded are Cretaceous, over most of the county, and Upper and Lower Pennsylvanian.

Name and location of well	TD	Elev	Miss	Ord	Camb	p-Camb
Armstrong 1, P. L. Tippit; H.T. &B.Ry.Co. Surv. 13; 3 mi. N, 2 E Comanche	3120	1283		2781	*	*
Brittain 1, Simms Oil Co.; B.B. B.&C.Ry.Co. Surv., Sec. 31; 1½ mi. from N, ½ from W county line	3590	1620		3280	*	*
Bryant 1, Republic Production Co.; 1½ mi. from NW, 8½ from SW county line	3360	1492		3325	*	*
Bryson 1, Sun Oil Co.; W. C. Sypert Surv.; 3 mi. W, 1 S Comanche	3136	1520	2580	2725	*	*
Calloway 1, Lone Star Gas Co.; H.T.&B.Ry.Co. Surv. 15; 9 mi. S, 4½ W Comanche	3525	1700T		2848†	*	*
Capers 1, Hopkins; H.&T.C.Ry. Co. Surv., Bl. 2, Sec. 44; 2½ mi. from W, 7 from N county line	3352	1369		3101	*	*
Davis 1, Sam Davis Oil Co.; J. Walker Surv.; Comyn Station; 13 mi. from NW, 2½ from NE county line	3525	1250		3300	*	*
Fisher 1, Copperas Creek Oil Co.; D. H. McFadin Surv. 190; 11 mi. N, 3 W Comanche	3075	1281		3075	*	*
Fisher 1, Roxana Petroleum Corp.; D. H. McFadin Surv; 11 mi. N, 3 W Comanche	3200	1271		3100	*	*
Fisher 1, Tex-Wa Oil Co.; E. Cooper Surv.; 9 mi. N, 2 W Comanche	3048	1250		3000	*	*
Foster 1, Kelsey et al; D.&D. Asylum Lands Surv., Sec. 54; 1 mi. SE Sipe Springs	3173	1369		2968	*	*
Fritz 1, Tulsa Prod. Co. (Maxwell and Ertel); G. L. Addison Surv.; 5 mi. N, 5 E Comanche	3276	1221	3040	3145	*	*

†From driller's log, unsupported by samples. The top of the Ellenburger may be at 2524 feet.

Name and location of well	TD	Elev	Miss	Ord	Camb	p-Camb
Goss 1, Humble Oil and Refining Co.; D.&D. Asylum Lands Surv., Sec. 59; 4 mi. W Sipe Springs	3275	1532	3120	3262	*	*
Goss 1, Sipe Springs; midway between Rising Star and Sipe Springs	3330	1490		3330	*	*
Hamlin 1, Manhattan Oil Co.; D. &D. Asylum Lands Surv. 23; 1½ mi. N Duster	3238	1402		3150?	*	*
Hilly 1, Gates Oil Co.; L. Birdsall Surv. 54; 2 mi. from N, 1¼ from E county line	3568	1343		3340	*	*
Kay 1, Henderson et al; J. P. Stevenson Surv., Bl. 10; 5¾ mi. S, ½ W Desdemona	3402	1258		3325	*	*
Martin 1, Dickerson et al; Wasson Surv.; 3 mi. SW Wilson	4520	1150T		4100	*	*
Montgomery 1, Maxwell and Ertel; R. Page Surv.; 7½ mi. S Comanche	3500	1420		3245	*	*
Poteet 1, Fain et al; D.&D. Asylum Lands Surv., Sec. 45; 4½ mi. from W, 1 from N county line	3415			3385	*	*
Powers 1, Milham Corp.; E. Cooper Surv.; 9 mi. N, 3 W Comanche	3120	1276		2995	*	*
Rasco 1, Hoffer Oil Corp.; J. Elliott Surv. 237; 3 mi. E, 4 N Sipe Springs	3180	1369	3075	3175	*	*
Rudd 1, Roxana-Wallace Oil Co.; D.&D. Asylum Lands Surv. 17; on north county line, 10½ mi. from NE corner	3111	1300	2985	3075	*	*
Scott and Utterback 1, Trojan Oil Co.; Wm. McClelland Surv.; 1 mi. S of Comyn	3553	1398		3520	*	*
Small 1, Humble Oil and Refining Co.; D.&D. Asylum Lands Surv., Sec. 38; 2 mi. N, ¼ E Sipe Springs	3355	1482		3286	*	*
Standaville 1, Chase, Knight and Miller; E. Whitesides Surv. 71; 12 mi. E, 2½ S Comanche	3824	1160		3776	*	*
Sturkie 1, Comanche Oil Assn.; A. Hoxey Surv.; 7¾ mi. E, 3½ N Comanche	3350	1151		3335	*	*
Tate 1, Crawford and Flynn; H. &T.C.Ry.Co. Surv., Bl. 2, Sec. 7; 6½ mi. W De Leon	3323	1369	3190	3301	*	*
Thompson 1, Hoffer Oil Corp.; H.&T.C.Ry.Co. Surv., Bl. 2, Sec. 16; 14 mi. N, 2 W Comanche	3146	1397	3030	3144?	*	*

Name and location of well	TD	Elev	Miss	Ord	Camb	p-Camb
Wasson 1, Dickerson et al; E.T. Ry.Co. Surv., Bl. 3, Sec. 46; 6 mi. NE Gustine	4520	1230		4150	*	*
Wiley 1, Humble Oil and Refining Co.; T.&N.O.Ry.Co. Surv., Sec. 3, 2½ mi. from NW, 3½ from SW county line	3420	1571	3205	3353	*	*
Wilhelm 1, Sun Oil Co.; A. Smith Surv.; 3½ mi. S Comanche	3310	1540		3310	*	*

CONCHO COUNTY

The formations in Concho County overlying those here recorded are Cretaceous, in the southern part of the county, and Lower Permian and Upper and Lower Pennsylvanian. Although not recognized in the wells here recorded the Barnett formation is probably present in this county.

Name and location of well	TD	Elev	Miss	Ord	Camb	p-Camb
Hartgrove 1, Arkansas Fuel Co.; H.&T.C.Ry.Co. Surv., Sec. 49; 18 mi. N, 8 E Eden		1669		3080	*	*
Waring 1, Leonard Petroleum Co.; Gideon Pace Surv. 2853; 3 mi. S Eden	3310	2036		3225	*	*

COOKE COUNTY

The formations in Cooke County overlying those here recorded include Cretaceous and Upper Pennsylvanian. The Lower Pennsylvanian is possibly locally present.

Name and location of well	TD	Elev	Miss	Ord	Camb	p-Camb
Alexander 1, Thurman and Maxwell; J. Gregg Surv.; on S county line, 7½ mi. from E county line	2083	663		1972?	*	*
Bailey-English 1, Duffy et al (Lesh and McCall); E. Faris Surv. 2273; 10 mi. S Muenster	2273	877	Abst?	Abst?	Abst?	2273
Ball 1, Benson Bros.; M. Hunt Surv.; 2½ mi. N Myra	1580	799		1571	*	*
Belz 1, Camp Drilling Co.; J. R. Davis Surv., A-334; ¼ mi. from S, 13 from E county line	1225	747	?	1220†	*	*
Biffle 1, McElreath and Suggett; R. Shannon Surv.; 7 mi. W, 1 S Gainesville	2202	839		2114	*	*
Brown (Blanton) 1, Skinner and Simms Oil Co.; B. A. Foreman Surv.; 7 mi. S, 8 W Gainesville	1793	949		1785	*	*
Campbell 1, Atlantic Oil Producing Co. (Green et al); B.B.B.& C.Ry.Co. Surv., Sec. 27; 9 mi. W, 2 N Gainesville	1924	904		1924	*	*

†The base of the Cretaceous in this well is probably at depth 1060 feet. The Ellenburger is entered at depth 1220 feet. There is, accordingly, only about 160 feet of Pennsylvanian in this well. Mississippian is probably absent or, if present, is included within the 160-foot interval.

Name and location of well	TD	Elev	Miss	Ord	Camb	p-Camb
Campbell 1, Faith Oil Co.; O. F. Leverett Surv.; 9 mi. W, 2 N Gainesville	1924	899		1667	*	*
Campbell 1, Green et al; O. F. Leverett Surv. A-607; 10 mi. W, 2 N Gainesville	1662	934		1607	*	*
Campbell 1, Tippit and Darnall; D. E. Moss Surv.; 3½ mi. N Myra	3000	950		1640	*	*
Clayton 1, Humble Oil and Refining Co. (J. G. Roe); E. Reed Surv.; 3 mi. NE Muenster	1644	927		1550	*	*
Cooke 1, McElreath and Suggett; S.P.Ry.Co. Surv. 7; 1½ mi. W, 1 S Hood	1890	1055		1859	*	*
Dayton 1, Abernathy et al; F. Godley Surv.; 6½ mi. S Gainesville	2147	735		1926	*	*
Dayton 1, Shasta Oil Co.; Cooke County School Lands, Sec. 26; 10 mi. S, 4 E Gainesville	2148	759		2114	*	*
Dennis 1, Shell Petroleum Corp.; T. Hutchinson Surv., A-484; 2 mi. from W county line; Bulcher pool	2043	830		2038	*	*
Dennis 2-A, Kewanee Oil and Gas Co.; J. B. McClyman Surv.; Bulcher Oil Pool	2526	867		2456	*	*
Donald 1, Gulf Production Co.; J. Guffey Surv., A-1545; 9 mi. S, 1 W Muenster	3135	906	Abst?	Abst	Abst	2900
Dougherty 1, Benson Bros.; B. Garner Surv.; 10 mi. S, 4 W Gainesville	2007	755		1046	*	*
English 1, Duffy et al; Faris Surv., A-387; 8 mi. S Muenster	2287	972	Abst?	Abst	Abst	2275
Felker 1, Deep Rock-Shell; S. E. Clements Surv., A-273; 1 mi. E, 8 S Muenster	1633	1016		1621	*	*
Fettie 1, Hanbury et al; Campbell Surv.; 3 mi. S Muenster	2032	911		1967	*	*
Fleitman 1-B, Danciger Oil and Refining Co.; L. Mikel Surv., A-747; 4 mi. N, ½ W Muenster	1680	1048		1670	*	*
Gwynn 1, Petroleum Producers Co.; Marshall Univ. Surv., A-619; 1 mi. S. 5 E Muenster	1875	896		1832	*	*
Hammond 1, Kewanee Oil and Gas Co.; E.T.Ry.Co. Surv. 3; ½ mi. from S, 3½ from E county line	2122	859		2119	*	*
Hires and Seagraves 1, Petroleum Investment Co.; H. Nail Surv.; 2 mi. S Hood	1642	974		1495?	*	*
Hundt 1, Hedrick Camp Drlg. Co. and Abernathy; F. Godley Surv.; 7 mi. S Gainesville	1915	752		1914	*	*

Name and location of well	TD	Elev	Miss	Ord	Camb	p-Camb
Hyman 6-B, Kewanee Oil and Gas Co.; T. J. Moss Surv.; 1½ mi. W Bulcher	1466	847		1418	*	*
Jacobs 1, Simms Oil Co.; J. T. Strickland Surv.; ½ mi. from S, 5½ from E county line	1635	606		1541	*	*
Jacobs 2, Hamilton; J. Strickland Surv., A-929; ½ mi. from S, 5½ from E county line	1490	620		1485	*	*
Johnson 1, United Production Co.; J. Clark Surv., A-194; 3½ mi. N Muenster	1770	950		1685	*	*
Jones 1, Texas-Pacific Coal and Oil Co.; 1 mi. from S, 5½ from E county line	1582	647		1560	*	*
Luderman 1, Sun Oil Co.; N. R. Sparks Surv., A-1496; 6 mi. N, 4 E Muenster	3334	909		2860?	*	*
Mitchell 1, Sowell Bros.; B.B.B. &C.Ry.Co. Surv., Bl. A, Sec. 147; 1½ mi. NW Hood	2392	993		2368	*	*
Mount 1, McElreath and Suggett; S.P.Ry.Co. Surv., Sec. 9; 3¾ mi. S Bulcher	2095	1152		1900?	*	*
Pierce 1, Porter-Holmes; B. Lusk Surv.; 2 mi. S, 4 E Bulcher	2225	914		2108?	*	*
Poteet 3, Humble Oil and Refining Co.; Stephens Surv.; 1½ mi. from W, 3 from N county line. Bulcher pool	1542	848		1467[80]	*	*
Poteet 4, Humble Oil and Refining Co.; J. L. Stephens Surv.; 1½ mi. from W, 3 from N county line. Bulcher pool	1525	838		1446	*	*
Purcell 1, Green et al (Deep Rock Oil Co. and Faith Oil Co.); C. F. Stanley Surv., A-907; 5 mi. from W, 3 from N county line	1524	995		1468	*	*
Shipley 1, Hamilton et al; M. Hunt Surv., A-506; ½ mi. from S, 6 from E county line	1678	637		1674	*	*
Stacy 1, Magnolia Petroleum Co.; J. Clark Surv., Bl. 194; 4 mi. N Muenster	2010	1030		1835	*	*
Timms 5, Kewanee Oil Co.; J. L. Stephens Surv., A-1001; 1½ mi. from W, 3 from N county line (Bulcher field)	1459	851		1426	*	*
Timms 6, Kewanee Oil and Gas Co.; J. L. Stephens Surv., A-1001; 1½ mi. from W, 3 from N county line (Bulcher field)	1466	856		1420	*	*
Vogal 1, Skinner et al; J. Trussell Surv.; 2 mi. S, 1½ W Muenster	2350	1030		2140	*	*

[80]This and some adjoining wells have produced oil coming wholly or in part from the Ellenburger limestone.

Name and location of well	TD	Elev	Miss	Ord	Camb	p-Camb
Walker 1, Amerada Petroleum Corp.; A. Dozier Surv.; 2 mi. W, ½ N Gainesville	2880	738		2665	*	*
Wells 1, Fain-McGaha; G. W. Jewell Surv.; ½ mi. from S, 13 from W county line	1644	864		1543	*	*
Whaley 1, McElreath and Suggett; S.A.&M.G.Ry.Co. Surv., A-999; 9 mi. S and ½ E Muenster	2340	916	Abst?	Abst	Abst	2312
Yosten 1, Muenster Oil Co.; G. Ivy Surv.; 1¼ mi. NW Muenster	3790	1059		1997	2468	2750

CORYELL COUNTY

The formations in Coryell County overlying those here recorded are of Cretaceous and Upper and Lower Pennsylvanian age. Of the Upper Pennsylvanian the Strawn only is represented and of the Cretaceous only the Comanche series is present.

Name and location of well	TD	Elev	Miss	Ord	Camb	p-Camb
Clark 1, Benedum and Trees, Francis Keystone Texas Oil Co.; G. W. Carlile Surv.; 9 mi. W, 1 N Gatesville	3630	870		3465	*	*
Gotcher 1, New York Syndicate; W. T. Whitley Surv.; 2¼ mi. W, ½ S Copperas Cove	3035	1132		3025	*	*
Strickland 1, Buckeye Mid-Kansas; John Winn Surv.; 1½ mi. S, ¾ W Pitcock	3628	946		3615	*	*
Tienert 1, New York Syndicate; E. Jones Surv.; 1½ mi. W, 2 N Copperas Cove	3384	1094		3384	*	*

CROCKETT COUNTY

The formations in Crockett County overlying those here described are Cretaceous, Permian, and Pennsylvanian.

Name and location of well	TD	Elev	Miss	Ord	Camb	p-Camb
Todd 1, Stanolind Oil and Gas Co.; G.C.&S.F.Ry.Co. Surv., Bl. UV, Sec. 67; 8 mi. W, 4 N Ozona	8041	2660	Abst	7247†	*	*

DENTON COUNTY

The formations in Denton County overlying those here recorded are of Cretaceous and Upper Pennsylvanian age. In addition the Lower Pennsylvanian is present, although probably locally removed by erosion previous to

†Above the Ellenburger is middle Ordovician, Simpson series, which was reached at depth 7006 feet. Resting on the Simpson is a crinoidal limestone of Pennsylvanian or Pemian age similar in character to the crinoidal limestone of the deep wells in Reagan County.

the deposition of the Upper Pennsylvanian. Mississippian is possibly present in this county, although not recognized in these wells.

Name and location of well	TD	Elev	Miss	Ord	Camb	p-Camb
Atkins 1, Rondeau and Sanford; W. Thompson Surv.; 5 mi. E, 2 S Sanger	2023	631		2020	*	*
Hampton, Chapman, Garrett and Moore; J. Chesson Surv.; 3 mi. SE Sanger	2210	695[81]		2125	*	*
Hughes 1, Rondeau et al; J. Morton Surv.; 3 mi. E, 2 N Sanger	1316	665		1297	*	*
Jacobs 1, J. W. Peel Trust (Lloyd); J. Johnson Surv., A-670; 13 mi. N, 4 E Denton	1800	590		1773	*	*
Waide 1, Jenkins and Kelsey and Jones and Eubanks; T. Carpenter Surv.; 1 mi. from N, 7 from W county line	1913	797		?	?	1870
Wright 1, McMahon and Daniels; S. Noling Surv. 4; 2 mi. S, 3 W Sanger	2530	666		2453	*	*
Wright 1, McNeill and Blackstock; S. Flint Surv., A-418; 11 mi. E Sanger	1640	632		1475	*	*
Yeatts 1, The Texas Co. and Benson and Benson; W. J. Hendrix Surv.; 4 mi. N, 5 W Bolivar	2026	771		Abst	Abst	2013

EASTLAND COUNTY

The formations in Eastland County overlying those here recorded are Cretaceous, locally present in the southern and eastern parts of the county, and Upper and Lower Pennsylvanian.

Name and location of well	TD	Elev	Miss	Ord	Camb	p-Camb
Allen 1, Gulf Production Co.; Wm. Fields Surv.; 4¾ mi. S, 3¾ E Ranger	4010	1446		3765?	*	*
Alsobrook 1, Havermeyer and Seamans; H.&T.C.Ry.Co. Surv. 14; 1½ mi. SW Gorman	3525	1400		3190	*	*
Barber 2, States Oil Corp.; H.& T.C.Ry.Co. Surv., Bl. 4, Sec. 2; 3 mi. N, 2 E Eastland	4505	1542		3960	*	*
Barnes 1, Prairie Oil and Gas Co.; F. P. Barnett Surv. 657, Bl. 40; 2 mi. N, 2 W Ranger	4300	1584		4080	*	*
Bourland 1, Goodwin et al; W. Van Norman Surv.; 4 mi. S Ranger	3625	1368	3486	3577	*	*
Branford 1, Prairie Oil and Gas Co.; Rosseau Surv. 25; 5 mi. S, 2¾ W Eastland	3955	1479		3717	*	*
Brashear 1, Farabee; 4 mi. S Ranger	4000	1473		3628	*	*

[81]The Bend is reported in this well at depth 1904 feet. The elevation is also given as 558 feet.

Name and location of well	TD	Elev	Miss	Ord	Camb	p-Camb
Brashear 1, Leon Oil Co.; Wm. Van Norman Surv.; 5 mi. S, 2 W Ranger	4000	1477		3628	*	*
Brashear 2, Leon Oil Co.; Wm. Van Norman Surv.; 5 mi. S Ranger		1471		3618	*	*
Brashear 1, Westheimer et al; Wm. Van Norman Surv.; 5½ mi. S, 2 W Ranger		1460		3615	*	*
Brown 1, Central Oil Development Co.; G. E. Moore Surv.; 1 mi. E, ½ N Desdemona		1450T		3545	*	*
Collins 1, Kokomo-Phillips; H.& T.C.Ry.Co. Surv., Bl. 1, Sec. 11; 10 mi. S, 6½ E Eastland	3410	1449	3278[82]	3388	*	*
Connellee 1, Benedum and Trees; N. Ussury Surv.; 3 mi. S, ¾ E Eastland	3800	1541		3737?	*	*
Cooke 1, Texas and Pacific Coal and Oil Co.; W. Cooper Surv.; 3 mi. N Ranger	4359	1546		4187	*	*
Davis 1, S. A. Hopkins et al; H. &T.C.Ry.Co. Surv., Bl. 4, Sec. 54; 7 mi. W, 7 N Cisco	5591	1449	3833	3930	4926	5425±
Duffer 1, Prairie Oil and Gas Co.; S. N. Mathais Surv.; 1 mi. E, 3½ S Ranger	3770	1446		3680	*	*
Dulin 1, O. R. Cupper (Transcontinental); H.&T.C.Ry.Co. Surv., Bl. 4, Sec. 42; 3 mi. W, 2 N Eastland	3905	1500		3898	*	*
Eppler 1, Connollee and Aguire; Wm. DeMoss Surv.; 3½ mi. NE Gorman		1356		3238	*	*
Falls 1, Prairie Oil and Gas Co.; E. Finley Surv.; 3½ mi. S, 1½ W Ranger	3700	1441		3685	*	*
Fee 1, Sun Co.; H.&.T.C.Ry.Co. Surv., Bl. 4; 6½ mi. W ,1 N Ranger	4012	1538		4000	*	*
Fee 1, Texas and Pacific Coal and Oil Co.; Robertson County School Lands; 8 mi. E, 1½ S Ranger	3710	1240		3520	*	*
Fields 1, Atlantic Oil Producing Co.; J. Rubarth Surv. 100; 17 mi. S Eastland	3340	1504	?-3335[82]	3339	*	*
Green 1, J. E. Thompson and McMillan; S.P.Ry.Co. Surv., Sec. 458; 2 mi. E Leeray	4051	1493	?-3990	3990	*	*

[82]Mississippian in the Collins well includes the Barnett formation from 3278 to 3378 and "pink crinoidal" limestone from 3378 to 3380; in the Jones well Barnett is at depth 3698 to 3740 and the "pink crinoidal" from 3740 to 3894; from 3894 to 3935 in this well is a detrital zone which may also be Mississippian; in the Sibley well the "pink crinoidal" is at depth 3495 to 3582 (L. C. Cartwright). In the Fields well the base of the Barnett is at depth 3335 or 3337 with "pink crinoidal" at 3337 to 3339 (R. E. Giles). *Orbiculoidea* sp., probably Mississippian in age, was obtained from the Jones well at depth 3920.

Name and location of well	TD	Elev	Miss	Ord	Camb	p-Camb
Grove 3, Moody Oil Corp.; S.P. Ry.Co. Surv., Sec. 483; 5½ mi. from W, 2½ from N county line	4113			4040	*	*
Hagaman 1, Lone Star Gas Co.; W. C. & C. Boswell Surv.; 1½ mi. NE Ranger	3745	1426		3699	*	*
Hagaman 1, Sinclair-Gulf; S. Gafford Surv., 2 mi. NE Ranger	4082	1567	?-4075	4075	*	*
Holcomb 1, Cosden Oil Co.; H.& T.C.Ry.Co. Bl. 4, House Surv.; 1 mi. NE Eastland	3830	1485		3777	*	*
Jones 2, S. A. Hopkins et al; H. &T.C.Ry.Co. Surv., Bl. 4, Sec. 43; 4 mi. W, 1 N Eastland	3935	1474	3698[82]	*	*	*
McClellan 1, Moody Corp.; S.P. Ry.Co. Surv., Sec. 456; 5½ mi. W, 7½ N Cisco	4124	1514		4120	*	*
Mann 1, Atlas Oil Co.; Thos. Mullryne Surv.; 8⅓ mi. E, 2⅓ N Carbon	3500	1371		3428	*	*
Martin 1, Donley Drilling Co.; J. Haig Surv.; 1½ mi. S Eastland	3745	1426		3670?	*	*
Parrock 1, States Oil Corp.; H. &T.C.Ry.Co. Surv., Bl. 4, Sec. 7; 6¼ mi. N, ¾ E Eastland	4083	1619		4078	*	*
Pelfry 1, Root et al; H.&T.C. Ry.Co. Surv., Bl. 4, Sec. 61; 12 mi. from W, 8½ from N county line	4090	1568		3843	*	*
Pence 1, Phillips Petroleum Co.; T.E.&L. Surv., Sec. 2981, A-504; 5½ mi. W, 6½ N of Cisco	4165	1538	4008	4100	*	*
Pitcock 1, Texas and Pacific Coal and Oil Co.; Wm. Frels Surv.; 2 mi. S Ranger	4020	1454		3575	*	*
Poe 1, Independent Oil Co.; H.& T.C.Ry.Co. Surv., Bl. 3, Sec. 15; 5 mi. W, 11 S Eastland	3589	1572		3550	*	*
Ramsower 1, Larson (West Adams Petroleum Corp.); H.& T.C.Ry.Co. Surv., Bl. 4, Sec. 38; 14 mi. from W, 2 from N county line	4390			4362	*	*
Ray 4, Root et al; H.&T.C.Ry.Co. Surv., Bl. 4, Sec. 38; 3½ mi. W, 6 N Eastland	4230	1528	3895	4005	*	*
Rush 1, Mid-Kansas Oil and Gas Co.; E. Finley Surv.; 3 mi. S Ranger	3945	1420		3720	*	*

Name and location of well	TD	Elev	Miss	Ord	Camb	p-Camb
Schoor, 1 Humble Oil and Refining Co.; H.&.T.C.Ry.Co. Surv., Bl. 3, Sec. 50; 6 mi. S, 2 E Cisco	3791	1603	3672	3755	*	*
Sibley 11, Mook-Texas Oil Co.; W. Van Norman Surv., Bl. 19; 4 mi. S Ranger	3642		3495[82]	3595	*	*
Stewart 1, Leon Oil Co.; Wm. Van Norman Surv.; 6 mi. S, 1 W Ranger	3560	1413		3658	*	*
Stockton 1, Cosden Oil and Gas Co.; Wm. DeMoss Surv.; 6 mi. E, 16 S Ranger	3250	1322	3100	3180	*	*
Turner 24, Barclay and Crotly; H.&T.C.Ry.Co. Surv., Bl. 4, Sec. 3; 3½ mi. N, 1 E Eastland	3948	1527		3935	*	*
Underwood 1, Systems (Tidal Oil Co.); D. S. Richardson Surv.; 4 mi. W, ¾ N Desdemona	3582	1379		3510	*	*
Vaught 5, Atlantic Oil Producing Co.; W. DeMoss Surv.; 3 mi. W, 1½ S Desdemona	3245	1250T	?-3160	3160	*	*
Ward 1, Gilman and Simmons; S. J. Robinson Surv.; 4 mi. N, 1 E Cisco	3992	1436		3925	*	*
Ward 1, New Domain Oil Co.; J. B. Hoxie Surv.; 4½ mi. N, 1 E Cisco	3976	1415		3825	*	*
Whitesides 1, Sipe Springs Oil Co.; J. Rubarth Surv.; 16 mi. S, ½ W Eastland	3170	1493		3160	*	*

EDWARDS COUNTY

The formations in Edwards County overlying those here recorded include Cretaceous and Upper Pennsylvanian. The Lower Pennsylvanian (Bend series) is probably also present.

Name and location of well	TD	Elev	Miss	Ord	Camb	p-Camb
Holman 2, Phillips Petroleum Co.; C.C.S.D.&R.G.N.G. Surv., Sec. 25, 5½ mi. from W, ½ from N county line	8125	2274		7905	*	*
Peterson 1, Dalgish et al; H.E.& W.T.Ry.Co. Surv., Bl. E, Sec. 82; 6 mi. N, 11 E Rock Springs	5206	2353		4095	*	*
Peterson 2, Stout et al; H.E.&W. T.Ry.Co. Surv., Bl. E, Sec. 96; 12 mi. NE Rock Springs	4610	2360		4410	*	*

†A "detrital" zone in this well at depth 4092 to 4141 is referred provisionally to the Mississippian although it may possibly be basal Pennsylvanian.

Name and location of well	TD	Elev	Miss	Ord	Camb	p-Camb
Schreiner 1, McMann Oil and Gas Co.; H.E.&W.T.Ry.Co. Surv., Bl. F, Sec. 50; 7 mi. from N, ½ from E county line	3897	2326	3745[83]	3805?	*	*

ERATH COUNTY

The formations in Erath County overlying those here recorded are Cretaceous and Upper and Lower Pennsylvanian. Of the Mississippian formations the Barnett is probably present. This formation in the Thompson well probably extends from 3655 or above to 3755.

Name and location of well	TD	Elev	Miss	Ord	Camb	p-Camb
Fee (Allen) 1, Texas and Pacific Coal and Oil Co.; I.R.R. Surv., Sec. 24; 3½ mi. from W, 2 from N county line	4025	1102		3900?	*	*
Fulfer 1, Texas-Manhattan Oil and Gas Assoc.; M. Goff Surv.; 6½ mi. from W, 5 from N county line	4001	1060		4000	*	*
Thompson 1, Gulf Production Co.; F. R. Lubbock Surv.; 9 mi. S, 2 W Thurber	3935	1383	3655?	3755	*	*

FISHER COUNTY

The formations in Fisher County overlying those here recorded are of Permian and Upper and Lower Pennsylvanian age.

Name and location of well	TD	Elev	Miss	Ord	Camb	p-Camb
George 1, Cranfill and Reynolds; B.B.B.&C.Ry.Co. Surv., Bl. 1, Sec. 200; 5 mi. from E, 6 from N county line	6494	1789	5960	6175[84]	*	*

FOARD COUNTY

The formations in Foard County overlying those here recorded are Permian and Pennsylvanian in age. The Mississippian and some older formations are possibly present although absent on the uplift where these wells were drilled.

Name and location of well	TD	Elev	Miss	Ord	Camb	p-Camb
Johnson 1, Humble Oil and Refining Co.; S.P.Ry.Co. Surv., Bl. L, Sec. 37, 1½ mi. from W, 8 from S county line	5003	1670	Abst	Abst	Abst	4950?
Mathews 1, Shell Petroleum Corp. (Roxana) and Fain and McGaha; G. C. & S. F. Ry. Co. Surv., A-117, Bl. 3, Sec. 3; 10 mi. E, 2 N Crowell	2858	1384	Abst	Abst	Abst	2215

[83]The Mississippian of Boone age, "pink crinoidal", is found in this well at 3745 to 3805 (Spencer).

[84]Between 6045, and the Ellenburger, 6175, is found green shale, white chert, and limestone of undetermined age (H. A. Hemphill). This well terminates in sand.

Name and location of well	TD	Elev	Miss	Ord	Camb	p-Camb
Mathews 3, Shell Petroleum Corp. and Fain and McGaha; G.C.&S.F.Ry.Co. Surv., Bl. 3; 10 mi. E, 2 N Crowell	2550	1377	Abst	Abst	Abst	2465
Miller 1, Gulf Production Co.; H.&T.C.Ry.Co. Surv., Bl. 8, Sec. 32, 2½ mi. from E, 4 from N county line	3360	1347		2380?	*	*

GILLESPIE COUNTY

The formations in Gillespie County overlying those here recorded are of Lower Cretaceous and Upper and Lower Pennsylvanian age. Although absent in some of the wells here recorded the Lower Ordovician (Ellenburger group) is generally present in the county. The presence of Mississippian in the county is undetermined.

Name and location of well	TD	Elev	Miss	Ord	Camb	p-Camb
Becker 1, Kothman et al; J. T. Stell Surv. 44; 5 mi. SW Fredericksburg	580	1650T	Abst	200	*	*
Boos 4, 3 mi. SW Fredericksburg	151			130	*	*
Dickey 1, Gillespie Development Co.; 2 mi. N Stonewall	660	1600T	Abst	Abst	Abst	304
Hayden 1, Thousand Island Oil Co.; Surv. 144; 8 mi. W Fredericksburg	1505	1850	Abst	Abst	180	1182
Kott, Lewis; N side of Fredericksburg	418	1725T	Abst	Abst	Abst	168

GRAY COUNTY

The overlying formations and other stratigraphic conditions in Gray County are in general similar to those of Carson County described above.

Name and location of well	TD	Elev	Miss	Ord	Camb	p-Camb
Beavers 1, Bock-Anderson; H.&G.N.Ry.Co. Surv., Bl. B-2, Sec. 124; 7 mi. from W, 15 from N county line	3800	3144	Abst	Abst	Abst	3305
Bowers 1, Operators' Oil Co.; H.&G.N.Ry.Co. Surv., Bl. B-2, Sec. 93; 9 mi. from W, 14 from N county line	3090	3038	Abst	Abst	Abst	2800
Bradford 1, Danciger Oil Co.; H.&G.N.Ry.Co. Surv., Bl. B-2, Sec. 123; 7 mi. from W, 14 from N county line	2741	3091	Abst	Abst	Abst	2670
Heitholt 1, Skelly Oil Co.; I.&G.N.Ry.Co.Surv., Bl. 3, Sec. 153; 4 mi. SW Pampa, N of railroad[85]	3000	3275	Abst	Abst	Abst	2835

[85]This well, according to H. E. Crum (letter of December 19, 1930), after drilling through 120 feet of granite encountered a fracture in the rock resulting in a flow of 40,000,000 cu. ft. of gas and 8,000 barrels of oil daily. A well drilled by the Magnolia Petroleum Company (Latham 4) and another by Cree, Hoover and Graham (Sullivan 1) about one-half mile east

Name and location of well	TD	Elev	Miss	Ord	Camb	p-Camb
Latham 4, Magnolia Petroleum Co.; I.&G.N.Ry.Co. Surv., Bl. 3, Sec. 153, S of railroad, 3 mi. from W, 9 from N county line	2922	3276	Abst	Abst	Abst	2875
Sullivan 1, Graham et al (Taconian Oil Co.); I.&G.N.Ry.Co. Surv., Bl. 3, Sec. 136; 4 mi. from W, 9 from N county line	2990	3273	Abst	Abst	Abst	2900

HAMILTON COUNTY

The formations in Hamilton County overlying those here recorded are of Cretaceous and Pennsylvanian age.

Name and location of well	TD	Elev	Miss	Ord	Camb	p-Camb
Eidson 1, Jas. W. and Geo. F. McCamey; W. J. Merrifield Surv.; 4 mi. W Hamilton	3854	1157	3645	3790	*	*

HARTLEY COUNTY

The formations in Hartley County overlying those here recorded are of Cenozoic, Triassic, and Permian age. The general stratigraphic conditions are similar to those of Carson County previously described.

Name and location of well	TD	Elev	Miss	Ord	Camb	p-Camb
Coots 1, Holmes and Heck; Bl. XR, Sec. 58; 4 mi. from S and W county lines	2990	4181	Abst	Abst	Abst	2965
Shelton 2, Humble Oil & Refining Co.; Rio Bravo Subd., Sec. 63; 11 mi. from W, 1 from S county line	3076	3869	Abst	Abst	Abst	2977

HUDSPETH COUNTY

In the Diablo Plateau of Hudspeth County, where this well is located, Cretaceous, although absent in this well, is elsewhere locally present. The surface formation over much of the Plateau is Permian in age. Underneath the Permian is Pennsylvanian and, locally at least, Mississippian, Devonian, Silurian, Ordovician and Cambrian. To what extent these early Paleozoics are represented in this well is imperfectly determined. South of the Diablo Plateau the Cretaceous thickens, and in the Malone Mountains Jurassic is present. The intermontane valleys contain fill which in the Hueco Bolson is known to attain a thickness in excess of 3500 feet.

Name and location of well	TD	Elev	Miss	Ord	Camb	p-Camb
University 1, California Oil Co.; Bl. E, Sec. 19; 13½ mi. from W, 11½ from N county line	4848	5109	1664[86]	2817	4390	4725

obtained similar results. That these three wells were interconnected was shown by the sensitiveness of each to the others. A well on the Holmes ranch, 5 miles southeast of these wells, obtained production from fractures near the surface of the granite. After drilling into granite, some other wells of this county have obtained production of oil after the granite had been fractured by shooting, thus allowing oil to enter the wells from the adjacent granite wash.

[86]The Devonian is present in this well from 2096 to 2264, and the Silurian (Fusselman formation) from 2264 to 2817. Ordovician in this well includes both upper and lower Ordovician (Montoya and El Paso formations). Identifications by C. L. Baker.

HUTCHINSON COUNTY

The formations in Hutchinson County overlying those here recorded are of Cenozoic and Permian age. Pennsylvanian is probably present and older formations come in under the Permian and Pennsylvanian off of the uplift.

Name and location of well	TD	Elev	Miss	Ord	Camb	p-Camb
Smith-Capers 1, H. T. McGee and Co.; M. & C. Surv., Bl. Y, Sec. 10; 14 mi. from W, 1 from S county line	3175	2908	Abst	Abst	Abst	3135?
Whittenburg 12, Phillips Petroleum Co.; Tumlinson Surv., Sec. 3 (Elva lease)	5333	2916		5100[87]		

IRION COUNTY

The formations in Irion County overlying those here recorded include Cretaceous, Triassic, Permian, and Pennsylvanian.

Name and location of well	TD	Elev	Miss	Ord	Camb	p-Camb
Ash 1, Williams et al; Washington Co. Ry. Surv.; Sec. 20; 7 mi. from S, 9½ from W county line	8900	2712	[88]	8825	*	*
Suggs 1, Kingwood Oil Co.; H.& T.C.Ry.Co. Surv., Bl. 1, Sec. 18; 11 mi. from E ,14 from S county line	7818	2334	[88]	7770	*	*
Suggs 1, Benedum and Trees; H.&T.C.Ry.Co. Surv., Bl. 28; 12 mi. from W, 13 from N county line	8286	2376	[89]	8267	*	*

JACK COUNTY

The formations in Jack County overlying those here recorded are Upper and Lower Pennsylvanian. Although not recognized in the two wells listed; the Mississippian, Barnett formation, is probably present.

Name and location of well	TD	Elev	Miss	Ord	Camb	p-Camb
Bryson 1, Republic; I. Hughson Surv.; 2 mi. from W, 12 from S county line	5264	1267		5175	*	*
Williams 1, Watchorn Oil and Gas Co.; B.S.&T. Surv. A-88; 6 mi. from S, 11 from W county line	5635	1193		5325?	*	*

[87]According to determinations made by Scruggs this well entered Viola (Fremont) at 4810, Simpson (Hardin) at 4875, and Arbuckle or Ellenburger (Manitou) at 5100. Mississippian may be present in this well.

[88]A detrital zone occurs in the Ash well at depth 8816 to 8850 and in the Kingwood Oil Co. Suggs well at depth 7751 to 7777.

[89]The Ellenburger in this well is overlain by a detrital zone. The middle Ordovician (Simpson) of the Big Lake oil field of Reagan County is apparently absent (H. A. Hemphill).

KENDALL COUNTY

The formations in Kendall County overlying those here recorded include Cretaceous and Upper and Lower Pennsylvanian. The Paleozoic of the southern part of this county south of Boerne is within the Llanoria geosyncline and the wells in that part of the county are listed under that heading.

Name and location of well	TD	Elev	Miss	Ord	Camb	p-Camb
Behr 1, Dixon Co.; J. W. Wilson Surv.; 10 mi. W, 1½ S Kendalia	1899	1264		1640?	*	*
Kasten 1, Mowinckle et al; Surv. 311; 7½ mi. W Kendalia	1543	1386	1092	1127	*	*
McCracklin 1, Sterling et al; B. E. Owen Surv.; 3½ mi. NW Kendalia	1480	1398		752	*	*
Werner 1, Sterling et al; J. F. Torrey Surv., Sec. 781; 6½ mi. W, 2 N Kendalia	926	1405		780	*	*

KERR COUNTY

The formations in Kerr County overlying those here recorded include Cretaceous and Upper and probably Lower Pennsylvanian.

Name and location of well	TD	Elev	Miss	Ord	Camb	p-Camb
Leigh 1, Walker-Van Duyn; J. Goodbread Surv., Sec. 38; 6 mi. from E, 9 from S county line	2828	1530		1624?	*	*
Love 2, Evans et al; C.C.S.D.R. G. Surv., Sec. 1593; ½ mi. from S, 1 from W county line	5878	2380		5605	*	*
Real 1, Cannon-Page (L. C. Adams); Kendall County School Surv., Bl. 15, Sec. 2; 8 mi. W, 5 S Kerrville	4706	2235		4665†	*	*

KIMBLE COUNTY

The formations in Kimble County overlying those here recorded are Cretaceous and Upper and Lower Pennsylvanian. A detrital zone found immediately above the Ellenburger in the Beasley, Bode, Means, and Patterson wells probably represents the base of the Pennsylvanian, although this material may be Mississippian in age.

Name and location of well	TD	Elev	Miss	Ord	Camb	p-Camb
Amberson 1, Wahlenmaier et al; Hubinger Surv., Sec. 167; 9 mi. N, 8 E Junction	995	1693		410	*	*
Beasley 1, Delva-Tex Petroleum Corp.; T.W.&N.G.Ry.Co. Surv., Sec. 19, A-655; 5 mi. S, 3 E Junction	2670	2124		2570	*	*
Bode 1, Dixie Oil Co.; J. S. Patterson Surv., Sec. 80; 13 mi. W Junction	3025	1902		2995	*	*

†Cannon-Page No. 1 Real probably did not reach the Ellenburger limestone.

Name and location of well	TD	Elev	Miss	Ord	Camb	p-Camb
Cannon 1, McLean et al; R. Cochran Surv., Sec. 741; 12 mi. N, 9 E Junction	1650	1728		110	795	*
Hodges 1, Mudge Oil Co.; G. Kimble Surv., Sec. 27; 6 mi. NE Junction	2902	1660		1635	2441?	*
Mears 1, Brazos-Menard Oil Syndicate; T.W.&N.G.Ry.Co. Surv., Sec. 26; 12 mi. N Junction	3350	2257		2708	*	*
Patterson 1, Delva-Tex Petroleum Corp.; Kimble Co. School Lands, Sec. 750; 6 mi. from S, ½ from W county line	3980	2171		3980	*	*

LAMPASAS COUNTY

The formations in Lampasas County overlying those here recorded are Cretaceous and Upper and Lower Pennsylvanian.

Name and location of well	TD	Elev	Miss	Ord	Camb	p-Camb
Abney 1, American Well and Prospecting Co.; near Santa Fe Depot, Lampasas	2012	1000T	440	470	?	?
Alexander Bros. 1, Mark Alexander et al; S. Berry Surv., A-31; 6 mi. SE Lampasas		1025		1000	*	*
Bunch 1, Roeser and Pendleton; W. G. Martin Surv.; 9 mi. from NE, 12 from NW county line	3008	1250		1570	*	*
Conradt 1, Robarts et al; E.T. Ry.Co. Surv., Sec. 1; 5 mi. N, 2 W Lometa	2001	1500T	?-1880	1880	*	*
Grove 1, White et al; J. A. Abney Surv.; 6½ mi. NE Lampasas	2066	1100T		2050	*	*
Hill 1, Hill River Oil Co. (Champion); David Evans Surv.; 8 mi. S Lometa	1602	1450T		417	*	*
McCree 1, Reaney-Nevels Oil Co.; Wm. F. Nicholson Surv.; 11 mi. W Lampasas	1120	1400T		20	*	*
Morgan 1, Sunshine Oil Co.; Whittenburg Surv.; 6 mi. W, 2 N Lometa	896		795	886	*	*
Smith 1, C. H. White; T. R. Stiff Surv. 16; 13 mi. W, 1 S Lampasas	65	1400T		29	*	*
White 1, Texoleum Trust Co.; Hill Surv.; 13½ mi. W, 1½ N Lampasas	3000	1250T		136	?	3000†
Whittenburg 1, Western Lampasas Oil Co.; John Boyd Surv. 612, Bl. 229, Sec. 38; 3 mi. W Lometa	4180	1450T	863	979	2976	3580

†Pre-Cambrian sample at 3000 feet. The top of the pre-Cambrian may be higher.

MASON COUNTY

The formations occurring locally in Mason County overlying those here recorded are of Cretaceous and Upper and Lower Pennsylvanian age. Although not recognized in the one well here recorded, Mississippian, Ordovician, and Cambrian are locally present.

Name and location of well	TD	Elev	Miss	Ord	Camb	p-Camb
Brandenburger 1, Cochran and Steward; M. Patton Surv. 118; 12 mi. W Mason	1900	1700T	?	?	30	1065

McCULLOCH COUNTY

The formations in McCulloch County overlying those here recorded include Cretaceous locally and Upper and Lower Pennsylvanian over the greater part of the county. The Mississippian and Ordovician formations are exposed locally in the southeastern part of the county.

Name and location of well	TD	Elev	Miss	Ord	Camb	p-Camb
Baumgartner 1, Texas Hurst Syndicate; P. H. Schaff Surv. 402; 1½ mi. SSE Brady	1384	1660	50	61	910?	*
Beasley 1, Dallas Milburn Valley Oil Co.; F. Winkle Surv.; 2½ mi. N, 2½ E Mercury	2526	1280	844	945	1896?	*
Brady water well, Brady	2114	1685		187	980	*
Cawyer 1, Burford and Brimm; D. Mechels Surv. 968; 3 mi. SE Mercury	2130	1422		685	1486?	2100?
Craig 1, Thomas et al; C. Usner Surv., Sec. 1351; 4½ mi. N, 1 W Melvin	3666	1755		2065	2625?	3473?
Crews 1, Southwestern Petroleum Co.; U. Heinrich Surv., Sec. 782; 1 mi. SW Rochelle	1965	1675		605	1435?	*
Dutton 1, Thad O'Day (Day-Daley Petroleum Assoc.); J. H. Gibson Surv. 1; 11 mi. N, 1 W Brady	2643	1637	1270	1370	2150?	*
Haby well, Haby and Allison; C. Volmar Surv., Sec. 138; 15 mi. SW Brady	1920	1935			940±	1900
Morgan 1, J. E. Morgan; State School Lands Surv. 2; 2 mi. NNW Brady		1712A		420		
Sellman 1, Texas Eastern Oil Co.; C. Beag Surv. 904; 3½ mi. ENE Rochelle	2005	1650T		578	1350	*
Shelton 1, Case Oil Co.; W. Rasche Surv., Sec. 1066; 3¼ mi. N, ½ E Lohn	1545	1450T		1500	*	*
White 2, A. H. Bell et al; C. Mendell Surv., Sec. 811; 8 mi. from E, 6½ from N county line	1360	1580T		1275	*	*
White 1, Henderson et al; B.S.& F.Ry.Co. Surv. 1; 17 mi. N, 1½ E Brady	1401	1508T	1116	1285	*	*

Name and location of well	TD	Elev	Miss	Ord	Camb	p-Camb
White 1, Thomas et al; Fisher and Miller Surv. 2586, A-362, 1 mi. E Whiteland	3406	1750T		1140	1840?	2982
Zelle 1, Prairie Oil and Gas Co.; H.&T.C.Ry.Co. Surv. 89; 4 mi. NW Lohn	3516	1498		1870?	2485?	3309

MENARD COUNTY

The formations in Menard County overlying those here recorded are Cretaceous and Upper and Lower Pennsylvanian. Although not recognized in the wells listed, the Mississippian is probably locally present.

Name and location of well	TD	Elev	Miss	Ord	Camb	p-Camb
Callan City Investment Company 1, Barnett and Drake; B.S.&F. Ry.Co. Surv., Bl. 22, Sec. 7; 7 mi. N, 5 E Menard	2207	2130		2075	*	*
Callan City Investment Company 2, J. C. Barnett; B.S.&F.Ry.Co. Surv., Sec. 1; 6 mi. N, 4 E Menard	2124	2068		2060	*	*
Davis 1, Sabens et al; Surv. 31; 1¾ mi. NW Hext	720	1809		Abst	434†	*

MILLS COUNTY

The formations in Mills County overlying those here recorded are Cretaceous and Upper and Lower Pennsylvanian.

Name and location of well	TD	Elev	Miss	Ord	Camb	p-Camb
Cryer 1, Mills County Oil Co.; J. M. Clark Surv. 14; 12 mi. W, 5 N Goldthwaite	1950	1317		1885	*	*
Harrison and Slayden 1, Venture Oil Co.; T. Carroll Surv. 401; 14 mi. W, 8 N Goldthwaite	3268	1271		1540	?	?
Hendry 1; L. Bostic Surv.; 10 mi. E Goldthwaite	2448		2357	2417	*	*
Howell 1, Atlantic Production Co. (Atlantic Oil Producing Co.); M. Kenedy Surv., Sec. 647; 4½ mi. S, 3 W Goldthwaite	2430	1228		2007	*	*
Locklear 1, The Texas Co.; Sam Cates Surv.; 8 mi. W, 1 N Goldthwaite	3324	1248	1848	1913	*	*
Ratliff 1, Bowers et al; Dawson Surv.; S part of county	1275		1233	1260	*	*
Robertson 1, Clarion Oil Co., J. M. Douglas; Caldwell County School Lands Surv. 112, Bl. 16; 5½ mi. W Goldthwaite	2716	1338		2118	*	*
Tyson 1, A. R. Forstner et al; T.&N.O.Ry.Co. Surv. 2; 10 mi. W, 10 N Goldthwaite	2520	1372		2324	*	*

†No samples were received between 203 and 434 feet. The top of the Cambrian may be above 434 feet.

Name and location of well	TD	Elev	Miss	Ord	Camb	p-Camb
Ware 1, Ware Haywood Oil Co.; H. Thurmester Surv.; 6 mi. S, 1 E Goldthwaite	2513	1248		2473	*	*
Whittenburg 1, Sterling Oil Co.; A. Thompson Surv. 2; 2 mi. E Ebony	1285	1435		1175	*	*
Young 1, Fidelity Oil Co.; Boatright Surv.; 15 mi. W, 1½ S Goldthwaite	3314		1971	2036		

MONTAGUE COUNTY

The formations in Montague County overlying those here recorded are Cretaceous, in the eastern part of the county, and Upper Pennsylvanian. The presence or absence of the Lower Pennsylvanian is undetermined.

Name and location of well	TD	Elev	Miss	Ord	Camb	p-Camb
Bouldin 1, Bridwell Oil Co.; E. Votaw Surv.; 19 mi. N, 1½ E Montague	3024	795		?	2235?	2683
Edmondson 11, Bridwell Oil Co.; T. R. Edmonson Surv., A-222; 20 mi. N ½ E Montague	2133	758			2078?	
Hinton 1, Humphreys Corp.; A. Coates Surv.; 7½ mi. N Nocona	1844	802				1841
Jones 1, Pure Oil Co.; W. Donoho Surv.; Lot 41 (82-acre tract); 7 mi. N Nocona	1966	782	Abst	Abst	Abst	1797
Jones 2, Pure Oil Co.; W. Donoho Surv.; Lot 41; 7 mi. N Nocona	2795	861	Abst[90]	Abst	Abst	2084
Jones 1, Red River Oil Co.; W. Donoho Surv.; 7½ mi. N Nocona	2595	858		?	?	2500
Lemons 1, The Texas Co.; S. Little Surv., A-417; 7½ mi. N Nocona	2915	891	?	?	?	2707
Maddox 3, Boyd Oil Co.; C. W. Thompson Surv.; 10 mi. N Nocona	2273	864		?	?	2262
Monroe 1, Warner Oil Co.; Fielding-Seacrest Surv.; 9 mi. N St. Jo	3243	946		?	2910±	2950
Rowland 3, Pure Oil Co.; J. Chambliss Surv.; 10 mi. N, 2 E Nocona	2700	848	?	?	?	2622

[90]A core of micaceous shale and sandstone, probably Pennsylvanian, was taken from the Pure Oil Co. No. 2 Jones at depth 1978. Pre-Cambrian was entered at 2084, the early Paleozoic being absent. The absence of early Paleozoic, Cambrian to Mississippian or Lower Pennsylvanian, is indicated in several other wells in this and adjoining counties on the Red River uplift.

MOORE COUNTY

The formations in Moore County overlying those here recorded are of Permian and Cenozoic age. Pennsylvanian and older deposits are possibly also present in the county.

Name and location of well	TD	Elev	Miss	Ord	Camb	p-Camb
Kilgore 1, Gulf Production Co.; E.L.&R.R.Ry.Co. Surv., Bl. PMc, Sec. 22; 2 mi. from S, 10 from W county line	3645	3743				3450

OLDHAM COUNTY

The formations in Oldham County overlying those here recorded are of Cenozoic, Triassic, and Permian age. These wells are located on the Bravo dome. On this dome Permian rests on pre-Cambrian. Off of the dome some of the intervening Paleozoic systems are probably represented.

Name and location of well	TD	Elev	Miss	Ord	Camb	p-Camb
Matador 2, Benedum and Trees; E.L.&R.R.Ry.Co. Surv., Bl. 7, Sec. 26; 12½ mi. from W, 11 from N county line	2390	3635	Abst	Abst	Abst	2380?
Shelton 1, Benedum and Trees; Bravo Subd., Sec. 137; 6 mi. from W, 6½ from N county line, N of Canadian River near New Mexico line	2580	3850	Abst	Abst	Abst	2462?
Shelton 1, Humble Oil and Refining Co.; Bravo Subd., Sec. 43; 11½ mi. from W, 6 from N county line	2590	3699	Abst	Abst	Abst	2560?

PALO PINTO COUNTY

The formations in Palo Pinto County overlying those here recorded are Upper and Lower Pennsylvanian.

Name and location of well	TD	Elev	Miss	Ord	Camb	p-Camb
Chestnut 2, Shaw et al; T.P.Ry. Co. Surv., Bl. A, Sec. 40; 9 mi. S, 1 W Mineral Wells	5123	1124	4748	4918	*	*
Finch 2, Nelson Oil Syndicate; N. Dickerson Surv., Subd. 45, Bl. 44; 3 mi. S Gordon	4146	950	3685	3820	*	*
Guest 1, Goodwin, Lacey and White; Burleson County School Lands Surv.; Sec. 73; 4 mi. from S, 8½ from W county line	3850	993	3620	3835	*	*
McDonald (Watson) 1, The Texas Co.; T.P.Ry.Co. Surv., A-1077, Bl. 2, Sec. 31; 2 mi. W, 1 S Palo Pinto	4665	1033	4410	4590	*	*
McDonald 2, Gordon and Gholson; T.P.Ry.Co. Surv., Bl. 2, Sec. 33, 1 mi. S Palo Pinto	4887	1233	4650	4845	*	*

Name and location of well	TD	Elev	Miss	Ord	Camb	p-Camb
Pennington 1, Magnolia Petroleum Co.; T.E.&L. Surv., Sec. 1789; 12 mi. W, 4½ N. Mineral Wells	4650	946		4560	*	*
Rasmussen 2, Pender Production Co.; T.P.Ry.Co. Surv., Bl. 3, Sec. 46; 2½ mi. SE Brad	4245	1149	4080	4215	*	*
Ringo 1, Texas and Pacific Coal and Oil Co.; T.P.Ry.Co. Surv., Bl. 2, Sec. 85; 7½ mi. from S, 12 from W county line	4375	1006	4060	4250	*	*
Sanger 1, Owens, Burkett and Wheeler; J. J. Metcalf Surv., A-341; 10 mi. W, 3 N Mineral Wells	4890	1003		4706	*	*
Seaman 1, Roxana Petroleum Co.; T.P.Ry.Co. Surv., Bl. 3, Sec. 6; 9½ mi. from N, 1 from W county line	4535	1248	4370	4519	*	*
Strawn Coal Co. 4, Burton and McKee; A. Ashworth Surv.; 2½ mi. N, 2½ E Strawn	3797	1010	3607	3780	*	*
Stuart 153, Texas and Pacific Coal and Oil Co.; W. J. Betterton Surv., Bl. 1; 4 mi. W Strawn	3776	1152		3750	*	*
Taylor 1, Gordon and Gholson; T.P.Ry.Co. Surv., Bl. 1, Sec. 21; 2 mi. W, 1 S Palo Pinto	4792	1114	4527	4720	*	*
Texas and Pacific Coal and Oil Co., Fee 1, Lassiter et al; A.B. &M. Surv., Sec. 5; 1½ mi. NE Gordon	5630	948	3913	4029	*	*
Weldon 2, Zada Belle Oil Co.; C.E.P.I.&M.Co. Surv.; 2½ mi. S Pickwick	4700	1089	4540	4640	*	*

PECOS COUNTY

The formations in Pecos County overlying those here recorded include Cretaceous over the central and southern parts of the county, Triassic over much of the county, and Permian over the entire county. In the one well drilled to the pre-Cambrian, formations older than Pennsylvanian are absent. This well, however, is located on an uplift and these formations may have been eroded from the uplift in pre-Permian time and may come into the section on the sides of the uplift or in the basins.

Name and location of well	TD	Elev	Miss	Ord	Camb	p-Camb
University 1, Shell Petroleum Corp. and Humphreys Corp.; University Land Surv., Bl. 26, Sec. 23; 10 mi. E, 9 N Fort Stockton	5204	2620	Abst	Abst	Abst	4750

POTTER COUNTY

The formations in Potter County overlying those here recorded are of Cenozoic, Triassic, and Permian age. See University of Texas Bulletin 2330.

Name and location of well	TD	Elev	Miss	Ord	Camb	p-Camb
Bivens 1, Prairie Oil and Gas Co.; Gunter & Munson Surv., Bl. M-20, Sec. 42; E county line, 2 mi. S county line	3485	3238	Abst	Abst	Abst	2525
Masterson 1, Emerald Oil Co.; Gunter & Munson Surv., Bl. 3, Sec. 82; 20 mi. NW of Amarillo	2148	3465	Abst	Abst	Abst	2000
Masterson 1, Greater Amarillo Oil Co.; Gunter & Munson Surv., Bl. 3, Sec. 20; 30 mi. N Amarillo	2595	3423	Abst	Abst	Abst	2045
Masterson 1. Ranch Creek Oil Co.; D.&P.Ry.Co. Surv., Bl. 0-18; 25 mi. N Amarillo		3397	Abst	Abst	Abst	2480
Masterson 1. Ranch Creek Oil Co.; E.L.&R.R.Ry.Co. Surv., Bl. B-11, Sec. 2; 20 mi. N Amarillo	2675	3434	Abst	Abst	Abst	2200
Masterson 3, Amarillo Oil and Gas Co.; D.&P.Ry.Co. Surv., Bl. 0-18, Sec. 102; 24 mi. N Amarillo	3082	3455	Abst	Abst	Abst	2698
Masterson 5, Amarillo Oil and Gas Co.; Gunter & Munson Surv., Bl. 3, Sec. 31; 24 mi. NE Amarillo	2230	3279	Abst	Abst	Abst	2205

REAGAN COUNTY

The formations in Reagan County overlying those here recorded are of Cretaceous, Triassic, Permian, and Pennsylvanian age. See University of Texas Bulletin 2901, pp. 175–201, and Bulletin 3201.

Name and location of well	TD	Elev	Miss	Ord	Camb	p-Camb
University 1-B, Continental Co.	8671	2734	Abst	8512[91]	*	*
University 2-B, Continental Co.	8740	2705	Abst	8450	*	*
University 3-B, Continental Co.	9020	2734	Abst	8610	*	*
University 4-B, Continental Co.	8560	2722	Abst	8345	*	*
University 5-B, Continental Co.	8483	2738	Abst	8410	*	*
University 6-B, Continental Co.	8335	2716	Abst	8245	*	*
University 1-C, Big Lake Oil Co.	9562	2730	?	8618	*	*
University 2-C, Big Lake Oil Co.	8820	2704	Abst	8540	*	*

[91]All of the wells here listed for Reagan County are in the Big Lake oil field. The principal deep production of oil and gas in this field is from the Ellenburger limestone which has been drilled into from 103 to 947 feet. The Ellenburger in this field is overlain by Middle Ordovician Simpson series which ranges in thickness from 0 to 350 feet. The depth in feet at which the Simpson was reached in these wells is as follows: 1-B, 8305; 2-B, 8225; 3-B, 8390; 4-B, 8195; 5-B, 8325; 6-B, 8155; 1-C, 8346; 2-C, 8280; 3-C, 8470; 4-C, 8325; 5-C, 8205; 6-C, 8340; 7-C, 8160; 8-C, 8405; 9-C, absent.

Name and location of well	TD	Elev	Miss	Ord	Camb	p-Camb
University 3-C, Big Lake Oil Co.	8923	2736	?	8820	*	*
University 4-C, Big Lake Oil Co.	8833	2704	Abst	8606	*	*
University 5-C, Big Lake Oil Co.	8872	2697	Abst	8350	*	*
University 6-C, Big Lake Oil Co.	8836	2686	?	8465	*	*
University 7-C, Big Lake Oil Co.	8825	2697	?	8270	*	*
University 8-C, Big Lake Oil Co.	8368	2691	Abst	8610	*	*
University 9-C, Big Lake Oil Co.	8431	2680	Abst	8315	*	*

RUNNELS COUNTY

The formations in Runnels County overlying those here recorded are Lower Permian and Upper and Lower Pennsylvanian.

Name and location of well	TD	Elev	Miss	Ord	Camb	p-Camb
Giesecke 1, Russell Production Co. (M. D. Cerf); J. Huhges Surv. 227; 17 mi. SE Ballinger, 1 mi. from E, 2 from S county line	3450	1527		3395	*	*
Herring 1, Marland Oil Co.; Sec. 139; 3 mi. NW Talpa	4200	1850A		4085	*	*
Russel 1, Gulf Production Co.; James Hughes Surv.; 1½ mi. from E, 2½ from S county line	3505	1677		3440	*	*

SAN SABA COUNTY

The formations in San Saba County overlying those here recorded are Cretaceous, locally present, and Upper and Lower Pennsylvanian. In the southern part of the county, Lower Pennsylvanian, Mississippian, Ordovician, Cambrian, and pre-Cambrian formations are exposed.

Name and location of well	TD	Elev	Miss	Ord	Camb	p-Camb
Crane 1, Wilmott et al; ½ mi. NW San Saba	727	1200T	680	717	*	*
Cummings 1, Coline Oil Co.; C. Herberg Surv.; 3 mi. NNE Locker	1380	1362	760	805	*	*
Heatherly 1, Royal Duke Oil Co. (Duke-Knowles); L. Burchell Surv. 255; 6 mi. N Richland Springs	1900	1425T		605	*	*
Leverett 1, Texas-Mexia Drilling Syndicate; M. Gyton Surv. 79; 6 mi. N, 4 E San Saba	1003	1250T	893	940?	*	*
Maxcey 1, Moss and Keeling; C. Hernandez Surv.; ¾ mi. SE Richland Springs				180		
Moore 1, Cayce Petroleum Co.; C. Hernandez Surv.; 8 mi. NE San Saba	1659	1250T		1281?	1631	1655
Moore 1, Wilmott et al; C. Hernandez Surv., Bl. 78; 7 mi. NE San Saba†	3087	1250		1066	2870	*
Munsel 1, Cayce Petroleum Co.; Rogers Surv. 26; 6 mi. E, 2 N San Saba	798	1250T	404	486	*	*

†Moore 1, Cayce Petroleum Co. apparently drilled across a fault plane, accounting for the reduced thickness of Ellenburger and Cambrian.

Name and location of well	TD	Elev	Miss	Ord	Camb	p-Camb
Roper 1, Webb et al; 2 mi. S Bowser	750	1340T	625	665	*	*
Shaw 1, Graves et al; 2 mi. N Locker	1000	1350T		800	*	*
Winkler 1, Tyler et al; Sec. 626; 1½ mi. from N, 4 from W county line	1325	1368	1030	1079	*	*

SHACKELFORD COUNTY

The formations in Shackelford County overlying those here recorded are of Permian and Upper and Lower Pennsylvanian age.

Name and location of well	TD	Elev	Miss	Ord	Camb	p-Camb
Brazell 4, Phillips Petroleum Co.; B.A.L. Surv., Sec. 51; 1 mi. from E, 10 from S county line	4508	1320		4380	*	*
Cooke A-89-60, Roeser-Pendleton and Continental Oil Co.; E.T. Ry.Co. Surv., Sec. 60; 17 mi. from S, 14 from E county line	5331	1606	4820[92]	4950	*	*
Snider 2, Associated Oil Co.; Asylum Surv., Sec. 35; 7 mi. from E, 3 from S county line	4131	1384	4030[92]	4070?	*	*
Webb 7, The Texas Co.; Univ. Surv., Sec. 68; 2 mi. W Moran	4192	1394		4136	*	*
Witty 4, Phillips Petroleum Co.; B.A.L. Surv., Sec. 52; 1 mi. from E, 11 from S county line	4360	1300	?-4310	4310	*	*

STEPHENS COUNTY

The formations in Stephens County overlying those here recorded are of Upper and Lower Pennsylvanian age.

Name and location of well	TD	Elev	Miss	Ord	Camb	p-Camb
Bratton 1, Texas and Pacific Coal and Oil Co.; T.P.Ry.Co. Surv., Bl. 6, Sec. 72; 5 mi. from S, 5 from E county line	4270	1505		4263	*	*
Bratton 2, The Texas Co.; T.P. Ry.Co. Surv., Bl. 6, Sec. 72; 4 mi. S, 1¼ E Lacasa		1555	4130	4248	*	*
Corbett 1, Universal Oil and Gas Co.; R. Campbell Surv.; 1½ mi. from N, 5 from E county line	4775	1142		4685	*	*
Dunlap 1, Atlantic Oil Producing Co.; T.E.&L. Surv., Sec. 1411; 8 mi. E, 2 S Breckenridge	4382	1401		4350	*	*
Dunlap 6, Atlantic Oil Producing Co.; T.E.&L. Surv., Sec. 1411; 10 mi. from E, 14 from S county line	4325	1231	4100	4245	*	*

[92]In the Cooke A-89-60 well, the "pink crinoidal" limestone is recognized at depth 4925 to 4950; in Snider 2, the Mississippin, depth 4030, is "pink crinoidal" limestone (R. E. Giles).

Name and location of well	TD	Elev	Miss	Ord	Camb	p-Camb
Elliott 3, Lone Star Gas Co.; T. P.Ry.Co. Surv., Bl. 7, Sec. 55; 2 mi. from S, 4 from W county line	4085		3930	4045	*	*
Elliott 1, L. H. Wentz; T.P.Ry. Co. Surv., Bl. 7, Sec. 55; 1¼ mi. from W, 1-6/10 from S county line	4097	1425	3910	4015	*	*
Gardner 1, Magnolia Petroleum Co.; T.P.Ry.Co. Surv., Bl. 8, Sec. 17; 4 mi. SW Breckenridge	4515	1277	4206	4310	*	*
Gordon 1, Prairie Oil and Gas Co.; T.P.Ry.Co. Surv., Bl. 4, Sec. 34; 1 mi. from E, 14 from S county line	4550	1150		4490	*	*
Grimes 1, Hanlon Gasoline Co.; T.E.&L. Surv., Sec. 3394; 11 mi. from S, 10 from W county line	4297	1464		4133	*	*
Knott 5, Mid-Kansas; T.P.Ry. Co. Surv., Bl. 4, Sec. 54; 2¾ mi. S, 1½ E Caddo	4604	1453	4284	4425	*	*
Lee 1, Texas and Pacific Coal and Oil Co. and Mid-Kansas; T.P.Ry.Co. Surv., Bl. 5, Sec. 18; 6 mi. from E, 13 from N county line	4595	1312		4469	*	*
McClenny 1, Brown and Company and Landreth Production Co.; T.E.&L. Surv. 2261; 3 mi. SE Eolian	4166	1253	3974	4115	*	*
Martin 8, Texas Consolidated; T.E.&L. Surv., Sec. 1050; 8½ mi. from E, 6½ from N county line	4600	1154		4442	*	*
Newell 1, Texas and Pacific Coal and Oil Co.; T.E.&L. Surv., Sec. 1174; 11 mi. from E, 3½ from N county line	4710	1251	4483	4625	*	*
Proctor 2, Prairie Oil and Gas Co.; T.E.&L. Surv., Sec. 1325; 8½ mi. from E, 9 from N county line	4465	1164	4280	4410	*	*
Rogers 5, Texas and Pacific Coal and Oil Co.; T.P.Ry. Co. Surv., Bl. 5, Sec. 17; 5 mi. from E, 13 from N county line	4525	1340	?	4520	*	*
Veale 1-E, Prairie Oil and Gas Co.; T.E.&L. Surv., Sec. 1418; 9 mi. from E, 14 from N county line	4505	1230		4322	*	*
Ward C-28, Gulf Production Co.; T.E.&L. Surv., Sec. 1235; 11 mi. from W, 10 from N county line	4383	1228		4356	*	*

Name and location of well	TD	Elev	Miss	Ord	Camb	p-Camb
Winston 2, Texas and Pacific Coal and Oil Co.; T.P.Ry.Co. Surv., Bl. 4, Sec. 21; 2 mi. from E, 13 from N county line	4801	1340		4582	*	*

SUTTON COUNTY

The formations in Sutton County overlying those here recorded are of Cretaceous, Lower Permian, and Upper and Lower Pennsylvanian age.

Name and location of well	TD	Elev	Miss	Ord	Camb	p-Camb
Geo. Allison 1, Independent Oil and Refining Co. and Sun Oil Co.; G.W.T.&P. Surv., Bl. A, Sec. 39; 26 mi. E Sonora	4315	2291		4237	*	*

TAYLOR COUNTY

The formations in Taylor County overlying those here recorded are Cretaceous, locally present, Permian, and Upper and Lower Pennsylvanian.

Name and location of well	TD	Elev	Miss	Ord	Camb	p-Camb
Webb 1, Jamison et al; L.A.L. Surv., Sec. 46; 12 mi. SSE Abilene; 3 mi. from E, 13 from S county line	6016	1905	4705	4770	5304	5809

THROCKMORTON COUNTY

The formations in Throckmorton County overlying those here recorded are of Permian and Upper and Lower Pennsylvanian age.

Name and location of well	TD	Elev	Miss	Ord	Camb	p-Camb
Harrison 1-B, Humble Oil and Refining Co.; T.E.&L. Surv., Sec. 2354; 2½ mi. from E, 12 from S county line	4977	1320		4835	*	*
Swenson 1, Swenson Oil and Gas Co.; B.B.B.&C.Ry.Co. Surv., Sec. 173; 8 mi. from W, 7½ from N county line	5981	1506	5367[93]	5508	*	*

WHEELER COUNTY

The formations in Wheeler County overlying those here recorded include Cenozoic, Triassic, and Permian. The Pennsylvanian is present on the sides of the Amarillo uplift. Older Paleozoic formations may be present also as indicated by the doubtful presence of Lower Ordovician in the Company well.

Name and location of well	TD	Elev	Miss	Ord	Camb	p-Camb
Close 5, Murchison and Fain; H.&G.N.Ry.Co. Surv., Bl. 23, Sec. 76; 6 mi. from S, 9 from W county line	1290	2530	Abst	Abst	Abst	1290

[93]The formation at this depth (5367 to 5508 feet) probably represents the "pink crinoidal" limestone (L. D. Cartwright, Jr.). The Barnett shale has not been recognized in this well (Joseph Hornberger, Jr.).

Name and location of well	TD	Elev	Miss	Ord	Camb	p-Camb
Close 11, Murchison and Fain; H.&G.N.Ry.Co. Surv., Bl. 23, Sec. 77; 6 mi. from S, 10 from W county line	1510	2498	Abst	Abst	Abst	1490
Close 12, Murchison and Fain; H.&G.N.Ry.Co. Surv., Bl. 23, Sec. 77; 3 mi. from S, 11 from W county line	1415	2501	Abst	Abst	Abst	1385
Emler 1, W. D. Shedden, Jr.; H.&G.N.Ry.Co. Surv., Bl. 13, Sec. 70; 7 mi. from S, 10 from W county line	2385	2287	Abst	Abst	Abst	2167
George 1, Schenck et al; H.&G.N.Ry.Co. Surv., Bl. 17, Sec. 85; 4 mi. N Shamrock	2693	2270	Abst	Abst	Abst	2492
Kachelhoffer 1, Thomas and McFarland; H.&G.N.Ry.Co. Surv., Bl. 23, Sec. 70; 3 mi. from W, 6 from S county line	2393	2773	Abst	Abst	Abst	2155
H. C. Tyrell, Palaskie Oil Co.; H.&G.N.Ry.Co. Surv., Bl. 23, Sec. 128; 9 mi. from W, 10 from S county line	2132	2584	Abst	Abst	Abst	1435
Tindal 1, Best et al; H.&G.N.Ry.Co. Surv., Bl. A-8, Sec. 19; 12 mi. from S, 15 from W county line	2249	2332	Abst	Abst	Abst	2248

WICHITA COUNTY

The formations in Wichita County overlying those here recorded include Permian and Pennsylvanian. The Lower Pennsylvanian, as well as the Ordovician and Mississippian, is apparently absent on the pronounced highs, as in the Beach well. The Lower Pennsylvanian, Bend, is reported present in the Deep Oil Development Co. No. 1 Munger at depth 3645 to 4200.†

Name and location of well	TD	Elev	Miss	Ord	Camb	p-Camb
Beach 1, Continental and Magnolia; C.T.Ry.Co. Surv. 443; 4 mi. S, 1 E Burkburnett	3450	1005	Abst	?	2295[94]	3000
Burnett 43-A, Gulf Production Co.; H. T. & B. Ry. Co. Surv., A-752, Sec. 4; 5 mi. S, 2 E Electra	4295	1126		3775	*	*
Bywaters 44, The Texas Co.; S.P. Ry.Co. Surv., A-280; 2½ mi. E., 1½ N Electra	3307	1214		3150±	*	*
Herschi 1, Deep Oil Development Co.; D. Cowan Surv., A-43; 1 mi. from Red River, 10 from W county line	6002	1069		3580?	?	*

†H. F. Smiley, letter of December 15, 1932.

[94]May be Ordovician or Cambrian.

Name and location of well	TD	Elev	Miss	Ord	Camb	p-Camb
Herschi 1, Howell-Somers; D. Cowan Surv., A-43, Bl. 834; 12 mi. W Burkburnett	5283	1092		4850?	*	*
Munger et al 1, Deep Oil Development Co.; K.W.F.L. Subd. Bl. 30; 9 mi. from W, 1½ from S county line	5430	1025±		4247	?	*
Schnokenberg 1, Rollstone et al; Huseman Surv., A-93, Lot 1, Tidwell Subd., 2 mi. N, 5½ W Burkburnett	3595	1080		?	?	3575

WILBARGER COUNTY

The formations in Wilbarger County overlying those here recorded are of Permian and Pennsylvanian age.

Name and location of well	TD	Elev	Miss	Ord	Camb	p-Camb
Stevens 14-A, Barkley-Meadows Co.; H.&T.C.Ry.Co. Surv., Bl. 14, Sec. 83; 8 mi. S Vernon	3007	1058	Abst	Abst	Abst	2970
Wagner 2, Sloan Co.; H.&T.C. Ry.Co. Surv., Bl. 4, Sec. 32; 10 mi. from S, 11 from E county line; Rock Crossing pool	4095	1116		3957[95]	?	*
Zipperle 1, The Texas Co.; H.& T.C.Ry.Co. Surv., Bl. 14, Sec. 80; 8 mi. S, 1 E Vernon	2970	1253				2881

YOUNG COUNTY

The formations in Young County overlying those here described are Permian, in the western part of the county, and Upper and Lower Pennsylvanian.

Name and location of well	TD	Elev	Miss	Ord	Camb	p-Camb
Arnold 1, The Texas Co.; Jonathan and Lee Surv.; 8½ mi. W, 1½ N Graham	4711	1270	4705[97]	?	*	*
Bullock 1, Panhandle Refining Co.; M. Hamilton Surv.; 5 mi. W, 2 N Graham	4952	1117	4629[97]	4775	*	*
Bunger 1, The Texas Co.; J. L. Mercer Surv., A-1783, Bl. 11, 1½ mi. from S, 9½ from E county line	4760	1143		4690	*	*
Burnett 1, Pitzer and West et al; T.&N.O.Ry.Co. Surv. 6; 4 mi. W. Graham	4850	1243		4830	*	*
Corbett 1, Transcontinental Oil Co.; R. Campbell Surv.; 3 mi. SW South Bend	4590	1237		4550	*	*

[95]May be Cambrian.

[96]This well has been reported on the evidence of some fossils obtained from it as having probably entered Viola. However, the fossils are fragmentary, and the formation may be of Mississippian age. A few other wells in this field reach similar rock.

Name and location of well	TD	Elev	Miss	Ord	Camb	p-Camb
Grantham 3, Hinson-Tidwell; E. J. Ribble Surv.; 3½ mi. from S, 9 from E county line	4812	1084	4500[97]	4575	*	*
Kimbrell 1, Panhandle Refining Co.; W. A. Crumpton Surv.; 9 mi. SE Graham; 2½ mi. from E, 5½ from S county line	4892	1092	4630	4825	*	*
McClusky 7, Panhandle Refining Co.; South Bend pool, 1½ mi. W South Bend[96]	4201	1040	4148?		*	*
Morrison 1-A, Panhandle Refining Co.; B. N. Hammond Surv.; 1 mi. E, 1½ N Graham	4885	1203		4820	*	*
Newby 1, Gulf Production Co.; J. H. Fisher Surv., A-1598; 2½ mi. from S, 6 from E county line	4655	1185		4630?	*	*
Scott 9, Roxana Petroleum Corp.; I. Garrett Surv.; 1½ mi. S, 1½ W South Bend	4485	1075	4200[97]	4452	*	*
Stovall 3-A, Ruthada Oil Co.; J. Tobin Surv., Bl. 31, Stovall Subd., 1½ mi. SW Bend	4434		4400[97]	4430	*	*
Weldon 1, Jacob Oil and Gas Co.; W. B. Lyttle Surv., A-1776; 4½ mi. from S, 7½ from E county line	4548	1029	4320[97]	4530	*	*
Whitley 1, Continental Oil Co.; T.E.&L. Surv., Sec. 422; 1 mi. N Newcastle	5063	1197	4730[97]	5038	*	*

COTTLE COUNTY

Since this table of wells was set in type a well has been completed in Cottle County which reached rock probably of pre-Cambrian age. This well affords an important record since it shows that the Red River uplift extends westward through Cottle County. For this reason it has seemed desirable to add this Cottle County well to the list. Granite wash was entered in this well at 4645 feet; a flow of water was obtained at 4718 to 4720 feet. A fusulinid, which according to M. P. White is of Strawn age, was obtained from within the granite wash. The formations in Cottle County overlying those here recorded are of Upper Pennsylvanian and Permian age.

Name and location of well	TD	Elev	Miss	Ord	Camb	p-Camb
Puercel 1, Merry Bros. and Perini and Darby Petroleum Corp.; J. H. Stephens Surv., Bl. "B," Sec. 40; 1¼ mi. from W, 10 from S county line	4740	2018	Abst	Abst	Abst	4740

[97]The Mississippian in the Arnold, Grantham, and Stovall wells is probably "pink crinoidal" limestone. A similar limestone is found in Bullock 1 at depth 4747 to 4775, in Scott 9 at 4260? to 4410, in Whitley 1 at 4840 to 5035, and in Weldon 1 at 4480 to 4530 (R. E. Giles).

ILLUSTRATIONS OF SOME PALEOZOIC FOSSILS

Although fossils are present in some formations of all of the Paleozoic systems as developed in Texas, the number and kinds of fossils present vary with the varying living conditions and facies of deposition. The oldest Paleozoic represented, the Upper Cambrian, contains an abundance of fossils, the predominating forms being trilobites and brachiopods, Fossils abound in most of the shales and limestones of the Ordovician seas, although some of the dolomitic limestones are relatively barren. The Silurian, known in Texas only in the limestone facies, contains some, although not many, fossils. In the Devonian formations the shales, Percha formation, are highly fossiliferous, while the Caballos novaculite contains so few fossils as to be doubtfully placed in stratigraphic position. The Mississippian, most of the Pennsylvanian, and some of the Permian formations are highly fossiliferous.

Most of the Paleozoic fossils of the Texas formations are marine invertebrates. Land plants, however, are present in some of the Pennsylvanian and Permian formations, and land vertebrates, amphibians and reptiles, abound in the Permian. In contrast to the abundance of fossils, some of the Permian formations accumulated in the super-saline seas of the Permian basin, are notably unfossiliferous.

It is not practicable to illustrate in this volume more than a very few of the vast number of organic remains, plant and animal, preserved in the sediments of the Paleozoic systems.

Of the illustrations which follow, Plates II and III, Upper Cambrian and Lower Ordovician fossils, have been contributed by the United States Geological Survey. The illustrations were made in the Division of Illustrations, and the plates arranged, and the description of fossils written by Doctor Josiah Bridge of that survey. Plate IV, Ordovician graptolites, has been arranged, identification of fossils made, and descriptions written by Dr. Rudolf Ruedemann of the New York State Museum. Plates V and VI, Pennsylvanian and Permian fossils, have been arranged and the descriptions written by Professor F. B. Plummer. Figures 4–6 of this plate, illustrating *Schwagerina*, are from a manuscript prepared by Mr. G. G. Henderson on the Fusulinids of the Moran Formation of Texas. Grateful acknowledgment is made to the organizations and individuals who have contributed these illustrations of Texas Paleozoic fossils for this volume.

EXPLANATION OF PLATES II TO VI

PLATE II

CAMBRIAN FOSSILS

Figures—

1–3. *Eoorthis remnichia texana* (Walcott)

1. Dorsal valve. Paratype. United States National Museum No. 52369-d.
2. Ventral valve. Holotype. United States National Museum No. 52369-a.
3. Profile of ventral valve.
   All three figures x ⅔.
   Wilberns formation, Cold Creek Canyon, Burnet County, Texas.

4–5. *Eoorthis wichitaensis* (Walcott)

4. Dorsal valve. Paratype. United States National Museum No. 52379-b.
5. Ventral valve. Paratype. United States National Museum No. 52379-a.
   Wilberns formation, Cold Creek Canyon, Burnet County, Texas.

6–7. *Huenella texana* (Walcott)

6. Ventral valve. Holotype. United States National Museum No. 52494-a.
7. Dorsal valve. Paratype. United States National Museum No. 52494-c.
   Wilberns formation, Packsaddle Mountain, Llano County, Texas.

8–9. *Lingulella acutangula* (Roemer)

8. Partially exfoliated ventral valve. Plesiotype. United States National Museum No. 27412-a.
   Wilberns formation, Honey Creek, Llano County,[98] Texas.
9. Ventral valve. Holotype. Geological and Paleontological Museum, University of Bonn.
   Wilberns formation, San Saba River near the Mason-Menard county line, Texas.

10–11. *Lingulella texana* Walcott

10. Internal mold of a dorsal valve. Holotype. United States National Museum No. 51806-a.
    Wilberns formation, Morgan Creek, Burnet County, Texas.
11. Partially exfoliated dorsal valve. Plesiotype. United States National Museum No. 51805-a.
    Wilberns formation, Honey Creek, Llano County,[99] Texas.

12–13. *Billingsella coloradoensis* (Shumard)

12. Partially exfoliated ventral valve. Plesiotype. United States National Museum No. 34774-a.
    Wilberns formation, Packsaddle Mountain, Llano County, Texas.
13. Ventral valve. Plesiotype. United States National Museum No. 34777-b.
    Wilberns formation, Morgan Creek, Burnet County, Texas.

14, 15, 16. *Obolus matinalis* (Hall)

14. Ventral valve. Plesiotype. United States National Museum No. 52419-a.

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[98]In Monograph 51 of the United States Geological Survey, and elsewhere, this locality is cited as Honey Creek, Burnet County, but it is evident from Walcott's notes that the collections were made on Honey Creek, 8 miles southeast of Llano, which is a well known section.

[99]See note under fig. 8.

Figures—

Cap Mountain formation, Potatotop Mountain, Burnet County, Texas.

15. Partially exfoliated dorsal valve. Plesiotype. United States National Museum No. 51566-a.
Wilberns formation, Cold Creek Canyon, San Saba County,[100] Texas.

16. Profile of the specimen shown in Figure 15.

17, 18, 19. *Elvinia roemeri* (Shumard)

17–18. Profile and dorsal views of a medium sized cranidium.
Wilberns formation. Packsaddle Mountain, Llano County, Texas.

19. Pygidium of a larger specimen. Plesiotype. United States Museum No. 70261.
Wilberns formation. Packsaddle Mountain, Llano County, Texas.

20–21. *Burnetia urania* (Walcott)
Dorsal and lateral views of a cranidium. Holotype. United States National Museum No. 23861-a.
Wilberns formation, Packsaddle Mountain, Llano County, Texas.

22–23. "*Crepicephalus*" *texanus* (Shumard)

22. Dorsal view of a cranidium, in which the outline has been restored and the free cheeks added. Plesiotype. United National Museum No. 61647.

23. Ventral view of a fragmentary pygidium. Plesiotype. United States National Museum No. 61650.
Both specimens from the Cap Mountain formation, head of Clear Creek, Potatotop Mountain, Burnet County, Texas.

24–25. *Wilbernia pero* (Walcott)
Dorsal and lateral views of a cranidium. Holotype. United States National Museum No. 23859.
Wilberns formation, Morgan Creek, Burnet County, Texas.

26–27. *Pterocephalia sancti-sabae* Roemer

26. Dorsal view of cranidium. Holotype. Margins somewhat restored and free cheeks added from other specimens.

27. Dorsal view of a pygidium. Paratype. Margins restored.
Both specimens in the Museum of Geology and Paleontology of the University of Bonn, Germany.
Wilberns formation, San Saba River, near the Mason-Menard county line, Mason County, Texas.

28. "*Girvanella*" sp. Fragment of a block of limestone containing numerous globular bodies, presumably of algal origin.
Wilberns formation, Ft. Sill equivalent, 5 miles west of Cherokee, San Saba County, Texas.

NOTE:—Figures 1–8 and 10–16 are taken from Walcott, United States Geological Survey Monograph 51; Figures 19–21, 24–25 are from specimens figured by Walcott, Smithsonian Miscellaneous Collection, vol. 75, No. 3; Figures 22–23 are from specimens figured by Walcott, Smithsonian Miscellaneous Collections, vol. 64, No. 3; Figures 9, 26–27 are photographs of Roemer's types recently loaned by the University of Bonn.

In some instances the stratigraphic horizon is not the same as the one originally assigned, but all such changes are based on later and more exact information.

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[100]This locality is given as Burnet County in Monograph 51 of the United States Geological Survey, p. 213, but Walcott's personal copy contains a note in his handwriting changing this reference to San Saba County.

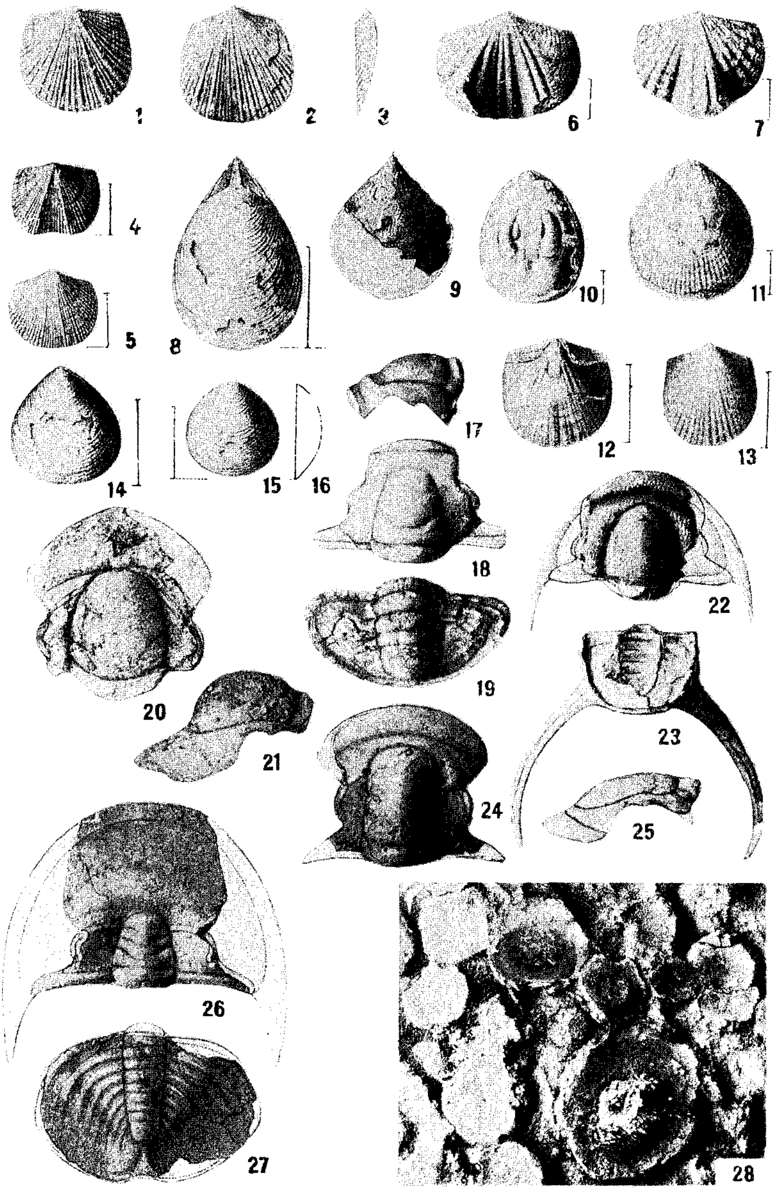
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PLATE III

FOSSILS FROM THE ELLENBURGER LIMESTONE

(Upper Cambrian and Lower Ordovician)

Figures—

1. *Scaevogyra swezeyi* Whitfield. Dorsal view. Basal Ellenburger (Potosi equivalent), west bank of Colorado River, 0.75 miles NE. of the mouth of Fall Creek, San Saba County, Texas.
Plesiotype.—United States National Museum No. 86944.
2. *Scaevogyra elevata* Whitfield. Lateral view. Same horizon and locality as the preceding.
Plesiotype.—United States National Museum No. 86945.
3. *Euptychaspis typicalis* Ulrich. Ventral view of an imperfect cranidium × 3. Residual cherts of the lower Ellenburger limestone (Eminence equivalent), 3.3 miles north of Cherokee, San Saba County, Texas, on the Cherokee-San Saba road.
Plesiotype.—United States National Museum No. 86946.
4. *Stenopilus* cf. *S. latus* Ulrich. Dorsal view of an incomplete cranidium. Residual cherts of the lower Ellenburger limestone (Eminence equivalent), 170 feet above base of formation, on west bank of Colorado River, 0.75 miles NE. of the mouth of Fall Creek, San Saba County, Texas.
Plesiotype.—United States National Museum No. 86947.
5. *Gasconadia* cf. *G. putilla* (Sardeson). Lateral view of an incomplete specimen × 2. Residual chert of the Ellenburger limestone (Gasconade equivalent), 2.5 miles north of Camp San Saba, McCulloch County, Texas, on the Mason-Brady road.
Plesiotype.—United States National Museum No. 86948.
6. *Eccyliomphalus gycoceras* (Roemer). Natural sections of two specimens showing the characteristic mode of occurrence. Lowest white limestone horizon of the Ellenburger (Gasconade equivalent), 1.45 miles north of Camp San Saba, McCulloch County, Texas, on the Mason-Brady road.
Plesiotype.—United States National Museum No. 86949.
7. *Helicotoma uniangulata* (Hall). Dorsal view of an average sized specimen. Residual chert of the Ellenburger limestone (Gasconade equivalent), 4.5–5 miles north of Cherokee, San Saba County, Texas, on Cherokee-San Saba road.
Plesiotype.—United States National Museum No. 86950.
8. *Pelagiella paucivolvata* (Calvin). Dorsal view. The spire is extremely low, scarcely rising above the body whorl. The latter is strongly compressed dorso-ventrally and sharply angled on the periphery. Same horizon and locality as the preceding.
Plesiotype.—United States National Museum No. 86951.
9. *Ozarkina typica* Ulrich and Bridge. Ventral view of an incomplete specimen. Residual chert of Ellenburger limestone. (Gasconade equivalent), 2.5 miles northwest of Camp San Saba, McCulloch County, Texas, on the Mason-Brady road.
Plesiotype.—United States National Museum No. 86952.
10. *Ophileta polygyrata* (Roemer). Dorsal view of the holotype. Ellenburger limestone (?Tribes Hill equivalent), San Saba River valley near the Mason-Menard county line about 15 miles southwest of Camp San Saba. Original in the Museum of the University of Bonn, Germany.

Figures—

11–12. *Roubidouxia umbilicata* Ulrich and Bridge

11. Lateral view of a silicified fragment of the body whorl, spire restored from other specimens.
12. Same specimen as seen from above. Fragments of this sort are common in residual cherts of the Roubidoux equivalent at several localities.

Plesiotype.—United States National Museum No. 86953; from residual chert of the Ellenburger limestone (Roubidoux equivalent) on the White Ranch road 1.3 miles southwest of the crossing of Llano River, Mason County, Texas. The species is also abundant in the limestones and dolomite of the Roubidoux equivalent at several localities.

13–14. *Leccanospira sancti-sabae* (Roemer)

13. Ventral view of the holotype.
14. Natural section of the body whorl at a.

Ellenburger limestone (Roubidoux equivalent) somewhere between Pontotoc and the San Saba River. Original in the Museum of the University of Bonn, Germany.

15. *Calathium* sp. A large silicified sponge which is rather common in upper portion of the Ellenburger (Jefferson City or Cotter equivalents). Sponges of similar types are also found in the Monument Spring dolomite of the Marathon region and in the El Paso limestone. The figured specimen, United States National Museum No. 86954, is from the upper part of the Ellenburger limestone (? Jefferson City equivalent) about 450 feet above the base of the section on Honey Creek, about 9 miles southeast of Llano, Llano County, Texas.

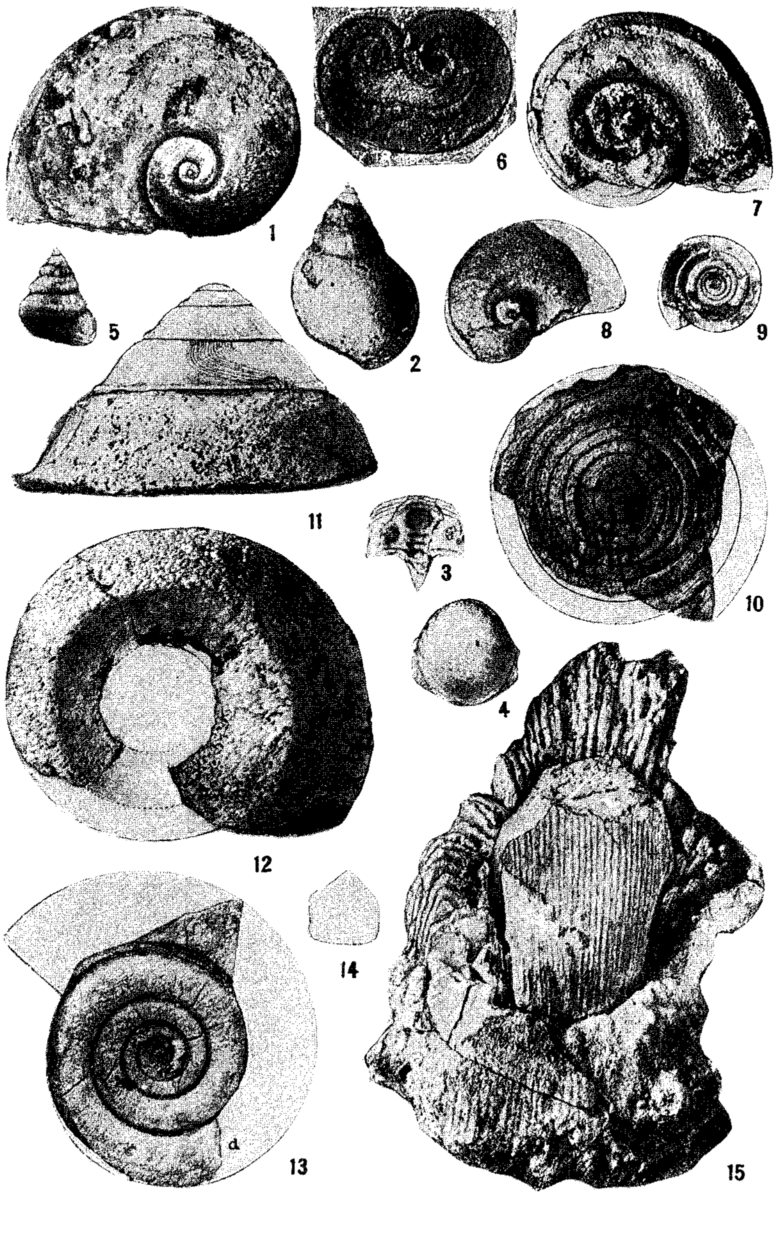
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PLATE IV

ORDOVICIAN GRAPTOLITES FROM THE MARATHON AND SOLITARIO REGIONS

All figures on this plate are reproduced × 1.5 from camera lucida drawings by R. Ruedemann. The identifications are all by Ruedemann, and the horizons and localities have been verified by P. B. King.

Figures—

1. *Didymograptus nitidus* Hall. Marathon limestone 8 miles southwest of Marathon, Texas, on road to Roberts ranch. R. E. King, collector. United States National Museum No. 85363.

2. *Didymograptus bifidus* Hall. Marathon limestone. The Solitario, Presidio County, Texas. Baker and Sellards, collectors.

3. *Tetragraptus fruticosus* Hall. Same formation and locality as preceding.

4. *Loganograptus logani* (Hall). Marathon limestone 1 mile northwest of hill having B. M. 4360, northwest of the Peña Blanca Mountains, near Marathon, Texas. Hosterman and Baker, collectors.

5. *Didymograptus* cf. *D. extensus* Hall. Same formation and locality.

6–7. *Phyllograptus ilicifolias* Hall. Marathon limestone. The Solitario, Presidio County, Texas. Baker and Sellards, collectors.

8. *Phyllograptus anna* Hall. Marathon limestone 1 mile northwest of hill having B. M. 4360, northwest of the Peña Blanca Mountains, near Marathon, Texas. Hosterman and Baker, collectors.

9. *Phyllograptus typus* Hall. Same formation and locality. Also from the Alsate shale.

10. *Oncograptus upsilon* T. S. Hall. Alsate shale 3 miles northeast of Woods Hollow Tank, south of Marathon, Texas. P. B. King, collector. This is an Australian species and this is the first recorded occurrence of it in North America.

11–12. *Glyptograptus amplexicaulus* (Hall) var. *pertenuis* Ruedemann. Limestone in the Maravillas chert, 0.8 miles east-southeast of B. M. 4361, southwest portion of the Hess Canyon quadrangle, north of Marathon, Texas. R. E. King, collector.
United States National Museum No. 85361.

13. *Glossograptus echinatus* Ruedemann. Woods Hollow shale, 100 feet below Maravillas chert, 3.75 miles N. 50° E. of Roberts ranch, southwest of Marathon, Texas. Sidney Powers, collector.
United States National Museum No. 85371.

14. *Glyptograptus amplexicaulis* (Hall). Limestone in the Maravillas chert, 0.8 mile east-southeast of B. M. 4361, southwest portion of Hess Canyon quadrangle north of Marathon, Texas. R. E. King, collector. United States National Museum No. 85358.

15. *Diplograptus dentatus* Hall. Woods Hollow shale near Louis Granger ranch south of Marathon, Texas. Hosterman and Baker, collectors.

16. *Climacograptus antiquus* Lapworth. Limestone of the Maravillas chert, 0.75 miles east of Skinner's gate and 3 miles northeast of Marathon, Texas, on the Fort Stockton road. R. E. King, collector.
United States National Museum No. 85364.

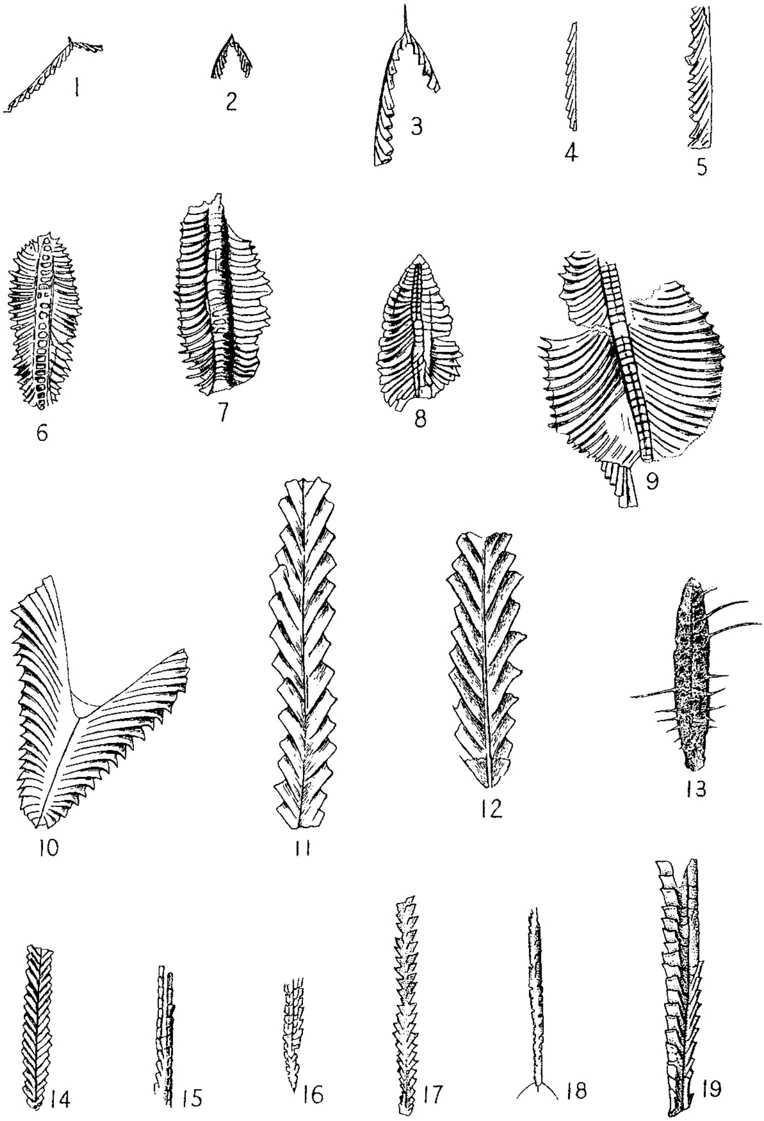
Figures—

17–18. *Diplograptus angustifolias* (Hall). Woods Hollow shale. The Solitario, Presidio County, Texas. Baker and Sellards, collectors.

19. *Glossograptus quadrimucronatus* (Hall) var. *angustus* Ruedemann, n. var. Limestone in the Maravillas chert, 0.75 miles east of Skinner's gate and 3 miles northeast of Marathon, Texas, on the Fort Stockton road. R. E. King, collector.

United States National Museum No. 85365.

Description: A well-marked variety of *G. quadrimucronatus*. The distinguishing character exhibited by all specimens in the collection is the slenderness of the long rhabdosomes, which, beginning with a width of 0.5 mm., widen very gradually to a maximum width of 2.6 mm. Specimens over 5 cm. in length do not exceed this width, while in the typical form the maximum width of 3 mm. is attained close to the sicular end. The thecae and apertural spines are of the character and type of the species and the thecae number 8 to 9 in 10 mm.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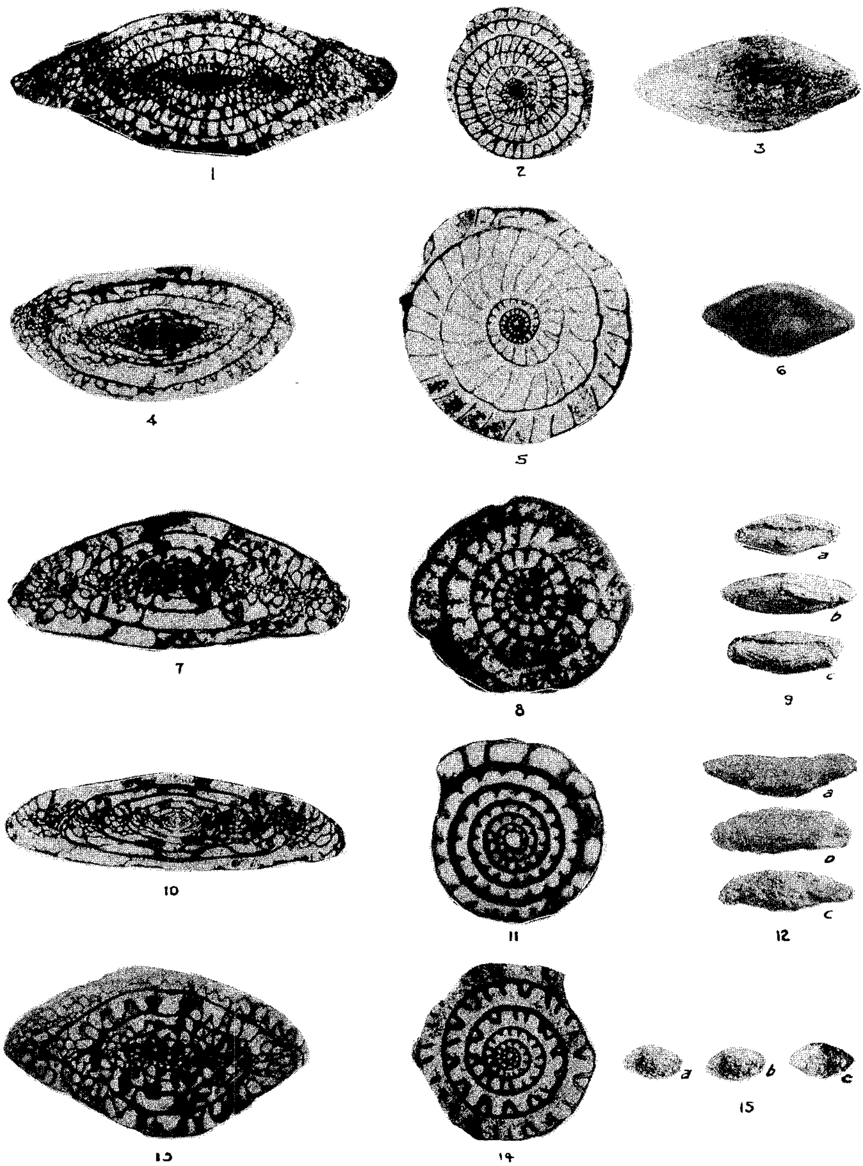
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PLATE V

PENNSYLVANIAN AND PERMIAN FUSULINIDS

Figures—

1–3. *Schwagerina gigantea* M. P. White, Wolfcamp formation. (After M. P. White.)
   1. Axial section, × 3.8.
   2. Median section, × 4.2.
   3. Adult specimen, × 6.5.

4–6. *Schwagerina* sp., Moran formation, about 70 feet below the Sedwick limestone. (After G. G. Henderson, MS.)

7–9. *Triticites moorei* Dunbar and Condra, Graham formation, 1 mile west of Graham. (After M. P. White.)
   7. Axial section, × 7.5
   8. Median section, × 15.
   9. Adult specimens, × 2.5.

10–12. *Triticites irregularis* (Schellwien and Staff), Brownwood shale, Graford formation. (After M. P. White.)
   10. Axial section, × 6.5
   11. Median section, × 15.
   12. Adult specimens, × 2.5.

13–15. *Fusulina meeki* (Dunbar and Condra) var. *similis* (Galloway and M. P. White) n. var. (MS.), Gordon limestone, Millsap Lake formation.
   13. Axial section, × 14 (photo by M. P. White).
   14. Median section, × 14 (after M. P. White).
   15. Adult specimens, × 2.5 (after M. P. White).

Fusulinids are known in the Texas formations from the Pennsylvanian and Permian formations. Those shown in Plate V illustrate several stages in the development of the group. The earliest species known, not illustrated on this plate, are found near the base of the Marble Falls formation and are very minute in size. Description of the two species obtained at that level will be found in University of Texas Bulletin No. 3101, 1931. The earliest fusulinid illustrated on this plate, *Fusulina meeki*, Figures 13–15, is limited to the Millsap Lake formation. This species is small in size and has a narrow tunnel angle. The genus *Triticites*, illustrated by Figures 7–12, ranges from the Mineral Wells formation of the Strawn group to the Permian. The species of this genus are elongate or spindle-shaped. *Triticites irregularis*, Figures 10–12, is characteristic of the Canyon group. The species of this genus are elongate or spindle-shaped and have a wide tunnel angle. In the Moran formation, at or near the level of the Horse Creek limestone, G. G. Henderson has obtained gradational forms from *Triticites* to *Schwagerina*. Some of the fusulinids of this horizon are typical *Triticites;* some apparently true *Schwagerina* (Figures 4–6) : and some intermediate between these two genera. *Schwagerina* from the Wolfcamp formation is illustrated by Figures 1–3. All specimens illustrated are from Texas.

PLATE VI

PENNSYLVANIAN AND PERMIAN AMMONITES

Figures—

1–3. *Perrinites hilli* (Smith), Double Mountain formation.
   1. Side view of holotype, × .35, Salt Croton Creek, Kent County.
   2. Youthful specimen, showing relatively larger umbilicus, × .65, same locality as holotype.
   3. Mature suture at whorl diameter 90 mm.

4. *Perrinites compressus* Böse, × 1.6, lower Leonard formation 2 miles west-northwest of Wolf Camp, Brewster County; suture at whorl diameter 40 mm.

5–7. *Perrinites cumminsi* (C. A. White), Clyde formation.
   5. Side view, × .65, 3 miles south of Electra, Wichita County.
   6. Ventral view (after C. A. White), × .65, Military Crossing on Wichita River, Baylor County.
   7. Mature suture at whorl diameter 50 mm.

8–10. *Perrinites bösei* Plummer and Scott, n. sp. (MS.), Admiral formation, 5 miles southwest of Coleman, Coleman County.
   8. Side view, × .65.
   9. Ventral view, × .65.
   10. Mature suture at whorl diameter 30 mm.

11–13. *Shumardites simondsi* Smith, Graham formation.
   11. Side view of type (after Smith), × .65, Salt Creek 1 mile west of Graham, Young County.
   12. Ventral view, × .65, 1¾ miles due east of Fife, McCulloch County.
   13. Very mature suture at whorl diameter 75 mm.

14–15. *Shumardites fornicatus* Plummer and Scott, n. sp. (MS.), Graford formation.
   14. Side view, × .65; 5 miles west-southwest of Bridgeport, Wise County.
   15. Mature suture at whorl diameter 22 mm.

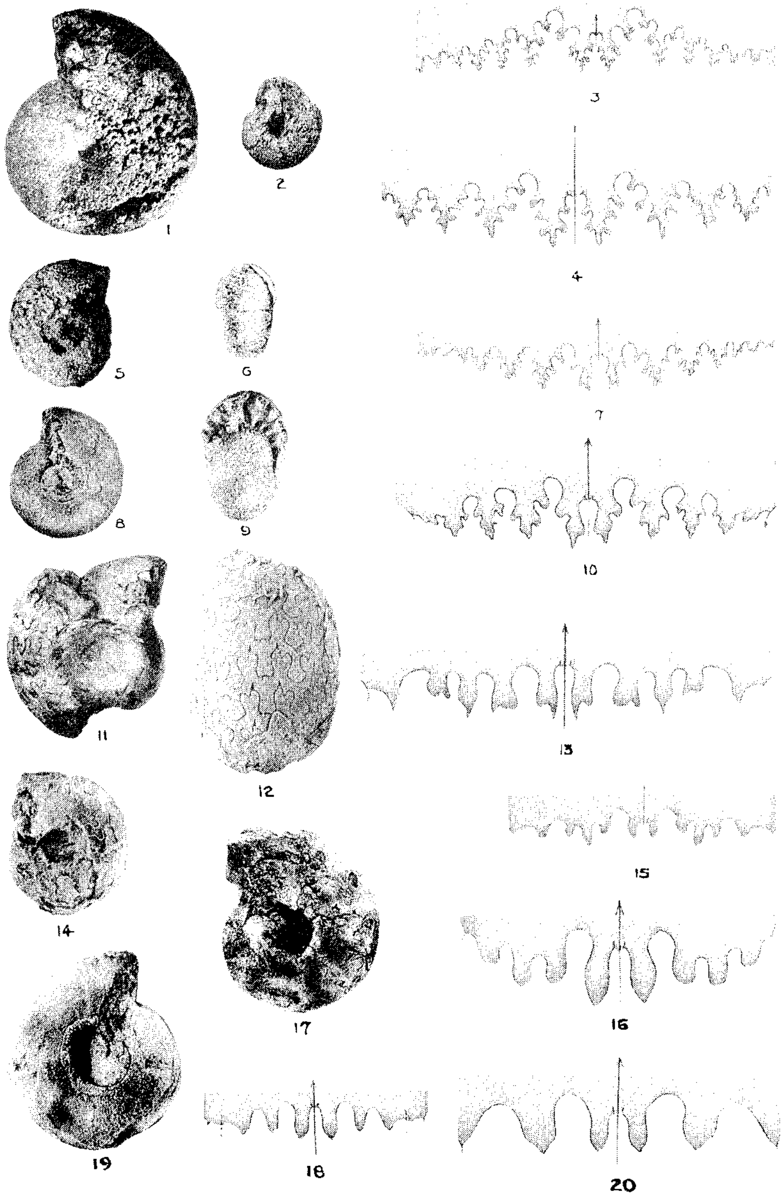
16. *Shumardites sellardsi* Plummer and Scott, n. sp. (MS.), Gaptank formation south of Gap Tank, Brewster County; suture at diameter approximately 65 mm. (specimen incomplete).

17–18. *Paralegoceras iowense* (Meek and Worthen), lower Strawn group.
   17. Side view of holotype, × .22, Alpine, Iowa.
   18. Suture at whorl diameter 103 mm.

19. *Gastrioceras* sp., × .65, Bend group, 5 miles southwest of Lampasas, Lampasas County.

20. *Gastrioceras* sp., × 1.6, Smithwick shale.

The figures illustrate a typical phylogenetic series of ammonites that lived during the Pennsylvanian and Permian periods. These evolved with sufficient rapidity so that species from one zone can be distinguished easily from those of overlying and underlying zones by the character of the suture line, which became more complex as the phyllum evolved. Species from the lower Marble Falls (fig. 19) have one lateral lobe; those from the lower Strawn (figs. 17, 18) have three; those from the Canyon and lower Cisco groups, four. In the upper Cisco the lobes develop subdivisions and become increasingly complex through the Permian (figs. 7, 10). All specimens illustrated, except those of Figures 17–18, are from Texas.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PART 2

THE MESOZOIC SYSTEMS IN TEXAS

W. S. ADKINS

During the Mesozoic era rocks were deposited in Texas in three periods, the rock systems in ascending order being Triassic, Jurassic, and Cretaceous. Based on the lead ratio of radioactive minerals, the following numbers of millions of years have been assigned (947a, p. 49) to these three rock systems:

Upper Cretaceous	33.8
Lower Cretaceous	23.4
Jurassic	14.3
Triassic	13.7

The length of time from the close of the Mesozoic to the present is given as 60 million years.

Triassic sediments occur in Texas over a wide area, including most of the Llano Estacado and parts of Pecos, Crockett, Upton, Reagan, and Glasscock counties. These beds are entirely non-marine and represent possibly less than the upper one-third (Keuper) of Triassic time. Jurassic deposits are known in Texas only in a restricted area of a few square miles near Torcer (Malone Mountain), Hudspeth County. These beds are marine and represent only a small portion of Upper Jurassic (Kimmeridgian and ?Tithonian). No Morrison or other non-marine Jurassic is yet known with certainty in Texas. The Cretaceous is extensively and rather fully developed in Texas. It was probably deposited over most of Texas, and its remaining outcrops cover nearlv one-third of the state.

The following new or emended names for stratigraphic units are used in the Mesozoic portion (part 2) of this bulletin:

	PAGE
Malone formation, *restricted* (Upper Jurassic)	254
Comanche series, *emended* (Lower Cretaceous)	272
Trinity group, *emended* (Lower Cretaceous)	284
Torcer formation (Lower Cretaceous)	286
Cedar Park member (Lower Cretaceous)	331
Pepper formation (Upper Cretaceous)	417
Tarrant formation (Upper Cretaceous)	425
Britton formation (Upper Cretaceous)	425
Arcadia Park formation (Upper Cretaceous)	425
Chispa Summit formation (Upper Cretaceous)	426, 437
Colquitt formation (Upper Cretaceous)	441, 452
Burditt formation (Upper Cretaceous)	449
Neylandville formation (Upper Cretaceous)	488, 516
Corsicana formation, *restricted* (Upper Cretaceous)	488, 516
Aguja formation (Upper Cretaceous)	505

Approximate maximum thicknesses of these Mesozoic rocks in Texas are: Triassic, 2200 feet; Jurassic, 580 feet; Cretaceous 15,500 feet.

TABLE OF MESOZOIC ROCKS IN TEXAS

		European stages
CRETACEOUS	Gulf series (marine)	Cenomanian to Maestrichtian
	Comanche series (marine)	Valanginian to Cenomanian
JURASSIC	Malone formation, restricted (mostly marine)	Kimmeridgian and ?Tithonian
TRIASSIC	Dockum group (non-marine)	Keuper

TRIASSIC SYSTEM

The Triassic Pacific sea covered considerable areas west of the present Rocky Mountains and extended southwards across central Mexico, but never reached farther east toward Texas than central Arizona. The Texas Triassic[1] is entirely non-marine, and is part of an eastward extension of red beds deposited in Arizona and New Mexico. In Texas these red beds and other materials are comprised in the "Dockum beds" of Cummins, and in certain parts of western Texas the lithologic portions of the Dockum have received separate formation names.

Triassic outcrops in Texas are almost entirely confined to the Llano Estacado, or Staked Plains, a plains area occupying the Panhandle of Texas and part of eastern New Mexico. The Llano Estacado is bounded on the east by a prominent escarpment, the "edge" or "break" of the Plains, on the west by an escarpment lying east of the Pecos and parallel to it, and on the north and south by an indefinite boundary. The escarpments contain the main Triassic outcrops and, south of Lat. 33°, the overlying Comanche rocks. The body of the Llano Estacado inside the escarpment boundary, is probably a wide,

[1]*Literature.—Panhandle:* Cummins, 340, 342, 343; Darton, 395; Baker, 42, 43, 52. *Northern Panhandle:* Baker, 42; Case, 216; Drake, 448; Gould, 615; Patton, 1180. *Southern Panhandle:* Adams, 7; Blanchard, 122; Dumble and Cummins, 467; Hoots, 841; Liddle, 991. *Oklahoma-New Mexico-Arizona:* Darton, 395; Lee, 978; Bullard, 175; Darton, A résumé of Arizona geology, Univ. Ariz. Bull. 119, 1925. Rothrock, Okla. Bull. 34, 1925. *Paleontology:* Branson, 147; Case, 224, 225, 226, 228, 229, 230, 231, 232, 233, 234, 235, 236; Cope, 306, 314, pp. 11–17; Reeside, 1292b; Simpson, 1487; Cope, A contribution to the history of the vertebrata of the Trias of North America, Proc. Amer. Phil. Soc., 24: 209–228, pls. I–II, 1887. *Mexico:* Burckhardt, 181; Burckhardt, Inst. Geol. Mexico, Bol. 21, 1902. Burckhardt, Soc. Sci. Ant. Alzate, 41:189, 1923. Kellar Ecl. geol. Helv. 21:327, 1928; Jaworski, Eine Lias-Fauna aus Nordwest-Mexiko, Abh. schweiz. pal. Ges., 48:1–12, 1 pl., 1929; Frech, Ueber Aviculiden von palaeozoischem Habitus aus der Trias von Zacatecas, 10 pp., 2 pls., Mexico, 1906. *Triassic fishes:* Case, 225; Warthin, 1710. *Faunal summary:* Von Huehne, 858a; von Huehne, Neue Beitrage zur Kenntnis der Parasuchier: Jb. preuss. geol. Landesanst. (for 1921) 42: 49–160, 1922; von Huehne, Die fossile Reptil-Ordnung Saurischia, ihre Entwicklung und Geschichte, 2 pts., 360 pp., 41 fig., 56 pl., Berlin, 1932. *Limits of Triassic:* Roth, 1353c.

shallow syncline in the Permian. This surface was beveled in pre-Dockum times, the weathered surface being a part of the Wichita Paleoplain. On it the Dockum beds were deposited. They now dip gently to the southeast. They were covered by rocks of the Comanche series, which were later removed from much of the northern Llano Estacado, and over much of the Llano Estacado by Dakota, now largely removed. In Cenozoic times a gravel mantle covered most of the area.

Dips in the Triassic beds in Texas depend in part on local structure, and at several places southeast dips have been recorded, as in the following publications:

	Locality	*Direction*	*Amount*
Drake (448)	Llano Estacado	SE	8 ft./mi.
Drake (448)	Potter, Oldham cos.	SE	15–18
Baker (42, p. 19)	Llano Estacado	SE	
Dumble and Cummins (467, p. 350)	Double Mountain	SE	slight
Patton (1180, pl. IX)	Potter County	NNE?	

Adams (7, p. 7) states that the Dockum beds were deposited in a basin which underwent folding both before and after the Triassic deposition, and intimates (7, fig. 2) that the Dockum beds dip toward the axis of this basin.

"In the southern Triassic area, the dip of the beds is very irregular because of the lenticular nature of the strata, which were laid down as river channel and flood plain deposits. The regional dip, measured on the top of the Santa Rosa, is toward the center of the Llano Estacado. This suggests that the downwarping of the Permian basin continued into the lower Mesozoic, and also that the western margin of the basin was elevated with the upfolding of the Front range" (Adams, personal communication).

Western marine Triassic.—A rather full section of the marine Triassic above the *Meekoceras* zone is known in northern California and central Nevada. In Utah, Idaho, and Wyoming, considerable sections of marine lower and middle Triassic, including the basal *Otoceras* zone (in the Woodside formation), are known. Here, and in southwestern Colorado, northern Arizona, northern New Mexico, and the Llano Estacado in Texas, the upper Triassic, known variously as Jelm, Popo Agie, Ankareh, Dolores, Chinle, and Dockum, is non-marine. In Arizona and New Mexico, the lower Triassic Moenkopi, containing *Meekoceras* near its base, is in part marine. In Zacatecas[2] and Sonora,[3] marine upper Triassic (Carnic, Noric)

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[2]Burckhardt, C., La faune marine du Trias supérieur de Zacatecas. Inst. Geol. Mexico Bol. 21, 1902.

[3]Burckhardt, C., Quelques remarques critiques sur l'ouvrage de M. W. Freudenberg, "Geologie von Mexico." Soc. Sci. Antonio Alzate, vol. 41, p. 189, 1923. Keller, W. T., Stratigraphische Beobachtungen in Sonora (Nordwest Mexico) Ecl. geol. Helv., vol. 21, 327–335, 1 map, 1928.

occurs; these and the Moenkopi are the known marine occurrences nearest to Texas.

Economic Products: Glass sand is known in the Triassic from the Trujillo formation (1180, pp. 105–107). Some clays from the Tecovas suitable for certain grades of tile and brick have been tested (1180, pp. 108–109). Gravels, sands and hard sandstones from the Triassic can be used for road metal. Near the outcrop several Triassic sands bear fresh water.

DOCKUM GROUP

Nomenclature.—The entire known Triassic in Texas, non-marine and probably Upper Triassic in age, is included in the Dockum group. Cummins, in 1890 (340, p. 189), described and named the "Dockum beds" (type locality, Dockum, western Dickens County, Texas), and in a second report (342, pp. 424–431) stated their age as Triassic. Drake (448, pp. 227–247) studied and correlated the Triassic along a section from Big Spring northwards to near Amarillo, and thence westwards to near Tucumcari, and subdivided it into three units. Hoots (841) and Adams (7) later made studies near the southern end of Drake's section. At the northern end of Drake's section in Oldham and Potter counties where Drake's upper shale member is absent, Gould (615) subdivided the Dockum beds into two formations: a basal shale (Tecovas; type locality, Tecovas Creek, western Potter County), and an upper sandstone and shale (Trujillo; type locality, Trujillo Creek, western Oldham County). These formational differences, as well as other stratigraphic names (Barstow, Quito, Camp Springs, Dripping Springs, Taylor), indicate local lithological variations in non-marine deposits.

Stratigraphy and Contacts.—Dockum beds in Texas overlie Permian formations at all points, unconformably according to most observers. The main evidences for unconformity are: (a) the Dockum is Upper Triassic (Keuper) and the area apparently was not receiving deposits in the Lower and Middle Triassic; (b) there is a discordance in dip between Permian and Triassic; and (c) unconformities are visible at many places. Baker (42, p. 19) says: "An unconformity between the two formations (Permian and Triassic) is denoted by a slight difference in dip, which in the Triassic is nearly always in a southeasterly direction, and is generally less than the dip of the Permian. On the east side of the Llano the dips of the two formations are in opposite directions. In many places, but not everywhere, there is a pronounced erosion unconformity between the Permian and the Triassic." Gould (615, p. 21) records that locally on Trujillo Creek the upper red shales of the Quartermaster (Permian) have been removed down to the Alibates dolomite lentil, and that throughout the region, although very little Permian has been subsequently removed, the Triassic lies unconformably upon it. However, there are no fossils near the contact, the beds on both sides of it are in general similar (except for some color differences), and some writers have stressed the gradational appearance of the boundary. Thus Case (228, p. 9) states that he has repeatedly crossed the boundary in every county in Texas where it occurs, and has been unable to draw any line that can be used to separate the two formations. The Triassic red beds are more shaly than those of the Permian, and in general contain some gypsum, which may occur in beds of from a few inches to as much as 3 feet thick, or may be in the form of fine seams running in all directions through the red sandy clay. From the Canadian Valley south to beyond Big Spring the intermediate beds are capped by a grit and conglomerate, which is at most places overlain by Tertiary deposits with well rounded quartz pebbles.

The Dockum beds in Texas are unconformably overlain by Comanchean or Cenozoic. In northeastern New Mexico and in the western part of the Oklahoma Panhandle they are generally overlain by Wingate (Jurassic) sandstone or by Morrison beds (Upper Jurassic).

Subdivisions.—Correlations of the Texas Triassic are attended with many difficulties. In the absence of zonal fossils, criteria used for correlation have been mainly stratigraphic and lithologic. The proposed units of the Triassic in Texas may be arranged as follows:

Eastern New Mexico (Darton, 395)	Southern Panhandle (Adams, 7)	Southern Panhandle Hoots (841)	Central Panhandle (Drake, 448)	Northern Panhandle (Gould, 615)
Chinle shales	Chinle shales	Upper red clay	Sandy clay, some sandstone	(thin or absent)
"Santa Rosa" sandstone	"Santa Rosa" sandstone	Basal red clay and sandstone	Sandstone and conglomerate, some clay	Trujillo sandstone and shale
(generally absent)	Basal shales	(generally absent)	Sandy clay	Tecovas basal shale

Roth (1353c) has proposed that his Custer formation, with material formerly considered the upper part of the remaining Permian be considered lower Triassic. A portion of his proposed correlation follows:

	Grand Canyon	Southeastern New Mexico	Central-northern Texas (Panhandle)
Upper (Keuper)	Chinle Shinarump	Dockum [Chinle Santa Rosa	Dockum [Trujillo Tecovas Camp Spring cgl.
Middle (Muschelkalk)	*absent*	*absent*	*absent*
Lower (Bunter)	Moenkopi	Red beds Rustler Castile	Upper Double Mtn. [Custer Channel ss. locally at base

Mode of deposition: Darton[4] states that there is no evidence that the Dockum beds are in any part marine, and that they are probably deposits of the flood-plain or braided stream type, somewhat like the Great Plains formation. Presumably the Llano Estacado in lower and middle Triassic times was an area of denudation, and became markedly a plain of aggradation only during Dockum (upper Triassic) time. The extent of lake deposits, if any, in the Dockum beds is still an open question. Baker (42, p. 14) considers that the Dockum beds represent "deposits laid down on a land surface, mainly by rivers." Lee (978, p. 10) states that, in the later Triassic, "some change in the relation of highlands and lowlands was effected, which caused the streams to spread out, over a wide area, the sand, gravel, and mud of the Shinarump conglomerate and other rocks of late Triassic age, both west and east of the mountains." Case (228, pp. 10–11) states that "the more uniformly deposited beds of clay and shale were apparently laid down in deep water or in water far from the shores; it is only in the disturbed beds, which bear evidence of having been deposited by great flood washes, that the remains of animals and plants have been found." The Tecovas clays generally lack fossils, except wood; the Trujillo sands and conglomerates contain vertebrate and molluscan remains. "It is only in the irregular beds which were deposited in stream channels and local pools that any remains are

[4]Personal communication.

found" (Case). For conditions of deposition, see also: Hoots, 841, pp. 125–126, and Branson, 147.

Source of materials.—From the supposed location of Triassic shore lines and from the regional thickening and size gradation of the conglomerates, it has been assumed that the source of supply of the non-marine Triassic in New Mexico and Texas centered around south-central Colorado. The Triassic in Texas thickens and coarsens toward the northwest. Baker has supposed that the coarse micaceous sandstones and conglomerates, composed generally of smooth, water-worn quartz, granite and limestone pebbles, may have originated from the Rocky Mountains or from the Wichita Mountains in Oklahoma. The Triassic red clay and clay-ball conglomerate likely came from the underlying Permian.

In contrast to a northwestern source of materials in the Dockum beds in the northern Llano Estacado as supposed by Baker, Adams says that "in the southern areas in Texas an eastern and southern source appears more probable. The coarseness of materials on the east side of the basin compared with the center suggests an eastern source for the material, possibly from the exposed Pennsylvanian conglomerates. The Triassic gravels were possibly reworked from the exposed edges of the Pennsylvanian and Permian beds or from the same source as to the older gravels" (personal communication).

Lithology.—Adams has summarized the more usual and striking lithologic features of the Triassic as contrasted with the Permian in the southern area. Among the more useful are the poor lithification of Triassic shales as compared to the hardness and compactness of Permian shales, the heterogeneous sandstones of the Triassic as compared to the very fine sandstones of the Permian, and the presence of bones, gravel, limonitized and silicified wood, and abundant mica in the Triassic. Bedded anhydrite and salt occur in the Permian, gypsum and anhydrite occur in the Triassic in only minor amounts. Beds of very fine sandstone are rare in the Triassic, common in the upper Permian. Uncolored, well rounded, frosted quartz grains are common in the Permian; colored, subrounded, partially frosted quartz grains generally distinguish the Triassic. The clastic sediments of the Triassic are more heterogeneous than in most Permian formations, and subangular gravel, ranging from fine to coarse, is common in the Triassic. The abundance of water sands, mica, phosphate, limestone, and calcareous shale and sandstone is generally more indicative of the Triassic. Marine fossils, detrital limestone and *Chara* oogonia are more indicative of the Comanche series.

The deep maroon color characteristic of the southern Triassic shales is very rare in the Permian. Impalpable shales, common in the Triassic, are very uncommon in the Double Mountain (Permian) beds (Adams, personal communication).

In the northern Panhandle, color distinctions seem more valuable than in the Pecos Valley region. The color features of the Tecovas and Trujillo have already been mentioned. Baker lists the following as the more characteristic features of the Triassic: mica, conglomerate, color of sandstones (gray, brown), color of shales (variegated, in contrast to the brick-red of the upper Permian), extensive cross-bedding, and unconformities. Certain reptilian bones and species of Unio mark the Triassic.

Paleontology.—(a) Invertebrates are limited to Unios, so poorly preserved as to be specifically indeterminable. Four species have been described from Dickens and Garza counties (Simpson, 1487; see also Reeside, 1292b).

(b) Fossil wood was found to have been so badly rotted before fossilization and so deeply impregnated with gypsum as to destroy the cell structure (228, p. 8). Locally lignite occurs.

(c) Vertebrates have been studied by Cope, Case, Branson, Mehl and others. The reptiles Phytosauria, dinosaurs, Parasuchians (crocodiles); amphibians (Stegocephalia); a fish (*Ceratodus dorotheae* Case, 225); and other forms have been described from the Dockum beds or their equivalents. Most of these fossils are restricted to the Triassic, but their value for minute zonation is unknown. No marine invertebrates are recorded from the Texas Triassic, but the lower Triassic (Moenkopi) in Arizona contains *Meekoceras* and other mollusca.

Some Fossil Vertebrata from the Western Triassic

(Species described from Dockum beds indicated by*)

Ceratodus crosbiensis Warthin (1710)*
Ceratodus dorotheae Case (225)*
Macropoma sp. Warthin (1710)*
Metoposaurus jonesi Case*
Metoposaurus fraasi Lucas
Buettneria perfecta Case*
Buettneria bakeri Case*
Typothorax coccinarum Cope
Eupelor sp. Cope*
Desmatosuchus spurensis Case* (224, 226)
Coelophysis sp. (230, 231)
Phytosaurus doughtyi Case
Machaeroprosopus andersoni Mehl
Ptomystriosuchus ehlersi Case*
Leptosuchus crosbiensis Case*
Leptosuchus imperfectus Case*
Dinosaurs, indet. Case*
Cf. Phytosaurus sp. Case (232)*
Palaeoctonus cf. P. orthodon Cope*
Palaeoctonus dumblianus Cope*
Episcoposaurus haplocerus Cope
Belodon superciliosus Cope*
Clepsysaurus sp. Cope*

Mollusca described from Dockum beds

Unio subplanatus Simpson*
Unio dumblei Simpson*
Unio dockumensis Simpson*
Unio graciliratus Simpson*

Thickness and Dip.—In the southern Llano Estacado the general Triassic dip is to the southeast, averaging 8 feet per mile. In Oldham and Potter counties it is 15–18+ feet per mile. The outcrop thicknesses are less than those preserved in the central syncline of the Llano Estacado, where as much as 1200 feet has been recorded. The following are some recorded Triassic thicknesses in west Texas:

	Feet
Eastern Randall County	400
Potter County (average)	225
Western Oldham County	135
Eastern Howard County	500–600
Southeastern Crane County	95+
Southern area	450±
Midland County (Bryant well)	1200?
Martin County (Wolcott well)	1100?

Mr. J. E. Adams has very kindly supplied the following approximate thickness of the Triassic in Texas:

	Feet
Andrews County (central)—	
Deep Rock 1, Kuykendall	1520
Bailey County (western)—	
Humble 1, Fuqua	2160
Cochran County (central)—	
Penn 1, Slaughter	2125
Crockett County—	
Magnolia 1, Hoover (central)	210
Powell pool (north-central)	320
Crane County—	
McElroy pool (eastern)	690
Waddell pool (northern)	850
Dawson County (eastern)—	
Magnolia 1, Jeter	1290
Ector County—	
Judkins pool (south-central)	730
Exploration 1, Slater (west-central)	1280
Stanolind 2, Cowden (northern)	1590
Floyd County (western)—	
Exploration 1, Boone	760
Gaines County (southwestern)—	
Humble 1, Carswell	1480
Garza County—	
Gulf 1, Slaughter (southwestern)	620
Marland 1, Pippin (northwestern)	560

	Feet
White Eagle 1, Dunbar (south-central)	585
California 1, Settles, Settles pool (northern)	840
Penn 1, Habenstriet (western)	840
Hale County (northern)—	
Exploration 1, Goodman	1260
Howard County—	
Sinclair 1, Dodge (eastern)	715
California 1, Fisher (central)	1715
Phillips 1, Thomas (north-central)	800
Marland 1, Quinn (western)	865
Irion County (northwestern)—	
Fuhrman 3, Sugg	220
Lamb County (eastern)—	
Graham 1, Elwood	1405
Martin County (northern)—	
Phillips 1, Slaughter	1330
Midland County (southeastern)—	
Pure 1, Hutt	1215
Mitchell County—	
Foster pool	950
Westbrook pool	450
Thraves 1, Sanders (eastern)	400
Pecos County—	
Yates pool	35–65
Vacuum, Elsinore	225
Phillips 1, Pryor (northwestern)	340
Phillips 1, Nutt (24 mi. NE. Ft. Stockton)	140
Dixie 1, Hershenson (western)	210
Sun 1, University (SE. of Taylor-Link pool)	290
Terry County (northeastern)—	
Penn 1, Carlysle	2230+
Upton County—	
Shell, Halamiceke (central)	1135
Atlantic 1, Live Stock Exchange (eastern)	1000
Winkler County—	
Llano 1, Scarbrough (northern)	725
Llano and McCamey 1, Cowden (eastern)	900
Yoakum County (southwestern)—	
Weekly 1, Knight	1860

AREAL GEOLOGY

Contacts.—The Dockum beds overlie Permian strata at practically all points on the Texas outcrop and in wells. The Permian was generally eroded and beveled before the deposition of the Triassic so that the Triassic rests on a beveled Permian surface, the strata of which range in age from basal Double Mountain to the local top of the Permian.

The Triassic is unconformably overlain by marine Comanche series or by non-marine Cenozoic.

The Dockum beds underlie practically the entire Llano Estacado south of the Canadian River valley, and probably extend, at least sporadically, farther north, for they occur in the Cimarron and North Canadian valleys in the Oklahoma Panhandle.[5] They outcrop in the east and west escarpments of the Llano Estacado, in outliers such as Double Mountain, and in the deep valleys cutting into and across the Plains; on the main body of the Llano Estacado they are folded in a syncline and buried beneath Cenozoic sands and gravels, or south of Lat. 33°, beneath Lower Cretaceous. Farther east they are unknown; and the eastward limit of their deposition is unknown. In eastern New Mexico, east of the Pecos

[5]Kansas Geological Society, fourth Annual Field Conference, general geological map, 1931; Rothrock, Okla. Geol. Surv., Bull. 34, 1925.

and south of the Canadian, the Triassic has extensive outcrops; and westward it thickens into Arizona and the basal formation (Moenkopi) becomes in part marine. Darton (395, p. 32) considers the Lobo formation, red and gray shales, pinkish limestone, and conglomerates, in the Deming area, as possibly Triassic.

SOUTHERN LLANO ESTACADO

In southeastern New Mexico the Triassic is stated to be composed of (a) a basal shale; (b) a medial sandstone (Santa Rosa); and (c) an upper shale. The basal shale disappears south of the Canadian Valley, leaving the medial Santa Rosa sandstone resting directly on the Permian. Adams (7, p. 1052) adopts the name Santa Rosa[6] for the medial sandstone and the name Chinle[7] for the upper shale, which he states disappears in the southern part of the Texas Triassic area, leaving the Santa Rosa as the sole representative of the Triassic in Pecos, Crockett, Irion, Sterling, Mitchell, Scurry, Fisher, Nolan and Coke counties. Hoots (841, pp. 86–96) in describing the same area, divides the Dockum beds into (a) basal red clay with numerous gray sandstone seams (275— feet); (b) upper red clay (maximum 175 feet). These may correspond to Adams' Santa Rosa and Chinle respectively, assuming that the sandstones and conglomerates are more segregated in one part of the section. Locally in this area the basal Triassic seems to consist of red clay. At other places a basal Triassic conglomerate is called *Camp Springs* (type locality, Camp Springs, near the center of the east line of Scurry County) by Beede and Christner (97, pp. 16–17). Also the upper red clay locally contains some sandstones.

In the southern area, Drake considered his three divisions to be present, but the basal shale is absent in many sections, as noted by Hoots, Adams, and others. The Santa Rosa can be traced from New Mexico southeastward into this area. At Red Point, southeastern Crane County, Hoots records about 95 feet of Dockum beds, consisting mostly of cross-bedded and partly micaceous sandstones, light gray, light brown, grayish-brown, light red, red and green streaked, with some red and light brownish-red sandy clay, and a little conglomerate containing rounded quartz pebbles. In northeastern Loving County and in Ward County, according to Hoots,

[6]Described from near Santa Rosa, N. M., by N. H. Darton, U. S. G. S., Bull. 726-E, p. 183. The name is preoccupied by Santa Rosa of Dollfuss and Montserrat, 1868, from Nicaragua.

[7]Described from Arizona by H. E. Gregory, U. S. G. S., P.P. 93, p. 42, 1917.

the lower Dockum consists of 40–50 feet of the main sandstone (quarried at Quito), which is red and gray, cross-bedded, and locally ripple-marked, underlain by sandy clay and sandstone. In eastern Howard County, Hoots gives a section of 283+ feet of Dockum beds, about three-fourths being dark red clay, and one-fourth being light gray or gray-green sandstone with some conglomerate containing fragments of gray limestones and pebbles up to 2 inches in diameter. In Scurry County, Hoots records at the top of the Dockum beds as much as 150 feet of dark red clay, only slightly sandy and with no bedding; and in Borden County, in addition, a small thickness of greenish-gray, cross-bedded, very micaceous sandstone. In these counties greenish-gray, micaceous, cross-bedded sandstone is common in the basal Dockum beds; and the top part consists largely of dark red clay with only sporadic sandstones. Farther west on the Pecos the sandstones seem more widely distributed in both base and top, and redder. They are massive, of medium texture, cemented with iron oxides, and interspersed with some thin conglomerate lenses. The outcrop reveals only a small portion of the Dockum thickness, for in wells in Midland and Martin counties the Dockum is thought to have a thickness up to 1200 feet, if all fresh-water sandstones are included, the greater part of this thickness being shale or sandy shale. In eastern Crosby County (216, p. 248) the Dockum beds consist of thin bluish-green sandstone at the base, followed by about 130 feet of light brown, white, red, and maroon clays, capped by 5–20 feet of fine, cross-bedded conglomerate. The basal part of the clay contains Unios, vertebrates, and fossil plants. Thence northwards to the Canadian Valley, Drake records his upper shale as absent.

The southern boundary of the Triassic occurs in part on the surface, in part underground. It is stated approximately to follow the east bank of the Pecos downstream from the New Mexico-Texas line, past Quito quarry to eastern Reeves and northern Pecos counties. It outcrops near Grandfalls, and occurs underground in northern Pecos County but is not now considered to be present under most of Reeves County. It is absent in the Sierra Madera, crosses the Pecos near Sheffield, is present in the Yates (707) and Big Lake (1414) oil fields. Thence it passes northeast to northeastern Sterling County, includes much of Mitchell, Scurry and Borden counties, and thence follows the scarp of the Llano Estacado northward to the Canadian River valley. In the northern Texas Panhandle it is not exposed. Farther north the Triassic is exposed in the Cimarron Valley in Cimarron County, Oklahoma, where the section consists of Permian, Triassic, Jurassic (Morrison), basal Comanche, Dakota and Cenozoic; in this county 2000 feet of red beds of undetermined age is known, the exposed upper part being Triassic by correlation into New Mexico.

CENTRAL LLANO ESTACADO

Drake's (448) general section was carried from Signal Peak, 10 miles southeast of Big Spring, Howard County (section given by Hoots, 841, p. 106), northwards through Amarillo to near Tucumcari, New Mexico. He divided the Dockum into three parts: (a) lower sandy clay (maximum 150 feet); (b) medial sandstones, conglomerates and some clays (maximum 235 feet); (c) upper sandy clay and some sandstone (maximum 300 feet). Drake states that his lower clay thickens from Big Spring northwards along the eastern part of the Llano Estacado to Amarillo, and thence westward to Tucumcari. The medial sandstones (Santa Rosa of some authors) thicken to a maximum of 225 feet in Armstrong County, and thence westwards thin rapidly to 25 feet near Tucumcari. Near Amarillo they apparently form one bed. Drake's basal shale is apparently the same as Gould's Tecovas; Drake's medial sandstone the same as Gould's Trujillo (1180, pp. 48, 66–67). Drake's upper shale (called Chinle by Adams), present in the southeastern Llano Estacado as far north as Garza County, is missing from Garza County northwestward to Oldham County, and thence westwards gradually thickens until at Tucumcari it reaches a thickness of 300 feet. The following table expresses these proposed equivalencies:

	Southern Llano Estacado	Central Llano Estacado	Canadian Valley in Texas	Tucumcari region
CHINLE	Drake's upper clay, thick	(thin)	(absent)	(300 ft.)
TRUJILO	Drake's medial sandstone and conglomerates	(present)	(present)	(present)
TECOVAS	Drake's basal clay (thin)	(thin)	(65–115 ft.)	(present)

However, because of the irregular and lenticular deposition, the above equivalences are by no means certain.

NORTHERN LLANO ESTACADO

In the northern section, including the Canadian Valley, Gould (615) divided the Dockum beds into two formations: basal part, largely shale, called the Tecovas formation; and upper part, including from one to five prominent sandstone ledges, the Trujillo formation.

The Tecovas typically consists of two parts: (1) a basal member of vari-colored shales, including generally a lower zone of white, gray or lavender, a middle zone of maroon or wine color, and an upper zone of light yellow or sulphur-yellow color (total 70–700 feet in Palo Duro Canyon, 15–40 feet along Canadian River); and (2) an upper magenta shale (120–150 feet in Palo Duro Canyon, 50–75 feet on Canadian River). The brick-red color of the Quartermaster shale (Permian), the lavender, maroon, and yellow of the lower Tecovas variegated shales, and the magenta of the upper Tecovas, form a characteristic color contrast in this area. Locally the variegated shales are represented by a characteristic, soft, friable, massive, white, yellow or light brown sandstone weathering into distinctive rounded or dome-shaped masses.

The Trujillo formation consists of one to five or more, but typically three, sandstone or conglomerate ledges with interbedded red and gray shales. On Trujillo Creek the section is as follows (216, p. 253):

4. Conglomerate, the pebbles variable in size and character; locally replaced by sandstone, occasionally by arkose; contains thin layers of clay and shale; generally grayish, but locally reddish; locally overlain by red sandstone.
3. Thin, blue, sandy clay.
2. Red clay, with some blue streaks, some calcareous material, and, near the bottom, shaly layers with worm casts (250 feet).
1. Sandstones and shaly layers with Triassic bones. This layer can be traced westward to Tucumcari and Montoya.

The lower sandstone (615, pp. 26–29) is 60–75 feet thick in Palo Duro Canyon, but only 25 feet thick on the Canadian; it is massive and resistant, and weathers into pedestal forms. Above a 15–60 foot bed of red or gray shale is the middle sandstone ledge, 10–40 feet thick. It is a coarse, heavy, cross-bedded, red or gray sandstone, or a cross-bedded, lenticular conglomerate (pebbles of granite, quartz, sandstone, clay and limestone) with pockets and lenses of clay. Locally the ledge consists of small fragments of clay or limestone imbedded in a matrix of sandy clay. At places where pre-Tertiary erosion has not cut so deep, there is a third upper sandstone-conglomerate ledge lithologically like the second (in Palo Duro Canyon 30 feet). The three sandstones locally are divided by clay partings or lenses; the upper two contain Triassic bones. Down the Canadian in Potter County (1180, pp. 66–77) the Trujillo is generally represented by one sandstone and conglomerate ledge 10–25 feet thick or more. It contains fragments of bone and silicified wood.

The Double Mountain outlier in southwestern Stonewall County has 35 feet of "purple, red and mottled sands which pass at the bottom into a conglomerate of bright-colored pebbles" (Dumble and Cummins, 467, p. 350). Similar pebbles occur throughout the sands in nests, in strata, or singly. The formation lithologically resembles the Trujillo. It has a slight dip to the southeast.

Subsurface extent.—Probably the entire Llano Estacado interior to the outcrop and south of the Canadian Valley is underlain by Dockum beds. These reach a thickness of as much as 1200 feet and are deposited generally in a broad, shallow syncline.

JURASSIC SYSTEM

The North American continent during the Jurassic, as during the Cretaceous period, was invaded by three seas: Pacific, Arctic, and Gulf. Only the last two concern Texas. A branch of the Arctic sea known as the Logan (Sundance, Argovian) Sea extended southwards along the site of the Rocky Mountains to Colorado. In late Jurassic times, the non-marine Morrison formation was deposited in the dried-up bed of this sea and extended south of it to the north tip of the Texas Panhandle. The Gulf sea, advancing northwards along the southern extension of the Rocky Mountain geosyncline between the sites of Jurosonora and Jurolaurentia, covered parts of northern and central Mexico and reached as far as Malone Mountain, leaving deposits of upper Jurassic age in Texas over only a few square miles in Hudspeth County.

Near the end of the Jurassic (Tithonian, "Lower Berriasian"), the continent had largely emerged and its southern shore was an irregular line in northern Mexico running from the tip of the Big Bend gulfwards and parallel to the Rio Grande. The Cretaceous seas transgressed northwards from this shore line (133a, 181, 334).

In the following discussion the marine Jurassic Malone beds and the non-marine Morrison formation adjacent to Texas are briefly reviewed.

MARINE JURASSIC IN TEXAS

MALONE FORMATION[8] (restricted)

Nomenclature.—Cragin (328,331) applied the name "Malone formation" to rocks of both upper Jurassic and lowermost Cretaceous age, which outcrop near Malone (now Torcer) station on the Southern Pacific Railway, southwestern Hudspeth County, Texas. The name Malone, in accordance with Cragin's apparent intention, is here restricted to that portion of these rocks which is of Jurassic age. These beds are only a small terminal residue of Jurassic strata of much greater extent which were deposited in a northwardly narrowing arm of the Kimmeridge sea in north-central Mexico, and must be considered in relation to these more extensive Mexican deposits (excellently reviewed by Burckhardt, 181).

Stratigraphic position and contacts: The Malone beds rest unconformably upon Permian strata (46, p. 11). Baker and Beede found *Richthofenia* in the limestone overlying the gypsum at a locality ½ mile north-northeast of Torcer station. Near Torcer they found about fifteen Permian species, including ammonoids, and in the conglomerate above the limestones, limestone boulders containing *Fusulina elongata.* Regarding the unconformity Baker says:

> The Permian gypsum . . . is overlain by a heavy limestone and chert conglomerate with brown chert as a part of the matrix-cementing materials. Boulders in the conglomerate are as large as 8 inches in diameter. Two of the limestone boulders contained *Fusulina elongata.* This conglomerate is apparently the basal bed of the Jurassic. Above come mainly limestones with some conglomerates and brown sandstones; the limestones locally contain chert

[8]*Literature.—Northern Mexican Jurassic:* Castillo and Aguilera, Fauna fosil de la Sierra de Catorce, San Luis Potosi. Com. Geol. Mex., Bol. 1, 1895. Burckhardt, 181; Böse, 133a; Burckhardt, La faune jurassique de Mazapil avec un eppendice sur les fossiles du crétaceque inférieur, Inst. Geol. Mexico, Bol. 23, 1906; Burckhardt Nuevos datos sobre el jurásico y el cretácico en México, Inst. Geol. Mexico, Parerg., 3: 281–301, 1910; Burckhardt, Neue Untersuchungen über Jura und Kreide in Mexiko, Centr. Min., 1910: 622–631, 662–667; Burckhardt, Faunes jurassiques et crétaciques de San Pedro del Gallo, Inst. Geol. Mexico, Bol. 29, 1912. Baker, C. L., General geology of Catorce mining district (San Luis Potosí, Mexico), Trans. A. I. M. E., 66:42–48, 1922. *Malone beds:* Baker, 46, 55; Böse, 133a; Burckhardt, 181; Cragin, 328, 331; Crickmay, 334; Gillet, 586; Haug, 673; Kitchin, 944; Spath, 944; Stanton, 331; Taff, 1573; Udden, 1652; Uhlig, 1674, 1674a. Dacqué, E. Die Stratigraphie des marinen Jura an den Rändern des Pazifischen Ozeans, Geol. Rundschau, 2: 464–498, 1911.

pebbles. The gypsum here is apparently overlain on its eastern side with a southeastward-dipping brown sandstone with brecciated pebbles, upon which rests a blue limestone.

The Malone formation, mostly of Kimmeridge age, is overlain, with an inferred unconformity, by Valanginian Cretaceous. Baker states that at the northwest end of Malone Mountain, near Briggs spur, the gypsum is overlain by about 200 feet of conglomerate and light brown conglomeratic sandstone, and above this by gray fossiliferous limestone with interbeds of light brown conglomeratic and quartzose sandstone, the pebbles of which are quartz and chert. In a sandstone near the top of this ridge Baker found an *Astieria*, indicating early Cretaceous age, but the amount of strata at this locality which are probably Jurassic has not been determined.

Lithology.—The Malone Jurassic consists mostly of conglomerates, brown sandstones and limestones. The sandstones are in part conglomeratic, with well rounded limestone and chert pebbles. Some of the limestones contain chert pebbles. The conglomerates contain pebbles of various materials, including limestone boulders. The section contains a subordinate amount of shale. Both lithology and position of the Malone in the narrow arm of the Jurassic sea indicate a near-shore facies.

Fossils, Age, Correlation.—The age of these deposits has been discussed by Stanton (331), Cragin (321), Burckhardt (181), Baker (46), Uhlig (1674), Kitchin (944), Böse (133a), Spath (944), Gillet (586), Haug (673), and others.

Uhlig (1674, p. 69) says: "Of the ammonites of this fauna, *Perisphinctes potosinus* Castillo and Aguilera, *P. felixi* C. & A., and *P. schucherti* Cragin belong to Burckhardt's genus *Idoceras,* and *P. aguilerai* Cragin and *P. clarki* Cragin to the group of *P. victoris* Burckhardt or to the genus *Kossmatia* Uhlig."

Kitchin (944, pp. 457–458) says:

The Jurassic age of the ammonites described by Cragin cannot be questioned. The opinion of so eminent an authority as Uhlig should scarcely need confirmation, but in view of the mixed character of the described fauna, its partial misinterpretation by Cragin, and its discrepant indications of geological age, I have asked Dr. L. F. Spath if he can give a confirmatory opinion based on an examination of Cragin's figures of the ammonites. Dr. Spath kindly informs me that he sees nothing among the illustrations to suggest a Cretaceous age. He is able, in fact, to confirm Uhlig's reading, remarking that the predominant forms of *Idoceras* are certainly Middle Kimmeridgian, while "the *Haploceras,* *'Olcostephanus'* (=*Lithacoceras* of what I called the *cystettensis-fructicans* group) and *'Aspidoceras' (Simaspidoceras?)* may well be of the same age or Upper Kimmeridgian. The doubtful *'Perisphinctes aguilerai'* could only be a little later, possibly even a Tithonian *Kossmatia* (*pronus* zone of my Somaliland zones)."

Thus all the ammonites recorded from Malone, except Baker's *Astieria*, are Jurassic; and all the Trigonias are Cretaceous. However, it is to be noted that large, poorly preserved ammonites associated with *Trigonia vyschetzkii* and other Cretaceous fossils occur at the south end of Triple Hill in the flat east of Torcer station. The fossils at this locality are exclusively Cretaceous.

Jurassic in northern Mexico.—Recorded Mexican marine Jurassic localities nearest to Texas are: Placer de Guadalupe, Santo Domingo, Cuchillo Parado, Sierra Rica, San Marcos, Alamos, Monterrey-Saltillo, and Sierra de Cruillas (181, pp. 101, 266). In the Altar and Hermosillo districts, Sonora, crinoid fragments, some referred to the Oxfordian, have been recorded (181, p. 82). Liassic has also been recorded from Sonora.[9] The following zonal parallels exist between northern Mexican localities and Malone in the upper Jurassic:

	Northern Mexico	Malone
TITHONIAN ("Lower Berriasian," Purbeckian)	Steueroceras Hoplites aff. Köllikeri Kossmatia Proniceras	Kossmatia aguilerai
PORTLANDIAN	Aulacosphinctes Mazapilites Waagenia	?
KIMMERIDGIAN	Haploceras fialar Idoceras	Haploceras Lithacoceras Simaspidoceras? Idoceras spp.
ARGOVIAN DIVESIAN CALLOVIAN		

The recent discovery in the Sierra de Cruillas southeast of Burgos and about 100 miles southwest of Brownsville, Texas, of upper Portlandian marls containing *Kossmatia* spp. (181, p. 266) makes it probable that Jurassic sediments underlie a part of the southern

[9]Keller, W. T., Stratigraphische Beobachtungen in Sonora (Nordwest-Mexico), Ecl. geol., Helv., 21: 327–336, one map, 1928. Jaworski, E., Eine Lias-Fauna aus Nordwest-Mexiko, Abh. schweiz. geol. Ges., 48: 1–12, one plate, 1 map, 1929.

Coastal Plain of Texas. No direct evidence of such strata has yet come to light in Texas. In deep wells in northern Louisiana, marls bearing foraminifera have been conjectured to be of Jurassic age, but so far on insufficient grounds.

Facies, Source of Material.—The Malone exposures are exceptionally isolated in Texas; the nearest known marine Jurassic is near Cuchillo Parado on the Conchos, west-southwest of Presidio, though intervening exposures will doubtless come to light with further search. Here the Jurassic is comprised of Burrows' Plomosas formation bearing deposits of zinc, lead, and copper, and composed of 1150 feet of quartzites and limestone basally, a 60-foot conglomerate medially, and superiorly shales and limestone. Probably in the mountain ranges west of Pilares other similar exposures will be found. The Malone section is even more marginal in character, as its frequent conglomerates attest. Besides, the upper part of the Malone section contains, alternating with marine sediments, beds containing fresh-water fossils, in the following sequence: (1) fresh-water limestone with *Viviparus* and *Unio;* (2) gray limestone with *Kossmatia aguilerai* (Cragin) of upper Portlandian (Tithonian) age; (3) conglomerate with chert and quartzite pebbles; (4) limestone with fresh-water fossils. At present there is no evidence that this arm of the Mexican Jurassic sea extended north of Malone Mountain. Baker (55) even suggests that the Malone mass was overthrust into Texas over the lubricating layer of Permian gypsum, from locations farther west in Chihuahua.

NON-MARINE JURASSIC ADJACENT TO TEXAS

The non-marine Upper Jurassic Morrison beds[10] are mapped[11] as extending eastwards beneath the northwestern margin of the Llano Estacado practically to the northwestern corner of Texas. They have never been reported from Texas, but the fact that they are

[10]*Literature.*—Simpson, George Gaylord, The age of the Morrison formation, Am. Jour. Sci., (5) 12: 198–216, 1926. Simpson, George Gaylord, The Fauna of Quarry Nine. American Terrestrial Rhynchocephalia, Am. Jour. Sci. (5) 12: 1-16, 1926. Schuchert, Charles, Age of the American Morrison formation and East African Tendaguru formations, Bull. Geol. Soc. Amer., 29: 245–280, 1918. "Morrison Symposium," Bull. Geol. Soc. Amer., 26: 295–348, 1915. Crickmay, C. H., 334, pp. 91–93. Kitchin, F. L., On the age of the Upper and Middle Deinosauer-deposits at Tendaguru, Tanganyika Territory, Geol. Mag., 66: 193–220, 1929. Parkinson, John, The dinosaur in East Africa, 192 pp., Witherby, London, 1930.

[11]Mook, Charles Craig, A study of the Morrison formation, Ann. N. Y. Acad. Sci., 27: 39–191, pl. VI, 1916. Lee, Willis T., 978.

known in northeastern New Mexico[12] and in Cimarron County, Oklahoma,[13] only a few miles from the Texas line, makes it appear possible that they will be found, perhaps with Upper Cretaceous formations, in synclines in the northern Llano Estacado.

Recent field work by C. L. Baker has disclosed probable Morrison, Purgatoire, and Dakota outcrops in northern Dallam County, in the northwestern corner of Texas (compare Gould, 615, p. 30). Baker has kindly furnished the following notes on this area (see also page 283):

Rocks lithologically like the Morrison are exposed in a small tributary of Spring Gully, near Buffalo Spring (XIT ranch headquarters), about 17 miles east of the northwest corner of Texas and ½ mile south of the Texas-Oklahoma state line. Here there occur, interbedded with each other, dark blue-gray mudstone stained purple, and buff and yellow-green sandstone. The mudstone and the purple color suggest the Morrison as identified in northeastern New Mexico.

At the head of a spring draw south of the ranch house and stratigraphically higher than the preceding beds, there is a section of rocks weathering chalky cream color, the top 10 feet consisting of a wedge of limy, fine-grained fucoidal sandstone, blue-gray when unweathered, containing shaly interbeds; and the basal part consisting of cross-bedded, ripple-marked sandstone weathering a brown to buff color, and containing small pebbles and seams of coarse grit. This section resembles the Cheyenne sandstone; it is correlated with the Purgatoire of northeastern New Mexico.

At a locality about 1½ miles north of the XIT headquarters ranch house, ½ mile north of the state line, and stratigraphically higher than the rocks described above, there occurs about 15 feet of Dakota in a small isolated knob. It is a ferruginous, fine-grained, cross-bedded, quartzitic sandstone (cp. Gould, 615, p. 30).

In northeastern New Mexico, the Morrison thins eastwards to its last known outcrop in the Oklahoma Panhandle. The following thicknesses have been recorded: Cuervo Hill, 20 miles northeast of Santa Rosa, 315 feet; Canadian escarpment, Carro Mesa, 90

[12]Darton, N. H., *395*, esp. pp. 300–307, and pl. 13-B.

[13]Lee, W. T., The Morrison shales of southern Colorado and northern New Mexico, Jour. Geol., 10: 43, 1902; Stanton, T. W., The Morrison formation and its relations with the Comanche series and the Dakota formation, Jour. Geol., 13: 657–669, 1905; Rothrock, E. P., Geology of Cimarron County, Oklahoma, Okla. Geol. Surv., Bull. 34, pp. 31–36.

feet; west side Ute Valley below Gallegos, 65 feet; 3 miles south of Montoya, 100 feet; Mesa Rica 10 miles east of Isodore, 50 feet; Tucumcari Mountain, 20–30 feet; Cimarron County, Oklahoma, 80 feet. Eastwards down the Canadian Valley the Morrison outcrop is mapped as disappearing before reaching the western boundary of Texas. A careful study of Panhandle well samples will be necessary to discover whether any remnants of Morrison have been penetrated in this area. In Union County, New Mexico, the Morrison consists "mostly of typical light-colored clay or massive shale, in general pale greenish-gray with some maroon and brown portions, and thin sandstone"; it unconformably overlies the Triassic Dockum beds and is about 360–375 feet thick (395, p. 306, fig. 144). Below the middle of the formation there occurs a conspicuous sandstone, correlated by Darton with Lee's Exeter sandstone. Lee (978, p. 22) portrays the sandstone under the Purgatoire as thinning into northeastern New Mexico, where it is represented by the Exeter, apparently correlated by him with the Wingate sandstone.

Bones of the supposedly Jurassic dinosaur, *Brontosaurus*, have been recently recorded[13a] from a locality on highway 64, just east of Kenton, Cimarron County, Oklahoma. The bones, including the fifth and sixth left ribs, two caudal vertebrae and some fragments, were found near the top of the valley wall in dark brown, gray mottled shale referred to the Morrison. *Brontosaurus* has been recorded from the Morrison at Como Bluff (Mook, *op. cit.*, p. 138).

CRETACEOUS SYSTEM

The Cretaceous is one of the most important rock systems in Texas, both areally and economically. Soon after the earliest settlement of the state, the main north-south trending Cretaceous belt in central Texas was found to possess many advantages of soil, climate, and water, and it is now the most densely settled portion of the state. The Cretaceous outcrop comprises some of the best farming land in Texas, including the Black Land cotton belt; and its western portion, the Edwards Plateau, is an important stock raising area. About 34% of the state's population resides on the Cretaceous outcrop, and on it are built most of the largest cities, Dallas, Fort Worth, Waco, Austin, San Antonio, and El Paso. Important artesian water reservoirs are in the Woodbine, Edwards, Paluxy,

[13a]Stovall, J. Willis, The Jurassic in Oklahoma, Science (n.s.) 76: 122–123, August 5, 1932.

and Travis Peak formations. Some of the largest oil fields, notably those in east Texas and along the Mexia and Luling fault zones,[13b] produce from Upper Cretaceous formations. Upper Cretaceous coal occurs in the Rio Grande embayment (Eagle Pass, Big Bend). The second largest quicksilver district in the United States is near Terlingua in Lower Cretaceous rocks. Most of the Portland cement plants in the state and many brick pits use Cretaceous materials. An increasing amount of Cretaceous building stone is being quarried.

Rocks belonging to this system supposedly were originally deposited over practically the entire area of Texas. At the present time about 75,000 square miles (28%) of the state consists of Upper and Lower Cretaceous outcrops; 35%, lying gulfwards from the outcrop, has the Cretaceous buried beneath younger rock formations; and from the remainder of Texas the Cretaceous has been stripped by erosion, laying bare the underlying rocks. The combined maximum thicknesses of various Cretaceous formations in Texas reach a total of about 15,500 feet, but no single section includes all of this thickness. The thickest local sections are in the geosynclines of the Rio Grande embayment and the eroded and buried remnants of the Sabine uplift.

History of Cretaceous deposition in Texas.—At the end of the Jurassic, the North American continent was practically all dry land, the late Jurassic seas of the Western Interior (Logan sea, Argovian) and of Mexico (Kimmeridgian - Tithonian) having retreated. The eroded land surface in Texas at this age has been called the Wichita Paleoplain by R. T. Hill. Upon this land surface Cretaceous seas advanced from the south and east of Texas, and Cretaceous history in this region is largely a record of the deposits of these northward advancing seas. As during Jurassic times, western North America was the scene of three advancing seas, the Pacific sea, the Arctic sea, and the Gulf (or Coloradian) sea. The stages of advance of the Gulf sea are shown in Fig. 22. By Eagle Ford time it had reached Colorado and had united with the southern end of the Arctic sea, and during this and the succeeding Austin

[13b]Certain structural features and physiographic subdivisions mentioned in the text of Part 2 are shown on various figures in this bulletin, as follows: High Plains, Llano Estacado, Marathon Basin, Osage Plains, Solitario Basin, on Fig. 2 (page 28); Balcones Fault, Llano Uplift, Ouachita Mountains, on Fig. 3 (page 29); East Texas embayment, Mississippi embayment, Sabine Uplift, Balcones Fault, Nueces embayment, San Marcos arch, on Fig. 28; Mexia-Powell faults, on figs. 28, 31, 32; Luling faults, on Fig. 36.

(Niobrara) stage the maximum advance of the seas over the Western Interior occurred. Near the end of the Cretaceous the Coloradian sea had retreated gulfwards, and in both the Rocky Mountain and northern Mexican regions, considerable oscillations of marine and non-marine conditions occurred. The Cretaceous marked the last great epicontinental marine invasion, and succeeding Tertiary seas were restricted to relatively narrow areas near the continental margin.

Facies.—Corresponding to the conditions of deposition, various lithologic facies occur in Texas. The marginal belts of whatever age contain prevailingly sandy or conglomeratic materials, the epicontinental deposits farther offshore consist of shale, clay, marl, chalks, limestones, reef coquina, and various other materials. The prevailing facies in the Texas Cretaceous may be summarized as follows:

- Continental deposits
- Marginal facies
  - Fluviatile, palustrine deposits
  - Littoral deposits (between tides)
  - Lagunal, deltaic, and brackish deposits
- Neritic facies
  - Normal neritic: clays, marls, chalks, limestones
  - Reef deposits: coquina, reef limestones

No adequate study of the varied facies of the Texas Cretaceous deposits has been made.[14] It has been claimed that many common deposits, such as black, pyritiferous muds and chalky foraminiferal limestones are of very shallow-water origin. Many Trinity and Fredericksburg limestones show rain drops, ripple and wave marks, mud cracks, dinosaur and other animal trails, association with gypsum or salt, and other evidences of extremely shallow water. Eagle Ford flags show markings which have been called ice imprints. Cycads and other plant remains characterize certain sandy formations (Paluxy, Gillespie, Woodbine). Brackish water mollusca mark certain sandstones (Trinity, Tulillo), as do dinosaur bones (Paluxy, Trinity, Aguja). The reef facies is marked by certain typical mol-

[14] A study in Recent facies is outlined in Steinmayer: Phases of sedimentation in Gulf coastal prairies of Louisiana, Bull. Am. Assoc. Petr. Geol., 14: 903–916, 1930. For classifications of facies: 631, ch. XV. For Recent materials deposited on the continental platforms, see Shepard, Françis P., Sediments of the continenital shelves: Bull. Geol. Soc. Amer., vol. 43, pp. 1017–1040, 1932.

lusca (Edwards, Anacacho). Tuff, bentonite and other volcanic materials occur at many levels, especially in the Upper Cretaceous.

Areal Geology. — Any purely geographic division of the Cretaceous outcrop is arbitrary, and a more natural division, according to facies and zonation, will require much further study. Geographically, the Cretaceous in Texas occurs in five areas: central Texas, the Edwards Plateau, the Llano Estacado, Trans-Pecos Texas, and the Gulf Coastal Plain.

The central Texas outcrop extends from the northeast corner of the State up the Red River valley and across the East Texas embayment, thence southward to near San Antonio, and thence westward to the Rio Grande embayment near Uvalde and Eagle Pass.

The Cretaceous extends down-dip for an unknown distance beneath the Gulf Coastal Plain, and has been found near the Gulf Coast in wells on the South Liberty salt dome (1142). The following salt domes in Texas have Cretaceous formations exposed at the surface:

Steen dome (1250, pp. 209–216; 1252, pp. 231–237). Upper Cretaceous clays are stated to outcrop near the vertically tilted Midway.

Bullard dome (1298, p. 540). Navarro and Taylor are stated to outcrop on this dome.

Brooks dome (1250, pp. 191–209; 1252, pp. 237–243). Navarro clays, Taylor chalk (with microfauna), and Austin chalk (with *Baculites, Ostrea plumosa, Gryphaea, Inoceramus, Hamites* (?) outcrop on this dome.

Keechi dome (1252, pp. 243–253; 843, pp. 266–268; 461, p. 305). Austin chalk and Navarro grayish-yellow lumpy clay (with *Exogyra cancellata, Nucula* cf. *eufaulensis* Gabb, *Trigonia, Plicatula, Crassatellites, Ringicula, Baculites, Belemnitella americana, "Pachydiscus"*) outcrop.

Palestine dome (461, 843, 1189, 1252, pp. 253–261) Buda, Woodbine (?) Eagle Ford, Austin, Taylor and Navarro outcrop on this dome.

Butler dome (404, pp. 647–663; 1252, pp. 262–268). Navarro outcrops on this dome.

Marquez dome, Leon County. According to C. L. Baker, Navarro (carrying *Scaphites*), and Taylor outcrop.

Several northern Louisiana domes[15] also have Cretaceous exposed; among them are: Arcadia (with Arkadelphia exposed), Bistineau (with Marlbrook), Kings (with Marlbrook), Prothro (Blossom, ?Brownstown, Marlbrook), Rayburns (Blossom), and Vacherie (Arkadelphia).

[15]Spooner, W. C., Interior salt domes of Louisiana, Bull. Am. Assoc. Petr. Geol., 10: 217–292, 1926, and Geol. Salt Dome Oil Fields, pp. 269–344, 1926. Veatch, A. C., The salines of northern Louisiana, La. State Exp. Sta., Spec. Rept. II, pp. 47–100, 1902.

The Edwards plateau comprises a large area west and north of the Balcones fault. At its southeastern corner is the Llano uplift, which was formerly covered by Lower Cretaceous rocks. North of it to the Red River is a large Pennsylvanian-Permian area from which Cretaceous rocks have been stripped by erosion. The Callahan divide is a remnant of their former extent, but how much farther north they, and particularly the Upper Cretaceous, extended is unknown.

The edges of the southern half of the Llano Estacado contain Lower Cretaceous rocks, lying above the Triassic and beneath the Cenozoic cover. Cretaceous is absent in much of the Canadian River region, and present farther north along Cimarron River in the Oklahoma Panhandle.

In the Trans-Pecos Texas, the Cretaceous, much affected by tectonic movements and by bolson fill, now outcrops in several scattered areas.

The Texas Cretaceous is continuous, stratigraphically and structurally, with that in the Rocky Mountain region and in northern Mexico.

For reference, the following table shows the commonly accepted equivalence of Texas Cretaceous groups with those in the Western Interior (southeastern Colorado) and in eastern Mexico (Tampico embayment).

Stage	*Tampico Embayment*	*Eastern San Luis Potosí*	*Texas*	*Southeastern Colorado*
	Velasco			
Maestr. Campan. Santon.	Mendez	Cárdenas Mendez equiv.	Navarro Taylor	Fox Hills Pierre
Coniac.	San Felipe (upper)	Tamasopo	Austin	Niobrara
Turonian	San Felipe (lower)[15a]		Eagle Ford	Benton
Albian	El Abra Tamaulipas (Taninul)		Washita Fredericks-burg ?Trinity	Purgatoire
	Unnamed Lower Neocomian		?	

[15a]Dr. L. W. Stephenson has given the lower (Eagle Ford) portion of the San Felipe a new name.

Topography, Soils, Vegetation.—Two sets of differences account generally for the great but systematic diversity in lithologic and topographic expression of the Texas Cretaceous: from north to south, changes of facies, agreeing with the prevailing direction of transgression of the seas (as for example, the great development of the reef facies in the Fredericksburg in south Texas); and from central Texas to west Texas the change in amount of rainfall from humid to semi-arid conditions, with resulting differences of vegetation, weathering, and soil. Progressive lateral changes in the physiographic expression of rocks of the same age under these conditions constitute a study yet to be made.

The humid region, with more than about 25 inches of annual rainfall, extends westward in Texas to the 99th meridian along a line from Red River to San Antonio, and thence southeastward to the Gulf near Rockport. The sub-humid region with 15 to 25 inches of annual rainfall, extends thence westward to a line just east of the Pecos and parallel to it. This line marks a pronounced change in soil, vegetation, and topographic expression of the Cretaceous formations, and the part of Texas east of it will be referred to loosely as the "humid" region, that west of it as "semi-arid." The line dividing the humid from the sub-humid region is stated to continue northward to the Canadian boundary and to divide the soils of the United States into two large groups: western, sub-humid, called pedocals, in which some horizon of the fully developed soil profile contains more calcium carbonate than does the underlying geological formation from which the soil is derived; and eastern, humid, called pedalfers, in which the maturely developed soil profiles contain no more calcium carbonate than does the formation, and a shifting or accumulation of sesquioxides occurs (199a, pp. 18–19).

More specifically, the groups of the Texas Lower and Upper Cretaceous are mostly characterized by definite soil series. Thus the Upper Cretaceous Black Prairie is composed of the "Houston-Wilson" soil series (*op. cit.*, pp. 51–70), the Lower Cretaceous Grand Prairie of the "Denton-San Saba" series (*op. cit.*, pp. 68–76), the Western Cross Timbers (Trinity) by the "Winthorst-Nimrod" group (*op. cit.*, pp. 76–82), the Edwards Plateau by the "Denton-Valera-Ector" groups (*op. cit.*, pp. 113–125).

The westward decrease of rainfall has two general effects on topographic expression of the Cretaceous formations: decrease in the amount of vegetation, and consequent sparseness of the soil cover, which is largely removed by erosion. The same hard and soft formations on passing west acquire sharpened profiles and other characteristic effects of arid weathering. Thus the topographic expression of a given formation changes markedly on passing from the humid to the semi-arid region.

Another marked regional change in topographic expression is a result of change in the lithologic facies of a given formation. The change from the prairie type of soft Georgetown between Waco and Denison to the limestone plateau type in the lower Pecos drainage is an example. In central Texas the Austin chalk forms prairies; in the Trans-Pecos region it is softer and forms flats.

The physiography of the humid region of Texas remains to be written. It has been treated incidentally by Hill and a few other writers (803, 506, 878). The semi-arid region has been briefly treated in several papers (44, 537a, 538, 139, 936, 12; references in 12, p. 17; also 1288a, pp. 5–6, 10–16.

Structures affecting the outcrop.—Various regional structures in Texas, although their implications are much more extensive, markedly affect the outcrop and subsurface occurrence of Cretaceous formations, and accordingly are listed here.

Sabine uplift (761, 1248, 1124, 1125).—A complicated structurally high area in northwestern Louisiana and adjacent Texas counties. The Trinity group is generally present, and on certain high areas the Fredericksburg and most of the Washita have been subsequently removed, but are present on the flanks. In east Texas fields, the basal Gulf formations overlap against the uplift and some are absent; the Bingen and higher formations are generally present. Some of the formations are in the marginal facies. Somewhat similar relations hold for other structurally high areas in northern Louisiana. The Louisiana Cretaceous section is entirely underground, except in the salt domes mentioned above.

East Texas embayment (415, 542, 543, 1232, 1232a, 1691, 987a). —This structurally low area roughly parallels the western side of the Sabine uplift (1232a, pl. I), extending from central Cass County southwest to central Wood County, thence southwards to Anderson County. The strata elevated on salt domes indicate that the Upper Cretaceous section is relatively complete; the Comanche series has at most places not been reached by the drill.

Preston anticline (803, 1530, 174, 177, 844).—This southeast-trending, plunging anticline marks the turning point of the Cretaceous outcrop, as it turns south from the Red River valley. The structure appears to affect the formation thicknesses only in minor details.

Fort Worth basin (10, p. 13).—A southeast-trending depression, produced by mid-Paleozoic foldings, and largely filled by late Paleozoic sediments. However, the Cretaceous formations thicken toward its center, and are thinned over the adjacent highs. Plummer (1234a) has outlined the Mineral Wells geosyncline (1228, pp. 60, 205), arising at the end of the Bend epoch, located between the Bend arch and the Balcones Mountains, and running from Bridgeport south to near San Saba.

San Marcos arch.—Running southeastward from the Llano uplift, this broad, plunging arch crosses Blanco, Hays, Guadalupe, Caldwell and Gonzales counties. The San Marcos River, for which it is here named, flows almost down its crest. Cretaceous formations, notably the Eagle Ford and Austin, thin on crossing this structure.

Llano uplift.—This name is used instead of the misnomer "Central Mineral Region," prominent inlier of pre-Cambrian and Paleozoic formations outcropping in Burnet, Llano, Mason, San Saba and adjacent counties. Locally around this high area, as around some areas farther west and now buried in the Edwards Plateau, the basal Cretaceous seas contained islands against which the Trinity or even lower Fredericksburg seas overlapped, and which contributed locally coarse (marginal) detritus. So far as is known, middle Fredericksburg and all later seas completely covered the area (1580, 1581, 1583, 1587, 1589, 274, 350a).

Chittim arch (1681, 578a).—Vanderpool (1681, p. 252) calls this structure the Chittim anticline. It trends generally southeast through central Maverick County into northwestern Dimmit County, and causes a prominent gulfward displacement of the Cretaceous outcrops. Down-dip and underground there is a notable thickening of the Escondido section through intercalation of marine and non-marine beds not present at the outcrop. A subordinate structural feature on this arch was called the *Lampasitas arch* by Udden (1625, pp. 88–90).

Rio Grande embayment (578, 578a, 1681).—The greatly thickened Upper Cretaceous and Tertiary formations in the lower Rio Grande valley indicate synclinal deposition. Evidences for this are the thick uppermost Cretaceous section below Eagle Pass and the thick basal Tertiary in the Salado arch (along Rio Salado, Nuevo Leon[16]) and in the Guerrero well. Besides the thickening of beds, the most notable stratigraphic feature is the appearance of near-shore and fresh-water facies, including coal beds, in the Upper Cretaceous in this embayment. The limits of the embayment proper up the Rio Grande have not been worked out. In the Big Bend region the uppermost Cretaceous (Aguja, Tornillo) is composed of near-shore sandstones and apparently non-marine clays containing saurian bones.

Terrell arch.—This name is here given to the structurally high area in which the Paleozoic floor is reached at shallow depths, extending west of north apparently from the Burro Mountains, and reached in drilling in Terrell and adjacent counties. It affects the thickness of certain Cretaceous formations: for example, the Grayson (=Del Rio) disappears on crossing it, but thickens again on either side. The Zambrano well, with thick marginal arkoses as near Cuatro Ciénegas, lies to the east of this structure.

Terlingua arch (1648).—This name is here applied to the prominent, structurally high, faulted strip passing southeast from the Solitario dome through the Terlingua quicksilver district and plunging toward the structurally low Chisos Mountains.

Solitario dome (1652, 44, 1436, 1442, 1249).—This almost perfectly circular dome, displaying many remarkable geological features, is centrally unroofed and forms a basin. It is an alleged, but not demonstrable, laccolith. Many Trans-Pecos structures show similarity in form and geology: Finlay Mountains, Cox Mountain, Sierra Madera, Christmas Mountain, Payne's Water Hole, and several unnamed structures in or near the Terlingua Quadrangle. For map of Solitario, see Fig. 9, p. 119.

Marathon dome (1652, 44, 1643, 927, 930, 932, 935, 936, 940).—This large and unsymmetrical dome is unroofed and eroded to form a basin. Along its extensive margins Trinity formations change facies and the Glen Rose disappears northwards, but these effects

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[16]Jones, R. A., A reconnaissance study of the Salado Arch, Nuevo Leon and Tamaulipas, Mexico. Bull. Am. Assoc. Petr. Geol., 9: 123–133, 1 fig., 1925.

are regional and not direct effects of the structure. However, in the northern part of the Marathon dome, overlaps in the Lower Cretaceous involving levels up to high Fredericksburg (936, p. 95), are an effect of original structure.

Balcones fault zone (544, 672a, 766, 803).—It was first recorded by E. D. Cope (On the zoological position of Texas, U. S. Nat. Mus., Bull. 17, pp. 5–8; also Hill, 732, pp. 292–293, footnote, 1887). The type locality is on Helotes Creek, Bexar County, about 18 miles northwest of San Antonio, where the fault was first observed by the zoologist, G. W. Marnoch. The Balcones fault was first named by Hill in 1890 (766, pp. 117, 134–135).

Gulf Coastal Plain (538, 803, 1536, 1537).—The Gulf Coastal Plain in Texas has been defined as limited landwards by the basal contact of the Comanche series as far south as Austin, thence by the Balcones fault southwards and westwards to the Rio Grande embayment near Del Rio.

Paleontology. — The general faunal complexion of the Texas Cretaceous is as follows: in common with the circum-equatorial Cretaceous of the world, it has in its southward extent a great development of rudistids, mostly segregated in limestones of the reef facies, and farther northwards the rudistid reefs finger out into normal sediments, and the rudistids diminish and disappear. The normal sediments are marked by ammonites and generally lack rudistids; the reef facies generally has rudistids, corals, or sponges, and lacks ammonites. The Texas Cretaceous shows a large provincial development of banks or aggregates of the oyster *Gryphaea* and ammonites of the family Engonoceratidae at several stratigraphic levels. It appears to be characterized by the absence or great rarity of several ammonite groups: lytocerids, phyllocerids, hoplitids, tissotids, and many Indo-Pacific genera. Like the Cretaceous in Africa, India, and western Europe, it has a large development of parahoplitids in the Aptian, *Douvilleiceras* in the lower Albian, dipoloceratids in the middle and upper Albian, pervinquierids in the upper Albian, acanthoceratids in the Cenomanian, vascoceratids in the lower Turonian, prionotropids in the upper Turonian, mortoniceratids in the Santonian, *Inoceramus* in the Upper Cretaceous, and various desmoceratid groups in both Lower and Upper Cretaceous. Many ammonite genera and subgenera and a few other fossils are cosmopolitan, short-range (zonal) fossils, and provide a zonation of the Texas Cretaceous valid for the area and agreeing in essentials with zonations established elsewhere. Some other fossils, as certain ammonites and oysters, appear to be provincial. The Texas Cretaceous contains many genera of cosmopolitan and long-range fossils, of which echinoidea, foraminifera, ostracoda, pelecypoda, and gastropoda, have been best studied. As in eastern and northern Africa, certain clays contain a large development of pyritic dwarf (micromorph) fossils.

The Texas section, except for the basal Neocomian, which is well developed in the adjoining area of Coahuila and Chihuahua, is practically complete. It is exceptionally well exposed, the fossils at many places are well preserved, and with further study it will undoubtedly prove to be one of the best standard sections in the world.

Although great gaps exist in the knowledge of the Cretaceous plant succession in the Southwest, it appears that Angiosperms were practically missing during the Trinity but may have arisen in the Fredericksburg (Cheyenne sandstone).

Upper Cretaceous (Berry, 100 c)

Ripley (Berry, U. S. Geol. Surv., Prof. Paper 136): some Pteridophytes and conifers, mostly Angiosperms.
Taylor (Udden, 1627; Wieland, 1758a): one cycad.
Woodbine or *Eagle Ford* (Berry, 105): Cycadophytes, 1; Conifers, 1; Angiosperms, 38.

Lower Cretaceous (Berry, 98a, 99)

Pawpaw (Stephenson, 1530): undetermined fragments.
Cheyenne (Berry, U. S. Geol. Surv., Prof. Paper 129–I): Pteridophytes, 4; Cycadophytes, 2; Conifers, 4; Angiosperms, 12.
Walnut: Verticillate algae; undetermined stems.
Paluxy and *Gillespie* (Wieland, 1759a): cycads, and ? gymnospermous wood.
Glen Rose (Fontaine, 545; Groves, 633; Torrey, 1608; Wieland, 1759): Algae (*Chara*), one *Equisetum*, a few ferns and cycads, mostly gymnosperms; no angiosperms.

Partition of Texas Cretaceous.—In Texas and adjacent areas the Cretaceous strata are divisible into two well-marked series: Comanche (= Lower Cretaceous), and Gulf (= Upper Cretaceous). Neither series can be regarded as a system: they are essentially provincial and not world-wide. On the other hand, their validity as series can be maintained on several grounds. The stratigraphic break between them is persistent and widespread in the southwestern

TABLE OF CRETACEOUS

Group	Arkansas North Louisiana	Northeast Texas	Trinity-Brazos Rivers	Austin	Eagle Pass
Navarro	Arkadelphia Nacatoch Saratoga	Kemp Nacatoch Corsicana (restricted)	Kemp Nacatoch Corsicana (restricted)	Navarro	Escondido Farias Olmos
Taylor	Marlbrook Annona Ozan Brownstown	Unnamed Marls Pecan Gap Wolfe City Unnamed Marls Gober	Unnamed Marl Marlin (Cooledge) Lott Durango Rogers Unnamed Marls	Taylor	San Miguel (Anacacho) Upson
Austin	Tokio	Blossom Bonham	Austin	Burditt Austin Chalk	Austin
Eagle Ford	————	Eagle Ford	Arcadia Park Britton Tarrant	Arcadia Park- Britton Tarrant	Val Verde- Eagle Ford
Woodbine	"Wood- bine"	Woodbine	Lewisville Dexter ? Pepper	———— ? Pepper	————
Washita	———— Washita (undiffer- entiated)	———— Grayson Main Street Paw Paw Weno Denton Fort Worth Duck Creek	———— Grayson Main Street Paw Paw Weno Denton Fort Worth Duck Creek	Buda Grayson Georgetown	Buda Grayson Georgetown
Fredericks- burg	Fredericks- burg (undiffer- entiated)	Kiamichi ———— "Goodland" Walnut	Kiamichi Edwards Comanche Peak Walnut	Edwards Comanche Peak Walnut	Edwards Comanche Peak
Trinity	Upper Red Beds Upper Glen Rose Anhydrite Zone Lower Glen Rose Lower Red Beds	(Paluxy) Antlers	Paluxy Glen Rose Travis Peak	Glen Rose Travis Peak	Glen Rose

UNITS IN TEXAS

Big Bend	Chispa Summit-San Carlos	Pecos County	Sierra Blanca-Quitmans	European Stages
Tornillo Aguja (Upper)	Tornillo Aguja (Upper)	———	———	Maestrichtian
Aguja (Lower) Taylor	Aguja (Lower) Taylor	Taylor	———	Campanian Upper Santonian
Terlingua (restricted)	Colquitt	Austin	Austin	Lower Santonian Coniacian
Boquillas	Chispa Summit	Boquillas	Eagle Ford	Turonian Upper Cenomanian
———	———	———	———	Middle Cenomanian
Buda Grayson Georgetown	Buda Grayson Georgetown	Buda Grayson Main Street Weno Denton Fort Worth Duck Creek	Buda Grayson Georgetown	Lower Cenomanian ——— Upper Albian
——— Edwards- Comanche Peak Walnut	Kiamichi Edwards	Kiamichi University Mesa Comanche Peak	Kiamichi Finlay	Middle Albian
Shafter Presidio	Glen Rose	Maxon Glen Rose	Cox Glen Rose Cuchillo Las Vigas Torcer	Lower Albian ——— Upper Aptian ——— Valanginian

United States. The break in the megafauna is practically complete. In Louisiana and east Texas at least, a period of orogeny and perhaps vulcanism intervened.

Grouping of the strata into smaller units, such as formations, is less satisfactory, and, on account of changing lithologic facies, is of only local value. The practice of giving formation names to local lithologic units would eventuate logically in a separate name for each facies of each lithologically distinguishable age. If carried out for Texas alone, this would result in many more formation names than are here presented. An inspection of Taylor equivalents, for instance, will show that a much more involved nomenclature is possible than that now existing. For purposes of correlation, even interstate, the establishment of a detailed, reliable fossil zonation is imperative. In the following discussions, existing formation and member names are recorded for reference and comparison, but their correlation is only provisional. The correlations here given between Texas and the Gulf States, the Western Interior, New Mexico, Arizona, northern Mexico, Europe and elsewhere, are necessarily only provisional. Many further zonal details and refinements are necessary, both in Texas and in Europe, before a good correlation is possible.

The basal contact of the Cretaceous is everywhere in Texas marked by a major unconformity, and the Cretaceous rests upon a diverse patchwork of formations ranging in age from pre-Cambrian to Jurassic (Kimmeridge or ?Tithonian). The upper contact of the Cretaceous is unconformable and represents a break of unknown magnitude.

In the table, on pages 270 and 271, the formations of the main outcrop areas in Texas are shown, with their approximate equivalences.

COMANCHE SERIES[17] (Lower Cretaceous), emended

The Comanche series was first named by Hill in 1887 (731, pp. 298, 300; 732, p. 299) from the town Comanche, Texas, where he first studied these rocks, and from the Comanche Indians, who inhabited the central denuded region of Texas.

[17]*Literature.—Ark.-Okla.:* Dane, 392; Bullard, 174. *Northeast Texas:* Matson, 1059; Renick, 1298. *North-central Texas:* Bullard, 176, 177; Bybee, 189; Hill, 731, 732, 772, 780, 803; Lahee, 969; Marcy, 1055; Shuler, 1453; Taff, 1575; Winton, 1789, 1790, 1791. *South-central Texas:* Adkins, 11, 16; Hassan, 672a; Hill, 743, 803, 808; Pace, 1168; Roemer, 1330; Sellards, 1402.

Synonyms.—Upper Cretaceous (part), Shumard, 1463, pp. 582–590. Middle Cretaceous, and Lower Cretaceous (part), Marcou, 1042, pp. 86–97. Texas Group, Hill, 731, p. 300. Shasta Series (part), J. S. Diller, Potomac Group (part).

Emended definition.—The rocks of earliest Cretaceous (pre-Travis Peak) age exposed in Malone Mountain, southern Quitman Mountains, and the Rio Conchos region, described by Cragin in 1897 and 1905, and later by Burrows and others, were unknown when Hill defined the Comanche series and the Trinity group, and were never included in the definitions of those units. Various writers have accordingly criticized the definition of Comanche series for not including even all of the Lower Cretaceous present in Texas (as 181, p. 153, footnote). This earliest Cretaceous is localized in an arm of the late Jurassic-lower Neocomian sea whose tip barely entered Texas at the above mentioned localities, and its position elsewhere in Texas is represented by an unconformity at the base of the Trinity as now defined. The Comanche series and the Trinity group are therefore here emended to include also all Neocomian strata existent in Texas. This early Neocomian, with other sediments, continues southwards into Mexico and is there part of a relatively complete Eocretaceous section. It is clear therefore that the limited amount of Cretaceous in Cragin's "Malone formation" in Texas is incidental to the greater development of these beds in northern Mexico, and cannot be classified independently of those beds. For present purposes it is impracticable to assign them to higher than formational rank, and accordingly the formations as described in the following text are referred to the Trinity group of the Comanche series (both in the emended sense).

1429, 1430; Taff, 1574. *Coastal Plain:* Brucks, 164, 165; Deussen, 421. *Edwards Plateau:* Beede, 87, 92; Henderson, 704; Hill and Vaughan, 795; Paige, 1172. *Rio Grande Embayment:* Calvert, 192; Christner, 248; Dumble, 480; Getzendaner, 578, 578a; Liddle, 992; Schmitz, 1373; Vanderpool, 1681. *Trans-Pecos Texas:* Adkins, 12; Baker, 44, 46, 55; Böse, 129; Cragin, 331; Hill, 722, 799, 805, 820; Hoots, 841; King, 936; Kitchin, 944; Lonsdale, 1013; Powers, 1249; Richardson, 1304; Roberts, 1324; Shumard, 1477; Stanton, 1521, 1524; Taff, 1573; Udden, 1623, 1626. *Northern Mexico:* Böse, 134, 135; Dumble, 480; Tatum, 1590. *Western Interior:* Bullard, 175; Darton, 395; Twenhofel, 1621; Hill, 789; Reeside, 1290. *Paleontology:* Adkins and Winton, 9; Adkins, 13; Alexander, 27, 30; Berry, 99; Boehm, 124a; Böhm, 125, 127; Böse, 134; Boyle, 144; Carsey, 199; Clark, 253; Conrad, 280a; Coquand, 320; Cragin, 324, 325, 326, 331; Cushman, 357; Ellisor, 520; Fontaine, 545; Gidley, 583; Giebel, 584; Hall, 643; Hill, 735, 755, 796; Hyatt, 867; Kniker, 947; Lasswitz, 976; Lambert, 974; Marcou, 1041; Marcy, 1055; Plummer, 1238; Roemer, 1331; Shumard, 1456, 1464a; Whitney, 1756, 1757, 1758; Wieland, 1759. *Igneous:* Dawson, 398; Sellards, 1429, 1444a; Vaughan, 1686.

Economic Importance.—In the more humid central part of Texas, the Comanche series, mostly composed of softer rocks, underlies the more thickly settled, industrialized, and agricultural part of the state. The more arid western Comanchean, the Edwards Plateau, is more sparsely settled, and is devoted largely to sheep and goat raising. The east-central Texas area of Comanche is generally divided into the following strips from west to east: (1) the Western (Trinity, Upper) Cross Timbers; (2) the Lampasas Cut Plain, underlain by the Fredericksburg group; (3) the Grand Prairie, underlain by the Washita group, and overlain to the east by the Eastern (Woodbine, Lower) Cross Timbers.

In addition to its soils and timber, the Comanche series contains some of the most extensive artesian water reservoirs in the state, in the Trinity sands, the Glen Rose, and the Paluxy, and to a lesser extent in higher formations. The Trinity group contains high-gravity oil in several fields, and other Comanche levels locally produce oil and gas. In northern Louisiana fields the Glen Rose produces oil and gas. In Panola County the Glen Rose produces gas (612, p. 1477). Glen Rose casinghead gasoline is produced from the Chittim arch in eastern Maverick County (578, 578a, 1681, 1625). The Walnut is the horizon of the oil at South Bosque (11, pp. 93–98). Edwards produces oil in the Luling field (164, 165, 1262, 1412), at Salt Flat (728a, 1076), at Darst Creek (1355, p. 1387; and H. D. McCallum: The Darst Creek Oil Field, Guadalupe County, Texas, MS., 1932), and at Larremore (Weeks, 1716).

Other economic products from the Comanche series are stone, clay, gypsum, sand, manganese, quicksilver, and several other non-metallic products.

Fossil wood from the sand formations of the Trinity group is used somewhat for building bungalows, tourist camps, chimneys, and fences in Glen Rose, Waco, Austin, Walnut Springs, Itasca, Stephenville, and elsewhere. This is hauled from near Glen Rose, Stephenville, Comanche, and other Trinity outcrops. Taff (1574, p. 310) records that in the Paluxy near Paluxy and Bluff Dale "silicified trees and fragments of logs are so abundant that one is reminded of driftwood, which doubtless they were at the time of deposition of the Trinity sands."

Duck Creek ammonites have been used for ornamental building near Fort Worth (1789, pl. 4).

Stratigraphy and Contacts.—The basal contact is the old land surface called the Wichita Paleoplain by Hill (803, pp. 363–367).

During early Cretaceous times the reduced land mass of Llanoria reached southwards from east Texas into northern Mexico, and the shore line extended from the Malone area southeastwards to the tip of the Big Bend and thence gulfwards roughly parallel to the Rio Grande (133a, 181, 334). During Lower Cretaceous time the Mexican (or Coloradian) sea spread northwards over Llanoria, leaving coarse sandy and conglomeratic marginal sediments in many parts of northern Mexico and Texas. The approximate limit of the Trinity sea is shown on Fig. 16. In central Texas the sandy margin (of diverse Trinity ages) is known as the Travis Peak, Gillespie, Paluxy, Maxon, and Antlers formations. Profiles indicate that some sands of true Trinity age extended farther north than the present outcrop in southern Oklahoma. In western Texas the exact limit of the Trinity is vague, through lack of diagnostic fossils in the marginal facies, but it is present in the structurally low areas near Fort Stockton (12, pp. 33–37). It is practically or entirely missing in the western Oklahoma outliers, in Double Mountain, in the northern Llano Estacado, and at Tucumcari. The Fredericksburg and Kiamichi seas extended farther north, to limits not definitely located but approximately shown in Fig. 13. The land surface upon which the Comanche seas encroached had been planed down through some of Permian, all of Triassic, and most of Jurassic time, and is composed of diverse rocks of most ages from pre-Cambrian to Jurassic. Locally, as in Burnet County, west of the Llano uplift, and on the Marathon dome, this land surface was irregularly submerged and islands remained in the earlier Trinity seas, to be buried by later Comanche deposits. Islands in the Trinity sea are recorded in Choctaw County, Oklahoma, by Miser (Bull. Am. Assoc. Petr. Geol., 11: 444, 1927).

The question of the validity or importance of the Comanche series is bound up with the extent and nature of its upper contact, a question not yet well elucidated. It may be stated that ammonite zonation tends in general to reduce the magnitude of the Comanche-Gulf unconformity in central Texas. The highest Comanche formation, the Buda limestone, is of Cenomanian age; so are the Woodbine and basal Eagle Ford. In the present state of knowledge of the ammonites concerned (*Acanthoceras* and *Mantelliceras*, with related genera), an exact correlation with Spath's Cenomanian zones is not possible, but the ammonites of the Buda, Pepper, and

Woodbine formations are closely related to each other. In east Texas and northern Louisiana the Comanche series was uplifted and eroded before the deposition of the basal Gulf formation. In central Texas south of the Brazos, and in Trans-Pecos Texas, the break is apparently less, and the two series are generally concordant; the continuity of the zonation here is questionable, but until better zonal work is available the amount of break of the zones will remain unknown.

From Denison, Texas, east to Cerrogordo, Arkansas, the Woodbine unconformably overlies Comanchean formations from Grayson marl down to Kiamichi; thence eastwards the Trinity group is overlain by Woodbine, at the outcrop.

Areal Extent.—The conjectured original extent of the Comanchean rocks is shown in Fig. 13. They occur underground at least as far east as the Richland field. Northwards it extends past central Kansas and eastern Wyoming, east of the Rocky Mountain front ranges, but some of its members here are non-marine. Westward it outcrops in eastern and central Sonora. Southward, in passing off the Comanchean overlap, the series has not been delimited and probably loses its individuality, but rocks of its age outcrop in central and southern Mexico and into Central America. In the Texas Coastal Plain it is elevated in the Palestine and other salt domes, and extends gulfwards for an unknown distance. Rocks with some identical fossils outcrop in Porto Rico.[18]

Regional Structure.—Over high structures in northern Louisiana, the Sabine uplift and various local highs, the Comanche formations are in part beveled or removed by subsequent erosion. The outcrop across the western part of the East Texas embayment shows a slight thickening of the formations toward the center of the depression. Some formations (as Eagle Ford) are thinned across the San Marcos arch. Others (as Grayson) are thinned over the Terrell arch. Shorewards the formations thin, assume the marginal facies, and are affected by numerous gaps in the stratigraphic sequence. Gulfwards they thicken enormously, especially in the Trinity group. Exact correlation and the proof of the magnitude of various stratigraphic breaks, both await more accurate zonal studies; most of what has been written on these subjects to date is largely conjectural and speculative.

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[18]Hubbard, Bela, Proc. N. Y. Acad. Sci., Vol. 3, pt. 2, 1920.

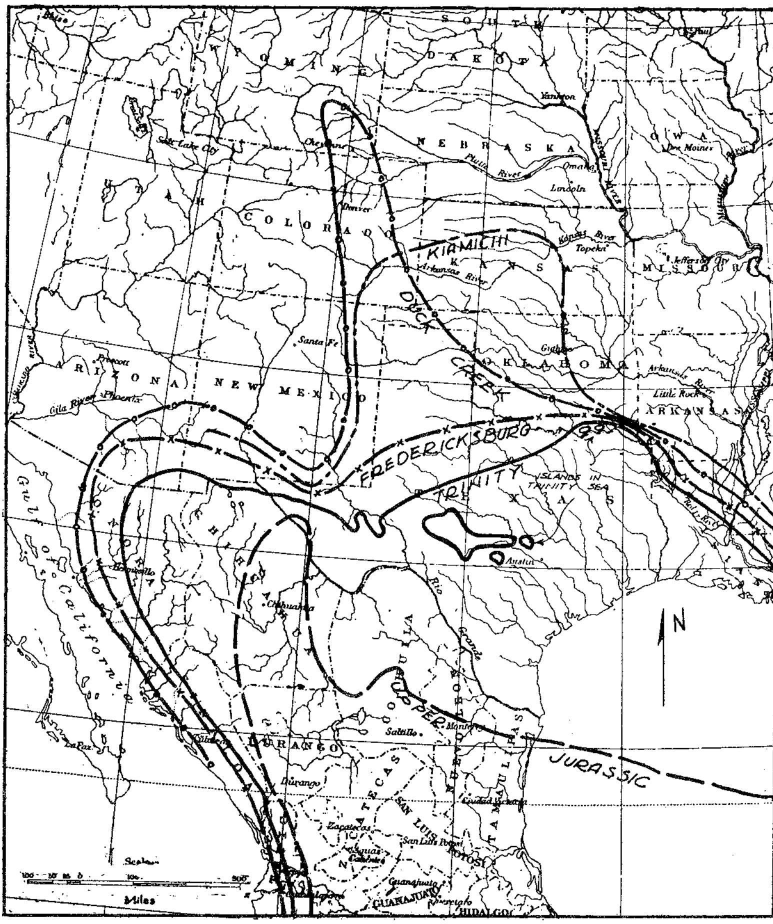

Fig. 13. Known extent of Upper Jurassic, Trinity, Fredericksburg, Kiamichi, and Duck Creek localities in and near Texas is shown inside the respective lines. The areas enclosed (to the south and east) by the respective boundaries were sea. This is not a paleogeographic map.

Slumped blocks in Comanche formations.—Solution has produced slump near the Gulf-Comanche contact at many places in Trans-Pecos Texas, giving an appearance which some geologists have misinterpreted as an unconformity. Along laterals of the Pecos between Del Rio and Sonora, especially along faults, blocks of Eagle Ford and Buda have fallen onto the Georgetown. At localities 2 miles north-northeast and 1.5 miles northeast of Black Mesa, northwest of Terlingua, there are two occurrences possibly explainable by solution and slump. Here hills of Buda-Grayson have been dropped at least 500 feet and rest with gentle or steep dips on an apparently recent Edwards floor. There is a possibility that these are narrow down-faulted blocks.

Facies; Mode of Deposition; Source of Materials.—All Comanche sediments known in Texas are of near-shore or of epicontinental, probably shallow-water origin. They belong to (1) the marginal facies, near-shore neritic or partly littoral sands, silty clays, conglomerates and saline or gypsiferous sediments; (2) neritic marls, clays, shales, and limestones; and (3) reef (zoogenic) limestones, coquina, and shell aggregates or marls. In the Louisiana Trinity and locally elsewhere, there occurs a red bed facies, which has been claimed to be of continental origin. Numerous local and subordinate facies also are known.

Each of the three groups of the Comanche is distinctive in Texas. The Trinity was deposited on an irregular land surface, downwarped gulfwards, and it filled up most of the irregularities in that uneven surface. Gulfwards and in large synclines it thickened enormously. On the rather even surface of the Trinity the Fredericksburg was deposited. It has less pronounced changes in thickness, but is distinguished by a great diversity of lithologic facies, corresponding to differences in the sources of its sediments. It is doubtful if Walnut, Comanche Peak and Edwards can be retained as formations in the usual sense, but possibly those terms might be used to designate respectively the shelly marl, the soft nodular limestone, and the rudistid reef facies, for in each of the three supposed formations all three types of lithology occur. The succeeding and topmost group, the Washita, is distinguished by its partially cyclical mode of deposition, corresponding to some periodic change in the conditions of deposition, perhaps oscillations of level or temperature changes. This cyclical deposition is more apparent in the northern than in the southern Washita area.

Topography, Vegetation, Soils.—The Trinity group in its northern, more sandy, facies forms the Western Cross Timbers. The combined Fredericksburg and Georgetown, in their southern and thicker rudistid limestone facies, form the Edwards Plateau and the region of incised river canyon topography rejuvenated by late Tertiary faulting and uplift. Fredericksburg rocks form the Lampasas

Cut Plain. The alternating clays, marls, and limestones of the northern phase of the Washita group form the Grand Prairie. Numerous minor physiographic divisions are discussed by Hill (803.) The Comanche and Gulf strata in the Gulf Coastal Plain dip gulfwards, producing long strike cuestas of the more resistant formations, with prominent west-facing scarp faces.

The vegetation and soils are results in part of the peculiarities of the rock formations, in part of the amount of rainfall. Some vegetation is locally distinctive of formations, but much more indicates types of soil or living conditions (385, 1789). The same Cretaceous formations may be traced westwards from humid central Texas (30 or more inches annual rainfall) to semi-arid western Texas (15 inches or less), and typical corresponding changes in physiographic processes and forms confirmed (12, 936).

Igneous rocks in Comanche series.—Dikes have been recorded in Travis County (1429, p. 43), in Bandera County (398; 1009, p. 12), and in Comal County (1009, p. 12). Plugs occur in Hays and Bexar counties (1009, pp. 12–13) and in Medina County (992). Other Cretaceous occurences are listed by Lonsdale (1009) and by Sellards (1444a). Sills, dikes, plugs, and laccolithic bodies are common in the Trans-Pecos Lower Cretaceous. The intrusives are probably mostly of post-Cretaceous age.

Caves and springs.—Some caves are located in Cretaceous strata in Texas. Near Salado, Austin, and San Marcos, there are caves in the Edwards limestone. A large cave near Boerne is in the Glen Rose limestone. Along the Rio Grande, Devils River, and Pecos River, many small caves and rock shelters occur in the thick Fredericksburg-Washita limestones.

Some of the largest springs in the country occur in Cretaceous rocks in Texas (Meinzer, 1086c). Springs occur along the Balcones fault zone near Salado, Georgetown, Austin, San Marcos, New Braunfels, San Antonio, and farther west. Some of these exit through the Edwards limestone, though much of their water may come from Trinity aquifers. Large springs in the Cretaceous occur near Del Rio, Fort Stockton, Toyah, and elsewhere in west Texas.

Outlying Areas of Comanche Series.—Stratigraphically the Texas Comanche (including the Valanginian "Malone" Cretaceous) was deposited on a sloping old land, which was invaded by seas from the south and southeast of Texas. In those directions the section is more nearly complete, and to the north of Texas only attenuated fingers of the Comanchean were deposited. In northern Mexico and in western Cuba (near Viñales) Upper Jurassic deposits occur;

the Upper Jurassic seas reached northward to Texas only in the Malone-Quitman mountains area, and possibly near Brownsville (see Fig. 13). The successive Comanchean seas extended farther into the southwestern states, until during Duck Creek time, they had reached Tucumcari, N. M., and southeastern Colorado. There are no certain records of higher Comanchean in the Western Interior, and after Duck Creek time the sea may have withdrawn temporarily, or the formations, if deposited, were subsequently eroded. The "'outlying areas" of the Comanchean are discussed in the following paragraphs. After the close of Comanchean time, the Dakota-Woodbine sea occupied a large territory in the Western Interior and in north-central Texas (Fig. 23).

Sonora.[19]—Near Arivechi in northeastern Sonora, a fauna described in 1869 by Gabb includes Fredericksburg species, and contains *Engonoceras pierdenale* (von Buch), *Lunatia pedernalis* (Roemer), *Scalaria texana* Roemer, *Tylostoma, Cerithium, Turritella seriatim-granulata* (Gabb, not F. Roemer), *Tapes gabbi* Böse, *Gryphaea pitcheri* Morton, *Gryphaea navia* Hall, *Gryphaea mucronata* Gabb, *Pyrina parryi* Hall, *Phymosoma texanum* (Roemer) and others. This fauna requires amplification and restudy. Kellar records in western Sonora a neritic fauna like that of the Bisbee section, containing rudistids and large oysters, and in part referred to the Albian.

Bisbee, Arizona.—This section consists of four formations, in ascending order, as follows: Glance conglomerate, consisting of bedded conglomerates with coarse pebbles of schists and limestones; Morita formation, buff, tawny and red sandstones, alternating with dark red shale, and near the top a few thin beds of impure limestone; Mural limestone with Trinity fossils, basally thin-bedded sandy limestones, and in upper part gray, massive, hard limestone; Cintura formation, red nodular shales with cross-bedded, buff, tawny and red sandstones, and basally a few beds of impure limestone. The Mural limestone contains *Orbitolina texana* (Roemer), *Glauconia branneri* (Hill), *Lunatia pedernalis* (Roemer), *Pecten stantoni* Hill, *Trigonia stolleyi* Hill, *Ostrea* sp., *Trigonia* n. sp., *Cyprina* sp., *Astrocoenia* sp., *Rhynchonella* sp., *Terebratula* sp., *Terebratella* sp., *Caprina* cf. *occidentalis* Conrad, *Turritella* cf. *seriatim-granulata* Roemer. and *Actaeonella* cf. *dolium* (Roemer) (Ransome, U. S. Geol. Surv., Prof. Paper 21, 1904; Bisbee folio No. 112, 1904). The first five named indicate the Trinity group, and the others, though they may be of Fredericksburg age, are not diagnostic.

Southern New Mexico.—The Hatchet Mountains in southwestern New Mexico contain a Trinity fauna like those in the Mural limestone near Bisbee and in the Quitman and Shafter districts in Texas. The following fossils have been reported (Darton, U. S. Geol. Surv., Bull. 618, pp. 43–44; Darton, U. S. Geol.

[19]Kellar, W. T., Stratigraphische Beobachtungen in Sonora (Nordwest-Mexico), Ecl. geol. Helv., 21: 321–355, 1928.

Surv., Bull. 794, pp. 38–39, 1928.): *Exogyra* aff. *quitmanensis* Cragin, *Kingena* aff. *wacoensis* (Roemer), *Orbitolina texana* (Roemer), *Ostrea* sp., *Corbula* sp., *Anchura* sp., *Turritella* sp., *Enallaster* sp., *Hemiaster comanchei* Clark, *Requienia texana* (Roemer), *Tylostoma* sp., *Tapes* sp., *Limopsis* sp. In the Potrillo Mountains there have been recorded: *Caprina occidentalis, Cyprina, Trigonia,* and *Actaeonella dolium.* In Luna County, New Mexico, and in the Deming region, the basal Cretaceous Sarten formation is a poorly exposed coarse sandstone, from which the following fossils are recorded: *Cardita belviderensis, Cardium kansasense, Protocardia texana, Protocardia quadrans, Tapes belviderensis, Turritella* aff. *seriatim-granulata, Ostrea, Nucula, Trigonia, Lunatia, Leptosolen, Homomya, Turritella, Anchura, Cyprimeria.* This is a Fredericksburg fauna, and most resembles the Kiowa and Belvidere faunas of Kansas.

Northeastern New Mexico.—At Tucumcari Mountain, above the Dockum Triassic, there is recorded 100 feet of Jurassic Wingate sandstone, 20 to 30 feet of Morrison (Exeter?) white sandstone, and about 60 feet of sandy fossiliferous clay called Purgatoire. The fossils recorded from the Purgatoire are: *Exogyra texana* Roemer, *Ostrea quadriplicata* Shumard, *Gryphaea tucumcari* (Marcou), *Gryphaea corrugata* Say, *Ostrea* cf. *subovata* Shumard, *Plicatula* sp., *Pecten occidentalis* Conrad, *Trigonia emoryi* Conrad, *Protocardia* sp., *Pinna comancheana* Cragin, *Cardita belviderensis* Cragin, *Tapes belviderensis* Cragin, *Cyprimeria* sp., *Turritella seriatim-granulata* Roemer, *Pervinquieria "leonensis"* Conrad, *Pervinquieria shumardi* (Marcou). The last-named fossil, identified by Alpheus Hyatt (796, p. 21), is a Duck Creek marker. Most of the other fossils listed are obviously high Fredericksburg in age, and are doubtless to be correlated with the Kiowa (=Kiamichi). To the northwest of Tucumcari, fossiliferous Comanchean shortly disappears. Stanton records (Jour. Geol., 13: 666, 1905) on the north side of Canadian River 15 miles northwest of Tucumcari 20 feet of fossiliferous Comanchean, the northwesternmost place at which it was found. Near Sanchez and on the upper Rio Concha the stratigraphic position of the Comanchean is occupied by a non-fossiliferous thin shaly band. Baker (Am. Jour. Sci., (4) 49: 121, 1920) records nearby localities with *Gryphaea tucumcari, Ostrea quadriplicata, Cardium,* and *Turritella.*

Cimarron County, Oklahoma (Stanton, Jour. Geol., 13: 664, 1905).—Near Garret, the Morrison is overlain by Purgatoire, 4 to 15 feet of basal, coarse, brown, or gray, cross-bedded sandstone, with irregular bands of pebbles, followed by dark shales containing the following Comanchean fossils: *Hamites fremonti* Marcou, *Desmoceras brazoense* (Shumard), *Inoceramus comancheanus* Cragin, *Gryphaea corrugata* Say, *Ostrea subovata* Shumard, *Ostrea quadriplicata* Shumard, *Plicatula incongrua* Conrad, *Gervilliopsis invaginata* (White), *Trigonia emoryi* Conrad, *Protocardia multistriata* Shumard, *Pholadomya sanctisabae* Roemer?, *Anchura kiowana* Cragin, *Turritella seriatim-granulata* Roemer. The first three are Duck Creek fossils, the others indicate nothing higher than Kiowa (Kiamichi).

Texas County, Oklahoma (175, p. 90).—A small outlier of about 5 feet of soft, white to yellowish sandstone, contains *Oxytropidoceras belknapi* (Marcou), *Inoceramus, Trigonia, Turritella, Cucullaea?* and *Tapes?*, and is of Kiamichi age.

Western Oklahoma.—Bullard (175) has run a section across these outlying areas and has shown that the highest marine level observed is Kiamichi. Avila Hill, on the Oklahoma-Kansas line, contains *Gryphaea navia* Hall in the topmost stratum of a 138-foot section, the upper 91 feet of which contains *G. navia.* In the Supply area, the Permian red beds are overlain by 25 feet of sandy strata followed by about 36 feet of fossiliferous Kiamichi, of which the uppermost clay contains *Oxytropidoceras belknapi* (Marcou), *Gryphaea navia* Hall and *Gryphaea corrugata* Say. In the Seiling-Cestos area there is 15 feet or less of clay, limestone, and shell bed, containing *Oxy. belknapi* (Marcou), *Oxy. acutocarinatum* (Shumard), *Gryphaea navia* Hall, *Gryphaea corrugata* var. *hilli* Cragin, and other fossils. In the Butler-Foss area, essentially the same lithology and fossils are recorded.

Southern Kansas.—The Cretaceous formations are, in ascending order: Cheyenne sandstone, Champion shell bed, Kiowa, Spring Creek shale, Greenleaf sandstone. The last formation is overlain by Dakota sand. The Cheyenne, divided into several members, consists of white, yellow, and gray sandstone and shale, and contains no fossils except plants, a cycad (*Cycadeoidea munita* Cragin), and 23 species of dicotyledons and other forms monographed by Berry. The formation is apparently non-marine, but was deposited directly on a coast. The Cheyenne represents a non-marine Fredericksburg facies, probably about Comanche Peak in age. The Kiowa is marine, and contains a fauna of 17 vertebrates (fishes, plesiosaurs, turtle), insect wings, and 40 species of invertebrates including the following, which nowhere occur in beds higher than the Kiamichi: **Gryphaea navia, Exogyra texana,* **Oxy. belknapi, Oxy.* two other species, *Pecten irregularis* or *occidentalis.* (Fossils indicated with asterisk are Kiamichi markers.) No fossils definitely indicates Washita age, *i.e.*, Duck Creek or higher. The Spring Creek contains 13 species, of which the following definitely suggest an age not higher than Kiamichi: *Lingula* sp., *Ostrea quadriplicata.* Nothing proves Washita age. The Greenleaf contains: *Cyprimeria kiowana, Pholadomya* cf. *belviderensis, Turritella, Lingula,* shark teeth. The identified species all occur in the Kiowa, and nothing suggests any higher horizon.

Central Kansas.—In ascending order the stratigraphic units of the Comanchean are: Natural Corral shale, Windom fossiliferous limestone, Marquette sandstone and shale, Mentor sandstone with marine fossils. The Windom contains fossils identical with those of the Kiowa. The Mentor contains mostly Kiowa species, and the following also known to be from the Kiamichi: *Ostrea quadriplicata, Trigonia emoryi.* No species recorded is distinctively Washita (*i.e.*, Duck Creek or younger).

Colorado.—At Two Buttes, southeastern Colorado, Stanton and Lee (Jour. Geol., 13: 666, 1905) found *Desmoceras brazoense* and other Duck Creek fossils. In Purgatoire River, *G. corrugata* and *I. comancheanus* occur. In the

Apishapa quadrangle the Purgatoire contains: *Avicula, Pecten, Trigonia?, Protocardia, Tapes?, Pholadomya sancti-sabae, Trigonia emoryi, Cardium kansasense, Cyprimeria, Protocardia texana, Leptosolen conradi, Inoceramus comancheanus.* Stanton correlated this fauna with the Kiowa. It suggests a high Fredericksburg age, except that *I. comancheanus* ranges from Duck Creek down into the post-Kiamichi beds at Fort Stockton, and therefore lies near the Washita boundary. At a locality near Canyon City, the Purgatoire contains *Pholadomya sancti-sabae, Lingula, Tapes,* and a mactroid. Reeside (1290) records Purgatoire fossils, including unidentified ammonites, from as far north as Laramie County, Wyoming. They include species of *Inoceramus* and *Ostrea, Pteria salinensis* White, *Anchura kiowana* Cragin?, *Pachydiscus* sp.? [*Beudanticeras?*], an ammonite, and fish scales and bones. These localities must be near the Kiamichi-Duck Creek contact.

Dr. Moore verbally reports Purgatoire fossils at several localities north of central Kansas.

Several localities in the Llano Estacado in Texas show Comanche Peak, Edwards, Kiamichi, and Duck Creek zone fossils (pages 355–358).

Purgatoire formation in Dallam County.—C. L. Baker has lately restudied the isolated Mesozoic exposures in Dallam County, the northwesternmost county in the Texas Panhandle, and has kindly furnished the following notes on these exposures. Although no animal fossils were collected, the lithology permits identification in this area of the formations usually considered Morrison, Purgatoire, and Dakota in northeastern New Mexico.

Composite section on North Perico Creek, 2 miles north of Texline from ½ mile west of Texas-New Mexico state line to ⅜ mile east of that line, and South Perico Creek, about 1 mile south of Texline.

Purgatoire formation (Cheyenne?):

Caliche at top of section

	Feet
6. Sandstone, soft, fine-grained, tawny yellow; like Tucumcari beds (½ mile west of New Mexico line)	5
5. Sandstone, slabby, brown, ferruginous	3
4. Shale, the lower half sandy, the upper half bentonitic. Most of the bentonitic shale is green, and contains many thin irregular seams stained brown by limonite, dendrites of manganese, and botryoidal masses of barite up to 8 inches in diameter	15
3. Sandstone, buff to dark brown, fine grained, cross-bedded, ripple-marked, containing many dark brown to black ferruginous concretions, plant fragments, and some fucoidal markings	8
2. Sandstone, somewhat blue-gray, weathering light buff, fine-grained, with platy and shaly bedding, and containing many fucoidal markings	4
1. Sandstone, buff, fine-grained	2

TRINITY GROUP (emended)[20]

Sediments of this group were deposited in Texas in a transgressing sea, whose margin moved northward during Trinity time; the limit of its advance is shown roughly in Fig. 16. Practically everywhere its base consists of sand or conglomerate, which of necessity is of different ages at different places along the line of advance. It follows that this basal lithologic unit is not a formation, if by formation is meant a rock body of a single restricted contemporaneous age. It is the combined marginal facies of various Trinity levels. The middle of the Trinity group generally though not everywhere consists of a limestone, usually somewhat sandy. The uppermost Trinity is likewise a sand shorewards, a limestone seawards. As in the Fredericksburg group, formations, even though useful in small areas, may not be of the same age over greater distances. Rocks of the same facies are of different ages at different places, and rocks of the same age laterally change rapidly in facies. Therefore the Trinity group will be treated as a whole, and the various, in part overlapping, formations which have been used in different parts of Texas will be mentioned in their appropriate stratigraphic connection.

FORMATIONS OF TRINITY GROUP IN TEXAS

	Northern and central Texas	*Marathon basin*	*Sierra Blanca-Quitman Mtns.*	*Stages*
Antlers	Paluxy	Maxon	Cox	Lower Albian
	Glen Rose	Glen Rose	Glen Rose-Cuchillo	
	Travis Peak	"Basement sands"	Mountain-Las Vigas	Upper Aptian
	(absent	(absent)	Torcer	Valanginian

[20]*Literature.—Arkansas:* Dane, 392; Hill, 753. *Oklahoma:* Hill, 803; Bullard, 174, 175; Taff, Atoka, Tishomingo folios; Honess, 839, 840. *Louisiana:* Spooner, W. C., Interior salt domes of Louisiana, Bull. Am. Assoc. Geol., 10: 217–292, 1926, and, Geol. Salt Dome Oil Fields, 269–344, 1926; Veatch, A. C., Salines of north Louisiana, La. Geol. Surv., Spec. Rept., 2, 1902; Shearer, H. K., and Hutson, E. B., Dixie oil pool, Caddo Parish, Louisiana, Bull. Am. Assoc. Petr. Geol., 14: 743–764, 1930; Ross, J. S., Deep sand development in Cotton Valley field, Webster Parish, Louisiana, Bull. Am. Assoc. Petr. Geol., 14: 983–996, 1930; Crider, A. F., Pine Island deep sands, Caddo Parish, Louisiana, Str. Typ. Amer. Oil Fields, II: 168–182, 1929; Fletcher, Corbin D., Structure of Caddo field, Caddo Parish, Louisiana, Str. Typ. Amer. Oil Fields, II: 183–195, 1929; Spooner, W. C., Homer Oil Field, Claiborne Parish, Louisiana, Str. Typ. Amer. Oil Fields, II: 196–228; Teas, L. P., Bellevue oil field, Bossier Parish, Louisiana, Str. Typ. Amer. Oil Fields, II: 229–253, 1929. *North-central Texas:* Bullard, 176, 177; Winton,

Hill (731, p. 298) at first placed Shumard's "Caprotina limestone" (= Glen Rose) in the Fredericksburg group and separated the "Upper Cross Timbers" (= Travis Peak) as an independent and earlier unit. The term "Trinity division" was first used by Hill in 1889 (735, pp. xiv–xv). Taff's "Bosque division" (1574, p. 280, 1891) is a synonym. The name "Travis Peak sands" was applied by Hill (766, p. 118) in 1890 to the basal marginal facies of the Trinity group in Travis County; the succeeding limestones were called "Glen Rose or Alternating Beds" by Hill in 1891 (772, pp. 504, 507; 780, p. 83), and the upper Trinity sands were called Paluxy in 1892 (780, p. 84). These three formations comprise the standard type section of the Trinity group. The basal marginal facies, where its exact correlation appears doubtful, has been generally referred to in the literature as "Basement Sands." Along a line (Fig. 18) through Brown, Parker, Wise, and Denton counties, the Glen Rose facies interfingers out into sand on going northwards, and the combined Trinity sand here has been called Antlers (788, p. 303). Much of it is Trinity, but its upper part may be of Fredericksburg age. In west Texas the nomenclature of the Trinity has met with similar difficulties, and some authors, through lack of knowledge of the fossil contents of the beds, have introduced much confusion into the nomenclature. Richardson, in describing the section northwest and northeast of Sierra Blanca, called the basal conglomerate "Campagrande" (1304a, p. 47), the type locality being in the Finlay Mountains; a higher sandstone was called "Cox" (1304, p. 47) from Cox (Tabernacle) Mountain. The overlying Finlay limestone (1304, p. 47) is of Fredericksburg (Comanche Peak-Edwards) age. The basal conglomerate 4 miles west of Sierra Blanca was called "Etholen" by Taff (1573, p. 723). These formations, and the Maxon sandstone of King (936, p. 92), about Paluxy in age, situated in the eastern part of the Marathon basin, all lie in the thinned shoreward northern extension of the Comanche series in Trans-Pecos Texas. Just south of Sierra Blanca, Taff partitioned the Trinity section into Etholen, Yucca (1573, p.

1789, 1790, 1791; Shuler, 1454; Adkins, 11, 16; Hill, 742, 746, 803; Scott, 1394; Miser, 1113a; Vanderpool, 1679. *Central Texas:* Hill, 803, 795, 808; Jones, 888, 891; Sellards, 1402; Liddle, 992. *Trans-Pecos Texas:* King, 936; Baker, 46; Adkins, 12; Udden, 1623, 1625, 1626. *Edwards Plateau:* Liddle, 991; Beede, 87, 92; Henderson, 704; Hill, 803. *Paleontology:* Hill, 762, 767, 783; Rauff, 1286; Burckhardt, 180a; Vanderpool, 1678, 1679. *Paleobotany:* Groves, 633; Fontaine, 545; Torrey, 1608; Sellards, 1416; Wieland, 1758a, 1759, 1759a; Adkins, 12, 13. *Transgressions and regressions:* Grabau, 629b; Hill, 803; Scott, 1394.

725), and Bluff (1573, p. 727) beds; farther southwest and down the overlap near Quitman Gap he partitioned the Trinity equivalents into Mountain (1573, p. 730) and Quitman (1573, p. 728) beds. In the Shafter district Udden established the Presidio beds for the basal sands and conglomerates of the Trinity (1623, pp. 25–30), and the Shafter beds (1623, p. 30) for the overlying limestones. In the Conchos River region in Chihuahua, west of Presidio, Burrows has established several formations, which are discussed in the following section.

At Malone (Torcer), in the Conchos River valley west of Presidio, and probably near Hot Springs south of Sierra Blanca, the earliest Cretaceous in Texas, here included in the emended Trinity group, occurs. It will be discussed first. The Trinity elsewhere in Texas may be conveniently divided into thicker, off-shore, sections, and thinner inshore, in part marginal, sections.

EARLIEST TRINITY IN TRANS-PECOS TEXAS

From north-central Mexico a narrow arm of the late Jurassic and earliest Cretaceous seas extended as far north as Malone Mountain, and left above the Jurassic sediments already considered certain earliest Cretaceous beds, which are older than any other in Texas. The main areas to be compared are Malone Mountain, the Conchos Valley, Chihuahua, Mexico, and the southern Quitman Mountains near Hot Springs south of Sierra Blanca (Fig. 15).

MALONE MOUNTAIN SECTION

TORCER FORMATION[21]

Nomenclature.—The name Torcer is here applied to the portion of the section at and near Torcer (formerly Malone) station on the Southern Pacific Railway west of Sierra Blanca which is of early Neocomian age, overlies the Jurassic and underlies the *Dufrenoya* (Gargasian) level. The type locality is taken in Malone Mountain, though exposures occur also in Malone Hills in the flat about a mile east of the station, and in the southern and western foothills of Malone Mountain. This name covers the Cretaceous portion of Cragin's "Malone formation," that name having been restricted to rocks of Jurassic age. The thickness of the Cretaceous

[21]*Literature.*—Taff, 1573; Stanton, 331; Cragin, 331; Kitchin, 944; Baker, 46, 55; Burckhardt, 181.

portion is, according to the records, more than 831 feet. The formation belongs to the emended Trinity group of the Comanche series.

Stratigraphic position and contacts.—The following section by Taff (1573, p. 726) is selected from among several studied, and is interpreted in accordance with the facts published later by Stanton (in 331) and Baker (46, 55).

SECTION OF CENTRAL MALONE MOUNTAIN NEAR TORCER STATION (Modified from Taff):

Torcer formation (Eocretaceous):

(These beds are continued farther south and west.)

		Feet
1.[22]	Limestone, flaggy, compact and finely crystalline, blue to pale yellow, weathering yellow or brown	100
2.	Limestone conglomerate, maximum	10
3.	Milky white calcite	2
4.	Limestone, blue, slightly siliceous; pelecypods, gastropods; *fresh water facies;* this bed may duplicate other limestones in the section	100
5.	Calcareous, ferruginous, sandy grit	5
6.	Siliceous limestone, with chert and limestone pebbles	45
7.	Limestone, light blue, weathers yellow, compact	4
8.	Shale, conglomeratic, calcareous, black, weathers purple	10
9.	Pisolitic limestone conglomerate with siliceous matrix, some chert pebbles	20
10.	Persistent *rusty conglomerate:* hard conglomerate, brown, rusty, calcareous, partly siliceous, matrix, containing chert and limestone pebbles	40
11.	Limestone, thin- and thick-bedded alternating, siliceous, gray	450
	This basal portion of the Torcer has been subdivided by other writers. Its upper 250 feet is stated by Stanton to contain a fresh water limestone with fossils. Beneath this is about 35 feet of sandstone with marine fossils. At a level about 125 feet above the base (Stanton's No. 25, in 331, p. 26), there is a 15-foot limestone containing *Pygurus* sp., *Gryphaea mexicana, Pinna quadrifrons,* and *Pleuromya inconstans.*	
12.	Calcareous grit and cherty conglomerate	15
13.	Calcareous sandstone and siliceous limestone. A thick, light buff to yellow brown sandstone in this position above Briggs switch yielded *Astieria* and another ribbed Cretaceous ammonite. From this limestone (Stanton's No. 22, in 331, p. 26) fragmentary fossils including ammonites were reported	30

[22]Taff's numbers are used.

Malone formation, restricted (Upper Jurassic):

14. Limestone, light blue siliceous, with occasional bands of siliceous shell breccia. Nos. 9 and 10 of Stanton's section II (331, p. 27), presumbaly the lower part of this bed, consist of blue limestones with echnioids and large *Nerinaea*, and shales 300
15. Massive conglomerate, with siliceous limy matrix and limestone pebbles. Similar conglomerates occur in the Briggs section 150
16. Alternating limestone and conglomerate layers: the strata are each 10–20 feet thick; the limestones are siliceous; there are some shaly strata. At various levels from 220 to 320 feet above the gypsum, Stanton has reported several Jurassic fossils, including *Idoceras schucherti, Kossmatia clarki,* nautili and pelecypods. Stanton's Malone Mountain bed No. 13 (at about 188 feet above the gypsum) contains Jurassic fossils.

Leonard formation (Permian):

17. Limestone, light blue; locally absent 40
    Some limestones overlying gypsum in this vicinity contain *Richthofenia,* ammonoids, and other Permian fossils.
18. Gypsum, white, granular 110
19. Limestone, dark blue granular, minutely cleaved, metamorphosed, and veined with calcite 120
20. Gypsum 50
21. Limestone, siliceous, light gray .... 25+

At many places the thickness of the limestone above the gypsum is variable, and the gypsum is so squeezed and distorted as to involve the adjacent limestones. The incompetence of the gypsum permits much crumpling in its vicinity, and as a result the exact sequence and relations of the basal beds cannot be everywhere seen, especially where folding is intense. In Stanton's Malone Mountain section three gypsums are reported, alternating with limestones or with some conglomerate. How much repetition exists, or whether more than one gypsum is present, requires further field study.

The following interpretation of the stratigraphy is made from the published sections of Taff (1573), Cragin (331), Stanton (in 331), and the structural profiles of Baker (46, 55), together with observations by the writer.

Permian.—At or near the top of the Permian section, a 100-foot bed of gypsum occurs. Locally, perhaps everywhere, it is overlain by a limestone bed, 40 feet thick in Taff's section (1573, p. 726, across Malone Mountain near Torcer station); in this limestone *Richthofenia* occurs (46, p. 11). Altogether the visible Permian section consists of two (or ?three) gypsum layers interbedded with limestone. The maximum thickness exposed is recorded as 470 feet.

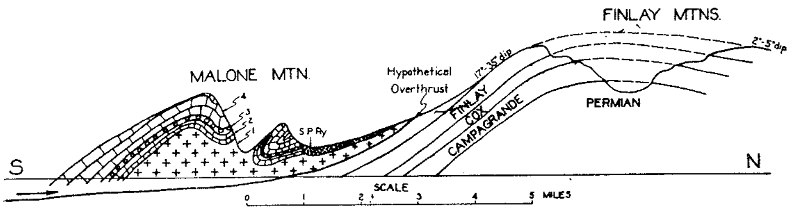

Fig. 14. Profile from Malone Mountain to Finlay Mountains, south-central Hudspeth County, Texas.

4 = Valanginian (*Astieria*)
3 = Tithonian (*Kossmatia aguilerai*); Kimmeridgian (*Idoceras*)
2 = Permian (Richthofenia, ammonoids)
1 = Permian gypsum

Jurassic.—Taff's numbers 16–14 (1573, p. 726) and Stanton's 6–17 (331, p. 25) and 2–10 (331, p. 27) are considered Jurassic. The maximum recorded thickness is 580 feet. Fossils from about the middle of this section recorded in Stanton's lists 5 and 7 (331, p. 18), include *Idoceras schucherti* and *Kossmatia clarki;* the former demonstrates Kimmeridge age, and the latter the same or a slightly higher age. *Kossmatia aguilerai,* found in the foothills west of Malone Mountain and about 2 miles north of its southern end, in a level not tied into those of the main sections, is regarded by Spath as possibly Tithonian (944, p. 458). The basal half of the Jurassic consists of conglomerates, sandstones, and conglomeratic sandstones and limestones; some black, bituminous shales weathering brownish to purple-lavender are Kimmeridgian and nearly typical of shales of that age in northern Mexico; the remainder, about the upper one-third of the Jurassic, is predominently limestone. Possibly higher levels are filled in on the southern part of Malone Mountain, a feature as yet insufficiently checked.

Cretaceous.—Only 830 feet of Cretaceous is recorded, some of it possibly repeated, and all apparently early Neocomian. Farther south and west, near Malone Mountain, upper beds come in. No complete survey of the section up to the *Dufrenoya* (Travis Peak) level has yet been published. The Cretaceous section begins with 25 to 45 feet mostly of sandstone, siliceous limestone, cherty and calcareous conglomerate, and grit. These basal strata contain ammonites at various places. In one of the sandstones near this level, at the top of the ridge south of Briggs switch, Baker found an *Astieria,* and in a nearby limestone, a ribbed Cretaceous ammonite.

Above this comes 450 to 550 feet of mostly limestone. This is capped by a 40-foot bed of typically rusty-weathering conglomerate, containing siliceous grit and pebbles; this bed is persistent and easily recognized. It is overlain by 300+ feet mostly of limestone, with some conglomerates, grits, and shales. This upper part of the section is notable for containing two or more levels of fresh-water limestones with *Unio, Viviparus,* and other genera. One such fresh-water level, may underlie the rusty conglomerate (which Burckhardt refers to the Jurassic). This fresh-water section is interesting through demonstrating that Malone lies on the very margin of marine sedimentation, and through being a reduced Texas representative of the Wealden facies.

Fossils and age.—The age relations of both Jurassic and Cretaceous at Malone Mountain have been discussed by many writers (see section on Jurassic), and the general features are now well known. The Cretaceous portion is mostly of infra-Cretaceous (Valanginian) age, an ammonite *(Astieria)* and certain pelecypoda *(Trigonia, Ptychomya)* being most conclusive as evidence, but further research will doubtless reveal more fossils of both this and other Cretaceous ages.

Spath's and Uhlig's statements concerning Malone ammonites have already been quoted. Kitchin (944) summarizes the evidences for Valanginian age, as shown by the Malone pelecypoda, in part as follows:

(1) *Trigonia calderoni* (Castillo and Aguilera) is suggestive of *T. vau* and *T. v-scripta.*

(2) *Trigonia goodelli* is analogous to *T. recurva* Kitchin.

(3) *Trigonia vyschetzskii* belongs to the section Pseudo-quadratae (Steinmann),[23] characteristically and exclusively Lower Cretaceous everywhere.

(4) *Trigonia proscabra* is distinctly like Neocomian species from Chile.

(5) No Malone *Trigonia* belongs to the section Undulatae, nor is that section exclusively Jurassic. The sculpture of *T. rudicostata* and *T. conferticostata* has its closest analogues in Costatae from the Trigonia beds in the Oomia series in Cutch (Kachh).

(6) The genus *Ptychomya,* represented at Malone by *P. stantoni,* is elsewhere known only from the Cretaceous.

(7) The characters of *Astarte (Eriphyla) malonensis* recall those of Lower Cretaceous species in the South Andean and Africo-Indian regions.

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[23]Steinmann, G., Die Gruppe der Trigonia pseudo-quadratae, N. Jahrb. f. Min., 1882-I: 219–228, pls. VII-IX.

(8) Some Malone oysters, as *Gryphaea mexicana* and *Exogyra potosina,* likewise common in northern Mexican localities, have the characters of Lower Cretaceous species.

(9) *Pleuromya inconstans* Cragin shows much resemblance to forms of *Panopea* occurring in the Lower Cretaceous in Europe.

The ammonites of contemporaneous beds have been described from many regions, such as the late Valanginian Uitenhage beds of South Africa[24] and more immediately, Valanginian ammonite-bearing beds in northern Mexico.[25] The *Astieria* sp. and several other ammonites from Malone localities have not yet been precisely identified. It is possible that other levels, in both the Jurassic and the Cretaceous, will be identified near Torcer.

CONCHOS RIVER VALLEY SECTION

Burckhardt (181, pl. 12 opp. p. 160) has correlated the Morita formation of the Bisbee section, the arkoses, conglomerates, and shales below the main limestone near Cuatro Ciénegas, Coahuila, and the Mountain bed of Taff (at Quitman Gap), with the Hauterivian-Barremian sandstones containing copper veins near Las Vigas on the Rio Conchos (Las Vigas formation of Burrows). The basal red sandstones and shales near Hot Springs are apparently a continuation of these beds. The beds are overlain by the Gargasian marls and limestones containing *Dufrenoya* and lower Albian with *Douvilleiceras,* which are overlain by the thick *Orbitolina*-bearing Glen Rose (Trinity) limestones.

Sections in northern Mexico.—Two noteworthy sections of Eocretaceous are those near Cuatro Ciénegas, Coahuila (181, pp. 83, 144–147), and in the Conchos Valley, Chihuahua (181, pp. 83, 147–149). In the former section the early Cretaceous marginal and neritic beds consist mainly of (in ascending order): (a) clays alternating with sandstones or limestones, 800 ft., containing *Trigonia* aff. *vau* and other pelecypoda; (b) arkose and conglomerate, shaly

[24]Spath, L. F., On the ammonites of the Speeton clay and the subdivisions of the Neocomian, Geol. Mag., Vol. LXI, 1924; Spath, L. F., On the cephalopoda of the Uitenhage beds, Ann. S. Afr. Mus., 28: 131–157, pls. XIII–XV, 1 fig., 1930; Kitchin, F. L., The invertebrate fauna and paleontological relations of the Uitenhage series, Ann. S. Afr. Mus., 7: 21–250, pls. II–XI, 1908.

[25]Böse, Emil, Algunas faunas cretacicas de Zacatecas, Durango y Guerrero, Inst. Geol. México, Bol. 42, 219 pp., 19 pls., 1923; Burckhardt, C., Faunes jurassiques et crétaciques de San Pedro del Gallo, Inst. Geol. México, Bol. 29; del Castillo, A., and Aguilera, J. G., Fauna fosil de la Sierra de Catorce, San Luis Potosí, Bol. Com. Geol. México, No. 1, 1895; Burckhardt, C., La faune jurassique de Mazapil avec un appendice sur les fossiles du Crétacé inférieur, Inst. Geol. México, Bol. 23, 1906.

at base, 765 ft.; (c) sandstone and arkose, 2300 ft.; (d) sandstone and arkose, 200 ft. These are overlain by Gargasian, containing *Dufrenoya texana.* The Zambrano well (N.E. Coahuila) contains a somewhat similar arkosic section.

The Conchos Valley section consists of (a) Boquilla[26] slate, possibly Paleozoic, 1000 ft.; (b) Plomosas formation, possibly Jurassic, limestones, with subordinate quartzite, conglomerate, and shale, 1150 ft.; (c) Las Vigas formation, Neocomian, basal half sandstones with four commercial copper veins, upper half shales with thin sandstones, some fossil plants, 1940 ft.; (d) Cuchillo formation, its basal 1500 ft. of gypsum with rock salt near base, shales, limestones with *Dufrenoya* and *Douvilleiceras* (Gargasian), more clayey to south, 2000 ft.; Aurora ("Mountain") limestone, cherty, fossiliferous limestones with big springs, the main mountain-forming rock of the region, 1500 ft. This is overlain by the Upper Cretaceous.

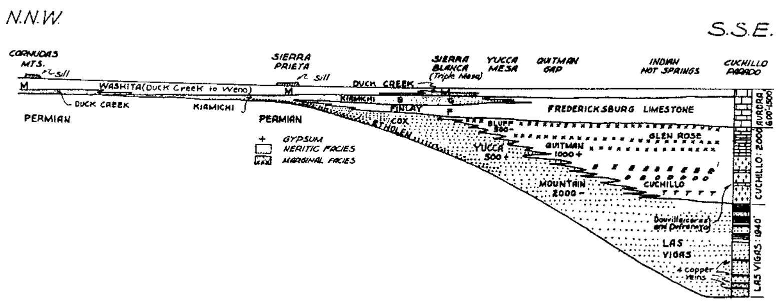

Fig. 15. Profile from Cornudas Mountains (Texas-N. M.) to Conchos Valley south of Indian Hot Springs.

Northwards the section thins greatly, transgressive overlap involves successively higher Comanche levels up to the Duck Creek, and the sandy marginal facies becomes progressively younger to the north.

The following letters indicate persistent fossil zones:

M = Mortoniceras (Washita species)
G = Gryphaea navia (Kiamichi)
F = Rudistids (Fredericksburg)
x = Orbitolina texana (Glen Rose)
E = Exogyra quitmanensis (Quitman, Cuchillo)
D = Douvilleiceras and Parahoplites (Cuchillo)
T = Trigonia aff. taffi (Cuchillo)

SOUTHERN QUITMAN MOUNTAINS SECTION

The southwestern part of these mountains near Hot Springs (Eagle Mountain sheet) contains a thick section of early Cretaceous beds reaching from an unknown base up to the *Orbitolina* (Glen Rose)

[26]Name preoccupied by Udden's Boquillas, 1907.

limestone. The beds mostly dip eastward in uninterrupted succession, with some folding and minor faulting, and afford a more straightforward section than the Malone Mountain district. The basal observed formation is the Las Vigas, a large thickness of red sandstones in beds up to 50 feet thick, gray sandstone, red sandy shale, and gray shale. These beds are generally poor in fossils. They are of early Neocomian age. They are overlain by several hundred feet of gray limestones and marls, of Gargasian and perhaps Lower Albian age, referred to the Cuchillo formation. These are overlain by Glen Rose equivalents.

LAS VIGAS FORMATION

Nomenclature.—This formation was described, without age assignment, by Burrows[27] in 1910, from exposures in the Conchos River valley in northern Chihuahua, west of Presidio, Texas. According to Burckhardt's (181, pp. 83, 148–149), interpretation, it overlies the upper Jurassic Plumosas formation of Burrows. It consists of gray, black, and red quartzitic sandstone, gray limy sandstone, black shales, and sandy limestones. Some of the sandstones and shales contain veins of copper. The upper portion, transitional to the overlying Cuchillo formation, contains gypsum and fossiliferous limestones *(Exogyra)*. Its thickness in the Conchos Valley reaches 1968 feet (600 meters).

Outcrop in southern Quitman Mountains.—On the Sierra Blanca road, within 2 miles of Hot Springs, the east-dipping red sandstones, siltstones, and sandy clays beneath the fossiliferous Gargasian-Upper Aptian marls are more than 500 feet thick. The section here includes the following rocks:

6. Rhyolite tuffs and extrusive igneous.

5. Limestone with some red sandstone, siltstone, and red beds. Near north exit of Hot Springs road onto Quitman Arroyo flat.

4. *Cuchillo formation* (Gargasian) and Lower Albian): Thin gray or blackish limestones and gray marls interbedded. At Quitman Summit on the Hot Springs road. Fossils: *Douvilleiceras, Parahoplites* (several species), *Trigonia* aff. *taffi* Cragin, *Exogyra quitmanensis* Cragin, *Trigonia* spp., *Alectryonia* aff. *carinata* (or *rectangularis*), and many others. Thickness (estimated), 400+ feet.

3. Massive gray limestone. No fossils collected. Thickness (estimated), 200 feet.

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[27]Burrows, R. H., Geology of northern Mexico (eastern Chihuahua), Bol. Soc. geol. Mexicana, 7: 1–15, 1910.

2. Gray calcareous clay with thin bands of nodular clayey limestone. No fossils collected. Thickness (estimated), 250+ feet.

1. *Las Vigas formation* (Eocretaceous): Red sandstone in beds up to 50 feet thick, some red sandy shale, gray sandstone in members up to 50 feet, gray sandy shale; near top of formation, a little shale and limestone. No fossils collected. Thickness (estimated), 500+feet. The base was not seen.

These beds dip eastwards, at places steeply. A considerable area of fossiliferous marls and limestones is exposed on and near the road, about 5 miles north of Hot Springs. In a long valley at a sharp bend of the Rio Grande, 1¼ miles downstream from Hot Springs, Messrs. Baker and Arick and the writer collected *Parahoplites, Douvilleiceras*, a large ammonite, and various *Trigonia*. This level is the same as that at Quitman Summit, and lies several hundred feet below the main *Orbitulina* zone. So far, *Dufrenoya*, a marker for the Gargasian (= Upper Aptian), has not been found here, and the Cuchillo fauna marks the lowermost Albian. However the similarity with the Mexican Cuchillo leads to a provisional correlation with that formation. The correlation of the underlying red sandstones with Burrows' Las Vigas formation is even less well established, on account of lack of fossil evidence, but this is the nearest lithologically similar formation to which the lower beds at Hot Springs can be referred.

CUCHILLO FORMATION

Nomenclature.—Burrows (*op. cit.*, p. 8) described this formation, without age assignment, from the Conchos Valley section north of the Kansas City, Mexico and Orient line, a short distance southwest of Presidio. It clearly overlies the copper-bearing basal Las Vigas sandstones, and underlies the heavy-bedded main limestone (Aurora of Burrows; Mountain limestone of Hill, not of Taff nor of European authors; upper Glen Rose-Fredericksburg). The Cuchillo is identifiable as the main horizon of *Dufrenoya* and *Douvilleiceras*, which have been found at many places in this region. Böse collected them near the Aurora mine, 5 km. south of Cuchillo Parado, in the San Vicente valley in the Burro Mountains, southwest of Del Rio and in the Cañon de Vallas near Saltillo; and Burckhardt collected them from the Rio Nazas in Durango. A similar fauna has long been known from the Travis Peak beds in western Travis County (783, 180a). It contains *Dufrenoya texana* (Hill), *D. justinae* (Hill), *Pseudosaynella walcotti* (Hill), and the overlying Glen Rose contains *Parahoplites* and *Douvilleiceras.* At several places in the rim of the Solitario, in nodular limestones above the basal conglomerate and above limestones containing *Exogyra quitmanensis,* a large *Pecten,* and *Nerinea* (several species), there are lower Albian marls containing *Douvilleiceras* spp., *Parahoplites* spp., *Procheloniceras* n. sp. aff. *albrechti-austriae, Nautilus neohispanicus* Burckhardt, and other cephalopods. These may be referred to the Cuchillo. In this sense the Travis Peak would be in part the marginal facies of the Cuchillo.

Outcrop in southern Quitman Mountains.—Nos. 2–5 of the preceding tabulation, composed of fossiliferous marls and marly limestones outcropping on the Hot Springs road near Quitman Summit, are referred to the Cuchillo. Their age is Lower Albian, and, probably, in their basal part, Upper Aptian (= Gargasian). It appears that the ammonites here have considerable zonal thickness; the following expresses the supposed zonal arrangement in this locality:

Glen Rose:	6. Orbitolina zone	
Cuchillo:		
	5. Exogyra quitmanensis	Douvilleiceras and Parahoplites (5–4)
	4. Trigonia taffi	
	3. Dufrenoya (?)	
Las Vigas:	2. Fossils not known	
	1. Malone fossils (?)	

The Malone Cretaceous apparently comes below the main section of Las Vigas near the Hot Springs road. The Travis Peak is equivalent to zones 3–5. The base of the Solitario rim section lies in zone 5.

SYNCLINAL (OFF-SHORE) TRINITY SECTIONS

Southern Hudspeth County.—In southern Hudspeth County the Trinity rapidly thickens southwards and loses the marginal facies. Various authors, not fully appreciating these two features, have given numerous overlapping names to Trinity beds south of the Southern Pacific Railway, as has been already mentioned. The Trinity section surrounding Sierra Blanca Peak, which consists of two formations: Etholen conglomerate below, and Cox sandstone above, is in the marginal facies. On passing southwards the section thickens and passes into the offshore neritic facies, the formations becoming more marly and limy, especially near the top. Near Bluff Mesa, 3 miles south of Sierra Blanca station, Taff described the basal Yucca sand, overlain by the marly and limy Bluff formation. Near Quitman Gap, a basal 2000 feet of sandstone is called Cox by Baker, and Mountain by Taff, who recorded 4060 feet but failed to report its repetition by folding. It is overlain by a thick limestone and marl section, the Quitman of Taff. Passing southwards to near Hot Springs the section further thickens and is here divided into equivalents of the Las Vigas, Cuchillo, and Glen Rose formations. The accompanying profile depicts the writer's opinion of the general relation of these various formations, based on the known zonal fossils (Fig. 15).

Taff's (1573, p. 730) "Mountain" bed was mentioned above. The type locality of his "Yucca" bed is in Yucca Mesa at the west end of Devils Ridge, 3½ miles south of Sierra Blanca; the type locally of his "Bluff" bed is in Bluff Mesa, 2 miles southwest of Sierra Blanca; and that of his "Quitman" bed, in Quitman Gap across the Quitman Mountains, about 9 miles southwest of Sierra Blanca. Much further field work in this faulted and alluvium-covered region is necessary to define the relations of these formations. They are in part equivalent to each other.

The Yucca bed includes the basal, more sandy and conglomeratic strata in Devils Ridge and Yucca Mesa. It consists generally of alternating arenaceous limestone and quartzitic sandstone, with flaggy sandstones and limestones, pisolitic limestones, shell debris, and limestone breccias and conglomerates. At the top is a caprinid limestone. Fossils are rare; *Arca, Ostrea,* and caprinids are recorded.

The Bluff bed overlies the Yucca bed. It consists of alternations of sandstone or quartzite with oyster-bearing limestones. Recorded fossils are *Arca, Exogyra texana,* large flat oysters, other oysters, *Orbitolina texana,* and caprinids. *Orbitolina* and caprinid limestones occur near the top of the Bluff bed. It is to be emphasized that these two formations occur together in the ridges and mesas near Sierra Blanca, and that the Quitman and Mountain beds occur in another region, Quitman Gap, separated from the first by large faults which obscure the stratigraphic succession. Baker has mapped a major overthrust in this region.

At Quitman Gap, the Quitman bed is described as consisting of, basally, calcareous flaggy and yellow friable sandstone, containing *Exogyra quitmanensis* Cragin, *Ostrea* aff. *owenana* Shumard, *Pecten*, and a peculiar *Trigonia*-like fossil; medially, a massive siliceous shelly limestone; and at the top a massive caprinid limestone. A total thickness of 330 to 380 feet is recorded. According to Taff, the Quitman is overlain at Quitman Gap and in the west flank of the southern Quitmans by the Mountain bed, 4060 feet thick. Baker states that these beds are repeated by compressed folding and gives them a thickness of about 2000 feet (46, p. 20). Taff describes them as consisting of members of varicolored flaggy and calcareous sandstones alternating with members composed of limestones, marbles, and sandstones. Near the base there are some oyster shell limestones.

The Quitman bed, with *Exogyra quitmanensis*, resembles the beds at Quitman Summit (Cuchillo), and the Mountain bed in lithology resembles the Las Vigas formation. The Bluff bed contains *Orbitolina* in abundance, and corresponds to the Glen Rose. In the Hot Springs section the abundant *Orbitolina* zone is several hundred feet above the main *Exogyra quitmanensis* zone.

Val Verde-Maverick counties (578, 578a, 1625, 1681.—Near Del Rio the entire Comanchean has been penetrated in several wells, and metamorphosed slates and soft shales found beneath. In Maverick County wells have not reached pre-Comanchean rocks. The following are reported thicknesses of Glen Rose in the area: Rock Springs, 500 ft.; Juno, 500 ft.; Del Rio, 900 ft.; north line of Uvalde County, 1000 ft.; Uvalde County, maximum, 2250 ft.; Maverick County (Sullivan, Chittim leases), 3600+ ft. Details of the Travis Peak are lacking in many wells. The Glen Rose contains large amounts of limestone, much of it silty, sandy, or marly; mineralized waters with calcium sulphate, magnesium sulphate, and sodium chloride occur; and cavities containing pure sulphur or celestite, veins of gypsum, and small veins or stringers of anhydrite are found. On the large northwest-trending Chittim structure, the Glen Rose produces a large quantity of casinghead gas.

The Cretaceous section in northern Coahuila between the Burro Mountains and the Rio Grande has been described by Dumble (480). The Burro Mountains are a large domal uplift dissected by deep canyons, which however do not seem to reach the pre-Cretaceous rocks. C. L. Baker reports the section to be as follows: Washita-Fredericksburg mountain-forming limestone, 1200 feet; greenish-gray Walnut marl with calcareous concretions and many marcasite fossils (*Exogyra texana*, echinoids, etc.), 50 feet; Glen Rose alternating beds of marly limestone and purer limestone, the base not seen, 2000 feet. Near the base of the Glen Rose section, an ammonite (*Douvilleiceras?*) was found. Georgetown, thinned Grayson (Del Rio), Buda and Eagle Ford (Boquillas facies) form a 50-mile dip slope east of the Burros.

Bexar County (888, 1145, 1401, 1402).—From about 600 feet on the outcrop, the Glen Rose thickens gulfwards to 1785 feet (at 3097–4882) in the Milham Corporation, Eastwood No. 1 well in southwestern Bexar County. Here the Travis Peak is 479+ feet thick (at 4882–5361 ft., T.D.). The Glen Rose consists almost entirely of yellow, or blue, sandy limestone, dark colored sandy and shaly limestone with oil shows, and, in the basal 750 feet, of gray-yellow limestone. The Travis Peak consists of light, fine-grained sandstone and sandy shale with minor seams of limestone and quartzite, and basally some grits and conglomerates.

The Quitman-Eagle Mountains, the Maverick and the Bexar sections of the Trinity were deposited to great thickness in subsiding synclines of the Rio Grande embayment, and, in most levels, preserved shallow water conditions, with deposition of coarse sandstones, conglomerate, and anhydrite. The Louisiana section of the Trinity likewise contains a large thickness of shallow water sediments.

MARGINAL TRINITY SECTIONS

In consequence of the landward (northward) overlap of Trinity sediments onto the old basement rocks across Texas, the Trinity group forms a wedge-shaped mass of rocks, the thin edge pointing inland, and the thicker, buried, seaward extension pointing gulfwards. The Trinity rock sheet reaches inland to an irregular line (Fig. 16) running approximately through El Paso, Fort Stockton, Big Spring, and thence across the central area, denuded of Comanchean rocks, to southern Oklahoma; south of this line there are restricted areas in which Trinity rocks are absent and Fredericksburg rests directly on the old land.

Louisiana sections.—The Trinity section in the northern Louisiana oil fields shows different formations and facies different from those on the outcrop. The Trinity members are, in descending order: Upper Glen Rose limestone, Anhydrite zone, Lower Glen Rose limestone, non-marine red beds, Basal Trinity sand, basal fossiliferous clay (pre-Trinity?). The following sections are recorded:

	PINE ISLAND-CADDO	HOMER	BELLEVUE
Washita and Fredericksburg	1600+ ft. red shale and gumbo; west flank of Caddo field		
——Major erosional unconformity on tops of domes, removing Washita and Fredericksburg sediments——			
Upper Glen Rose limestone	200 ft. limestone	850 ft. red and gray-black shale; sandy shale, sandy limestone, fine sand, sandstone; *Ostrea, Pecten.*	200–600 ft. limestone and clay.
Anhydrite zone	450 ft. anhydrite	500 ft. sedimentary anhydrite interbedded with limestone; dwarf fossils.	500 ft. anhydrite
Lower Glen Rose limestone (at top, Wickett oolitic limestone; below, Dillon and Dixie pays)	900 ft. limestone *(Douvilleiceras)*	1000 ft. gray-black shale and shaly limestone, red shale, some fine sand and sandstone.	1150 ft. limestone, foraminifera *(Miliolidae)*, Dierks, ostracoda *Serpula.*
Red beds (non-marine red shale)	2000–2515 ft. red beds	not reached	991–1800 ft. red beds
Basal Trinity sand	thin	not reached	1072 ft. white and red sand and sandstone.
Neocomian? or Jurassic? clay	not reached	not reached	330+ ft. fossiliferous clay and limestone* (Bliss and Wetherbee No. 30, at 4972–5302 ft.)

*Contains *Polymorphina, Haplophragmium, Haplophragmoides,* gastropoda and ostracoda. Exact age unknown; stated to resemble Cretaceous.

In facies, all Trinity rocks at the outcrop in Texas are epicontinental, and consist of two classes: (1) marginal sediments, conglomerate, sandstone, sandy shales in the typical Travis Peak formation, some sandy phases of the Glen Rose, and the type Paluxy; and (2) an offshore, neritic facies, consisting of limestone and marl, as in the type Glen Rose. The marginal facies is characterized by clastic and detrital material, coarse sands, gravel, and conglomerate, red color, rarity of typical marine invertebrates, presence of fossil wood, cycads, dinosaurs, fish remains, and cross-bedding. The other facies contains limestone (shell breccias, coquina, or organically precipitated limestone), some of it of shallow water origin and containing ripple marks, rain marks, mud cracks, dinosaur tracks, and coral reefs, some black shale, and anhydrite, sulphur, celestite, strontianite and mineral salts. In Louisiana deep wells there is a third, red bed facies, which may be of continental origin.

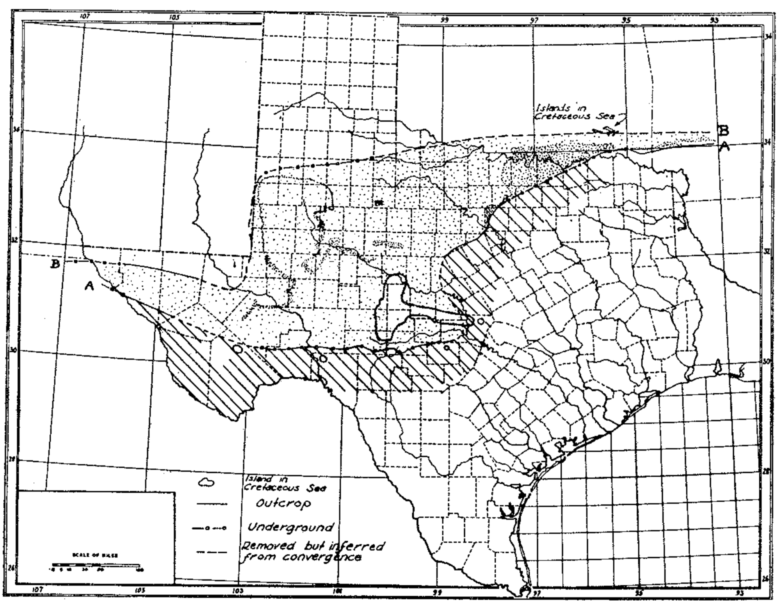

Fig. 16. Extent and facies of the Trinity group in and near Texas. Ruled area = landward margin of Glen Rose limestone wedge; dotted area = shoreward extent of Antlers sand (heavier dots indicate actual outcrop).
A–A, northern margin of Glen Rose. B–B, northern margin of Trinity sand.

The formations of the Trinity group have only local validity, because, if viewed regionally, they are facies of one continuous and laterally changing mass of sediments. For convenience they are here treated as local formations, with the reservation that on being traced into the marginal area the offshore units become lithologically similar. The Gillespie near Fredericksburg is a marginal, cycad-bearing facies of the upper Glen Rose. The Paluxy is a sandy facies of the uppermost Glen Rose. The Antlers in southern Oklahoma is the combined marginal equivalent of the entire Trinity group, and perhaps includes basal Fredericksburg strata.

The limy and marly Trinity is marked by an upper Aptian and lower Albian assemblage of pelecypods and gastropods, corals (resembling those from the Tehuacán, San Juan Raya, and Puebla districts in southern Mexico), and ammonites *(Dufrenoya, Parahoplites, Douvilleiceras)*. The marginal facies is marked by cycads *(Cycadeoidea boesiana, C. bart-johnsoni)*, wood, conifers, no angiosperms, brackish-water mollusca, and dinosaurs.

Anhydrite.—In Arkansas, Louisiana, northern Mexico, and Texas, rocks of the Trinity group contain anhydrite. The De Queen limestone in southwestern Arkansas contains, along the outcrop, lenticular masses of celestite and thin beds of gypsum, which thicken gulfwards and become massive beds of anhydrite. They are reported to be about 20 feet thick on the surface. At Pine Island-Caddo, there is about 450 feet of anhydrite between the upper and lower Glen Rose limestones; in the Homer field, 500 feet of sedimentary anhydrite, interbedded with limestones (fauna of dwarfed fossils); in Bellevue, 500 feet of anhydrite. Farther east, in the Richland field, and in the Bethany gas field, Panola County, Texas, the anhydrite thicknesses are as follows (612, p. 946):

	Richland field Eubanks No. 1	Bethany field
Anhydrite	28	5
Shale and limestone	155	248
Anhydrite	196	238
Limestone	60	67
Anhydrite	40	3

In Fannin County, Texas, in a well on the Owens farm, anhydrite was cored at the depth 2656 feet, and the driller logged 50 feet of anhydrite. At 2675 feet, calcareous sandstone was cored.

In the city well at Hubbard, Hill County, Dr. T. W. Stanton found anhydrite in cores at 2855 feet. Gypsum is logged (803, p. 557) at the depths 2848–2878 feet. The base of the Glen Rose in this well is at or near 2640 feet, and the well ended in Travis Peak at 3166 feet. In the North Currie field, the Sun Company's H. A. Swink No. C-1 had gypsum cuttings at a level of about 1225 feet below the "Tritaxia zone," which is located just above the top of the Glen Rose. In the Mexia field in E. L. Smith's Steubenrauch well, anhydrite cuttings were recorded at 1100, and gypsum cuttings at 1400 feet below the "Tritaxia" zone (969, p. 334). In the Kelly No. 1 well, Luling field, anhydrite was cored at the depth 4422 feet, its thickness being undetermined; at 4728 feet the base of the Cretaceous was reached.

In the McAngus well at Elroy, eastern Travis County, the Glen Rose contains an anhydrite stratum at the depth 2367 feet. The Travis Peak contains an anhydrite stratum cored at 2988 feet.

At the outcrop in Maverick County, anhydrite occurs in the Edwards, and thin beds and veins of it occur at eleven levels in the Glen Rose. Gypsum occurs at the outcrop in the northern part of Gillespie County. In the Edwards, or Comanche Peak, limestone, 3 or 4 miles south-southwest of Menard, a few feet of gypsum is found in shallow excavations. Gypsum outcrops in the Glen Rose near the mouth of Bull Creek, western Travis County.

Burckhardt reports gypsum at the outcrop in the Conchos River region in northern Chihuahua, a short distance west of Presidio, Texas. Near the top of the Neocomian-Aptian copper-bearing sandstones ("Las Vigas" of Burrows) near Coyamé, intercalations of gypsum and limestone seams occur. In the overlying Gargasian shales ("Cuchillo" of Burrows), gypsum and rock salt occur (181, p. 148); the rock salt has been locally exploited for a century.

In Smackover field, Arkansas, the salt was found at depths of 5974–7255 feet, beneath the lower marine series of Trinity. Spooner[28] says: "The age of the salt is not determinable, but the probability that it is older than Comanche is suggested."

Celestite pockets and nodules are widespread in the Glen Rose in central Texas.

Celestite.—Professor L. S. Brown has kindly furnished the following comments concerning the Trinity celestite in central Texas:

[28]Spooner, W. C., Bull. Am. Assoc. Petr. Geol., 16: 602, 1932.

Concerning the deposits of celestite in the limestones, it is my opinion that these are of primary (syngenetic) occurrence. The evidence supporting this view is as follows:

1. Petrologic Structures.—In many cases the enclosing limestone shows distortion without fracturing, diverging and bending around the celestite nodule. This is easily seen only in case of the larger nodules, around six inches in diameter or more. In several cases, immediately above the nodule, bedding planes can be seen, showing no bending or other disturbance in the vicinity of the nodule, though succeeding strata contained similar nodular inclusions. These features are especially evident in the Mt. Bonnell region.

2. Distribution.—Celestite nodules, similar in appearance, are found in a rather wide belt through central Texas. Ordinary stratigraphic descriptions make no particular observations on celestite, but, so far as I am aware, the occurrence of the mineral is limited to the Glen Rose limestone, though I have no particular reports of its absence from other horizons. This strongly bespeaks marine distribution, and almost definitely excludes secondary entry.

3. Associated Minerals.—Within the Glen Rose, gypsum, anhydrite, and celestite occur in similar manner and in some abundance. Hill has reported epsomite and strontianite, but I have not observed either. However, the occurrence of all of these minerals of similar character is indicative of marine concentration.

4. Precedent.—The literature contains several descriptions of syngenetic celestite in limestones, notably several papers by Kraus on the "vermicular" limestones of New York, Put-In-Bay Ohio, etc.

ANHYDRITE, GYPSUM AND CELESTITE LOCALITIES IN THE CRETACEOUS

* = underground occurrence

TRINITY GROUP

	Feet
Louisiana—	
Pine Island-Caddo (anhydrite)	450*
Homer field (anhydrite)	500*
Richland field (anhydrite)	244*
Bellevue field (anhydrite)	500*
Arkansas—	
DeQueen outcrop (gypsum, celestite)	20
Texas—	
Bethany field, Panola County (anhydrite)	246*
Northern Shelby County, near Paxton (anhydrite)	*
Fannin County, Owens farms (anhydrite)	50*
Parker County (anhydrite)	
Hill County, Hubbard city well (anhydrite)	30*
Navarro County, North Currie (gypsum)	*
Limestone County, Mexia, (anhydrite, gypsum)	*
Comanche County (anhydrite)?	
Somervell County, near Glen Rose (celestite)	*
Caldwell County, Luling (anhydrite)	*
Lampasas County, near Nix (celestite)	
Travis County, Elroy (anhydrite)	*

	Feet
Williamson County, near Leander (celestite)	
Travis County, Bull Creek (gypsum) outcrop	
Travis County, Mt. Barker (celestite)	
Mills County, outcrop (gypsum)	
Val Verde County, Del Rio (gypsum)	*
Uvalde County, Southern Crude O. P. Co., Washer 1 (anhydrite in Glen Rose at several levels)	100+*
Chihuahua—	
Conchos River west of Ojinaga, outcrop (gypsum)	
Coyamé, Las Vigas copper-bearing sandstone (gypsum); Cuchillo shales (gypsum)	

FREDERICKSBURG GROUP:

Maverick County, Edwards outcrop (anhydrite)	
Menard County, near Menard, Edwards outcrop (gypsum)	5
Kinney County, Fredericksburg outcrop, Cummins (gypsum)	
Gillespie County, Doss Valley road (alabaster gypsum)	10
Gillespie County, Mason road 13 miles nw. of Fredericksburg, (7 ft. alabaster)	
Maverick County, Rycade Chittim 2 (20 ft. rock salt, top Edwards)	
Van, Van Zandt County (Trinity gypsum level), several wells	*

Shafter section (1623, 53).—The Trinity of the Shafter section is composed of two formations:

B. SHAFTER formation (= Glen Rose).—Thin to medium-bedded, but mostly massive limestone, which differs from Fredericksburg limestones in being non-cherty; some interbedded limy marls. Thickness, 700 feet. Fossils: *Porocystis* in two zones, at top, and 170 feet above base; *Monopleura marcida*, 250 feet above base; *Orbitolina texana* and other species, from base to within 230 feet of top; *Caprina occidentalis* and *C. crassifibra*, at about middle; *Exogyra texana* and *Engonoceras* cf. *complicatum* Hyatt, in upper 200 feet.

A. PRESIDIO formation (= Travis Peak).—Unconformably overlies the Permian Cibolo limestone. It consists largely of sandstone, sand, sandy clay and conglomerates; so-called mortar rocks (conglomerates and lime-cemented sand and sandstone) occur throughout the formation. At the base there is 26 feet of indurated gray marl and clayey limestone with a few calcareous and organic fragments. In the upper half, *Orbitolina texana*, *Pecten*, *Trigonia*. The thickness is 400+ feet.

The increased thickness of basal Trinity from the Conchos River valley north-northwest to Torcer station coincides with the extent of a narrow arm of the late Jurassic-early Comanchean sea. The sections a short distance to the east of this sea, as at Shafter or in the Eagle Mountains, consist of sandy and marginal Travis Peak and Glen Rose equivalents, but lack the basal Comanchean formations.

Solitario, Brewster-Presidio counties (1249, 1436).—The Trinity group is exposed in the basal part of the inner rim of this unroofed dome, as 1000 feet of beds dipping about 45° radially outwards. The basal stratum is a thin (up to 50 ft.), massive, hard, silicified conglomerate, predominantly red, composed of angular cobbles of quartz, novaculite (from the eroded Hercynian ridges of Devonian Caballos novaculite in the Solitario basin), a little limestone, and other materials. The basal Trinity unconformably overlies at various points a variety of complexly folded and overthrust Paleozoic formations. Above the basal conglomerate there is locally fossiliferous limestone and marl, and generally a thick felsite sill encircling the rim. This is followed by thick fossiliferous Glen Rose limestone and marl in thin-bedded to massive strata, with *Exogyra quitmanensis, Pecten,* large sp., and gastropoda. Near the base they contain *Douvilleiceras, Parahoplites,* and other fossils. Near the middle are several zones with *Orbitolina texana* in great profusion. At many levels there occur echinoids, gastropods, and pelecypods, and the following fossils similar to those occurring in the Washita: *Haplostiche texana, Nautilus* aff. *texanus, Kingena* aff. *wacoensis, Alectryonia* aff. *carinata,* and others. Near the top is 50 to 75 feet of shell marl with predominantly Fredericksburg fossils, including *Exogyra texana,* which is assigned to the Walnut (Fig. 9).

Southern Arkansas (392, 1113a, 1114).—On the outcrop, from McCurtain County, Oklahoma, through Cerrogordo, Arkansas, where the Goodland and Kiamichi have their easternmost outcrop, to west of Antoine, the Trinity sands are overlapped by Woodbine and higher Gulf formations. Farther east the basal Gulf formations are successively cut out, and the overlap involves successively higher members, until, in northeastern Arkansas, the Tertiary supposedly was locally in contact with the basement rocks.

The Trinity dips southwards at the rate of about 100 feet per mile and, near the Arkansas-Oklahoma line, aggregates about 100 feet in thickness. It consists mostly of sand, with some quartz and other gravel from the underlying beveled Paleozoics, and with four lenticular members, in ascending order as follows: Pike gravel lentil, a basal member, 100 feet thick or less, which thins westwards; Dierks argillaceous, fossiliferous limestone member, 40 feet thick or less, thinning westwards; Holly Creek red clay, sand, gravel, up to 300 feet (1679, p. 1079); Ultima Thule gravel lentil, 100 feet thick or less, thinning to east and found only in western Arkansas and in McCurtain County, Oklahoma, where it overlaps westward onto the Paleozoic basement rocks; De Queen limestone lentil, maximum thickness 72 feet, thinning and overlapping to the west. The De Queen is notable for containing on the outcrop a 20-foot bed of gypsum, which can be traced southwards down-dip, into the anhydrite of the northern Louisiana oil fields. Both limestone lentils contain typical Glen Rose fossils: *Glauconia branneri, Eriphyla pikensis, Ostrea franklini,* and others. Both apparently pass in a west-southwest line underground across north Texas and connect with the thin limestone interfingerings of the northern Glen Rose into the Antlers sands in Parker and Wise counties, Texas. The remaining Trinity sand above the De Queen is called Paluxy (1679, p. 1071).

Southwards from the outcrop the Trinity rapidly thickens. A well in Little River County, Arkansas, contains a thickness of probably more than 2500 feet of Trinity. For the subsurface section in northern Louisiana, see page 299.

Southern Oklahoma.—Westward along the outcrop from Cerrogordo, Arkansas, the traceable Trinity members overlap out against the upward sloping Paleozoic basement. Presumably to the northwest only the higher members of the Trinity are present; but these levels have not been identified and are included in the Antlers sand, the marginal facies of the entire remaining Trinity section in this area. South of the turning point of the Comanchean formations in northwestern Grayson County, the Antlers has a north-south strike, and in Cooke County thin fingers of Glen Rose limestone appear.

The Antlers in southern Oklahoma is a whitish-gray, locally varicolored, quartz packsand, nearly devoid of fossil. Gould records a dinosaur in it (626). For several miles east of Ardmore along the southern outwash slope of the Arbuckles, the Antlers received much dissolved calcium carbonate from the mountains, uplifted and actively eroding during early Comanchean times. Locally it is a limy conglomerate, containing many limestone pebbles and boulders. The Antlers has a thickness of 600 feet or less. It consists mostly of fine, light colored, incoherent packsand, with lesser amounts of basal and intraformational conglomerate of quartz and chert pebbles, locally cemented to quartzite, and red or blue shale, and thin calcareous sandstones. The basal conglomerate, usually 25 feet thick or less, consists of loosely cemented, cross-bedded sand with streaks of clay, and interbedded conglomerate of rounded-to-subangular chert and quartz pebbles. The formation contains near its top *Ostrea crenulimargo* Roemer and *Exogyra texana,* and locally carbonized wood. Large deposits of silicified driftwood are recorded.

Texas outcrop.—The Trinity group thickens on passing from the Red River valley southwards into the Mineral Wells-Fort Worth-East Texas geosyncline, and on passing gulfwards from the boundary between the offshore and marginal facies. This boundary may be taken at the northern and western margin of the outfingerings of Glen Rose limestone into the Antlers sand (1394, 1679, 1574). The margin follows a line running from near Texarkana westward (underground) across northern Denton County, across Wise, Parker, northern Comanche, and eastern Brown counties (outcrop), thence in a large reëntrant (removed by erosion) down the Colorado River valley, across Gillespie County (outcrop), westward across the southern part of the Edwards Plateau (underground), through northern Edwards and Val Verde counties to the Pecos south of Pandale. West of the Pecos the thinned margin of the Glen Rose occurs in the northeastern quadrant of the Marathon basin (Purington ranch, and near Gap Tank) on the outcrop, sporadically near Fort Stockton off the high structures (underground), south of Kent (where absent on outcrop), between Black Mountain (where absent) and Sierra Blanca (where present), westwards to near El Paso (where unreported). South and east of this line, the Glen Rose limestone with its normal marine fauna is present; north of the line, the marginal sandy equivalents are present over a strip of variable width, 100 miles or less generally, but formerly extended farther inland for an unknown distance. The presumed northern limit of Trinity deposition is shown on Fig. 16.

A section (Fig. 17) from Cooke County southward through Denton to Fort Worth shows (1) that the Glen Rose limestone fingers out to the north into the Antlers sand facies; and (2) that the Trinity group maintains a nearly uniform thickness in these two facies, and, therefore, that much of the Antlers is of Trinity age. In the more northern wells, one thin lentil is logged as lime (in Hampton well, 11 feet); farther south three (Denton City, Lewis Atkins) or four (Hughes-Morton, Fritz-Mathis) thicker limes appear. In Tarrant County these consolidate to 347–418 feet of Glen Rose.

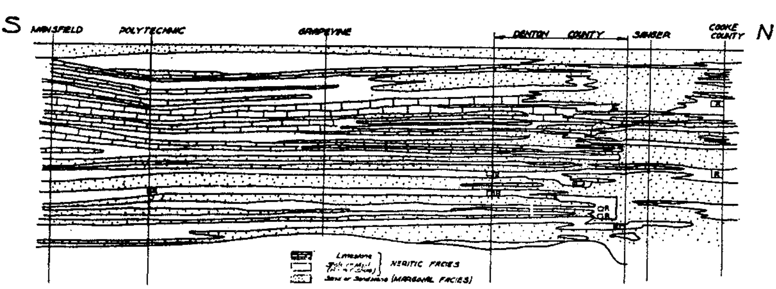

Fig. 17. Subsurface profile of Trinity group from Fort Worth to Red River. The limestone facies (Glen Rose) fingers out northwards into the sand facies (Antlers).

In the Red River counties the typical Comanchean well log shows the Woodbine distinct (400–536 feet), the combined Washita and Goodland limestone 425–650 feet thick, and the Antlers 456–1185 feet thick. This variation corresponds to irregularities in the basement, and to local overlap of basal beds.

Facies changes in the Trinity are shown on the outcrop in Parker and Wise counties (Coöperative maps Parker & Wise Cos.; Scott, 1394). About 4 miles west of Decatur a few thin limestone ledges with typical Glen Rose fossils occur. On the Weatherford-Millsap road the Glen Rose, in two limestone seams, is about 50 feet thick. Eastward and southward the Glen Rose thickens, partly by the addition of new limy members above and below. Along the Brazos valley at the Parker-Hood county line, the Glen Rose is about 200 feet thick. In central Travis County the Glen Rose is 359–418 feet thick. In Dallas it has a recorded thickness of 522 to 595 feet (1454, pl. XX). In Parker County, the basement sands and conglomerates, 150 feet thick or less, consist of quartz sand and pebbles up to 3 inches in diameter, well rounded in comparison with the underlying angular and heterogeneous Pennsylvanian conglomerates, and not derived from them. In both the basement sands and the Paluxy there are deep purple "red beds." The basement sands contain bone fragments, carbonized wood and plant remains, and much silicified logs and wood. The Paluxy is a packsand, bearing silicified wood.

An east-west section, from Erath, Comanche, and Brown counties to beyond Big Spring, shows the Glen Rose rapidly thinning westwards across Comanche County and disappearing near Brownwood, west of which only Paluxy represents the Trinity group (Fig. 16). At Round Mountain, northwestern Erath County, the Glen Rose is represented only by a 5-foot limy ledge. In the Santa Anna, Callahan Divide, and San Angelo area, the Paluxy consists of 150 feet or less of derived material, which rests on an irregularly eroded Permian basement. In Irion County, thin Trinity lime is logged. Near Big Spring and in the Llano Estacado the substratum is Triassic.

In the Colorado River valley, the lateral variation of the Trinity group has been studied by Taff, in a series of sections from Hickory Creek to Mount Barker near Austin (1574). These studies demonstrated that the clastic and conglomeratic features of the Trinity become more refined towards the southeast, and that the Glen Rose limestone thickens and becomes more calcareous and less sandy in that direction. If Taff's section were projected graphically westward, the limit of the Glen Rose limestone would lie in eastern Llano County.

In the Hays-Blanco county section, the Glen Rose thins westwards and disappears in eastern Gillespie County.

In the Kerrville-Fredericksburg section (Fig. 16) the same thinning is shown on outcrop and in subsurface. The marginal facies of the upper Glen Rose near Fredericksburg has taken on a great quantity of red color from the underlying decomposed Cambrian formations. This facies is called the Gillespie formation. It bears cycads and fossil wood.

In the southern part of the Edwards Plateau, numerous sections reveal the offshore thickening of the Trinity group, and the fact that several areas were islands in Trinity times. This area has been investigated by Mr. L. D. Cartwright (201b). The inner margin of the Trinity across the southern part of the Edwards Plateau, and some projecting irregularities in the old land floor (presumably islands) both within the limits of the Glen Rose limestone wedge and in the area of marginal sands are shown on Fig. 16.

Liddle and Prettyman have published numerous sections of the Trinity in the Pecos valley (991). The basement rocks are irregular in this district, and locally no Trinity was deposited (Fig. 16).

In the Marathon-Fort Stockton section, the Glen Rose outcrop occurs as far north as Gap Tank. To the west, in the northern Glass Mountains, the entire Trinity group is locally absent by non-deposition, and the Fredericksburg rests on the Paleozoic. In the Fort Stockton area, the Trinity limestone is of irregular distribution, generally absent on the highs. In several of the wells, sands, with *Chara* fruits are present, and are probably Trinity. Farther southwest, in the Hovey district, wells show several hundred feet of Glen Rose limestone. Kent is north of the margin of the Trinity limestone, and only thin Trinity sand is present at the outcrop.

In the Sierra Blanca area north of the Texas and Pacific Railway, beneath the Georgetown limestone is 100 feet or less of sandy beds with Kiamichi fossils. Under these is the Finlay limestone, which is of Edwards and Comanche Peak age. Beneath this is the Cox sandstone, probably of Maxon-Paluxy age at its top, of Glen Rose marginal equivalents basally. The Campagrande and Etholen have not been precisely dated by fossils, but are likely of Trinity age.

For Fredericksburg equivalents at Sierra Blanca, see page 352. From the Etholen, Baker records *Porocystis pruniformis;* in the sandstones near the base of the Etholen at the type locality, there are some poorly preserved oysters. Taff (1573, p. 724) records oysters and an *Exogyra?* in the Etholen conglomerate; Richardson does not mention any specifically Trinity fossils in the Cox or the Campagrande.

TRAVIS PEAK FORMATION

Nomenclature.—The Western, or Upper, Cross Timbers, underlain in part by the Travis Peak formation, was known to certain early explorers and writers (1329, 1463), but only in 1887, when studied at localities near Millsap, was it formally recognized by the name "Dinosaur sand" (731, pp. 301–302). The names "Trinity sand" and "Trinity division" were first applied by Hill in 1888 (742; 753), the type locality being in western Travis County.

Stratigraphy and Contacts.—The Travis Peak formation rests on early Cretaceous beds in the Malone and Quitman mountains districts. In the Rio Grande embayment and in Louisiana its substratum is unknown. Elsewhere in Texas it rests unconformably on a folded and eroded basement of pre-Paleozoic, Paleozoic, or Triassic formations. In a few places within its extent, it is locally absent: in part of the Llano-Burnet area, in the lower Pecos valley, in the northern Marathon basin. In some Denton County wells it rests on Ellenburger. Its upper contact has not been well studied. In north-central Texas, and generally, where the Glen Rose limestone is absent, no line can be drawn between it and higher Trinity sands. Scott states that its top is laterally continuous with outfingerings of Glen Rose. Data on the deep offshore zones of the Glen Rose (Louisiana, Chittim structure) have not been published, and it is not known whether they coincide with some zones referred to the Travis Peak in the marginal areas or not.

Facies.—Nearshore, the formation consists of packsands, grits, sandy clays, sandstones, conglomerate, and gravel. Offshore, it consists of sandstones, sands, sandy clays, thin seams of limy rock, and at the base a variable thickness (50 feet or less) of grits and conglomerates with subangular quartz grains and rounded quartz pebbles up to an inch long. Most of this material is the marginal, in part littoral, deposit of an advancing sea; other more limy and shaly beds are a part of the neritic facies.

Areal outcrops, local sections. — In the Red River region the Antlers sand, the sandy equivalent of the entire Trinity group, consists predominantly of poorly cemented or uncemented packsand. At Rock Bluff ferry, northwestern Cooke County, the base of the Trinity consists of 16 feet of gravelly conglomerate of chert and quartz pebbles up to 3 inches in diameter, and fine to coarse, poorly cemented, light colored sand. This is followed by about 68 feet of packsand, containing at places limy streaks, irregular concretions, layers of yellow to purple clay, and, near the top, some thin layers of gypsum. This is capped by a 3-foot, hard, pebble, conglomerate bed. Between Warren's Bend and Sivell's Bend (Bullard, Okla. Geol. Surv., Bull. 33, p. 21, 1925), there is a section of 181 feet of upper Trinity overlain by Goodland limestone. It consists of packsands and hard sands (mostly of light colors), some sandstone, and clay. In the upper part of the section, *Exogyra texana* Roemer and *Ostrea crenulimargo* Roemer, occur. On a tributary of Little Mineral Creek 4 miles north of Fink, 123 feet of Trinity is recorded (177, p. 17). It consists of light colored packsands with some clays, conglomerates, and limy streaks. The formation contains locally large amounts of fossilized logs and driftwood. Grayson County wells have almost a thousand feet of Antlers. In the city of Sherman well it is 953 feet thick and is largely packsands and sandstones, with some shale and sandy shale near the base. Red color is scattered throughout, except near the top. Water horizons are logged about 200 feet below the top, and at many levels near the bottom.

In Montague County (176, p. 69) the basement sand of the Trinity is about 600 feet of clean packsand and conglomerates with seams of clay. The fine, white to yellow, massive packsand occurs in beds up to 40 feet thick. Lentils, of yellow, purple, or varicolored clays, scattered throughout the Trinity, have a thickness ranging from a few inches to 40 feet. The basal Trinity consists of a quartzose conglomerate, about 3 feet thick, composed of well rounded quartz grains and pebbles up to an inch in diameter, with practically no mud or silt in the matrix. Near Montague and Bowie there are more than one of these thin basal conglomerate seams.

In Wise and Parker counties, the basement sands and conglomerates reach 150 feet in thickness. The basal conglomerate consists of quartz sand and pebbles up to 3 inches in diameter, with little siliceous or calcareous cement, or, more generally, uncemented. These rounded quartz gravels are not derived from the underlying angular and heterogeneous Pennsylvanian conglomerates. The basal conglomerate grades upwards into unconsolidated white pack-sands, and thence into the sandy clays, and limestones of the Glen Rose. Locally the basal Trinity, like the Paluxy, contains red beds. Near the village of Brock there is a local concentration of salty sand which contaminates wells and makes the soil unusable (1394, p. 39).

Along the strike in Cooke, Denton, and Tarrant counties, the basement sand maintains a thickness of around 400 feet (Fig. 17), but down-dip it thickens somewhat (550 feet at Dallas, several hundred feet south of Mexia). From the Brazos River valley to the Colorado River valley, the western border of the Comanchean lies only slightly west of the farthest extent of the thinned Glen Rose limestone. Therefore to the west of this border the outliers of the Trinity group consist only of sandy deposits overlain by Fredericksburg clay and limestone, as at Santa Anna and in the Callahan Divide. From the Brazos Valley the Trinity border passes in a southwesterly direction across northern Erath and Comanche counties to the northern part of Brown County. Thence the margin follows southwards along high bluffs on the east side of Pecan Bayou to the Colorado River valley near Marble Falls (449, pp. 360–371). The basal Comanchean conglomerate and sands show two outstanding features: (1) they were deposited on an irregular Paleozoic floor, and change rapidly in thickness; (2) the basal conglomerate consists largely of materials derived from the immediate vicinity, and is more limy in the south (Burnet, San Saba, McCulloch counties) where the hard Ellenburger and Bend limestones furnished resistant materials, more sandy in the north (Brown, Eastland, Comanche counties) where the Paleozoics contained more soft sandstones, clays, and some limestones. From Comanche County, at Round Mountain, Hill (803, p. 207) gives a section of about 247 feet of sand, sandy shale, and thin conglomerate below the Glen Rose limestone. Along Rusk Creek north of Comanche the 50 to 75 feet of basal Comanchean is composed largely of a conglomerate of siliceous pebbles and grit of white (occasionally red) quartz grains (449, p. 364). At nearby localities the conglomerates in the basal

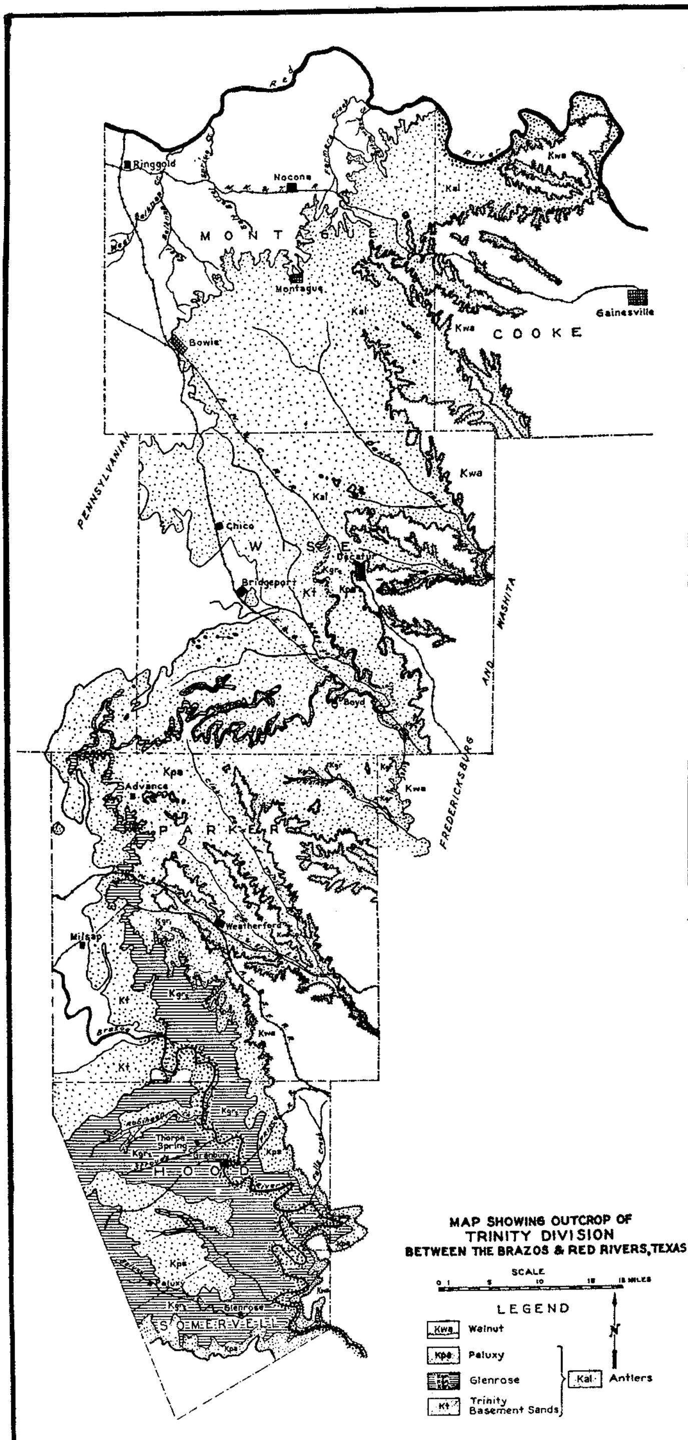

Fig. 18. Outcrop of Trinity group between Red River and Brazos River, showing interfingering into sand of the thin, interior margin of the Glen Rose limestone wedge (Dr. Gayle Scott).

Trinity sands and grits are very thin and local. In the escarpment east of Pecan Bayou, on account of the irregularity of the Paleozoic floor, there is a variable amount of basal conglomerate, 20 to 30 feet, overlain by red, pink, or yellow friable sandstone and grit, and by sandy limestone, followed by sands and sandy clays to a total thickness of 100 feet or more.

Near Nix, Lampasas County (449, p. 364; 803, p. 181), the basal conglomerate, 20 feet thick, contains pebbles of Paleozoic limestones, quartz, flint, and other materials, cemented in a matrix of argillaceous and arenaceous lime. It is followed by 30 feet of lime-cemented packsand and grit, then 20 feet of calcareous sandstone. Locally north of this point the basal conglomerate reaches 100 feet in thickness and is followed by as much as 100 feet of packsand.

Colorado River section.—Near the type locality, Travis Peak, basal sands are over 250 feet thick, and thin westwards. The basal conglomerates and sands have here been called the *Sycamore sands* by Taff. They typically consist of about 50 feet of basal conglomerate followed by cross-bedded calcareous shell grit. They contain the basal Trinity artesian water reservoirs in this immediate area. They are followed by the relatively impervious *Cow Creek beds,* about 30 feet of shale, grit, sand, and shell beds. Above these are the *Hensell sands,* typically 143 feet of red and yellow sand, conglomerate, and some limestone. This member contains the important middle Trinity aquifers. It is followed by yellow sandy fossiliferous (rudistid) basal Glen Rose limestone. The *Leon* sands in Comanche represent the local basement sands level. The *Gillespie* sands near Fredericksburg represent the entire local basal sands below the upper Glen Rose limestone, but may also be of Glen Rose age. Shorewards from Austin the Glen Rose thins rapidly, and the Trinity group is reduced to a thickness of 70 feet at Post Mountain, just south of Burnet.

The Travis Peak formation, studied by Taff (1574), was partitioned into three members by Hill (803, pp. 141–144).

HICKORY CREEK SECTION OF TRAVIS PEAK FORMATION

		Feet
D.	Thin-bedded sandy limestone, with some limy sandstone and conglomerate seams	40
C.	*Hensell sand member.*—Red or yellow sands, with subsidiary beds of conglomerate, sandy limestone, and magnesian limestone; few fossils; artesian water horizon	143
B.	*Cow Creek member.*—Grit or conglomerate, much of it calcareous, more limy near top, with many fossils at some levels; subordinate bluish shale, sands, and sandy limestones; forms prominent calcareous, fossiliferous bench	30
A.	*Sycamore*[29] *sand member.*—Conglomerate, sand, silt and shell grit; basally with cobbles up to 6 inches diameter; above, the pebbles decrease in size; near top, cross-bedded limy shell grit; downdip forms artesian water horizon; westwards it seems to disappear	50
	(Unconformably underlying rocks: Strawn or Smithwick.)	

Cuyler (Thesis MS., 1931) reports three levels at which fossils occur: two in the Cow Creek member, and one near the top of the Hensell. A large fauna occurs in the Cow Creek beds, including *Dufrenoya texana* (Hill), *D. justinae* (Hill), *D. roemeri, Pseudosaynella walcotti* (Hill), *Ostrea ragsdalei* Hill, *Trigonia stolleyi* Hill (Hill, 755, p. 47; 783; 803, p. 161, pl. XXI; Cragin, 324).

GLEN ROSE FORMATION[30]

Nomenclature.—This formation, the Caprotina limestone of Shumard (1463, pp. 583, 588), was first named Glen Rose by Hill (772, pp. 504–507) in 1891. The type locality is in the thinned shoreward extension of the formation along the Paluxy River near Glen Rose, Somervell County.

Stratigraphic position and contacts.—Basally, it is in gradational contact with the Travis Peak sands. It is absent west and north of the line shown in Fig. 16. North of about the latitude of Waco, it is overlain, probably in gradational contact, by the Paluxy sands, which Scott claims to be littoral deposition in a withdrawing sea at the end of Trinity time. Hill had previously indicated that the Paluxy is a sandy phase of the upper Glen Rose limestone.

Facies.—The Glen Rose is a calcareous formation, in part clayey and sandy, and is of the neritic facies. As already explained, it is

[29]This name has priority over the Sycamore limestone in Oklahoma (J. A. Taff, 1903).

[30]*Literature.*—Hill, 742, 753, 762, 767, 780, 783, 795, 803, 827; Rauff, 1286; Scott, 1394; Udden, 1623; Vanderpool, 1678, 1679, 1681a; Coöperative maps, Parker and Wise counties, 1853.

replaced shorewards by sand. Numerous features, ripple marks, dinosaur tracks, plants, gypsum, and general lithology, indicate that at many places it was deposited in shallow water.

Areal outcrop, local sections.—The Dierks and De Queen limestone lentils in southwestern Arkansas contain *Ostrea franklini, Anomia texana, Modiola branneri, Eriphyla pikensis, Glauconia branneri* and other Trinity fossils. Outfingerings of similar limestone outcrop in western Parker County, Texas, where the marginal Glen Rose contains three zones (1394, p. 41): (1) near the base, a zone characterized by *Orbitolina texana* (Roemer), *Porocystis globularis* (Giebel), *Pecten stantoni* Hill and *Trigonia stolleyi* Hill; (2) near the middle of the formation, a zone of abundant *Orbitolina texana,* and some *Loriolia texana* (Clark); and at the top, a mass of *Modiola branneri* and some *Porocystis* n. sp. (elongated). Just above the second zone is a *Monopleura-Toucasia* bank. In this section at least three limy outfingerings of the Glen Rose into the Paluxy facies are mappable. A similar situation is seen on subsurface profiles in Denton County, where several such limy outfingerings occur (Fig. 17).

The Glen Rose typically consists of thin- to medium-bedded hard continuous limestone strata alternating with marl or marly limestone, and weathering in stream cuts to steep canyons and on hillsides to a terraced or "staircase" topography. The narrow Glen Rose prairie passes from Mt. Bonnell northwest of Austin to near Burnet, and thence northwards to west of Lampasas, up the large scarp east of Pecan Bayou in Mills and eastern Brown County to near May, thence northeastwards to make a large southeast reëntrant down Leon River in northern Comanche County, thence northwards to near Desdemona, and northeastward to the Brazos in southwestern Parker County. Its last limy outfingerings occur near Decatur and elsewhere in Wise County. In its outcrop south of the Brazos, it gradually increases in thickness to about 720–800 feet near Waco. In Bell County, the 500–664 feet of Glen Rose consists of pure, solid limestone near the middle, thinner bedded, shalier, and sandier limestones near the base and the top, and two general water horizons, located respectively 130–175 and 240 feet below the top. In the Paleozoic inlier at Lampasas (1574, pp. 329–338), following about 20 feet of basal heterogeneous conglomerate and 30 feet of yellowish, brown, and whitish packsand, sandstone, and grit, there is about

80 feet of Glen Rose limestone, sandy and transitional in lithology at the base, and more calcareous above. It consists of soft, impure limestone, alternating with marly lime and soft yellow sandstone, the strata being thin-bedded and well stratified. From Twin Sisters Peak, to Bachelor Peak 18 miles to the southeast, it has increased in thickness from 90 to 200 feet.

The McAngus well near Elroy, eastern Travis County had in excess of 1066 feet of Glen Rose (1854–2920), and more than 180 feet of Travis Peak (2920–3100 T.D.). The city of Austin Blunn Creek well in Travis Heights had 800+ feet of Glen Rose (825?–1632), and 558 feet of Travis Peak (1632–2190).

Celestite occurs in pockets at a level near the top of the Glen Rose at many places in central Texas: on Donaldson Creek due east of Nix, in the escarpment north of Nix, in Rocky and South Rocky creeks near Lampasas, South San Gabriel River north of Leander, Mount Bonnell north of Austin, and elsewhere. Anhydrite is recorded in Comanche, Lampasas, and western Parker counties (803, p. 146). In the Hubbard city well, Hill County, a 30-foot layer of anhydrite occurs near the depth of 2855 feet. Anhydrite occurs in the Glen Rose in Arkansas, Louisiana, and Maverick County, Texas.

West of Austin the Glen Rose shows the same gulfward thickening and change of facies. At Fredericksburg (795, pp. 221, 314) it is about 55 feet thick, and at Kerrville about 600 feet thick. A similar change southwards occurs across Sutton, Edwards, and Kinney counties. For Glen Rose in Trans-Pecos Texas see pages 292–297.

Paleontology.—In the central Texas outcrop counties, where it has been most studied, the Glen Rose is from 400 to 800 feet thick, but underground in the Gulf Coastal Plain, it exceeds 3500 feet. Its fossil zonation is nowhere known, and it is probable that the reduced outcrop thickness represents only the upper portion of the complete formation. If so, all existing fossil partitions are very defective. Pending fuller study of thick subsurface sections, such as those in Maverick County and Louisiana, or thick outcrop sections, such as those in northern Mexico and the southern Quitmans, no general zonation for the formation can be outlined.

The Quitman section contains, associated with or slightly above Malone fossils, a prominent zone of *Exogyra quitmanensis* Cragin.

This, or a similar oyster, occurs at the base of the section in the rim and in Glen Rose inliers in the Solitario. Associated fossils are *Trigonia*, a large *Pecten* n. sp., *Alectryonia* aff. *carinata* and echinoids like *Toxaster*. Several hundred feet above this are the main *Orbitolina texana* zones. The succession of zones in the Quitmans and the Solitario is as follows:

Exogyra texana (abundant)	Walnut
Orbitolina texana, and Glen Rose echinoids	Glen Rose, Bluff bed
Douvilleiceras, Parahoplites and other ammonites	Basal Glen Rose
Exogyra quitmanensis	Quitman bed; Cuchillo
Trigonia taffi	Basal Quitman; Cuchillo
Fossils unknown	Mountain bed; Las Vigas
Malone fossils	Torcer

In central Texas, several zones of *Orbitolina texana* and other allied foraminifera have long been known; some ammonites (*Douvilleiceras, Parahoplites* and *Dufrenoya*) occur but have not been worked out; and a large smooth *Exogyra* resembling that from the Solitario occurs.

A *Douvilleiceras* n. sp., with depressed cross-section and reduced tubercles, was blown out of Dixie Dillon No. 43 well, Pine Island, Louisiana, from below the casing, at 3338 feet. It is from the lower Glen Rose limestone, above the 2000 feet of red shale.

Vanderpool (1678, 1679) lists the following ostracoda from the Trinity group in southern Arkansas, northwest Louisiana, and near Weatherford, Texas:

Bairdia dorsoventrus Vanderpool
Bairdia glenrosensis Vanderpool
Bythocypris rotundus Vanderpool
Cypridea diminutus Vanderpool
Cypridea tuberculata Sowerby var. gypsumensis Vanderpool
Cypridea ventrosa Jones var. bispinosus Vanderpool
Cypridea sp. indet.
Cytheridea trinitensis Vanderpool
Cythere ornata Vanderpool
Paracypris weatherfordensis Vanderpool
Pontocypris perforata Vanderpool

Algal (*Chara*) oögonia occur in many widely separated areas in the Trinity group in the Southwest. They have been reported from the De Queen limestone member of the Glen Rose in Arkansas (1678, p. 98), from the Glen Rose in northern Texas (1791, p. 64), from the Glen Rose in the Kokernot well near Hovey (633), and from strata referred to the Trinity in various wells in the Fort Stockton district (12, pp. 33–37). *Chara* oögonia appear to be more prevalent on the southern edge of the Salt basin and along the Fort Stockton-Yates high area. They occur in the Penn Alvis well about 2 miles south of Belding; the Lockhart Webb well west of Fort Stockton; in various wells along the southern flank of the Fort Stockton high; crest of Yates Pool; Riley Murphy well, west of Sheffield; Cosden Perner well, Crockett County; and well in central Irion County. Some *Chara* are found in a greenish-gray shale with limestone concretions, gypsum and ostracoda, which underlies the "Basement sand" (Maxon, Paluxy?). These basal shales are 100 or more feet thick near Fort Stockton, about 250 feet thick at Yates, and near 600 feet thisk at Belding.

Wieland (1758a, 1759, 1759a) records the following Trinity cycads:

Cycadeoidea boeseana Wieland (Basal Trinity sand; near Bridgeport)
Cycadeoidea barti Wieland (Paluxy, near Comanche; Gillespie sand, near Fredericksburg)
Cycadeoidea wolfei Wieland (Paluxy, near Stephenville)
Cycadeoidea dyeri Wieland (Paluxy; near Tolar and Stephenville)
Cycadeoidea johnstoni Wieland (Paluxy, near Stephenville)

Wieland says: "The Trinity beds must be ranked as one of the five great cycad-yielding terranes of North America—the other four being the Arundel of Maryland, the Lakota of the Black Hills region, the Como of the Black and Freeze Out Hills, and the Mesaverde of the Chuska Mountain region of New Mexico and Arizona . . . The Trinity was a flat, subsident, river and bayou, cycad-dinosaur-conifer, forest land, swept by the shallow edges of the sea."
Jones (888, p. 770) says: "The writer has seen nodules of pure coal imbedded in the Glenrose limestones of Bandera County, Texas."

The foraminifera from the Glen Rose have not been carefully studied, but probably *Orbitolina*-like forms of two or more genera exist. The corals show a great variety, some being reef-forming. Forty or more species have been collected and are being described by Mr. J. W. Wells (1727). The mollusca in the outcrop counties show a great variety; only a few have been described by Hill, Conrad, and others. The alleged bryozoon genus *Porocystis* marks the Glen Rose. Echinoids are abundant and as yet undescribed.

The most distinctive Glen Rose foraminiferal genus is *Orbitolina*, of which a common species, *O. texana*, was described by F. Roemer in 1849. The genus has been recently reviewed by Vaughan (1688a). He considers the larger *O. whitneyi* Carsey to be only a large-sized variant of *O. texana,* and *O. texana asaguana* Hodson and *O. texana monagasa* Hodson (from Venezuela) to be only growth forms of *O. texana.* He says (1688a, p. 610): "*O. walnutensis* Carsey [from the Fredericksburg group] differs so greatly from the other species that it may belong to another genus"; Silvestri (1479a) has referred it to *Dictyoconus.*

Glen Rose corals (Wells, 1727, 1727a) occur largely in reefs, located in the lower half of the formation, and built on great masses or layers of caprinids. The lowest reef, at the base of the Glen Rose in Hays, Comal, and Blanco counties, has afforded 6 species of *Isastrea, Orbicella, Astrocoenia,* and other genera, and has a height of 3 to 10 feet over an area of several square miles. Reefs located about 100 feet above the basal reefs are 15 to 30 feet thick, and contain numerous types of corals, some brachiopods, oysters, and other fossils. A third coral horizon occurs about 200 feet above the base of the Glen Rose.

Dinosaur bones were discovered by Hill near Millsap (731, p. 299; 753, p. 122). Dinosaurs, mostly tracks, are known from the following localities: Kinney County near northeast corner on the Edwards ranch; northeastern Uvalde County near Utopia on the Loman ranch; southeast corner of Kimble County on the Garner ranch, about 7 miles west of Kerrville and 13 miles north of the Kerrville-Junction road; southern Bandera County, in Hondo Creek 2 miles downstream, and 2½ to 3 miles upstream, from Tarpley; Medina County, Hondo Creek, about 13 miles northwest of Hondo; Travis County (reported), about 15 miles up Colorado River from Austin; near Glen Rose, Somervell County (1452); in Hamilton County (1805). Bones, said to be of a Morrison dinosaur *Elaps,* were found by Darton (N. H. Darton, oral communication) in the Middle Concho River in eastern Irion County, probably in Paluxy sand. Wieland (1759a) records a nearly complete dinosaur skeleton from the Paluxy?, on Paluxy River near Stephenville. Gould (626) records a dinosaur from the Antlers sand in southern Oklahoma.

Plants have been described (545) from the Glen Rose near the type locality.

PALUXY FORMATION

The upper Trinity sand was first given the name Paluxy by Hill (780, p. 84; 772, p. 510) in 1891. That it is laterally continuous with the upper Glen Rose was maintained by earlier writers, and can be observed at some places. Fossils hitherto found in the Paluxy do not give clear-cut age indications. *Ostrea crenulimargo* and *Exogyra texana,* recorded from the upper Antlers in the Red

River region, are Fredericksburg or Trinity forms, and may indicate that the upper Antlers is of Fredericksburg age. Fossil wood and fish remains (318) are of unknown value for age determination. Cycads (*Cycadeoidea barti* Wieland, 1759a) occur a few miles north of Comanche, and there are notable cycad localities near Stephenville.

Paluxy sand outcrops in a narrow timbered strip on top of the Glen Rose prairie, from the Antlers sand in the Red River region in Montague and western Cooke counties southward to the Leon Valley at the north boundary of Coryell County (latitude 31° 30′). McLennan County logs give no definite indication of Paluxy. Farther south it is absent both on outcrop and underground. Its exact subsurface extent has not been traced. A thin (about 20 feet) but persistent sand occurs at its level in many Hill County wells: in the Milford City well there is 30 feet of sand, hard above but containing good water basally; in the Wetherby well east of Hillsboro, 20 feet (at 1160–1180) of water sand occurs; in the R. C. Finley well in southern Hill County this is reduced to 11 feet (at 596–607 feet).

A noteworthy feature of the Paluxy is its extension westward over the Callahan divide. There is no doubt that the thin basal Cretaceous sand in this area is continuous with that above the westernmost outfingerings of the Glen Rose limestone (Fig. 18). At Santa Anna (449, pp. 11, 13, 14), the basal sand is 105 feet thick and is used for glass manufacture; at Buffalo Gap, Taylor County, it is 140 feet thick (1574, p. 321); at Signal Peak, Howard County, 70 feet thick (841, p. 76); at Double Mountain, Stonewall County, 25 feet thick (467). West of the Pecos, the Maxon and Cox sandstones are in part equivalent to the Paluxy.

Lenticular sands occur in the Colorado River drainage at the top of the Glen Rose, in the proper position for the Paluxy, and support the idea that the Paluxy is a sandy facies of the uppermost Glen Rose (see 803, p. 169). Such an area of sand occurs from 3 to 5½ miles south of Bertram, Burnet County, where it is about 20 feet thick, and consists of packsand with thin arenaceous limestone seams, capped by thin Walnut limestone and marl containing *Exogyra texana*. Another area of Paluxy is in and east of Bachelor Peak along the road between Briggs and Lampasas, where the sand is 10 to 15 feet thick.

GILLESPIE FORMATION

Hill and Vaughan (795, p. 221), in 1898, called the basal Comanchean sands at and near Fredericksburg the Gillespie formation. The formation consists of about 120 feet of cross-bedded, vermilion-red sands, silts, clays, and sandy grits, lying beneath the thin (55 feet) Glen Rose sandy limestone. They were considered to be probably the stratigraphic equivalent of the lower part of the Glen Rose formation. Two miles south of Fredericksburg on the Adolf Eckhardt land they contain cycads (*Cycadeoidea barti* Wieland) and fossil wood. Near Kerrville a considerable thickness of red material may represent the downward extension of this formation. The red color is derived from the underlying early Paleozoic beds; the formation is strictly a local facies, characterized by its lithology.

FREDERICKSBURG GROUP[31]

Nomenclature.—Roemer classified these rocks, including those at the type locality, Fredericksburg, in his "Kreide des Hochlandes," as Turonian or Senonian, overlying the Upper Cretaceous rocks of the Gulf Coastal Plain. Shumard, repeating Roemer's error in the Austin section, placed his Comanche Peak group and the overlying Caprina (= Edwards) limestone above the Austin chalk (1463, p. 583). In Hill's first classification (731, p. 298) the Fredericksburg division included rocks down to the Dinosaur sand (Travis Peak), but later, his Trinity division (772, pp. 504–511) was made to include the basal Trinity sands and the Glen Rose, the Paluxy being placed questionably as basal Fredericksburg. The town Fredericksburg is the nominal type locality, unfortunately chosen, as the group is unequally developed over Texas, its basal part (Walnut and Comanche Peak) being most fully shown in the Brazos and Bosque valleys, and its upper part (Edwards) most typically developed in the canyons of the Nueces, the Pecos, and the Rio

[31]*Literature.* — *Arkansas:* Dane, 392. *Oklahoma:* Honess, 840; Bullard, 174; Hill, 788. *Northeast Texas:* Lahee, 969; Shumard, 1463. *Coastal Plain:* Collingwood, 267; Brucks, 164, 165; Hill and Vaughan, 808; Hill, 803; Taff, 1574, 1575; McCollum, 1076. *Edwards Plateau:* Hill and Vaughan, 794, 795; Hill, 825. *Rio Grande Embayment:* Getzendaner, 578, 578a; Vanderpool, 1681; Udden, 1625. *Trans-Pecos Texas:* Hill, 799, 805, 820; King, 936; Adkins, 12; Baker, 46; Richardson, 1304; Udden, 1623, 1626, 1664; Wilson, 1787. *Lithology:* Adkins and Arick, 16; Alexander, 27; Hanna, 647a; Udden, 1656. *Paleontology:* Alexander, 27, 29, 30; Adkins and Winton, 9; Cragin, 324; Clark, 253; Hill, 784, 803; Lasswitz, 976; Marcou, 1041; Merrill, 1103; Plummer, 1238; Stanton, 1522, 1522a; Winton, 1789, 1791. *Kiamichi:* Adkins, 12, 16; Bullard, 175; Scott, 1398a; Stanton, 1524; Taff, 1574, 1575; Winton, 1789.

Grande. At a later date, disagreement arose concerning the proper classification of the Kiamichi clay, whether basal Washita or upper Fredericksburg; it is here included in the Fredericksburg (page 360).

Although in this discussion the Fredericksburg is divided into the usual conventional formations, it is the writer's opinion that all formations in this group should be suppressed and only the facies used. However, a decision on this procedure can be reached only after the zonation is better known and the meaning of the term "formation" better clarified.

Stratigraphic position and contacts.—North of Coryell County, where the Paluxy is present, Scott claims an unconformity at the base of the Fredericksburg, because the Paluxy was deposited in a regressive sea, which readvanced over the land, depositing the Walnut formation. In south and west Texas the Glen Rose-Walnut contact is apparently concordant (page 328). The Kiamichi is absent south of Bell County, and its position is marked by a disconformity. In north-central Texas there is some evidence (pebbles) for an unconformity at the top of the Kiamichi; over parts of Oklahoma and Kansas, Kiamichi is the last remaining marine deposition.

Facies.—The Fredericksburg group presents a complex assortment of facies, corresponding to various conditions of deposition. (1) Marginal facies: consists of sand, sandstone, and sandy shale; perhaps the upper part of the Antlers sand in the Red River counties of Texas and in southern Oklahoma is of Fredericksburg age; at Black Mountain (Sierra Prieta), north of Sierra Blanca, sandstone of the marginal facies, containing casts of *Alectryonia* cf. *carinata* and other pelecypods, has invaded the section as high as the base of the *Desmoceras-Hamites* zone of the lower Duck Creek limestone. (2) Neritic facies: the widespread marls, marly limestones, and chalky limestones in the Walnut, Comanche Peak, and Kiamichi formations. (3) Reef facies: coquina, shell debris, detrital and shelly limestone, and organic limestone of several types. In contrast to No. 2, it contains rudistids, but few ammonites; other common fossils are corals, echinoids, bryozoa, pelecypods, gastropods, worms, fish remains, and algae. There may be marly interbeds between or around the reefs. Typical Edwards reefs are found near Belton, Crawford, Oglesby, and Round Rock. Among the most famous ones is the El Abra limestone, largely organic-reef limestone with

Chondrodonta and *Eoradiolites*, in the Sierra del Abra west of Tampico, and in the buried mountain range now the producing horizon in the southern Vera Cruz oil fields ("Golden Lane"). From wells in this field many caprinids, rudistids, Pectens, and other fossils of the reef type have been blown out under high gas pressure. The rocks are mostly of Fredericksburg age. (4) Oyster aggregates, as in the Walnut and Kiamichi. (5) A non-marine, but near shore, plant-bearing sandstone facies of Fredericksburg age is represented by the Cheyenne sandstone in southern Kansas (1621; Berry, U. S. Geol. Surv., Prof. Paper, 129-I, 1922). (6) In the Rycade Chittim No. 2 well in eastern Maverick County, 20 feet of coarsely crystalline rock salt occurs near the top of the Edwards (578, p. 1426).

Areal outcrop, local sections.—In the Red River valley, the thinned Goodland-Kiamichi produces only a narrow band of outcrop. Southwards the formations thicken, and the outcrop forms a part of the Grand Prairie, lying east of the Western Cross Timbers (Trinity) and west of the Washita prairies. In central Texas, the dissected western border of the outcrop forms the Lampasas Cut Plain, whose top consists of interstream ridges and outliers of limestone (Edwards and Comanche Peak), overlooking to the west clay valleys (Walnut). Rocks of this group form the crest of the Callahan divide, the remnant of the formerly continuous plateau which covered the denuded area in north Texas between the main Comanchean outcrop and the Llano Estacado. Fredericksburg forms the resistant cap of the Llano Estacado as far north as 33° north latitude. It forms the cap of most of the Edwards Plateau. In western Texas the limestone plateaus have been rejuvenated, and the rivers have cut deep canyons in Fredericksburg limestones (Nueces, Pecos, Devils River, Rio Grande).

The easternmost outcrop of the group is near Cerrogordo, Arkansas. It is reached in wells on salt domes in East Texas. Over a large area in northern Louisiana the Fredericksburg and Washita sediments were uplifted and planed off the higher structures in pre-Woodbine time.

Thickness and dip.—On the Edwards Plateau, the dip is gentle to the south and east. South and east of the Balcones fault, the dip steepens, and the beds of this group are buried deeply beneath later sediments. The probable shore lines are indicated on Fig. 13.

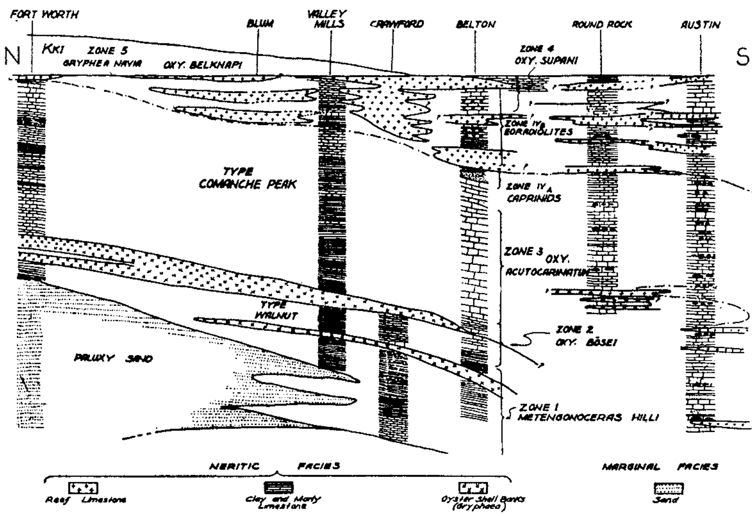

Fig. 19. Profile of Fredericksburg group from Fort Worth to Austin. The two right hand columns should show a small thickness of "Comanche Peak" and of "Walnut" at the bottom of the section.

Identifiable Fredericksburg is thin from eastern New Mexico to the Balcones fault, and in north-central Texas. Eastward, to the flank of the Sabine uplift, it thickens greatly, but it particularly thickens on passing southward to the Rio Grande embayment and northern Mexico. Over this area the Edwards (rudistid-reef) facies greatly thickens, and occupies the whole Fredericksburg column, extending even to the top of the Georgetown. This combined limestone mass, the Devils River limestone of Udden (1625), Mountain limestone of Hill (782, p. 309), Aurora of Burrows (Bol. Soc. G. Mexico, 7:85, 1910), reaches a thickness of 1500 feet west of Presidio.

Paleontology and zonation.—Some results have been reached in constructing a double zonation for the Fredericksburg, one for the ammonite facies, and one for the rudistid facies. Much work, however, remains to be done. The type Walnut seems to be characterized by forms related to *Metengonoceras hilli,* and some species of *Oxytropidoceras. Oxy. chihuahuaense* and *O. acutocarinatum* seem to mark the middle of the group. The top is marked by *Dipoloceras* aff. *cristatum, Oxy. supani, Chondrodonta munsoni* and others. The upper Edwards is marked by several species of *Eoradiolites (davidsoni, quadratus, angustus)* and by *Praeradiolites,* gen.

aff. *Polyconites,* caprinids like *Planocaprina,* and others. The Kiamichi is marked by *Oxytropidoceras belknapi* (Shumard), *Oxy.* several other species, *Gryphaea navia* Hall, *Gryphaea tucumcari* Marcou (also in basal Duck Creek), and others. At the Kiamichi-Duck Creek boundary, a restricted zone of *Elobiceras* occurs.

The most distinctive or zonal Fredericksburg fossils are as follows: among ammonites, *Oxytropidoceras* and *Dipoloceras,* so far as known, are restricted to the Fredericksburg group; radiolites occur in it (and the Washita) but have never been reported from the Trinity group; certain types of reef molluscs, as *Chondrodonta munsoni, Pecten duplicicosta, Cladophyllia,* and numerous minute fossils described by Roemer are unknown in the Trinity, occur in the Fredericksburg, and similar species occur in the reef facies of various Washita ages. The oyster *Gryphaea* is abundant at many Fredericksburg levels, but rare in the Trinity. *Exogyra* texana is present but rare in the Glen Rose. Many gastropods and pelecypods, occurring commonly as casts, cause confusion between Trinity and Fredericksburg, though many others are quite distinctive for each group. Common echinoid genera, are, so far, very confusing and undiagnostic, and data on those of the Trinity are still unpublished. Certain foraminifera are generally used in diagnosis: *Orbitolina texana* for the Trinity, *Orbitolina walnutensis*[32] for lower Fredericksburg, abundant large miliolids for the Edwards, an aggregation of arenaceous genera for the Grayson. Many fossils, alleged to be markers for certain formations, are quite unreliable, except perhaps locally and where found in abundance; among those whose currently quoted ranges need correction are: *Haplostiche texana* (Conrad), *Kingena wacoensis, Alectryonia carinata, Nautilus texanus, "Enallaster" texanus, Exogyra texana, Gryphaea marcoui,* and several others which are habituallly misidentified.

Until the thickened extensions of the Edwards in the Coastal Plain and the Rio Grande embayment have been studied, only provisional zonations of the group can be presented. A double zonation will be necessary, as in the Urgonian in the Mediterranean region, one set of ammonite zones, and a set of rudistid zones.

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[32]Referred to *Dictyoconus aegyptensis* Chapman var. *Walnutensis,* by Silvestri, 1479a, p. 159, footnote 1.

PROVISIONAL FREDERICKSBURG FOSSIL ZONES

	Ammonite Facies: Brazos-Colorado valleys	Ammonite Facies: Pecos-Rio Grande	Rudistid Facies: Brazos-Colorado	Rudistid Facies: Pecos-Rio Grande
Kiamichi:	Elobiceras Adkinsites[33] belknapi- Gryphaea navia	(absent)	(unknown)	(absent)
Edwards:	Oxytropidoceras supani	?	Eoradiolites zone	?
	Dipoloceras aff. cristatum	?	Planocaprina? zone	?
	Dipoloceras aff. cornutum	?		
Comanche Peak:	Oxytropidoceras acutocarinatum	?	(Rudistid zones unknown in basal Fredericksburg)	
Walnut:	Metengonoceras aff. hilli			

Correlation and age.—The upper Aptian (Gargasian) has been located by several writers as the *Dufrenoya* zone of the Travis Peak sands. Much of the Glen Rose and all of the Fredericksburg is placed in the lower and middle Albian. The top of the ranges of the ammonite genera *Dipoloceras* and *Oxytropidoceras*, and the bottom of the ranges of *Elobiceras* and *Pervinquieria*, mark the base of the upper Albian, and approximately coincide with the Kiamichi-Duck Creek boundary. The other fossils mostly agree with the assignment of the Fredericksburg group to the middle Albian.

Economic products.—Certain Edwards levels produce, locally, artesian water. The large springs along the Balcones fault make their exit through Fredericksburg rocks, but much of the water may be from Trinity aquifers. The Edwards is an oil reservoir at Luling, Larremore, Darst Creek and Salt Flat. Other economic products are limestone, lime, clay, gravel, quicksilver, silver, and several other metals in smaller amounts.

It is not certain whether or not the upper part of the basal sands (containing *Exogyra texana, E. weatherfordensis*) near Fort Stockton, and the upper part of the Cox sandstone near Sierra Blanca are Fredericksburg.

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[33]Genus described by L. F. Spath, 1511a, p. 350. Texas species: *belknapi* (genotype), *trinitensis* (Gabb), *chihuahuensis* (Böse), *kiowana* (Twenhofel).

FREDERICKSBURG FORMATIONS AND FACIES IN TEXAS

	North-central Texas	South-central Texas	Fort Stockton Post-Kiamichi and	Sierra Blanca Kiamichi
	Kiamichi	Edwards	Kiamichi	
Goodland	Edwards (thin)	Comanche Peak (thin)	University Mesa Marl	Finlay
Goodland	Comanche Peak			Finlay
	Walnut	Walnut (thin)	Comanche Peak	Finlay
			? Basal Sands (upper part)	? Cox ss. (upper part)

WALNUT FORMATION

Nomenclature.—The Walnut clays were named by Hill (772, p. 512; 780, p. 86) to indicate the yellow clays, flaggy limestones, and shell masses of *Exogyra texana* and *Gryphaea marcoui*, lying above the Paluxy sands near Comanche Peak. The type locality is at Walnut Springs, Bosque County.

Stratigraphic position and contacts.—In north-central Texas the basal part of the type Walnut is invaded by sand, up to the level of the prominent *Gryphaea marcoui* shell aggregate, and the basal portion is thus indistinguishable from Paluxy sand. It is therefore probable that, north of Fort Worth, some Walnut sand may be included in the Antlers formation; at least the upper Antlers contains *Exogyra texana* and *Ostrea crenulimargo*, which are known from the Fredericksburg group. The Walnut-Comanche Peak contact is apparently conformable. In the southern part of the Edwards Plateau and in northern Trans-Pecos Texas, the Walnut is either reduced locally to an insignificant "break" (receding ledge) less than 1 foot thick, or else is not positively identifiable. In the southern Pecos Valley, the underlying formation is Glen Rose limestone, but near Fort Stockton it is the basement sand. These contacts appear to be concordant, but whether they are conformable has not been discovered.

Facies.—The formation is in the neritic facies over most of its extent, and consists of clays, limestone seams and shell aggregates. From Fort Worth to the Red River valley its basal part is sand; this is possibly true at places in Trans-Pecos Texas, as at Kent.

Areal outcrop, local sections.—The section near the type locality represents only an extreme of the Walnut formation in Texas. To the north the base rapidly becomes sandy, and the only persistent feature is the aggregate of *Gryphaea marcoui* shells; to the south the oyster shell beds first became unconsolidated (in Williamson County), and then vanish, leaving only an insignificant and indistinctive marl, containing scattered oyster shells and few or no diagnostic markers, and, finally, in the southern part of the Edwards Plateau, only a thin "break" or receding ledge.

Near Goodland, Oklahoma the probable equivalent of the Walnut is 3 to 6 feet of persistent, hard, thin, coquina-like limestone, with interbedded thin layers of dark marly shale (1530, p. 135). On Red River, north of Gainesville, the Walnut is represented by 4 feet of marly clay containing *Exogyra texana* and *Gryphaea marcoui* (189, p. 15). Near Marysville, the Walnut consists of a small thickness of marl and marly limestone with the usual fossils. At Preston, and in Little Mineral Creek, Grayson County, the Walnut is represented by a few clay layers containing *Exogyra texana* (803, p. 208). The difficulties in mapping and identifying the Walnut in this district have been most clearly realized and expressed by Winton (1791, pp. 16–18) in treating the Denton County area. The top of the formation is a widely persistent, consolidated, and mappable *Gryphaea marcoui* shell aggregate, 16–18 feet thick. Under this cap are sands, sandstones, and a few clay seams, which continue down to a coarse red sandstone (Paluxy), which lithologically is distinguishable from the finer-grained and lighter-colored Walnut sands. On the Clear Fork of the Trinity west of Fort Worth, the shell aggregate of the Walnut is 5 to 8 feet thick, and is underlain by about 100 feet of Walnut sands. At Decatur (803, p. 208), the Walnut is about 27 feet thick, with only a thin shell agglomerate at the top. Wells in Tarrant and Johnson counties show about 100 feet of Walnut, with some water sands. Logs of Dallas County wells indicate 50 feet or more of the formation. In Johnson County, both outcrop and wells indicate a thickness of about 100 feet, of which the upper 25 feet is shell aggregate and the lower part mostly soft light-colored sands, with a few thin ledges of grayish sandstone, which form a water reservoir of small volume (1790, p. 20). At Comanche Peak, the formation consists of 30 feet of shale, marly limestone, and sands (803, p. 209). Various wells in eastern Hill County show 145–215 feet of Walnut; in western Hill County, 120–135 feet.

Scott and Hawley consider the Walnut to be uniformly about 27 feet thick in the area west and northwest of Fort Worth, and to be limited to the calcareous sediments, including the *Gryphaea marcoui* shell banks. The underlying sands they refer to the Paluxy.

In the Lampasas Cut Plain in Bosque, Coryell, McLennan, and Bell counties, the type Walnut is best developed. Here it has lost its sandy base, and retains the massive shell aggregates. It is 100 to 182 feet thick, and thickness down dip. It makes long westward reëntrants up the stream valleys, and, in general, covers large areas in the lowlands, as in Coryell County. It consists of gray-black, calcareous clay and seams of thin bedded limestone, thicker chalky nodular limestone, and shell aggregates. The formation is extremely rich in ammonites, pelecypoda, gastropoda, echinoidea, and other fossils. In Bosque County, Hill (803, p. 206) gives a section of 96 feet of Walnut, consisting of marly limestone beds, alternating with harder and more crystalline limestone and very limy marl. The formation contains a large assortment of fossils, with the usual oysters and *Oxytropidoceras.* At Comanche Peak, it is 121 feet thick. In the Iredell section Taff (1574, p. 305) lists 102 feet, with the same lithology and fossils. In the Walnut Springs section Taff (1574, p. 306) records 74 feet of Walnut, composed of marly and chalky limestone, compact crystalline limestone, and limy shell marls, containing a typical Walnut fauna: *Exogyra texana* Roemer, *Gryphaea marcoui* Hill and Vaughan, *Cyprimeria texana* (Roemer), *Protocardia texana* (Conrad), *Natica, Trigonia, Holectypus, Heteraster,* and others. Unfortunately the real zonal fossils of this formation are rare, and do not appear in usual lists.

Westward across the Callahan divide to the Llano Estacado, the Walnut forms a constantly thinning layer above the basal (Paluxy) sand and beneath the prominent Fredericksburg limestones (page 321). This formation has an irregular but small thickness: 55 feet at Twin Sisters Peak, Lampasas County; 10 feet in Brady Mountains, McCulloch County; 6 feet at Monument Mountain, Tom Green County; 12 feet at the Camp section, Crockett County; 8 feet at Castle Mountain, southeastern Crane County; a solid mass of 5 feet of *Gryphaea* aggregate at Double Mountain, Stonewall County. On a more northern, parallel, section the Walnut is 20 feet thick at Round Mountain, Comanche County; 5 to 10 feet thick at the Santa Anna glass sand pit; 20 feet thick at Baker Mountain, Callahan County; 4 feet thick at Buffalo Gap, Taylor County; 10 feet thick in Runnels County; 15 feet thick on Bitter Creek, Nolan County; no marl represented, at Stepp Mountain, Coke County; 8 feet thick at Signal Peak, Howard County; no marl represented, in the Fort Stockton area.

South of the Brazos, the marl facies of the Walnut becomes gradually thinner, and the remaining basal Fredericksburg probably equivalent to type Walnut, locally takes on non-Walnut facies. In western Bell County, typical Walnut is at least 150 feet thick; in northern Williamson County, near Bertram and Bagdad, it is given as 30 to 40 feet thick by Hill (803, p. 210), and south of Florence, in the same area, the *Gryphaea* banks are absent. Here much of the position of the Walnut is occupied by a limestone lentil, which is here designated *Cedar Park member* (type locality: quarries, about 2 miles northwest of Cedar Park). It occurs over a considerable area in western Williamson County, and grades out northwards into Walnut of the type facies. It typically consists[34] of about 58 feet (in core tests) of limestone, crystalline and porous above, and more marly and nodular below. The upper part (about 15 feet) is a solid, medium-grained, grayish limestone, weathering yellow, with but few scattered fossils (*Exogyra texana, Ostrea,* gastropods); beneath it is a few feet of porous limestone, with some caprinids and mollusca, and great numbers of cavities of *Trigonia;* other fossils are *Exogyra texana, Protocardia, Corbis,* and *Turritella.* Both limestones are used for building stone; the new Travis County courthouse is built of the *Trigonia* stone. The basal portion of the Cedar Park member is somewhat nodular and fossiliferous. The base is about 5 feet of typical Walnut marl with many *Exogyra texana* and other usual fossils. These three portions are exposed in a facies transitional to the type Walnut on the bluffs of the South San Gabriel at the highway crossing north of Leander, where they overlie the Glen Rose. In the Cedar Park area the limestone lentil in the basal Fredericksburg reaches 125 feet in thickness, and probably covers several square miles.

From this point south and west, the Walnut as ordinarily understood, is an insignificant shell marl less than 15 feet thick, which is persistent and has been used as a structural marker. Locally, in the southern Edwards Plateau, it dwindles to a mere "break,"

[34]From field work by H. C. Fountain.

a receding plane between thick Edwards strata. This marl has the usual long-range Fredericksburg species, most commonly *Exogyra texana* and *Gryphaea marcoui,* and may be lithologically indistinguishable from other thin Fredericksburg marls. Regarding Walnut as a facies only, this southern attenuated Walnut is a thin portion of the type Walnut.

In the Colorado Valley, Hill (803, pp. 210–211) assigns 10 to 15 feet to the Walnut. In the plateau region west of Austin, it makes a thin stratum of yellow, calcareous clay, lying above the Glen Rose limestone and below the Comanche Peak, and weathers into either a steep marl slope or, more typically, into a flat terrace or bench, forming a platform for the overlying Comanche Peak-Edwards limestones. This yellowish, untimbered band is conspicuous at many places in western Travis County. The Walnut here contains echinoids *(Holectypus, Heteraster, Salenia),* pelecypods, gastropods, and *Engonoceras* but no *Oxytropidoceras.* At places it contains *Loriolia texana* and *Porocystis,* which indicates that locally the band called Walnut may be of Glen Rose age. At a few localities, rare and undescribed ammonites have been collected. In a butte on the Travis-Blanco county line, Hill assigns 31 feet to the Walnut; at Shovel Mountain, Blanco County (803, p. 211), 20 feet; and at Fredericksburg, 10 feet of yellow calcareous clay with *Exogyra texana* (795, p. 221). At Kerrville it is assigned a thickness of 1 foot; in Real County it is an intermittent thin yellow-brown clay, absent at most places (Russell F. Ryan, oral communication). This situation largely persists west to the Pecos. In the Pecos Valley, only thin Walnut is on record, 8 to 14 feet in the lower Pecos Valley, and 2 to 3 feet farther north (991, pp. 52ff). Around Girvin and Fort Stockton, no clay is present in its position, and any limestone referred to Walnut must be confirmed by fossils, at present an impossible task.

In the Gap Tank area, 50 feet of marls, sandy marls, and thin limestones lie between the Maxon sandstone below and limestones of the Edwards reef facies above (936, p. 93); what part of this is of Walnut age is unknown in the absence of decisive zonal fossils. Other thicknesses in the Big Bend are: Solitario, about 50 feet; southern Quitmans, about 100 feet (46, p. 26); Van Horn Mountains, a considerable thickness; at Shafter, it is apparently absent.

From these facts it is clear that (1) the southern "Walnut" corresponds to only a small part of the type Walnut, and at most places is not identifiable as Walnut; (2) on account of facies changes, no correlation of the southern "Walnut" can be made on lithology alone (it is useful locally as a datum plane), but an accurate fossil zonation is necessary for any eventual correlation; (3) *Exogyra texana* and *Gryphaea marcoui* do not identify the Walnut, because where the facies is favorable they range far outside it; where the section contains rudistid, marginal, or other unfavorable facies, their apparently restricted range is illusory.

Lithology and microscopic features.—No material has been published on the numerous foraminifera and ostracoda of this formation, nor has the mineral content been well investigated.

Thickness and dip.—At what rate the formation dips coastward in the Gulf Coastal Plain can only be inferred from adjacent formations. It seems absent or unidentified in southern Texas, as in Maverick County (1681, p. 257) and at Luling (165, p. 646). In southwestern Bexar County (888, p. 770), it is only 20 feet thick. It is, therefore, a formation essentially local to north-central Texas. At Mexia there is 40 feet or less of Walnut; in the interior salt domes and the East Texas oil fields it has not been well identified.

Paleontology and zonation.—No good zones have been established, and probably the entire formation represents only a short time interval on account of rapid deposition. *Metengonoceras* sp. aff. *hilli* Böhm may mark the formation. Species of *Oxytropidoceras* seem common to it and the overlying Comanche Peak in its more marly phase.

Unidentified plant stems have been reported by H. C. Fountain from the Walnut along the Georgetown-Lampasas road 2 miles west of Briggs, Williamson County.

Foraminifera from Walnut formation

(From three localities in vicinity of Austin, the Mount Barker outcrop being richest in species)

Haplostiche texana (Conrad)
Cyclammina sp.
Choffatella sp. aff. decipiens Schlumberger
Lituola sp.
Ammobaculites goodlandensis Cushman and Alexander
Ammobaculites subcretacea Cushman and Alexander
Flabellammina alexanderi Cushman
Textularia rioensis Carsey
Textularia washitensis Carsey
Verneuilina schizea Cushman and Alexander

Valvulina sp.
Orbitolina walnutensis Carsey (=Dictyoconous according to Silvestri, 1479a)
Orbitolina sp. cf. texana (Roemer)
Vaginulina intumescens Reuss
Patellina subcretacea Cushman and Alexander
Globigerina washitensis Carsey

COMANCHE PEAK FORMATION (INCLUDING GOODLAND)

Nomenclature.—This formation was called the "Comanche Peak group" in 1860 by Shumard (1463, pp. 583–585), who placed it correctly below the Edwards ("Caprina") limestone and incorrectly above the Austin chalk. Its type locality is at the famous Indian landmark, Comanche Peak, central Hood County, and the formation is best developed in the Brazos and Trinity valleys.

Stratigraphic position and contacts.—Thickness relations indicate that the Comanche Peak is a facies of the Fredericksburg, and may be in part laterally continuous with Walnut below and Edwards above. No adequate zonation allows a check of this assumption, but certainly to the south the rudistid facies ("Edwards") invades all levels of the Fredericksburg group, and therefore is presumably equivalent in part to type Comanche Peak. Both upper and lower contacts of the Comanche Peak appear to be concordant, according to published reports.

Facies.—The Comanche Peak is a chalky-limy facies. To the north it is continuous with the "Goodland" limestone, which is of the same lithology and fossils (1575, p. 256). Throughout central Texas and the Callahan divide, it maintains the same lithology; in the marginal areas (Red River valley, southern Oklahoma, north of Fort Stockton and Kent, at Sierra Prieta), it presumably goes into a marginal sandy phase.

Areal outcrop, local section.—The Goodland limestone, first named and described by R. T. Hill (780, p. 88, 1891; 772, p. 514, 1891) in the Red River valley is the same as the Comanche Peak, because (1) Edwards is defined as consisting of the rudistid facies and similar rock, and does not outcrop north of Fort Worth; and (2) the Goodland contains *Oxytropidoceras acutocarinatum*, a species which marks the middle and lower parts of the Fredericksburg group. At Goodland (803, p. 217) the limestone is less than 20 feet thick. The rock is fractured, crystalline, whitish limestone, resembling Comanche Peak in lithology, and contains undiagnostic fossils: *Engonoceras* aff. *hilli* Böhm, *Exogyra texana* Roemer, *Cerithium bosquense* Shumard, and many pelecypods and gastropods.

The easternmost outcrop of the Goodland is north and east of Cerro Gordo, Arkansas, and about 4 miles down Little River from it. It consists of 50 feet or less of thick-bedded, gray, sandy limestone, containing some beds of hard, yellow-gray, calcareous sandstone. At some horizons, the Goodland beds are notably lenticular; lentils of limestone 6 feet long and a foot thick, of varying degrees of sandiness, stand at small angles with the normal bedding. The upper 8 feet of the formation, where exposed, is a less sandy limestone. The top is a ledge a foot thick, of hard, white limestone, which weathers into cavernous slabs. The Goodland is overlain by about 20 feet of Kiamichi clay containing *Gryphaea navia* (392, pp. 15–16).

In Grayson County, the Goodland, overlying 6 feet of marl, shale and thin seams of limestone and shell aggregates, consists of about 15 to 20 feet of hard, white, semi-crystalline limestone, generally in four beds each 4 to 6 feet thick. It weathers by conchoidal flaking, and develops a honey-comb surface by erosion of softer pockets. In Marshall County, Oklahoma, 15 to 20 feet is recorded; in Love County, about 25 feet. It contains *Oxytropidoceras* aff. *supani*, pelecypods, and gastropods, including a large smooth oyster somewhat like *Exogyra americana* Marcou. In northern Cooke County, the Goodland is 25 feet thick, in southern Cooke County, 40 feet. At a variable distance (2 to 16 feet) below the top, there is a horizon of *Exogyra plexa* Cragin. At a variable level (3 to 9 feet) above the base, a zone of abundance of *Gryphaea marcoui* is recorded . *Oxy. acutocarinatum* is reported throughout the formation. Other fossils are: *Remondia robbinsi* (White), *Protocardia, Pholadomya, Pecten, Turritella, Cerithium bosquense*, and *Heteraster*. The Walnut shell aggregate is absent, and the thin Walnut clay rests on sandy beds containing *Gryphaea marcoui* and *Ostrea crenulimargo* Roemer. This aggregation of fossils is not diagnostic, but suggests Comanche Peak, not Edwards.

The formation thickens, from 42 feet in northern Denton County and 75 feet in southwestern Denton County, to 116 feet near Lake Worth, Tarrant County. The marly limestones and limy marls of the Goodland form large hills on the Clear Fork and West Fork of the Trinity in western Tarrant and eastern Parker counties. Near Benbrook, there are large, richly fossiliferous exposures. At Lake Worth Dam, a complete section shows an alternation of more limy and more marly beds, lying above the massive *Gryphaea marcoui* aggregate capping the Walnut and the base of the Kiamichi clay. *Dipoloceras* and *Oxytropidoceras* range from bottom to top of this section. Local zones (9, pp. 15–31) are probably applicable from this area to the Red River valley. At the type locality, Comanche Peak (1574, p. 311), it is 66 feet thick. Its typical lithology is chalky, fossiliferous limestone in fairly massive beds. There is considerable jointing or flaking, which gives the limestone a fractured appearance. Some slight, irregular, marly seams bound the limy beds. It weathers to a dull whitish-chalky color. Calcite and calcitized fossils are frequent. Topographically it forms steep slopes, in contrast to the more massive, bluff-forming Edwards above, and the soft, valley-forming Walnut clay below; it forms numerous round-topped buttes and outliers where the more precipitous Edwards cap has been removed. This lithology is distinctive throughout central Texas; it may be seen on a large scale at Benbrook, Comanche Peak, and Valley Mills.

The ridges and buttes of the Lampasas Cut Plain in Somervell, Bosque, Coryell, western Bell, and western McLennan counties, show on their upper slopes typical Comanche Peak. In the breaks ot the Edwards scarp west of Oglesby and near Copperas Cove, it is excellently displayed.

It overlies the thin Walnut clay remnant in the buttes of the Callahan Divide, and occurs in the eastern rim of the Llano Estacado. At most of these localities it is with difficulty distinguished from the Edwards. At Round Mountain, Comanche County, 60 feet is reported; at Santa Anna, 40 feet; in Taylor County, 60 to 80 feet; in Runnels County, 21 feet; at Stepp Mountain, Coke County, about 90 feet; at Signal Peak, Howard County, about 70 feet; at Double Mountain, Stonewall County (467), 55 feet.

In southern Hill County, south of Blum, the Brazos bluffs show complete sections of the Comanche Peak for miles. Similar excellent exposures occur with abundant fossils in the Bosque valley near Valley Mills. Southwards, down the east side of the Leon Valley, long exposures cross Coryell County and continue to northern Bell County (16, pp. 33–34). In western Bell County the formation is about 100 feet thick, and weathers as grayish-white, flattened, nodular, fossiliferous limestone, forming the upper steep scarps of ridges and outliers in the Lampasas Cut Plain. In the Burnet quadrangle, it ranges from 70 feet in the north, to 40 feet in the south. Near Leander, it has a thickness of 75 feet or less. In the Austin area (1429, p. 44) its outcrop thickness is 49 to 55 feet. Here it consists of marly, grayish-white limestone, with compressed nodules, and the flaking and jointing already described. The Walnut differs from it in being more marly, and in having uncompressed nodules imbedded in a considerable amount of marly matrix. Here the formation contains echinoids, pelecypods, gastropods, tall conical *Orbitolina (O. walnutensis)*, and other fossils.

Along the southern margin of the Edwards Plateau, the formation consists of about 35 feet of nodular, whitish, sparsely fossiliferous limestone, overlying the soft, abundantly fossiliferous Walnut clay, and underlying the massive, hard, gray, flint-bearing Edwards limestone. The Comanche Peak contains *Exogyra texana, Gryphaea marcoui* and pelecypod and gastropod casts. In the Nueces quadrangle there is 40 to 50 feet, in the Uvalde quadrangle 60 feet, of yellow-weathering, nodular, argillaceous limestone, containing *Exogyra texana*, which represents the Comanche Peak. In these areas the Walnut is absent, but the *Exogyra* is more abundant at the base of the limestone. In the lower Pecos Valley 2 to 12 feet of nodular limestone, containing *Exogyra texana, Protocardia texana* and *Lunatia pedernalis*, occurs (991, pp. 52–60).

Thickness and dip.—The formation does not reach a thickness of over 150 feet. It is apparently gradational and conformable into the Edwards and the Walnut, and has the same attitude and dip as those formations. Its greatest thickness is in the Brazos and Colorado valleys. In the Red River valley, it is reduced to an insignificant thickness, and, on approaching the Rio Grande, it is either indistinguishable from the overlying greatly thickened Edwards limestone, or else persists as a thin nodular limestone. These facts strongly suggest that the Comanche Peak is not of the same age throughout its extent, but that it is a nodular facies, present at various Fredericksburg levels.

Paleontology and zonation.—No Comanche Peak zone fossils are known. The correlation is discussed under the "Edwards formation."

The following are the most distinctive ostracoda of the Goodland (Comanche Peak) in north-central Texas:[35]

Cythereis mahonae Alexander
Cythereis fredericksburgensis Alexander
Cytherella fredericksburgensis Alexander
Cytheropteron howelli Alexander
Cythereis carpenteri Alexander (lower Goodland only)
Cytheridea oliverensis Alexander
Bythocrypris goodlandensis Alexander (not common)
Cytheridea goodlandensis Alexander
Paracypris siliqua Jones and Hinde

The following are the most distinctive foraminifera of the Goodland:

Foraminifera from Goodland formation

(Three localities in the vicinity of Fort Worth)

Ammobaculites subcretacea Cushman and Alexander
Ammobaculites goodlandensis Cushman and Alexander
Frankeina goodlandensis Cushman and Alexander
Flabellammina alexanderi Cushman
Spiroplectammina scotti Cushman and Alexander
Spiroplectammina whitneyi Cushman and Alexander
Spiroplectammina sp.
Verneuilina schizea Cushman and Alexander
Valvulina sp.
Vaginulina marginulinoides Reuss
Vaginulina intumescens Reuss
Globulina exserta (Berthelin)
Patellina subcretacea Cushman and Alexander

Economic products.—At places the Goodland or Comanche Peak is a nearly pure limestone, and can be used with the Kiamichi clay for Portland cement. The El Paso cement plant uses lime from this level. Locally it is used for road metal.

EDWARDS FORMATION

Nomenclature.—The name Edwards,[36] of Hill and Vaughan (795), replaced the terms Caprina limestone of B. F. Shumard (1463, pp. 583–584), and Barton Creek limestone of Hill (735, p. 5; 751, p. 23). Other local members of the Edwards near Austin are the "Flag limestones" (lithographic horizon), the "Austin

[35]This and the following lists of ostracoda were kindly furnished by Dr. C. I. Alexander.

[36]*Literature.*—Hill, 803; Hill and Vaughan, 794, 795, 808; Hanna, 647a; Taff, 1574, 1575. *Paleontology:* Cragin, 324; Hill, 784; Merrill, 1103; Roemer, 1335; Stanton, 1522; White, 1738.

marble" (Caprotina horizon), and the "chalky limestone subdivision" (735, pp. xix–xxii). The type locality of the Edwards is on Barton Creek near Austin.

Stratigraphic position and contacts.—From Fort Worth to south of Waco, the Edwards gradually thickens, and is overlain, apparently unconformably, by the Kiamichi clay. South of Waco, the Kiamichi is absent, and the Edwards is overlain by Duck Creek limestone. The Edwards-Duck Creek contact shows evidence of unconformity in Bell County (16, p. 40). Its lower contact with the Comanche Peak is continuous and gradational where it has been recorded.

Facies.—(1) Marginal facies exists at Sierra Prieta north of Sierra Blanca, where brown cross-bedded sandstone containing *Alectryonia* cf. *carinata* and other poor casts composes the section below the basal *(Hamites-Desmoceras)* zone of the Duck Creek limestone. In the Rycade Chittim No. 2 well in eastern Maverick County, 20 feet of coarsely crystalline rock salt is recorded (578, p. 1426), presumably near the top of the Edwards, with 779 feet of limestone between it and the Del Rio clay. In nearly pure, heavy-bedded limestones, in the southern part of the Edwards Plateau, fossil logs are recorded (578, p. 1427): a dicotyledonous log 18 inches in diameter near Mine Creek, northern Uvalde County; a palm-like log 20 inches in diameter near Barksdale, southeastern Edwards County. Silicified wood also occurs in basal Edwards in southern Real County. It is not known whether these logs floated to their present locations, or whether they indicate proximity of the marginal facies. (2) Neritic facies occurs in the form of marl at Fort Stockton, here called *University Mesa marl.* Marly limestone occupies the top of the Fredericksburg at many places (El Paso, Round Rock). (3) Reef limestones and associated rocks compose the typical Edwards; these rocks, diverse in lithology, are discussed below. Dr. Decker has recently discovered a rudistid (caprinid) deposit in the Fredericksburg in southern Oklahoma, the northernmost known in this longitude.

Areal outcrop, local sections.—The northernmost recorded Edwards is at Fort Worth, where a few feet of crystalline, thin- to medium-bedded limestone contains masses of undetermined caprinid casts (Gayle Scott, personal communication); at Benbrook a rudistid was reported in the top of the Goodland (1575). Hill considers the Edwards to be 4 feet thick here. It is harder, more crystalline, and more prominently cliff-forming than the underlying Comanche Peak. In southwestern Johnson County, about 35 feet of Edwards is recorded. In the cap of Comanche Peak 33 to 35 feet remain, of which the upper 3 feet contains *Eoradiolites davidsoni* and *Chondrodonta munsoni.* The formation is composed of layers of hard white limestone, each from 3 inches to 10 feet thick, below which is a massive bed 15 feet thick, forming the main upper scarp of the peak. In Hill County below Blum, the Brazos has cut tall cliffs capped by Edwards, which continue downstream across Hill County, The Edwards is 50 to 75 feet thick, and consists of rudistid limestone, a hard, crystalline, medium-to-massive-bedded, white limestone, composed of considerable calcareous shell detritus and some precipitated limestone. It contains *Eoradiolites, Chondrodonta, Toucasia, Requienia,* caprinids, *Pecten,* and other reef forms. This limestone is exposed in Nolands River just north and west of Blum, and in road cuts south of the town. Tall cliffs occur along the Bosque Valley east of Clifton and around Valley Mills. In the upper strata of nearly pure, white, crystalline reef limestone, abundant rudistids occur, as *Caprina crassifibra* Roemer, *Caprinula anguis* (Roemer), *Eoradiolites* spp., *Toucasia texana* (Roemer); and *Chondrodonta munsoni* (Hill), pelecypods, and gastropods. At localities on the Meridian Highway 2 to 3 miles east of Valley Mills, the Edwards consists of alternations of whitish nodular limestone, with the usual upper Fredericksburg fauna of pelecypods and gastropods, and massive, harder, crystalline reef limestone with rudistids. Caves and rock shelters nearby contain many rudistids. In one of the softer layers east of Valley Mills, the plicate inoceramus, *Actinoceramus subsulcatiformis* Böse, was found. Other fossils include *Exogyra texana* Roemer, *Lima wacoensis* Roemer, *Cardita, Gryphaea marcoui* Hill and Vaughan, *Engonoceras,* and species of *Oxytropidoceras.* In facies, this soft, marly upper Edwards is similar to that at Round Rock; the top of the Edwards in Hill County is uniformly a massive pure limestone with a tangle of Caprinidae, rudistids, *Chondrodonta,* and other reef dwellers.

In McLennan County, the Edwards is massive, pure (99.4% $CaCO_3$), unstained, rudistid limestone. An excellent exposure, studied and collected by Dr. T. W. Stanton about 1890, is at the west crossing of Bluff Creek, 3.5 miles northwest of Crawford, where the limestone is 60 feet or more thick. The exposures consist of alternate, medium-bedded harder projecting and less resistant receding, pure, white limestone ledges. They contain much calcite, and so little iron that the exposures show practically no ferruginous stain. A few ledges at the top are softer. The limestone is a shell debris, as in the reefs west of Belton and at Oglesby. The Edwards here contains a large typical fauna, including *Caprina crassifibra, Caprinula anguis, Plagioptychus? cordatus* Roemer, *Eoradiolites davidsoni* (Hill), *Radiolites(?)* sp., *Toucasia texana, Toucasia* sp., *Caprina* sp., *Caprotina* sp., *Chondrodonta munsoni,* and others (11, pp. 35–37). The Edwards also outcrops in McLennan County along Middle Bosque River, from a point 2 miles west of Windsor northwest to the Bosque County line, including the area east of Crawford and along Bluff Creek. West of its reëntrant down North Bosque River at Valley Mills, the outcrop turns westward and follows down Leon River across western Coryell County to Belton. At Patton, in the bed of Hog Creek, the basal Duck Creek and 3 feet of Kiamichi marl occur; beneath them is the top layer of pure reef limestone with the rudistids mentioned above. On the Meridian Highway, 0.4 mile west of the McLennan-Bosque county line, beneath about 9 feet of Kiamichi marl, the top of the Edwards, with similar lithology and fossils, is exposed. In the creeks about a mile east of Crawford, the same contact is exposed, and beneath it, about 25 feet of fossiliferous Edwards. In the bed of North Bosque River, 3.5 miles southwest of China Springs, beneath 4 feet of Kiamichi, a few feet of uppermost Edwards occurs (11, p. 40). In Middle Bosque River, 2 miles west of Windsor, about 25 feet of upper Edwards, consisting of alternate reef and gray nodular limestones, occurs.

North of Bell County, the Edwards lithology shows three main types: soft, nodular, marly, gray limestone and marl with non-reef pelecypods, gastropods, and echinoids; harder chalky-gray limestone with slight clay content, and a non-reef fauna; and pure dazzling white, calcitic, limestone, hard to friable, much of it composed largely of shell debris and precipitated lime, with a reef fauna. From Bell County southwards other types appear. Here the formation caps the upland west of the Balcones fault zone, running from Leon River west to Sugar Loaf Gap north of Killeen, along the north county line. In the northwest quarter of the county it forms a large upland, deeply cut to the soft Walnut clay in the valleys of streams flowing down-dip. A broad plain is formed by the valley of Nolan Creek, west of Belton. In the southwest quarter of the county the main Edwards outcrop narrows to a few miles in width, and forms the back slope of a long cuesta running eastwards from the valley of Lampasas River. These Walnut valley interstream divides, buttes (outliers), and the west-fronting cuesta face of the Edwards-Comanche Peak scarp, compose the Lampasas Cut Plain of Hill. It is notable that late movements in connection with the Balcones Fault have produced typical intrenched meanders of considerable depth in Bell County (as Leon River) and McLennan County (as Bluff Creek), by rejuvenating the streams and increasing their gradients.

The Edwards here, and generally, is distinguished from the underlying Comanche Peak facies by having: (1) persistent strata of limestone, even-bedded and medium-to-massive in thickness, instead of compressed chalky limestone nodules with a subordinate amount of marly matrix; (2) flint, in nodules and in thin strata; (3) rudistids and caprinids, of the genera *Toucasia, Requienia, Monopleura, Caprina* (these four occur also in the Glen Rose), *Caprinula, Caprotina (?), Plagioptychus (?), Planocaprina (?), Polyconites (?); Praeradiolites, Eoradiolites, Sauvagesia,* and others; (4) other reef-dwelling fossils, as those from the Edwards described by C. A. White and F. Roemer, most of them apparently zone fossils: *Chondrodonta munsoni, Phacoides acute-lineolatus, Trochus texanus, Cladophyllia furcifera,* and others; (5) reef limestone: a nearly pure, white or light gray detrital or fragmental shell coquina and associated precipitated calcium carbonate, composed mainly of comminuted shell fragments, and containing much calcite as shells and as free masses; (6) other kinds of limestone, whose exact mode of deposition has not been investigated, as miliolid limestones, sandy limestone, and sandy, limy clay, both finely laminated, silty layers; and (7) pulverulent layers of finely divided, nearly pure, calcium carbonate, produced by intraformational solution and redeposition, and, associated with it, disintegrated remains of "honey-comb" limestone from which much of the lime has been dissolved. These pulverulent layers are at places associated with anticlinal structure; they occur on the Kolls place west of Belton, on Barton Creek and in Deep Eddy Bluff at Austin, in numerous caves near Crawford, Valley Mills, Austin, and in the Edwards Plateau and canyon region of the Pecos and Rio Grande valleys. Rudistids become disengaged in such weathering layers and occur free in large numbers. The pulverulent limestone has been used commercially on a small scale; the honeycomb rock, from Glen Rose, Edwards, and other formations, is locally used as ornamental stone. A soft formation, called "adobe," occurs near the top of the Edwards in central Texas, and forms the producing horizon in the Luling oil field.

In Bell County the top of the formation is a pure white rudistid-reef limestone, as farther north. However a few thin layers interbedded with the limestone are composed principally of flaky, yellow, shelly marl, containing the same fossils as the adjacent limestones, *Pecten duplicicosta, Chondrodonta, Praeradiolites, Eoradiolites, Goniopygus* cf. *zitteli*, corals, and other fossils. The base of the formation consists of a widespread, soft, water-bearing siltstone, weathering yellow, and containing few fossils except casts of *Planocaprina* (?) and other caprinids. The middle of the formation contains several limestones associated with the purer coquina and *Requienia*-limestones: (1) a dense, ringing, fine-grained, medium- to thin-bedded limestone, light bluish-gray or dull buff-gray, with faint salmon-reddish cast or streaks, which contains numerous imbedded small calcitic fossils, visible as cross-sections on fracture. This rock is mostly non-siliceous, but locally contains flints. It has a prominent conchoidal fracture, splits easily, and is a good building stone. In texture it resembles fine-grained Ellenburger limestone. (2) A prominent type is a shell coquina of rudistids, caprinids, gastropods, pelecypods, corals, echinoids, and other fossils, cemented into a porous or cavernous mass of shell agglomerate and debris. This rock is a part of the rudistid reef facies. At some places it is entirely calcareous, and may be sawed into building and paving stone. It is full of cross-sections of rudistids, caprinids, *Nerinea*, and other gastropods. At other places the fossils are partially silicified, and the matrix, only slightly so, decomposes into a very ferruginous clay, disengaging the fossils upon weathering. The rock and clay bear considerable iron, and weather to a dark red color. The fossils include foraminifera. (*Haplostiche texana, Orbitolina*, and others), many gastropods, corals, caprinids. and rudistids. (3) A common type, excellently exposed at the Santa Fe quarry 3 miles northwest of Belton, is a coquina of comminuted shell fragments, with many entire shells, of the rudistid reef facies. It is a white or light bluish-gray, entirely crystalline, rather soft calcareous deposit, with a composition of 3% or less of silica, and the rest practically pure calcium carbonate. Prominent fossils are foraminifera, corals, caprinids, rudistids *(Eoradiolites, Polyconites?)*, pelecypods *(Plagiostoma, Lima, Pecten)*, gastropods, echinoids, bryozoa, worms, corals, and other groups.

In Williamson County, the Edwards is thicker, and locally is used for building stone and for lime manufacture. Hill (803, p. 236) gives a thickness of about 230 feet for the Edwards near Round Rock. A persistent sulphur water horizon occurs near its top. The top is well displayed in Brushy Creek at Round Rock near the Balcones Fault. Beneath the Duck Creek member of the Georgetown limestone, there is 5.5 feet of gray-blue marl with *Oxytropidoceras supani* (Lasswitz), *Tylostoma* sp., *Exogyra texana* Roemer and other fossils, an upper Fredericksburg fauna. Taff (1574, p. 344) considers this stratum as Kiamichi, but classifies the Kiamichi as of Fredericksburg age. Pending the discovery of diagnostic Kiamichi fossils at this locality, the identification with Kiamichi will have to remain in doubt; but in any event, the Kiamichi is very close in age to upper Edwards, differing largely in the presence of *Gryphaea navia* and a few other zone fossils; *Oxytropidoceras supani* apparently occurs in both the Kiamichi (Fort Stockton) and the upper Goodland (southern Oklahoma), but this genus requires intensive study before this upper Fredericksburg group of fine ribbed species can be used for minute stratigraphic distinctions. The thin uppermost clay is underlain by a *Toucasia-Requienia* reef, about 5 to 10 feet thick, a massive limestone, in which are cemented innumerable rudistids. The upper one-third of the Edwards contains at least four zones of rudistid limestone; in the upper reef limestone, 6 feet below the top of the Edwards, is an abundance of *Eoradiolites*, and at a level about 50 feet below the top, both here and at Austin, a main level of *Chondrodonta*. The middle one-third of the limestone is non-reef limestone, and contains several prominent bands of flint nodules; the lower one-third contains in addition to the hard, gray limestone, with strong conchoidal fracture, at least one band of reef limestone.

Near Austin, the Edwards is 300 feet thick or more (808, 1429). Its upper one-third contains at least four levels of reef type of limestone and a prominent flint band. Its middle one-third contains mostly non-reef limestone and several flint bands. Its basal one-third contains four or more reef bands and basally some sandy strata. A widespread sulphur water horizon is located near the top of the Edwards. *Requienia* and *Toucasia* are present from top to bottom of the Edwards, and in the Glen Rose. Local correlation can be based on intervals and on the presence, in various horizons, of flints of characteristic shape or size.

The Edwards limestone caps the highest summits of the Callahan Divide, and extends westward to the cap of the Llano Estacado. In both these areas it possesses its typical lithology, flints and some characteristic fossils. In Comanche Peak, Hood County, it is 35+ feet thick. At Logan's Gap, Comanche County, Hill (803, p. 205) gives 83 feet, and at Round Mountain, 44+ feet. In all the thicknesses listed below, the Edwards outcrop is obviously remnental, but in some, as Comanche Peak, certain points on the Callahan Divide, the Llano Estacado, and in Double Mountain, the present cap is probably near the top of the Edwards, because of the reported presence of forms like *Eoradiolites davidsoni, Praeradiolites,* and *Chondrodonta munsoni,* which seem restricted to upper Edwards. In the Baker Mountain section, Callahan County, the combined Comanche Peak and Edwards limestones aggregate 110 feet, which included the basal part of the Edwards (1574, p. 321). In the Buffalo Gap section, Taylor County (Abilene sheet), the heavily bedded Comanche Peak and the Edwards aggregate 130 feet, of which Taff assigns 20 feet or more to the Edwards. Mrs. Kemp[37] states that the Edwards in this district consists of 20 to 50 (at most places 20) feet of medium hard, cream colored limestone, containing *Toucasia texana, T. patagiata, Caprina* sp., *C. planata, C. crassifibra,* and other fossils, overlying 60 to 80 feet of Comanche Peak, which is composed of an upper, hard, massive limestone, a medial, soft, yellow clay (4 feet), and a basal, hard limestone (14 to 16 feet). Church Mountain, Taylor County, is stated to have 75 feet of Edwards, massive chalky limestone above and below with intervening bedded limestone, and with flints in the upper

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[37]Kemp, Augusta Theckla Hasslock, The geology and geography of the area southwest of Abilene, Texas, M. A. thesis (Ms., 1910), University of Chicago.

part of the section (1574, p. 323). In the Horse Mountain section, Taff records 60 feet of massive chalky limestone, with bands of large flint nodules near the center.

In Stepp Mountain, Coke County, 55 feet of Edwards remains (841, p. 107); in Mt. Margaret, about the upper 23 feet is Edwards; in Mount Q 45½ feet; in southwest corner of Cole Mountains 112? feet; in south end of West Stepp Mountain 50 feet (92, pp. 53–59). Much of this limestone is crystalline, calcitic, and flint-bearing, and some ledges contain caprinids, *Eoradiolits,* and other radiolites, gastropods, foraminifera, and other fossils. In the southwest corner of Table Gap Mountain, northeastern Runnels County, there is exposed about 40 feet of Edwards, containing caprinids, cylindrical sponges or algae, and large fossils (87, pp. 50–51). In various exposures in Tom Green County, the Edwards, with caprinids, reaches 200 feet in thickness. The cap of Double Mountain, Stonewall County, an erosional remnant from the Llano Estacado, consists of 40 feet of Edwards, containing various forms of *Caprina* and "many *Hippurites*" of large size (467, pp. 347–351). Baker collected a new species of *Praeradiolites* from this locality, and probably *Eoradiolites* and other radioplites are present.

For Edwards fossils on the Llano Estacado, see pages 355–358.

The Edwards in northern (400–500 feet) and southern (724 feet) Bexar and Medina (460 feet) counties, retains its chief lithologic characters, but westwards it and the Georgetown limestone form one lithologic unit. The Edwards was described from the canyons of the Nueces; in the Nueces quadrangle, 628 feet is recorded, in the Uvalde quadrangle, 520+ feet (1686, p. 1). In the Southern Edwards Plateau, in the upper Edwards, *Kingena wacoensis* and *Ostrea* cf. *subovata* are recorded, which may suggest that the upper part of this formation is of Georgetown age. In the lower Pecos canyon, at the bridge on the Del Rio-Sanderson road, the entire visible limestone section is stated (1524, p. 406) to be of Georgetown age. Throughout Brewster and Presidio counties, below the Southern Pacific railway, the Edwards retains the same facies and thickens southwards. In the Solitario rim it has a thickness of 800 feet or more, south of Terlingua, an estimated thickness of 1000 feet. In these sections it has essentially the same lithology as in the lower Pecos Valley.

In the Fort Stockton area, the top of the Fredericksburg beneath the Kiamichi marl (Edwards equivalent) is a fossiliferous marl, here called *University Mesa marl.* It is about 50 feet thick, is underlain by Comanche Peak limestone, and overlain by a thin brown limestone seam, above which the Kiamichi marl occurs. At Kent and El Paso it is clay and marly limestone, and at Sierra Prieta, north of Sierra Blanca, the entire Fredericksburg is cross-bedded, brown, fossiliferous sandstone.

Lithology.—The Edwards reef and associated limestones are generally light gray, crystalline, coarse-grained, organic, nearly pure limestones, with much calcareous shell detritus. Its appearance has been described previously (pp. 341–2). Microscopically, the Edwards shows much diversity. The dense, sparsely detrital layers have a finely crystalline matrix, and few foraminifera or other shelly material. A common Edwards type is the miliolid limestone, a compact rock with finely crystalline, clear, calcite, matrix, in which are imbedded innumerable miliolid foraminifera of a complicated type, somewhat resembling *Massilina.* This rock occurs at certain Edwards levels, but locally the type contains admixtures of shelly material. Miliolid limestone is practically confined to reefy Fredericksburg in southern Texas, and in Mexico is known from northern Coahuila, southwards in the El Abra limestone of the Front Ranges, underground in the South Fields, along the mountain front west of Orizaba, to the Isthmus of Tehuantepec. It is abundant in the quarry (type locality) at El Abra, and occurs more sparsely in the nearby Taninul (rudistid) limestone. Miliolids are sparse in the Tamasopo limestone.

Some strata show a fine, granular, calcite matrix nearly devoid of fragments; some are practically pure miliolid limestone, with a clear calcite matrix (fig. Hanna, 647a, pl. I, figs. 3, 7); some are mixed miliolid and shelly material; some consist of shelly detritus practically devoid of foraminifera (*op. cit.*, pl. II, fig. 7). Hanna (647a, pp. 51–53, pl. I) gives analyses and figures of thin sections of several Edwards core samples. Some cores show only slight dolomitization, 0.3% or less of MgO. Analyses of the "adobe" lime in the upper Edwards show MgO present, from a trace up to 11.1%; and other limestones from Edwards show nearly complete dolomitization, having 33.3% of CaO and 18.3% of MgO.

Subsurface extent.—From drillers' logs, it is impracticable to separate the Edwards, but lithologically it is generally recognizable. Many thin sections show shell fragments, some show a dense, fine-grained, nearly homogeneous, calcitic material, with scattered sections of fossils, some show sparse or densely packed slices of miliolid foraminifera. These features generally distinguish it from adjacent formations.

Its thicknesses and features in the Gulf Coastal Plain have not been extensively studied. General thicknesses are: southern Bexar County, 724 feet; Uvalde County, 586 feet; Maverick County, 905 feet (1681, p. 253); near Mexia, 100 feet or less; in East Texas a considerable thickness of undifferentiated Fredericksburg rocks.

Paleontology and zonation.—No complete zonation of the full thickness of Edwards has been published; facts about zonation are given on page 327. The reef limestones of Fredericksburg and Washita are distinguished in several features: their lithology shows an abundance of coquina, shell fragments, precipitated massive limestone, chert; rudistids are abundant locally and in certain strata, ammonites rare, or present largely in the marly interbeds; pelecypods are of a special type (fluted Pectens, *Chondrodonta*); gastropods are of special types (*Nerinea, Actaeonella*), echinoids are of special types (as *Goniopygus*); corals are of special types (as *Cladophyllia* and abundant compound types); there are special types of verticillate algae (as *Cladopolia*).

Economic products.—The Edwards produces oil at Luling; it has local and weak water horizons; produces quicksilver, and in lesser amounts, silver and other metals; limestone for lime, Portland cement, building stone, and road metal; and contains small amounts of gypsum, anhydrite, celestite, strontianite, and other non-metallics. At many places near the outcrop, but especially down-dip, the Edwards is a prominent artesian water horizon.

KIAMICHI FORMATION

Nomenclature.—The formation was first called Kiamitia clays by Hill (722, p. 515) in 1891. The present spelling is the product of the Board of Geographic Names. The type locality is the plains of Kiamichi River near Fort Towson, eastern Choctaw County, Oklahoma, though Hill also mentions several typical localities west of that place.

Stratigraphic position and contacts.—Information on the contacts of this formation is meager. In the Fort Worth area, rounded pebbles have been taken from the upper contact, and the washed material at this level shows much grit and transported debris (Winton and Scott, personal communication). South of McLennan County, the formation is absent, and there are evidences of lack of conformity at the Edwards-Duck Creek contact. Writers have noted the sharp lithologic break at the lower contact, but definite records of the nature of this contact are lacking. The formation is well exposed at Marshall's Bluff, Grayson County, and at the Texas and Pacific Railway crossing of the Clear Fork, west of Fort Worth.

Facies.—The formation, to its southern disappearance, is neritic, and consists of marls, thin limestone seams, and shell aggregates (mostly of *Gryphaea navia* Hall, some loose, some cemented). If the Sierra Prieta sandstones below the Duck Creek *Desmoceras* zone include the Kiamichi, it occurs there in the marginal facies.

Areal outcrop, local sections.—At the outcrop, the formation is limited to central Texas north of the Brazos, and to the northern (more neritic) facies in Trans-Pecos Texas. Its easternmost outcrop is at Cerrogordo, Arkansas, its westernmost outcrop in Texas opposite the smelter at El Paso. There may be equivalents in southern New Mexico and in Arizona; its zone fossils occur near Lampazos, Nuevo Leon, and in the Sierra de Tamaulipas, eastern Mexico. Northwards it occurs in the Texas Panhandle, western Oklahoma, southern and central Kansas, Colorado, and northeastern New Mexico. In wells it is practically unrecorded, except near the outcrop.

One-half mile north of Cerrogordo, the Kiamichi consists of a few feet of one-foot beds of closely packed gryphaeas, set in a scant matrix of dense, hard, gray-green marl, and alternating with poorly exposed, softer, gray and green marls, containing *Gryphaea navia.* One-half mile northeast of Cerrogordo, 20 feet of Kiamichi consists of blue-gray and green-gray marls alternating with discontinuous beds and lenses of gray fossiliferous limestone. Near Goodland, Choctaw County, Oklahoma, Hill (803, p. 253) records 150 feet of Kiamichi. The formation in this region consists of shelly marl and indurated shelly limestone ledges in such quantity as to be commercially suitable for lime and road metal. The formation, as in the valley of Kiamichi River, contains countless *Gryphaea navia* and *G. corrugata,* together with other undescribed fossils. The first Comanchean fossil to be described from the Texas-Oklahoma region was *G. corrugata* Say 1823, collected by the botanist Nuttall in the lower Kiamichi River valley; the second, *Gryphaea pitcheri* Morton 1834 (=*G. corrugata* Say 1823) was collected in 1833 by Dr. Z. Pitcher from near Fort Towson, eastern Choctaw County, Oklahoma (796, pp. 33–34). In Bryan County, Taff records about 55 feet of Kiamichi (Taff, Atoka folio, No. 79, p. 6, 1902); in Marshall and Love counties Bullard records 35 to 36 feet. In Grayson County, thicknesses of 33 feet (803, p. 254), 36 feet (177, p. 25), 40 to 50 feet (844, p. 3), and 61 feet (Emil Böse, personal communication) are on record. The upper ledges of the Kiamichi occur at the Duck Creek type locality (803, p. 254), where the ammonite partition (ranges of *Oxytropidoceras, Adkinsites, Elobiceras,* and *Pervinquieria*) is well exposed. Along the outcrop to the Brazos, the following thicknesses are recorded: northern Cooke County, 36 feet; 2½ miles southwest of Era, 30 feet; southern Cooke County, 20 feet; western Denton County, 42 feet; Montague County, Sunset, 44 feet; at Rhome, 35 feet; northwest corner Wise County, 22 feet; Dallas County, nothing identifiable; Tarrant County, 27 feet; Johnson County, 18 feet; near Blum, Hill County, 19 feet; near Mexia, 13 to 16 feet; Bosque County, 3.6 miles east of Valley Mills, 10 feet; at the McLennan- Bosque county line, 9 feet; McLennan County, on the North Bosque, southwest of China Springs, 5 feet; near Whitson, Coryell County, less than 5 feet; in Bell County and southwards, unknown.

In Grayson County, the formation consists of an alternation of shale or clay with limestone or shelly bands. The indurated calcareous clay occurs interstratified with the dark blue clay; laminated limy flags in the lower half and indurated *Gryphaea* shell-ledges in the upper half alternate with the clay. In the northern area, the hard ledges are continuous between exposures. The seem to be composed of *Gryphaea corrugata* Say, with some other species less abundant. In Tarrant County the basal half of the formation is marly. The next one-fourth contains 6 thin limestone ledges alternating with marl. The top is marly, but on the Red River it is shelly. Near Fort Worth, *G. navia* is abundant in the middle third, and sparse above, but on Red River it forms shell aggregates in the top of the formation. *Exogyra plexa* occurs in the base of the upper one-third (and in the Goodland limestone). *Oxy. belknapi*, abundant at Fort Washita and at the Duck Creek type locality, seems to characterize the formation. *Oxy. "acutocarinata"* is also reported from the formation. In the Fort Stockton area *G. navia* is confined to the base, and *G. corrugata* is the abundant species above. South of Tarrant County the shell aggregates largely disappear and the limy ledges are reduced. *Gryphaea corrugata, Exogyra plexa*, and *Oxy. belknapi* seem more frequent in the top; *G. navia* and *Exogyra texana* in the base. Toward the Brazos, the dwindling Kiamichi is reduced to a thickness of less than 10 feet, mostly of marl; its southermost appearance is in Coryell County, near Whitson.

A second, disconnected area of Kiamichi outcrops in Trans-Pecos Texas. A persistent yellow marl and marly limestone, located about 250 feet below the top of the limestone section in western Crockett County, as at Yellow Peak, 4 miles east of the Sheffield-Ozona highway bridge over the Pecos, is Kiamichi (Shumard, 1477, page 77, entry for May 12, 1855). It contains *Oxytropidoceras belknapi, Exogyra texana, Pecten irregularis*, and other species (991, pp. 54–55; 12, p. 57). This horizon disappears in the lower Pecos Valley and in most of Brewster County. It is thin but very fossiliferous at localities about 15 to 18 miles north-northeast of Alpine, where it contains, below basal Duck Creek limestone with many typical ammonites, the following fossils: *Gryphaea navia, Oxytropidoceras belknapi, Exogyra texana, Elobiceras* (several species), and others. In the northeastern part of the Glass Mountains, at Pyramid Butte, 1 mile northeast of the Sibley Ranch, the Kiamichi underlies Duck Creek limestone with typical ammonites, and consists of 62 feet of marl, containing *Gryphea navia* at the top. In this region the Kiamichi is a striking unit, outcropping in prominent white or yellow slopes, with little vegetation, which may be traced for long distances with the eye (936, p. 96). Near Fort Stockton, the whole section from the base of the Duck Creek marly limestone down to the Comanche Peak limestone is prevailingly marly, and consists of three parts, distinguished paleontologically. The basal part corresponds to the Edwards or to part of the Comanche Peak; it contains *Oxytropidoceras supani* and numerous other fossils. The medial part contains *Gryphaea navia, G. corrugata*, the topmost *Exogyra texana*, and few *Oxytropidoceras*, and corresponds to the Kiamichi. The upper part seems transitional between the Kiamichi and the Duck Creek: it lacks *G. navia,* and contains *G. tucumcari, Elobiceras,* undescribed early species of *Pervinquieria, Hamites fremonti, H. comanchensis, Inoceramus comancheanus,* and other species ranging up into the Duck Creek. At Kent the situation is essentially the same as that just described.

Sierra Blanca area.—The Kiamichi is identifiable at many places north of Sierra Blanca, and furnishes the best starting point for understanding the Fredericksburg section. On the west slope of Flat Mesa, amphitheaters are excavated into the west dipping Finlay limestone, exposing the underlying Cox sandstone as small oval or pear-shaped inliers. On this mesa and on the southwest slope of Triple Hill, thin Finlay clearly overlies the reddish-brown Cox sandstone, and these two formations dip towards Sierra Blanca peak. In the gap between Flat Mesa and Triple Peak, near an abandoned well, the overlying Kiamichi is well exposed, and is about 95 feet thick. Above the gray, caprinid-bearing limestone (Finlay) there are exposed in ascending order: a thin, blocky sandstone stratum forming a dip slope; about 25 feet of sandy shale; 1.5 feet of yellowish-brown, semi-platy sandstone; 3 feet of sandy marl with *Gryphaea navia* and other fossils; 1 foot of *Gryphaea navia* shell aggregate, forming a bench, as at Kent and Fort Stockton; about 35 feet of soft, thin-bedded sandstone and sandy clay, with the fossils listed below; ½ foot of yellowish-gray, nodular limestone, containing *Parasmilia, Gryphaea, Trigonia, Pecten subalpinus, Plicatula incongrua,* and other fossils; and about 35 feet of thin-bedded sandy shale and light-colored sandstone. This is overlain by about 40 feet of massive brown sandstone, forming the caprock of the west end of Flat Mesa, and containing *Idiohamites fremonti, Hamites* aff. *comancheanus,* cross-sections of large ammonites (probably "*Desmoceras*"), and in the small conical butte in the gap, *Pervinquieria* sp. (of the *nodosa* group). The sandy marls above the *Gryphaea navia* bench contain: *Gryphaea navia, Gryphaea corrugata, Exogyra texana, Exogyra plexa, Alectryonia* cf. *carinata, Alectryonia quadriplicata, Pecten subalpinus, Pecten irregularis, Trigonia emoryi, Pholadomya* cf. *sancti-sabae, Protocardia, Turritella, Tylostoma, Parasmilia?, Haplostiche* sp.?, *Oxytropidoceras belknapi, Oxy.* n. sp., and other fossils, clearly a Kiamichi fauna. The underlying Finlay limestone nearby contains *Requienia,* caprinids, *Exogyra texana, Tylostoma* (large and small), *Amauropsis pecosensis,* a branched coral like *Cladophyllia furcifera,* and others. The Finlay is the attenuated northern representative of the Edwards and Comanche Peak limestones, and the underlying Cox red-brown sandstone is equivalent to the Maxon (Paluxy) sands and, perhaps in part, to the Glen Rose. The underlying Etholen is perhaps Glen Rose in age (Baker reports a *Porocystis* from it). It is recalled that Richardson stated that all three formations (Campagrande, Cox, Finlay) contain Fredericksburg fossils, the following being identified by Stanton (1304, p. 47): *Ostrea crenulimargo* Roemer, *Exogyra texana Roemer, Caprina occidentalis* Conrad, *Toucasia texana* (Roemer), *Eoradiolites davidsoni* (Hill) and *Actaeonella dolium* (Roemer). Taff (1573, pp. 716–719) correctly identified the Fredericksburg in Flat Mesa and in the south-facing scarp extending from Round Mountain, 11 miles north-northeast of Sierra Blanca, to the Sierra Diablo scarp. Taff's "Trinity sand" (Cox), in the northeast face of Flat Mesa (1573, p. 716), is overlain by 15 feet of "flaggy calcareous sandstone and siliceous limestone with numerous gastropods, bivalves and *Exogyra texana*"; this may be Walnut. It is overlain by 40 feet of "Caprina limestone," and, near Round Mountain, by 10 feet more of "Caprotina limestone," both evidently Finlay. In Cox (= Tabernacle) Mountain, King and others have collected many fossils which demonstrate the Fredericksburg age of the upper beds. In sandy marls in the "Finlay," King collected: *Gryphaea navia, G. corrugata, Pecten subalpinus, P. irregularis, Nerinea, Tylostoma?,* an engonoceratid, *Parasmilia,* and compound corals.

In Sierra Prieta (Black Mountain), the basal, reddish-brown, cross-bedded sandstone extends up to the base of the Duck Creek and contains *Alectryonia* cf. *carinata,* and other pelecypod casts. It is overlain by limestone containing *Desmoceras, Beudanticeras, Idiohamites comanchensis, Inoceramus comancheanus, Pecten wrighti,* and other Duck Creek species. In the El Paso, Sierra Blanca, Kent, and Fort Stockton areas, the Kiamichi is overlain by neritic Duck Creek fossiliferous marls, and limestones.

Section at northwest corner of Black Mountain (Sierra Prieta)
(Beede and Adkins, 1921)

	Feet
Sill	50+
Weno equivalent (?): Light gray limestone, largely a shell coquina, with *Macraster* and echinoid fragments; about	
Denton equivalent (?): Calcareous marl containing thin seams of gray, nodular limestone; *Micropedina symmetrica, Heteraster bravoensis, Diplopodia, Phymosoma, Pyrina* (abundant), *Salenia, Gryphaea washitaensis, Pecten* n. sp.; this distinctive echinoid assemblage is like that in the same level at Cerro de Muleros; about	40
Fort Worth: Brown marl and limestone flags; about	30
Duck Creek: Marl and limestone, with fossils	22.3
Yellow brown, platy limestone	0.8
Yellow brown marl with *Pecten subalpinus, Gryphaea* sp.	11.0
Massive conglomerate with calcareous matrix and rounded pebbles of various mateirals, from 1 to 5 mm. in diameter	0.5
Yellow brown marl with typical Duck Creek fossils: *Desmoceras brazoense, Pervinquieria nodosa, P. leonensis, P. trinodosa, P.* spp., *Idiohamites* spp.; hematitic micromorphs	10.0
Fredericksburg (*Kiamichi* and *?Cox*): Sandstones, at levels fossiliferous	95
Sandstone, brown, thin-bedded, cross-bedded, forms bluff	26
Sandstone, brown, cross-bedded, its basal half consisting of sandstone nodules 5 mm. in diameter cemented by sand, its top more massive. The top has a rich Fredericksburg fauna, including *Exogyra texana, Alectryonia carinata* (casts and molds), gastropods; about	40
Sandstone, nodular, cross-bedded, brown, the nodules up to 6 mm. in diameter. Irregular iron-stained sandy inclusions up to 1 foot long	8.5
Sandstone, massive, yellowish; about	20
Permian (Hueco Limestone)	

The Finlay limestone wedges out northwards between Sierra Blanca and Cox Mountain, leaving the overlying Kiamichi and the underlying Cox in contact at Cox Mountain and at Sierra Prieta. In the Cornudas Mountains the Washita is stated to rest directly on the Permian (45, p. 18; 91, p. 26; 1304, p. 49). Obviously, north of the last appearance of the Finlay (=Edwards-Comanche Peak-Goodland) limestone, the entire Cretaceous below the Duck Creek is in the marginal facies.

General section at Cornudas Mountains (M. B. Arick) *Feet*

Sill. Interval from top of basal sand to top of sill is about 250 feet. The bottom of the sill is concealed, and some of this interval is Washita rocks.

Denton and *Fort Worth* equivalents: Alternating marl and thin layers of marly, nodular limestone, with Georgetown fossils. The top is rich in

	Feet
large echinoids (*Macraster, Holectypus transpecosensis, Holectypus* small sp., *Salenia*), and suggests the Denton echinoid layer at Kent, Sierra Prieta, and Cerro de Muleros	20
Duck Creek equivalent (?): Calcareous shale, sparsely fossiliferous; *Pervinquieria, Gryphaea,* other mollusca	7
Duck Creek equivalent (?): Packsand, fine, almost uniform, apparently well-rounded, red-brown, cross-bedded, not very calcareous; no fossils seen	25
Basal conglomerate: Sporadic, containing well-rounded, subspherical pebbles up to 2 inches in diameter, of limestone and some black and white chert, in matrix mostly of finer limestone; maximum seen	3
Yeso (Manzano) limestone and gypsum.	

In this section the marginal facies at the base of the Cretaceous has extended upwards to include the Duck Creek, whereas at Black Mountain (Sierra Prieta) it reached only the base of the Duck Creek.

In lower Quitman Arroyo, about 2 miles east of the mouth of Rio Grande canyon through the Quitmans, the Kiamichi consists of *Inoceramus*-bearing, bituminous, fissile shale, passing upwards into flaggy, bedded limestone and calcareous shale. In the southern Quitmans, Stanton (331, page 31) records 300 feet of limestone and clay-shales, containing basally *Kingena wacoensis, Elobiceras serratescens, Hamites fremonti,* and *Oxytropidoceras acutocarinatum;* this is underlain by 50 feet of dark clays with brownish calcareous bands and abundant *Exogyra texana.* Part of these beds is of Kiamichi age. At the White Ranch on the Rio Grande, due south of Quitman Gap, 300 feet of blue-gray, finely fissile shale with thin interbeds of ripple-marked, sandy, and limy beds containing *Gryphaea corrugata,* is referred to the Kiamichi by Baker (46, p. 28). Böse's bed 3 at El Paso, 30 feet of sandy massive limestone, calcareous gray sandstones, brown and yellow marls, and black shales, represents part or all of the Kiamichi. In the Terlingua and Solitario sections the Kiamichi is unrepresented.

Texas Panhandle.—Beneath the Cenozoic cap of the Plains, remnants of Fredericksburg formations occur, in canyons, in resistant ledges, on the shores of lakes, and elsewhere. In the western Edwards Plateau, over Crockett, southern Reagan, Irion, Schleicher, western Menard, Sutton, and adjoining counties, Washita beds are exposed as the cap of the Plateau, and, in the northern part of this area, thin Kiamichi occurs. For instance, in Irion County west of Mertzon, about 5 feet of limy marl, with Kiamichi fossils, occurs beneath the Duck Creek limestone. Northwards to about Lat. 33°, over a broad belt through which the Texas and Pacific Railway runs, Walnut, Comanche

Peak, and Edwards are recorded at many localities, but no Kiamichi or Washita. In Garza County (E/4 cor. sect. 393, block 9, EL-&-RR.Co.), high Fredericksburg rocks, possibly Kiamichi, contain: *Alectryonia quadriplicata* (arched var.), *Exogyra texana* Roemer, *Gryphaea marcoui* Hill and Vaughan, and its slender variety, *Pecten* cf. *occidentalis* Conrad, *Cyprimeria texana* (Roemer), *Homomya, Tylostoma,* and *Heteraster* cf. *texanus* (Roemer). In Lynn County, high Fredericksburg, Kiamichi, and Duck Creek occur. In SE. ¼ sect. 19, Blk. H, EL-RRRR-Co., are found: *Gryphaea corrugata* Say (some of them large), *Exogyra texana* Roemer, *Plicatula* aff. *incongrua* Conrad, and *Pecten subalpinus* Böse, this is high Fredericksburg, possibly near the Kiamichi. The bed of Tahoka Lake is reported to be of hard Fredericksburg limestone, with rudistids, overlain by marly lime with Washita fossils. A lower level, typically Kiamichi, contains: *Gryphaea navia* Hall, *Oxytropidoceras belknapi* (Marcou), *Oxy.* 2 new species, *Exogyra texana* Roemer, *Exogyra plexa* Cragin (plicate and non-plicate forms), *Trigonia emoryi* Conrad, *Pecten subalpinus* Böse, *Pecten irregularis* Böse, *Cyprimeria* cf. *kiowana* Cragin, *Cucullaea recedens* Cragin?, *Cytherea?* n. sp.; at an upper level: *Pinna comancheana* Cragin?, *Protocardia* indet. (called *P. texana* by Twenhofel), *Remondia* sp. indet., *Turritella belviderei* Cragin, *T. irrorata* Conrad?. In the northwest corner of Sect. 8, Blk. H, EL-RRRR-Co., are fossils from the Duck Creek-Kiamichi: *Pervinquieria* sp., *Pecten texanus* Roemer, *Alectryonia quadriplicata* (Shumard), *Plicatula incongrua* Conrad, and *Exogyra plexa* Cragin (smooth). From the northeast ¼ of sect. 1, Blk. 11, EL-RRRR-Co. is a Duck Creek fauna: *Desmoceras brazoense, Desmoceras* sp., *Pervinquieria* aff. *trinodosa* (Böse), and *Gryphaea tucumcari* Marcou. Washita fossils have been reported from Twin Lakes *Oxy.* aff. *trinitense* (Gabb), associated with *G. tucumcari,* occurs in this county.

The following sections are by C. L. Baker, with fossil determinations by the writer:

Guthrie Lake, 3 miles south-southwest of Tahoka, Lynn County

		Feet
	Top: Cenozoic gravel and sand.	
5.	Clay, blue-gray, laminated, with thin, flaggy beds of tan, limy, fine sandstone at top and middle. Both sandstones contain casts of ammonites, *Oxytropidoceras (Adkinsites) belknapi* (Marcou) (Coll. 17077)	10
4.	Indurated marly limestone: mollusk bed, mainly of large *Gryphaea,* some Pecten, etc.	⅓
3.	Clay-shale, laminated, with some flaggy sandstone; to the north the sandstone thickens to 10 inches and is blue-gray, ripple- and rill-marked, cross-bedded, and like the other sandstones weathers tan	2
2.	Indurated marly limestone, a bed of mollusk shells; to the south it is largely a broken shell coquina; locally it contains lenses and pockets of fine-grained sandstone. This stratum and stratum 4 contain: *Oxytropidoceras* sp. aff. *multifidum* (Steinmann), *Oxy.* sp., *Gryphaea navia* Hall, *Gryphaea* aff. *navia, Exogyra texana* Roemer,	

Feet

Pecten irregularis Böse, *Trigonia emoryi* Conrad, *Cucullaea recedens* Cragin, *Tapes belviderensis* Cragin?, *Protocardia texana* (Conrad) typical form, *Turritella belviderii* Cragin (Coll. 17077a). The shell and sandstone layers form the rims of low scarps........ ⅓–½

1. Blue-gray clay-shale 10
   (Bottom of lake)

The above section may all be referred to the Kiamichi formation. Robert B. Campbell has collected Kiamichi fossils, including *Oxy.* aff. *multifidum* (Steinmann), *G. navia, Protocardia* and *Pecten,* at Guthrie Lake.

Twin Lakes, 9 miles west of Tahoka, Lynn County

2. Duck Creek clay and limestone. At south end of southwest lake. Contains: "*Desmoceras*" *brazoense* (Shumard), "*Pervinquieria*" sp. aff. *kiliani, Plicatula incongrua, Alectryonia quadriplicata, Gryphaea tucumcari* (Coll. 17078). Consists of a few feet of marly nodular limestone layers at the top of a Kiamichi black clay section. On the west side of the southwestern lake apparently a thicker section is exposed.
1. Kiamichi clay: Marly clay, dark gray, laminated, with some thin interbeds of platy, current-bedded, tan sandstone, and thin interbeds about 4 inches thick of light cream, nodular, concretionary, fossiliferous limestone with manganese dendrites. Fossils: *Gryphaea tucumcari, Ostrea, Pecten, Trigonia.* Exposed at north end of northeastern lake (Coll. 17080). Maximum thickness, about 30 feet.

Cedar Lake, Gaines County

Top: Caliche, sand and gravel with Cretaceous fragments.

Comanche Peak (Goodland): *Feet*

3. Cretaceous tan colored limestone with fossils........ 8
2. Light cream chalk and marl, with *Engonoceras* and *Oxytropidoceras (Adkinsites) trinitense* (Gabb) in the lower strata........ 30–40
1. Marl, blue-gray, containing: *Oxytropidoceras* n. sp., *Engonoceras pierdenale* V. Buch, *Exogyra texana* Roemer, *Gryphaea marcoui* Hill and Vaughan (narrow variety), *Pecten* sp., *Cyprimeria* sp., *Protocardia* aff. *texana* (Conrad), *Remondia robbinsi* (White), *Lima mexicana* Böse, *Plicatula incongrua* Conrad, *Homomya, Cucullaea, Tapes, Cardita belviderensis* Cragin, *Turritella belviderii* Cragin, *T. seriatim-granulata* Roemer?, *Anchura kiowana* Cragin, *Anchura subfusiformis* (Shumard), *Anchura* (?) sp., *Tylostoma elevatum* (Shumard), *T. chihuahuense* Böse, *T.* aff. *mutabile* Gabb, *Heteraster* sp. (abundant), *Callianassa* sp. (claw segment) (Coll. 17079)........ 6–15

At Illusion Lake, Robert B. Campbell has collected the following Kiamichi fossils: *Exogyra texana* Roemer, *Gryphaea navia* Hall, *Oxy. belknapi*, *Oxy.* n. sp. (elevated ribs), and *Oxy.* n. sp. 2 (with broad ribs like *Oxy. kiowanum* Twenhofel).

In southwestern Lamb County, Washita has been reported from Bull Lake, Illusion Lake, and Yellow Lake. In sect. 25, blk. 675, there is a Kiamichi fauna: *Gryphaea navia* Hall, *G. corrugata* Say (or young of *G. tucumcari* Marcou). In southeast corner of sect. 23, blk. 228, is a Kiamichi? fauna: *Serpula* sp., *Plicatula incongrua*, *Pecten subalpinus*, *P. irregularis*. In the southeast corner of sect. 14, blk. 228, is a fauna at the Kiamichi-Duck Creek boundary: *Gryphaea tucumcari* Marcou, *G. corrugata* Say, *Alectryonia quadriplicata* (Shumard), *Trigonia emoryi* Conrad, *Plicatula incongrua* Conrad, *Pecten subalpinus* Böse, *Parasmilia austinensis* Roemer; and a Duck Creek ammonite, *Pervinquieria* n. sp. aff. *trinodosa* (Böse).

In Bailey County, Monument Lake contains a Kiamichi exposure (175, p. 96) of about 20–30 feet, the lower half blue or yellowish clay with ferruginous layers, the upper half yellow clay with seams of white limestone, and *Gryphaea corrugata* Say (abundant and large), *Gryphaea* (small), *Exogyra texana*, *Pecten*, echinoid spines, and fucoids. Two lakes in the southeast quarter of the county are reported to contain fossiliferous Washita clay. In sects. 8–9, blk. 184, is a Kiamichi-Duck Creek fauna: *Gryphaea tucumcari* Marcou, *Plicatula incongrua*, *Ostrea*, *Pecten subalpinus*, *Lamna* tooth. A Kiamichi-Duck Creek fauna occurs at White Lake: *Gryphaea corrugata* Say, *Exogyra texana* Roemer, *Exogyra plexa* (smooth var.), *Ostrea marcoui* Böse, *Plicatula incongrua*, *Pecten ubalpinus* Böse; *Hamites* sp. indet., *Hamites comanchensis* Adkins and Winton?. In Labor 6, league 183: *Gryphaea corrugata* (large var. as in southern Kansas), *Pecten subalpinus*, *Parasmilia?* sp.

Probable *Gryphaea* limestone float is recorded by Bullard from near Estelline, Hall County. Dr. L. F. Spath donated to this Bureau a *Pervinquieria* collected from drift near Seymour, Baylor County. In sect. 8, blk. 697, Hockley County, Fredericksburg (likely upper) fossils occur: *Trigonia emoryi*, *Lima*, *Protocardia*. In eastern New Mexico, on the Plains, several Comanchean localities have been reported: Washita clay with oysters in a lake between Clovis and Portales, and at localities south and southeast of Portales (395, p. 39).

Northern Mexico.—Kiamichi marl is known from the Cañon de Buenavista in the western part of the Sierra de Tamaulipas. Here it is a prominent, somewhat calcareous, black clay, containing typical ammonites and other fossils. "*Hamites*" *comanchensis* and other Duck Creek fossils have also been collected by the geologists of the Gulf Company in the Sierra de Tamaulipas. Fredericksburg fossils are abundant in the Sierra del Abra and other localities in the Front Ranges west of Tampico (17, p. 82). A Kiamichi level occurs in the Sierra de Sabinas between Sabinas Hidalgo and Minas Viejas; and in the mountains southeast of Lampazos, Nuevo Leon, where *Oxytropidoceras* (several species), Fredericksburg oysters, and in the overlying Washita beds, *Macraster*, *Kingena* and other fossils occur. Other localities are described by Böse and Cavins (134, 135) and by Tatum (1590, 1590a).

Paleontology and zonation.—No distinct zones can be established in the formation; as a whole it is characterized by *Oxytropidoceras (Adkinsites) belknapi* (Marcou) and *Gryphaea navia* Hall. Locally it has been observed that the basal Kiamichi seems to be marked by *Exogyra texana* and *Gryphaea navia*, the top by *G. corrugata*, *Exogyra plexa*, and *Oxy. belknapi*. A more probable upper zone is the *Elobiceras* zone, present in the top of the post-Kiamichi beds at Fort Stockton, but not sufficiently tested elsewhere.

The following are the most characteristic ostracoda of the Kiamichi:

Cytheridea oliverensis Alexander
Cythereis fredericksburgensis Alexander
Cytheridea bairdioides Alexander
Cytheridea amygdaloides (Cornuel)
Cytheridea amygdaloides var. brevis (Cornuel)

Foraminifera from Kiamichi formation

(Steep bank on Fort Worth-Benbrook road along T. P. R.R. about 3½ miles west of center of Fort Worth.)

Samples from two levels have been examined, and both are exceeding lean in specimens of foraminifera, rich in ostracods, fish remains, and carry some holothurian fragments.

Ammobaculites sp.
Textularia rioensis Carsey
Lenticulina washitensis (Carsey)
Globigerina sp.

WASHITA GROUP[38]

Nomenclature.—Roemer described Georgetown and Grayson fossils from Hill and Comal counties, but gave the group no name. B. F. Shumard (1463, pp. 583, 586–587) described the "Washita limestone," mentioning as localities Austin and Grayson, Fannin, and Red River counties; he says that "according to Dr. G. G. Shumard, it is finely developed at Fort Washita" [northwestern Marshall County, Oklahoma]. He mentions in it various Georgetown fossils

[38]*Literature.*—Böse, 129; Baker, 46; Cuyler, 383; Adkins, 12; Hanna, 647a; Hill, 788, 803, 822; Hill and Vaughan, 795; Scott, 1389. *Paleontology:* Adkins and Winton, 9; Adkins, 13, 19; Bullard, 174, 175, 177; Cragin, 324, 326, 330; Böse, 129; Clark, 253; Roemer, 1331; Scott, 1388; Winton, 1791; Reeside, 1290. *Oklahoma:* Bullard,* 173a, 174, 175; Taff, U. S. Geol. Surv. Folios 79 (Atoka), 98 (Tishomingo); Rothrock, Okla. G. S., Bull. 34 (Cimarron County); Redfield, John S., Sub-division of the Bokchito formation in Love County, Oklahoma: Proc. Okla. Ac. Sci., 9: 76–77, 1929.

from *Hamites fremonti* to *Turrilites brazoensis,* making it evident that his formation includes substantially all the section from basal Duck Creek to upper Main Street, *i.e.,* the Georgetown limestone. He placed it correctly under the Grayson (indurated blue marl with *Exogyra arietina*), and incorrectly over the Eagle Ford blue marl, which he states had not been recognized south of Grayson County. Marcou (1042, pp. 86–97) placed it beneath the Grayson, and above the Caprotina limestone (Glen Rose?). Hill early elevated the Washita to the upper group of his Comanche series (731, p. 298), coördinate with the lower (Fredericksburg) group.

The type locality, as redefined, is nominally at Fort Washita, but the group, except for its upper formation (Buda), is best developed in the Red River and Trinity River valleys.

If judged by priority alone, the name Washita was not available in 1887 (C. A. White, 1741, p. 40) for a division [group] name, because it had been correctly used by Shumard in 1861 for what is now called "Georgetown" limestone. Therefore if priority and not usage should prevail, the name Washita would replace Georgetown, and the "Washita group" would require another name. The Washita group has also been called "Indian Territory division" by Hill (780, p. 88).

Stratigraphy and contacts.—The basal contact of Washita over Fredericksburg is unconformable south of McLennan County (16, p. 40). Near New Braunfels, Professor F. L. Whitney has reported that the Edwards is directly and unconformably overlain by Fort Worth or higher Washita formation.[39] It will be recalled that the Goodland-Kiamichi contact seems conformable, but that the Kiamichi-Duck Creek contact shows quartz pebbles and other evidences of unconformity (Scott, 1398a). These facts lend support to the assignment of the Kiamichi to the Fredericksburg.

The Washita group forms the top of the Comanche series in Texas, and its top seems everywhere unconformable. The basal Gulf formation as far south as the Brazos is the Woodbine; farther south, it is a black shale (Pepper). North of the Brazos, on the outcrop, the Grayson is the uppermost formation. In east Texas, underground, the Washita and Fredericksburg were uplifted and locally planed off to differing amounts in different places, but details of this unconformity have not been published. South of the Brazos, at the outcrop, the highest Comanchean formation is the Buda limestone.

[39]Whitney, F. L., Report to joint meeting of the San Antonio Geological Society and the Southwestern Geological Society, Austin, October, 1931.

Generally its contact with the Gulf series is at least disconformable. Unless the Woodbine is equivalent to existing deposits south of the Brazos, which now seems improbable but awaits further work on zonation for a final solution, there is an unconformity south of the Brazos between the Comanche and the Gulf series. Dumble (506, pp. 19–20) says: "West of the Pecos, in certain areas, the beds of the Comanchean were elevated a sufficient length of time for the complete erosion of the entire Washita series and the channeling of the Edwards limestone into deep canyons. This surface was again submerged during the Eagle Ford and these channels filled with its shales." This was probably a result of solution and slump.

Facies.—(1) The marginal sandy faciès occurs at certain levels (Pawpaw, Weno) in southern Oklahoma and in Grayson and Cooke counties, Texas; on the southwest side of the Sabine uplift (Shelby County); at the Main Street red-brown sandstone level at El Paso; and to a less extent at other localities. (2) The normal neritic facies of limestone, marl, clay and shale occurs at most places. Presumably a shore line existed in eastern New Mexico, and some of the sands and conglomerates in that area may be of Washita age. (Fig. 15). (3) Reef limestone occupies the entire Washita on the Rio Grande in the Big Bend and in the lower Pecos Valley, and extends northwards at certain levels, interfingering into the neritic facies (Fort Stockton).

Areal Geology.—The outcrop enters Texas in Grayson, Cooke, and eastern Montague counties, and passes southwards in a strip of narrowing width to the Brazos west of Waco; thence to the turning point of the Comanchean outcrop near New Braunfels. Over the strip from Williamson County southwards, no Washita remains west of the Balcones fault; and from there westward to the Uvalde region, none remains north of the Balcones fault. There are no Washita rocks on the Callahan divide. A large area in the western part of the Edwards Plateau, comprising northern Crockett, southern Upton, Reagan, Irion, Schleicher, western Menard, Sutton, and northern Edwards counties, is capped by Washita. Scattered areas in Lynn, Lubbock, Lamb, and Bailey counties in the Panhandle are composed of Washita rocks. West of the Pecos, Washita covers much of eastern Pecos, Terrell, and Brewster counties, forming a continuation of the Edwards Plateau. Other exposures of Washita are found in irregular areas, many of them on structural highs, in Brewster and Presidio counties; in several areas emerging from beneath or else covered by the Davis-Presidio-Chihuahua lava flows; in faulted and folded areas in the Van Horn, Tierra Vieja, Eagle, and Quitman mountains, and in the surrounding flats; in a part of the Diablo Plateau in Hudspeth County (Sierra Prieta, Cornudas); and in a small area at Cerro de Muleros (Monument Mountain) in New Mexico, and in Chihuahua, opposite El Paso. Uppermost Washita appears in thin outcrops in the Palestine salt dome; elsewhere its outcrops are unknown on the Gulf Coastal Plain.

Complete sections occur at many places: from Denison to the edge of the Red River valley; near Belton; at Georgetown; near Austin; near Rock Springs; in the Mesa de Anguila and the Solitario, Brewster County; in the Kent-San Martine area; and near El Paso.

In central Texas the Washita group underlies the eastern part of the Grand Prairie, and lies west of, and stratigraphically beneath, the Eastern (Woodbine) Cross Timbers. In north-central Texas the alternate marl and soft limestone formations are thicker and more individualized, and form wider and more distinct belts of outcrop than in south-central Texas. In semi-arid Trans-Pecos Texas, the topographic effects of hard and soft rocks, in this group as in others, is more striking than farther east. The Washita portion of the Edwards Plateau is of the same rudistid facies and the same topography as the rest of the plateau.

Thickness and dip.—The group has a large thickness on the flanks of the Sabine structure. In Grayson County, at the outcrop, it aggregates about 383 feet; in Tarrant County, about 344 feet; in Dallas County, about 390 feet; in McLennan County, about 312 feet; in Bell County, about 210 feet; in Williamson County, about 200 feet; in Travis County, 205 feet; in Medina County, 160 feet. Westwards the formations thicken, going into the Rio Grande embayment, but the thickness for the group depends on how much Georgetown is present. In Val Verde County, the Washita is likely at least 800 feet thick. In the Terlingua area the Washita is 600 to 900 feet thick, depending on the limits of the Georgetown. At El Paso, its equivalents are given as a maximum of about 850 feet. In the Kent and Fort Stockton areas they would aggregate much less, about 275 feet.

Correlation and age.—The Washita has been correlated with beds in northern and central Mexico by using zonal fossils; its basal part is represented in the Purgatoire in northeastern New Mexico, Colorado, and the Panhandle of Oklahoma. The Pawpaw is apparently about the dividing line between Upper Albian, represented by Duck Creek to Pawpaw inclusive, and Lower Cenomanian, represented by Grayson and Buda. Further work is necessary, however, in order to clarify the exact details of ranges of *Mantelliceras, Submantelliceras (Cottreauites), Stoliczkaia,* and other markers.

Economic products.—Some main Washita commercial products are limestone, used mostly for lime, materials for Portland cement, road metal, clay for bricks and earthenware, quicksilver, manganese, and minor occurrences of artesian water; at a few places the Washita is an oil reservoir.

Paleontology.—The following zones, provisional and in part overlapping, serve to partition the Washita strata in Texas:

Formation	Zone Fossil	Other restricted fossils	Zones in the Rudistid facies
Buda (Kbu)	Budaiceras spp.	Pecten roemeri Exogyra clarki Exogyra n. sp. Codiopsis texana	Caprinid, indet.
Grayson (Kgs)	Adkinsia spp. Graysonites n. gen.	Scaphites subevolutus Turrilites bosquensis Stoliczkaia n. sp.	
Main Street (Kms)	Turrilites brazoensis	Stoliczkaia n. sp.	Caprinula n. sp.
Pawpaw (Kpp)	"Neokentroceras" worthense	Flickia bösei Prohysteroceras worthense Starfishes	
Weno (Kwe)	?	Macraster obesus	
Denton (Kde)	Pervinquieria n. sp.		Eoradiolites n. sp.
Fort Worth (Kfw)	Pervinquieria maxima	Washitaster longisulcus Turrilitoides n. sp.	
Duck Creek (Kdc)	Pervinquieria kiliani Pervinquieria shumardi "Desmoceras" brazoense Idiohamites fremonti	Pervinquieria spp.	
Post-Kiamichi	Elobiceras spp.		

Many genera are confined to the Washita. Among them are:

Adkinsia (Kgs)
Budaiceras (Kbu)
Elobiceras (post-Kki-Kdc)
Flickia (Kpp)
Graysonites (Kgs)
Idiohamites (Kdc-Kwe)
Macraster (Kdc-Kms)
"Neokentroceras" (Kpp)
"Pervinquieria" (Kdc-Kms)
Prohysteroceras (Kdc-Kwe)
Stoliczkaia (Kde-Kgs)
Submantelliceras (Kpp-Kgs)
Washitaster (Kfw-Kpp)
Wintonia (Kgs)

The following are the known ranges of certain common ammonites:

Baculites (Kpp-Kna)
Engonoceras (Kgr-Kgs)
Hamites (Kcp-Kpp)
Metengonoceras (Kwa-Kef)
Scaphites (Kdc-Kna)
Turrilites (Kpp-Kef)

The following are among the most diagnostic ostracoda in the Washita:

Cythereis dentonensis Alexander (Kfw-Kgs)
Cythereis n. sp. Alexander (Kde?-Kgs)
Cytherella washitaensis Alexander (Kde?-Kgs)
Cythereis paupera (Jones and Hinde) (Kfw-Kgs)
Cythereis nuda (Jones and Hinde) (Kdc)
Cythereis sandidgei Alexander (upper Kwe-lower Kpp)
Cytheropteron bilobatum Alexander (Kwe, at Blue Cut, N. of Denison)
Cythereis worthensis Alexander (Kfw, common; Kgs, rare)
Cytheridea washitaensis Alexander (Kfw, rare; Kgs, common)

Other Washita ostracoda and foraminifera are listed in Vanderpool, 1681.

Ammonites vespertinus Morton, the genotype by original designation of *Mortoniceras* Meek, is a lower Washita "*Pervinquieria,*" and therefore the name *Mortoniceras* must be used for the Washita ammonites formerly called *Pervinquieria.* The Upper Cretaceous ammonites generally called *Mortoniceras* therefore require a new name, and have been called *Texanites* by Spath in Part IX of his "Monograph of the Ammonoidea of the Gault" (1511b, p. 379). In this paper he treats several subgenera of *Mortoniceras* which are common in the Washita group, including the following:

Subgenus *Durnovarites* Spath (type: *M. quadratum*); this is the quadri-tuberculate *wintoni*-group.

Leonites Spath (type: *Amm. leonensis* Conrad); this includes *M. nodosum* Böse and similar species.

Pervinquieria J. Böhm (type: *Amm. inflatus*); this includes *M. trinodosum* (Böse), *M. kiliani, M. pachys* and related species.

The holotype of *Hemiaster elegans* Shumard is an echinoid somewhat like *H. comanchei* Clark, with a distinct peripetalous fasciole, and is apparently referable to *Hemiaster,* not to *Macraster.*

Lithology.[40]—The limestone members of the Georgetown are generally light gray, compact, somewhat nodular, and crystalline, with a considerable intermixture of shell fragments and fossils. The matrix is finely crystalline and generally somewhat argillaceous. The strata are thin-bedded, and alternate with more marly strata. Some levels, both in the marl and the limestone, contain aggregations of innumerable *Gryphaea* shells.

Microscopically, Georgetown limestone generally shows the following features: (1) Shelly material is in abundance; it is less detrital than the average central Texas Buda and much more detrital than the Edwards. (2) *Globigerina washitensis* is often present; it is absent in the Austin chalk and in the Upper Cretaceous generally. (3) *Inoceramus* prisms are scarce; they are generally abundant in the Austin chalk. (4) Echinoid spines are frequent. (5) Miliolids are generally absent; they are abundant in many Edwards sections. (6) Spherical bodies may be abundant; they are absent in the Edwards and absent in most samples in the Austin chalk, or, if present are generally sparse. (7) The matrix is fine grained and generally more abundant than the shelly material. In the Buda, the shelly material is more abundant, in the Edwards and in some Austin chalk samples, shelly material is sparse. Details are given in Winton (1791, pp. 65–74).

Spherical bodies are abundant in most Duck Creek, many Fort Worth, and some Weno and Main Street samples (figured in 647a, pl. 3, fig. 2). They have been recently discussed by Helen Jeanne Plummer (1238, pp. 112–118), Brown (1238, p. 115), Twenhofel (1238, p. 115), and H. D. Thomas (1599a, pp. 100–101), and have been figured by Winton (1791, pl. 23). Similar bodies have long been known in the English Upper Cretaceous chalks, where they were described by Blake, Jukes-Brown and Hill, and Tarr, and in the Upper Cretaceous of Poland and elsewhere. Vaughan suggested that oolitic grains might have formed around gas bubbles in calcareous ooze. Similar structures apparently occur in rocks of diverse ages, from which their inorganic origin has been inferred. They are of course not zonal markers in Texas, but their abundance definitely suggests the Washita age of the containing rock.

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[40]*Literature.*—Alexander, 30; Hanna, 647a; Plummer, 1238; Smiser, 1493; Udden, 1656; Winton, 1791.

Chemical analyses.—Analyses of Washita and other Cretaceous rocks have been published by Schoch (1378), Hill (803), Winton and Scott (1790) and others. They show that most of the Washita marly limestones in north-central Texas are high in lime (85%–91% $CaCO_3$); that the Pawpaw and some Denton and Weno shales have as low as 13%–18% $CaCO_3$; but that most Kiamichi, Duck Creek, Weno and Grayson marl samples run high in lime (31%–83% $CaCO_3$).

DUCK CREEK FORMATION

Nomenclature.—The formation was named by Hill (722, p. 516; 780, p. 90) in 1891. The type locality is in Duck Creek, at the edge of Red River valley, about 3 miles north of Denison. The base of the formation (overlying uppermost Kiamichi), is exposed in the creek bed, and the remainder is exposed in the nearby railway cuts.

Stratigraphic position and contacts.—The Duck Creek limestone overlies the Kiamichi marl as far south as Bell County. Farther south, the Kiamichi is absent and the Duck Creek, here the thinned basal member of the Georgetown limestone, directly and disconformably overlies the Edwards. The Duck Creek is everywhere overlain, apparently conformably, by the Fort Worth limestone.

Facies.—Throughout Texas, so far as is known, the neritic facies of marl and marly limestone prevails. In north-central Texas and northern Trans-Pecos Texas, the Duck Creek is more marly and its limestones more nodular than farther south.

Areal outcrop; local sections.—Westward across Choctaw and Bryan counties, Oklahoma, the Duck Creek thickens till, in Love County, it has a thickness of about 120 feet (Bullard, Okla. Geol. Surv. Bull. 33, pp. 33–35, 1925). This consists of a basal 20 to 22 feet of alternating marly-chalky limestone and gray marl, the strata ranging from a few inches to 2 feet in thickness. Some of the limestone is partly crystalline, hard, white, with prominent conchoidal fracture and flaky weathering, somewhat like the Goodland. The base contains the *Hamites* zone, and *Desmoceras* occurs throughout this thickness. Overlying this is 56 feet of clay, as on Duck Creek. Then follow a 19-foot section of alternate thin clay and marly limestone strata, 17 feet of clay, and 8 feet of limestone and clay strata.

A succeeding 14 feet of clay may be uppermost Duck Creek, but is probably a part of the Fort Worth limestone.

At the type locality on Duck Creek, the formation consists of about 120 feet of limestone and marl, as follows: (a) Basal 40 feet of thin strata of limestone (up to 1 foot each) and thicker limy marl strata, forming the creek bluff north of the railway; *Elobiceras, Hamites* and many other fossils occur in the basal part, overlying the Kiamichi with *Gryphaea navia* and *Oxytropidoceras (Adkinsites) belknapi;* the entire thickness contains *Desmoceras* and *Beudanticeras* and *Pervinquieria,* and at the top there is a prominent zone of *Epiaster whitei* Clark. (b) A medial 40 feet is clay, with several species of *Pervinquieria, Gryphaea,* echinoids, and limonite fossils in two or three layers (this is the type locality of those described by Scott, (1388). (c) An upper 40 feet of clay, blue shale, and a few, scattered, thin, limy, seams, is exposed in the railway cuts southeast of the main creek cuts; these cuts contain many fossils, including pyrite micromorphs (*Pervinquieria* and others). The Fort Worth limestone caps this section. In Cooke and Denton counties, the Duck Creek is about 100 feet thick; in Tarrant County, 62 feet; in McLennan County it is reduced to about 30 feet; in Bell County to about 25 feet; at Austin, to about 20 to 25 feet. Farther south it is consolidated with the Fort Worth limestone to form the lower Georgetown. At Fort Stockton, it is about 48 feet thick; at Kent, 50 feet; at El Paso, about 100 feet at Sierra Prieta, about 25 feet. The division into an upper, more marly, and a lower, more limy, portion persists from Red River to at least Johnson County. In the Cooke County section (189, pp. 23–24), the basal 25 feet is an alternation of limestone and marl seams, containing *Desmoceras,* and some other fossils: *Pervinquieria,* several species, *Hamites, Inoceramus, Exogyra plexa, Gryphaea* and *Trigonia.* At Fort Worth (1789, pp. 39–51), several local zones have been discovered in the Duck Creek; the lower 27 feet is more limy and includes the zones of *Hamites, Desmoceras, Elobiceras* (top), *Pervinquieria shumardi-nodosa, P. kiliani,* the local *Kingena* zone, and others. The upper, marlier, part of the Duck Creek includes the local zones of *Scaphites worthensis, Kingena* (upper), the tiny echinoid *Goniophorus scotti* Lambert, and the lower range of *Pervinquieria maxima* (Lasswitz), *Macraster aguilerae, M. texanus* and others.

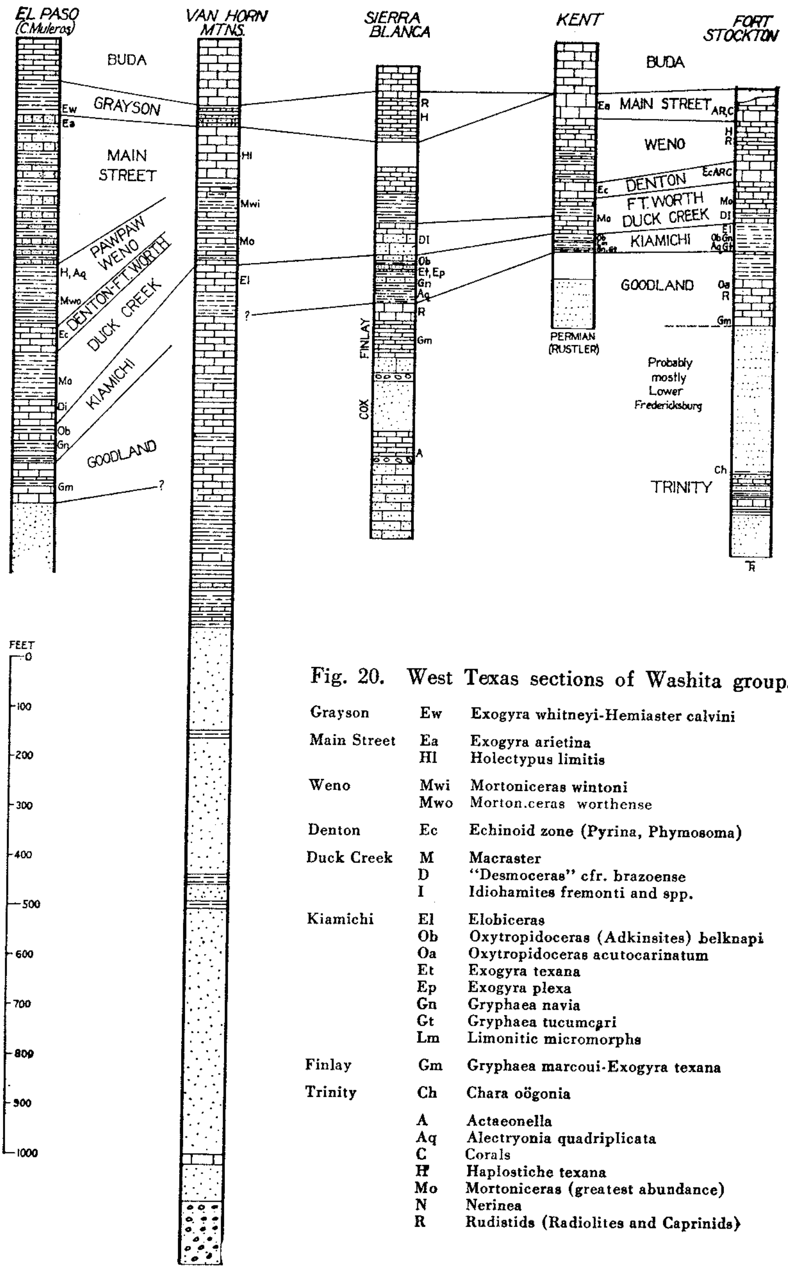

Fig. 20. West Texas sections of Washita group.

Grayson	Ew	Exogyra whitneyi-Hemiaster calvini
Main Street	Ea	Exogyra arietina
	Hl	Holectypus limitis
Weno	Mwi	Mortoniceras wintoni
	Mwo	Morton.ceras worthense
Denton	Ec	Echinoid zone (Pyrina, Phymosoma)
Duck Creek	M	Macraster
	D	"Desmoceras" cfr. brazoense
	I	Idiohamites fremonti and spp.
Kiamichi	El	Elobiceras
	Ob	Oxytropidoceras (Adkinsites) belknapi
	Oa	Oxytropidoceras acutocarinatum
	Et	Exogyra texana
	Ep	Exogyra plexa
	Gn	Gryphaea navia
	Gt	Gryphaea tucumcari
	Lm	Limonitic micromorphs
Finlay	Gm	Gryphaea marcoui-Exogyra texana
Trinity	Ch	Chara oögonia
	A	Actaeonella
	Aq	Alectryonia quadriplicata
	C	Corals
	H	Haplostiche texana
	Mo	Mortoniceras (greatest abundance)
	N	Nerinea
	R	Rudistids (Radiolites and Caprinids)

Near Belton, in Nolan Creek, Lampasas River, and Smith Creek, the condensed Duck Creek succession apparently lacks some zones that are present farther north, but perserves the most widespread zones. At Fort Stockton, Kent, Sierra Prieta, and El Paso, full Duck Creek sections occur (Fig. 20). In the southern facies, south of Belton, Sheffield, and Alpine, the Duck Creek is less satisfactory for zonation, partly through condensation, and partly through the presence of the rudistid facies.

The Duck Creek ammonite zones are very widespread in the Southwest. The *Desmoceras-Beudanticeras-Puzosia* zone of the basal Duck Creek is known from Two Buttes, southeastern Colorado; Cimarron County, Oklahoma; El Paso; Kent; Sierra Prieta; Fort Stockton; Sheffield; southern Texas Panhandle; southeastern Sutton County; Irion County; Georgetown; central Texas and southern Oklahoma; and in northern Coahuila (Fig. 13).

Paleontology and zonation.—Provisional Duck Creek zones are listed on page 363. Various species of *Elobiceras* and *Hamites* range from the upper- or post-Kiamichi beds into the basal Duck Creek; in Trans-Pecos Texas, *Gryphaea tucumcari* Marcou and *G. corrugata* (large var.) do likewise. The *Desmoceras* zone is characterized by *D. laevicaniculatum* (F. Roemer), *D. brazoense* (B. F. Shumard), *Puzosia* n. sp. (many fine ribs), *Beudanticeras* n. spp., and others. The formation contains a great and sudden development of *Pervinquieria* (20 or more species). *P. shumardi* appears to occupy a lower range, and *P. kiliani* an upper level. Both of these groups, however, had representatives in other levels as high as the Weno. *Prohysteroceras,* of several species, occurs throughout the Duck Creek. Pyritic micromorphs occur in the marly Duck Creek at several levels. *Macraster* began in this formation, as did the typical Texas *Holaster* (*simplex* group). The Duck Creek also contains several species of little value for correlation because they are unique, extremely rare, or horizontally very restricted.

Foraminifera of Duck Creek formation

(Ammonite Creek, west of Texas Christian University, Fort Worth)

Spiroplectammina sp. aff. anceps (Reuss)
Textularia rioensis Carsey
Textularia washitensis Carsey
Bigenerina wintoni Cushman and Alexander (reported in the literature from this formation)
Tritaxia pyramidata Reuss
Lenticulina washitensis (Carsey)
Saracenaria sp.
Vaginulina kochii Roemer
Vaginulina kochii var. striolata Reuss
Anomalina falcata Reuss
Globigerina washitensis Carsey

FORT WORTH FORMATION

Nomenclature.—In early literature, the term Fort Worth limestone was used as a synonym of Washita (= Georgetown) limestone. In 1891, Hill (772, p. 516) restricted the term to apply to the limestone above the Duck Creek and below the Denison beds. The term is still used in that sense. The localities mentioned include, near Fort Worth, the bluff of Trinity River just north of the Courthouse, the quarries near the Union depot, the Texas and Pacific Railway cuts in the city, and the railway cut at Hodge station, 3 miles north of Fort Worth. Some of these localities are now badly overwashed and overgrown.

Facies.—Neritic, mostly thin- to medium-bedded limestone, with a smaller amount of interbedded marl, on the outcrop.

Areal outcrop; local sections.—The Fort Worth formation is peculiar in retaining a nearly uniform thickness of 30 feet over much of its outcrop. In southern Oklahoma, the Duck Creek and Fort Worth formations together were called Caddo limestone by Taff. In Marshall County, Oklahoma (174, pp. 33–35), the Fort Worth consists of about 40 feet of hard, cream-colored limestone, lithologically somewhat like the Duck Creek limestones, alternating with thinner strata of limy marl. The lower 10 to 15 feet is composed of alternating beds of yellowish-white limestone and grayish to blue clay-marl. In the middle 10 to 15 feet thicker marl strata alternate with thinner limestone seams. The upper 10 feet is predominantly limestone, separated by thin marl seams. In Grayson County, Bullard (177, p. 29) records 45 to 50 feet of Fort Worth, the lower 15 feet being alternate layers 1 to 3 feet thick, of shale, or marl and limestone. The next 19 feet consists of clay-shale containing thin limy seams, with the following recorded fossils; *Pervinquieria leonensis* (Conrad), *Holaster simplex*, and *Pecten*. The upper 19 feet is thicker limestone strata alternating with subordinate marl beds; it contains, according to Bullard, *Exogyra americana* Marcou, *Macraster elegans* (Shumard), *Holaster simplex* Shumard, *Pervinquieria leonensis* (Conrad), and *Gryphaea washitaensis* Hill. The Tarrant County section of Fort Worth limestone is 30 to 35 feet thick. The beds are uneven and lenticular, and the limestones grade into the marls by a flaky transition zone. The limy strata differ from Duck Creek limes in being generally a foot or less thick, harder, and more regularly alternating. The soil weathers into a rolling, untimbered blackland prairie suitable for grazing. The upper part of the formation is locally marly, and contains abundant fossils, such as *Macraster pseudoelegans, M. texanus, M. aguilerae, M. nodopyga, Holaster simplex,* the rare but widespread *Washitaster longisulcus, Exogyra americana, Pervinquieria maxima,* and other species. From Bell County southwards, the Fort Worth is well compacted with the other members of the Georgetown limestone. It is overlain by the attenuated, soft-weathering Denton shell marl, a thin, persistent, soft ledge containing many *Gryphaea washitaensis, Alectryonia* cf. *carinata* and *Macraster* (several species), which weathers to a distinct bench and serves to separate the halves of the Georgetown in the southern section. Here the Fort Worth is a chalky, argillaceous, nodular limestone, dark to light bluish-gray on fresh exposure, whitish and somewhat disintegrated on prolonged exposure. It generally forms an upland prairie, bordered to the west by the narrow Duck Creek outcrop, and in stream cuts, it forms small bluffs.

Paleontology and zonation.—The Fort Worth probably represents only a brief interval in the zonation, and at present is assigned to the sole zone of *Pervinquieria maxima,* which in the Fort Worth section extends down into the top of the Duck Creek marl. After the explosive appearance of *Pervinquieria* in the basal Duck Creek, the genus became less abundant, but is represented in the Fort Worth limestone by several distinct lines, which have not been yet sufficiently studied, among them the groups of *P. nodosa, P. kiliani, P. trinodosa,* and some new species. *Prohysteroceras* persists from the Duck Creek to at least the Weno. *Macraster* has a thin zone in the Duck Creek, and reaches a considerable development, with several species, in the Fort Worth-Denton. *Washitaster,* so far as now known, first appears in the Fort Worth. Several rarities occur in the Fort Worth: *Turrilitoides* n. sp., a genus like *Ancyloceras* but much larger (*Tropaeum*-like), and micromorphs. The best guide fossils are *Pervinquieria maxima* and *Exogyra americana,* which occur in abundance.

Foraminifera from Fort Worth formation

(Creek bank .4 mile east of Texas Christian University, Fort Worth)

Textularia washitensis Carsey	Dentalina communis d'Orbigny
Textularia rioensis Carsey	Lingulina nodosaria Reuss
Gaudryinella delrioensis Plummer	Anomalina falcata (Reuss)
Lenticularia washitensis (Carsey)	Globigerina washitensis Carsey

DENTON FORMATION

Nomenclature.—The Denton marl of Taff (1575, p. 272), the Marietta beds of Hill (788, pp. 328–329), and the Denton subgroup of Hill (803, pp. 271–273), apparently refer to the same strata. The type locality by implication is on Denton Creek, west of Justin, Denton County, where Taff records a thickness of 38 feet.

Facies.—In central Texas, the formation is a marl, shell marl, and shell aggregate, with shelly and limestone seams. In the Fort Stockton and Kent sections, a rudistid limestone caprock is referred to the Denton.

Areal outcrop; local section.—Taff included the Denton, Weno, and Pawpaw formations in his "Bokchito" in southern Oklahoma. The lower 73 feet is recorded (Bullard, Okla. Geol. Surv., Bull. 33, page 36, 1925) as a clay with a thin medial sandstone, and some or possibly all of it is Denton. In Marshall County (174, p. 36) 45 to 55 feet is recorded, and in Bryan County 46 feet. In Grayson County (844, p. 4), the Denton is 45 to 52 feet thick. Down the strike the following thicknesses are on record: Cooke County, 45 to 60 feet; Denton County, 25 to 35 feet; Tarrant County, 25 feet; Johnson County, 20 to 25 feet; McLennan and Bell counties, about 5 feet; Travis County, about 5 feet. At Fort Stockton the beds of the middle rudistid caprock, assigned to the Denton, are about 38.5 feet thick, but the basal part of this may be Fort Worth limestone. At El Paso the Denton is a marly, nodular limestone about 50 feet thick (upper part of Böse's subdivision 5).

This is one of the most widespread horizons in the Washita, and some representative of its shell horizon may be found in the southern limy facies of the Georgetown. In the Red River region, Denton lithology is distinguished by these features: the body of the formation is clay or marl; the base, transitional to the Fort Worth limestone, is more calcareous and locally has thin limestone seams; near the middle of the formation there is a persistent, thin, fissile, laminated, ripple-marked, light-colored sandstone, which breaks into large slabs and covers the lower clay slopes; and at the top of the Denton there is a *Gryphaea washitaensis* shell aggregate, shell seams, or shelly limestone, one foot or more thick.

In Bryan County, Oklahoma (174, p. 37), the sandstone, brownish-yellow, hard, thinly laminated, ripple-marked, one foot thick, overlies 26 feet of basal Denton clay. In Grayson County, the yellow-brown, thinly laminated, ripple-marked sandstone is 20 to 30 feet and exceptionally more, above the base of the Denton. In Hampton Hollow, Cooke County (177, p. 35), the Denton consists of 67 feet of clay, with a 1.5 foot ripple-marked sandstone 30 feet above the base. To the south the sandstone shortly disappears. In Denton County the upper 6 feet of the formation is *Gryphaea* shelly limestone and shell marl, and the remainder is clay. In Tarrant County the medial sandstone is absent; the base of the formation above the thin limy seams, transitional to the underlying Fort Worth limestone, contains a small thickness of sandy marl and sandy ledges, followed by blue shelly clay; the top contains two harder *Gryphaea* shell strata in a very shelly clay. In Bell County the thinned Denton is a uniform shelly marl, which forms a connecting slope between the top of the Fort Worth limestone, exposed beneath as a terrace or narrow shelf, and the overlying Weno limestone. This marl break is distinguishable generally in the topography. Farther south, as the terranes lose the terraced expression characteristic of north-central Texas, the Denton outcrops become very narrow and inconspicuous. At Mexia, the Denton, Weno, and Pawpaw are very reduced in thickness. In some wells in the outcrop counties, the Denton may be recognized from logs; apparently on passing gulfwards it rapidly disappears as a marl.

In Trans-Pecos Texas, Denton is present in its usual facies at El Paso, Kent, and Sierra Prieta. At Cerro de Muleros it forms the upper part of Böse's subdivision 5, and is a marl and nodular dark bluish-gray, soft limestone, containing a fauna of beautifully preserved echinoids (*Pyrina, Phymosoma, Holectypus,* and others). This echinoid level appears at Kent, where the Denton forms a cap rock of nodular, non-rudistid limestone. At Fort Stockton the upper part of this limestone cap rock is in the rudistid reef facies and contains *Eoradiolites* n. sp., caprinids, *Chondrodonta,* reef *Nerinea* and *Pecten,* corals, sponges, *Actaeonella,* and other distinctive fossils. The same features occur near Gap Tank and in eastern Pecos County.

Paleontology.—The top of the Denton is a persistent mass of shell marl and shelly limestone, becoming almost entirely shell marl in south-central Texas. It contains innumerable *Gryphaea washitaensis* (all growth stages), which are present but less abundant lower in the Denton, and *Alectryonia* cf. *carinata, Leiocidaris hemigranosus* (plates and spines), *Heteraster,* and some less frequent, wide-ranging Washita species. One of the most prominent features is a great development of the large echinoid, *Macraster,* represented by several species. Several kinds of *Pervinquieria* occur, one of which (*P.* aff. *kiliani*) may prove to be a restricted zone fossil. Numerous ammonites (*Pervinquieria* and others), preserved as pyritic dwarfs, occur in the Red River section. Rarities are *Rhabdocidaris* n. sp., *Turrilites* spp., "*Vola*" [*Lima?*] *catherina* Cragin, and some ammonites. The Denton in the clay facies is notable for small crustacea. Miss M. J. Rathbun has kindly listed the following from Bureau collections:

Macrura	*Brachyura*
Callianassa n. sp. 1.	Raninella n. sp. 1.
Callianassa n. sp. 2.	Raninella n. sp. 2.
Linauparus n. sp. 1.	Notopocorystes n. sp. 1.
Hoploparia n. sp. 1.	Notopocorystes n. sp. 2.
Ischnodactylus n. sp.	Necrocarcinus n. sp. 1.
	Necrocarcinus n. sp. 2.
	Xanthosia n. sp. 1.
	Xanthosia n. sp. 2.

Foraminifera of Denton formation

Textularia washitensis Carsey
Bigenerina wintoni Cushman and Alexander
Gaudryinella delrioensis Plummer
Quinqueloculina sp.
Vaginulina recta Reuss (reported by Alexander)
Bolivina sp.
Anomalina falcata (Reuss)
Gyroidina nitida (Reuss)
Globigerina washitensis Carsey

WENO FORMATION

Nomenclature.—Hill (788, p. 329) used the term "North Denison sands" for all strata between the top of the Denton *Gryphaea* shell aggregate and the base of the Pawpaw formation. Taff (1575, p. 273) used for the Weno the term "Denison" marl, a name preoccupied for the "Denison subgroup" in Hill's earlier papers. The term "Weno subgroup" was used by Hill (803, pp. 269–271, 274 ff.) to include the Weno and Pawpaw formations, and the term Weno formation (803, p. 275) for the same strata as his original North Denison sands (his beds j-m). It is in this last sense that later writers have used the term Weno. The type locality is near the abandoned village of Weno, on Red River about 5 miles northeast of Denison.

Stratigraphic position and contacts.—Stephenson (1530, p. 142) records that in the Saint Louis and San Francisco Railway cut, ¾ mile north of the Union Station at Denison, the basal 3 to 12 inches of the 2-foot Quarry limestone is conglomeratic, containing scattered pebbles of waterworn calcareous sandstone, sandy limestone, and calcareous and ferruginous concretions, the largest 3 inches or more in length. A few borings filled with characteristic Quarry limestone material occur in the top of the underlying Weno clay, and otherwise the Quarry overlies the Weno with a sharply defined contact. In the absence of contrary evidence, this indicates that the Quarry is better classified with the Pawpaw beds. In Tarrant County this contact shows a sharp lithologic break, but no other evidences of unconformity are reported. The Denton-Weno contact is concordant and may be conformable.

Facies.—In the Denison, the southern Oklahoma, and the El Paso sections, the Weno is somewhat sandy. Its sediments in general are marl and limestone, of the neritic facies, with ironstone and ferruginous concretions. Near Fort Stockton a thin interfingering of *Toucasia* reef limestone occurs.

Areal outcrop; local sections.—In Love County, Oklahoma, the Weno consists of dark blue clay with many ironstone and ferrruginous sandy clay concretions, and segregations of mineral salts. It contains fossils, nacreous, and in the form of ironstone casts and impressions. It is 90 feet thick in southwestern part of Marshall County, and 135 feet thick in the northern part. Here the Weno contains many thin soft sandy layers and clay ironstone concretions. The northward increase in thickness is mostly in the sandy layers, which on the south limb of the Preston anticline average only 2 inches in thickness, but on the north limb, as at a locality 3 miles east of Kingston, are several feet in thickness. The sandy, ferruginous Quarry limestone maintains a thickness of 2 to 3 feet in this area. Several similar indurated layers occur in the lower Pawpaw; and in the Weno, 20 to 30 feet below the Quarry, there is a persistent hard, sandy limestone about a foot thick, weathering yellowish-white and resembling the Quarry. In Grayson County, there is about 117 feet of the Weno, consisting principally of clay; it is composed of dark gray shaly clay with subordinate thin partings, lenses and layers of fine, gray-to-yellow sand and sandstone, and, in the upper part, many small flattish ferruginous concretions and some small marcasite concretions. On the north limb of the Preston anticline, in the left bank of Washita River, 2¾ miles west of Platter, Oklahoma, there is a layer of sandstone 5 or 6 feet below the Quarry limestone and several layers of thin flaggy sandstone 25 to 40 feet below the Quarry. On the north limb of the anticline, in Marshall County, the Weno is 135 feet thick (1530, p. 141). At a level about 44 feet above the base, in Duck Creek, north of Denison, there is a layer of large (4 to 5 feet in diameter) indurated and laminated ironstone concretions ("niggerheads"). Above these the nacreous ammonites *(Engonoceras serpentinum)* are most abundant. In the upper 50 feet of the formation, as seen in cuts a mile north of Denison, there are many nacreous shells (*Turritella, Nucula, Yoldia, Corbula,* and others).

In Cooke County the Weno is 100 feet thick. In Denton Creek, east of Justin, the upper 42 feet is exposed; in the northern part of the county near Sanger it is 105 feet thick, and in the southern part, west of Roanoke, 66 feet thick. On Clear Creek, Hill records 81 feet of Weno (803, p. 275); limestone seams are already appearing in this section.

In the Tarrant County section of the Weno, limestone is the dominant material. The formation is 67 feet thick. The basal 15 feet is a blue clay, capped by two marly limestone ledges, containing *Gervilliopsis* and other fossils. This portion is very fossiliferous, and locally contains a zone of abundance of *Turritella wenoensis* (*T. ventrivoluta* Cragin?) and *Pecten georgetownensis* Kniker. The medial portion consists of 34 feet of marl and some soft limestone, with *Haplostiche texana* (Conrad) in its upper part. The upper 18 feet beneath the Pawpaw is medium-bedded, marly, grayish-white limestone, with subordinate marl layers, containing *Macraster obesus* Adkins and other fossils; it makes a distinct bench. These portions of the Weno are well exposed on Sycamore Creek. The Quarry limestone is not recognizable. In Johnson County 40 to 50 feet of Weno occurs. The upper one-half is mostly limestone, with subordinate marl seams, containing *Pervinquieria wintoni, Pecten georgetownensis, Haplostiche texana,* and other local markers. The lower one-half is marl with limestone seams. In McLennan and Bell counties it is reduced to 20 to 30 feet, and consists of limestone in thin to medium beds with slight marl interbedding. At Austin (803, p. 265) the Weno is probably represented by less than 10 feet of limestone (Hill's bed 6, on sect 29). South of Austin it has not been traced.

At Fort Stockton, the Weno, lying between the middle and upper cap rocks, is represented by 81 feet of marly limestone, marl, yellowish sandy limestone, and sandy marl. These strata contain a prominent ferruginous flint layer near their top. Fossils are: *Haplostiche texana, Pervinquieria* aff. *wintoni,* and a zone of *Toucasia* in a thin reef limestone finger near the middle. The section at Kent is similar. At El Paso the Weno is blue clay basally, with pyritic micromorphs (*Pervinquieria* n. spp., *Neokentroceras?*), and sandy clay above, with *Alectryonia quadriplicata.*

Paleontology.—In the upper Washita, as in the upper Albian, quadrituberculate *Pervinquieria* (*P. wintoni* group) appear. Several species are known from the Denton onwards: *P. wintoni* is widespread in the Weno and is a practical marker; new species of the *P. kiliani* group occur; *Prohysteroceras* occurs; *Macraster obesus* is a practical marker.

Miss M. J. Rathbun has identified from Weno material in the Bureau of Economic Geology the following macrourous crustacea: *Enoploclytia* n.sp., *Palaeastacus walkeri* (Whitfield); the latter species occurs also in the Fort Worth formation and in the Fort Worth portion of the Georgetown.

Foraminifera from Weno formation

(Sycamore Creek, east of Katy Lake, Fort Worth)

Gaudryinella delrioensis Plummer
Lenticulina washitensis (Carsey)
Saracenaria sp.
Vaginulina recta Reuss
Dentalina spp.
Nodosaria obscura Reuss
Lagena sulcata (Walker and Jacob)
Dentalinopsis excavata (Reuss)
Gyroidina nitida (Reuss)
Anomalina falcata (Reuss)
Globigerina washitensis Carsey

PAWPAW FORMATION

Nomenclature.—The "Pawpaw shales" or clays were first named by Hill (788, pp. 303, 328, 330) from the type locality Pawpaw Creek, starting in the city of Denison and running in a north-northeast direction to Red River. Here Taff considers the formation, mostly sand, to be 55 feet thick.

Facies.—(1) Typically, the Pawpaw is compacted, loosely cemented, ferruginous, cross-bedded, red-brown sandstone, with sandy clay and ironstone concretions. This is the marginal facies.

In Cooke and northern Denton counties, the formation consists of alternating red clay seams and ferruginous red-brown sandstone. (2) In southern Denton County the Pawpaw becomes more clayey and calcareous, and the sandstone ledges fewer, thinner, and lighter colored. The ironstones and jasper-like concretions persist, and in northern Tarrant County locally cover the surface. Here it is a blackish, partly lustrous clay, weathering reddish-brown and yellowish. The same lithology persists into Johnson County. (3) In Hill County the Pawpaw is more marly, having increased in lime content. Toward the Brazos it consolidates as a marly layer in the Georgetown. South of Hill County it is unrecognized. From central Denton to southern Hill County, therefore, it is of the neritic facies. At El Paso it is a similar, but more sandy, marl.

Areal outcrop; local sections.—In the Red River region, the Pawpaw is prevailingly sandstone and ferruginous sand, with interbedded dark-colored shales or clays. At Sugar Loaf Mountain, eastern Bryan County, Oklahoma (Winton, in 10, p. 28), it is 55.8 feet thick, and consists of fossiliferous ferruginous or ironstone ledges, alternating with cross-bedded red sand and sandstone. The fossils are typical Pawpaw ammonites, *Alectryonia quadriplicata*, *Arca*, and the usual assortment of small pelecypods and gastropods. In a cut near Sulphur Creek, on the Saint Louis and San Francisco Railway, 2 miles west of Bennington, beneath Main Street limestone, there is exposed 36 feet of Pawpaw marls, sands, and sandstone with nacreous and ironstone fossils: *Arca*, *Nucula*, *Corbula*, *Cerithium*, *Turritela*, and *Anchura*.

North of the railroad, 1½ miles east of Bennington, about 50 feet of massive brown Pawpaw sandstone underlies the Main Street. This sandstone contains limy layers bearing *Alectryonia quadriplicata*, *A. marcoui*, *A. subovata* (?), *Trigonia*, *Gryphaea* and *Pecten*. On the west bluff of Washita River (Bullard, Okla. Geol. Surv., Bull. 39, page 43), due east of Woodville, 60 feet of Pawpaw consists of a basal clay with ironstone concretions, and an upper soft yellowish-brown sandstone containing numerous veins of limonite (174, p. 43). The Pawpaw contains several thin lenses of highly fossiliferous, ferruginous, oxidized, soft sandstones similar to those in the Weno, but differing in containing few *Turritella*. The Pawpaw weathers to a very sandy, ferruginous soil, often covered with iron concretions and segregations, some hills being capped by a limonite residue. The outcrop is a typical "cross-timbers," like the Woodbine.

In Grayson County, typical Pawpaw is exposed in the cuts on East Main Street and in the upper part of Pawpaw Creek. In Denison it is a massive, poorly cemented but firm, veined, cross-bedded, brick-red sandstone. In the underpass south of the Missouri, Kansas and Texas Railway station, its contact with the overlying thin, gray Main Street limestone is exposed. Its thickness is given as 45 to 55 feet by various writers. Calcareous clay predominates in the lower half of the formation, and sand and interbedded, laminated sand and clay in the upper half. Stephenson records, 4 feet above the base of the Pawpaw clay, a limestone stratum 0.5 to 1 foot thick, and sandy limestones are known in the basal Pawpaw farther north. In an upper sandstone of the Pawpaw, he observed some comminuted plant fragments. In Big Mineral Creek, 1½ miles east of Cedar Mills, Taff records 40 feet of Pawpaw: basally, 35 feet of blue, laminated, arenaceous clay marl, containing lenses and nodules of clay ironstone in disconnected layers, with *Pachydiscus* and *Protocardia;* and at its top, a 5-foot bed with *Alectryonia quadriplicata.*

On the Pilot Point road east of Gainesville, Hill (803, p. 275) records 35 feet of Pawpaw, laminated, arenaceous, and marly clays, yellow at top, blue below. On Clear Creek, Denton County, Taff recorded 34 feet, the basal 9 feet being clay with numerous thin seams of soft sandstone or laminated, friable, brown sand, the upper 25 feet being marl. This locality shows the outfingering of the marginal facies southwards. The formation thins across Denton County: in the northern part it is 50 feet thick, in the southern part 30 feet.

At Blue Mound, 1½ miles south of Haslet, northern Tarrant County, the Pawpaw is 27.3 feet thick; on Sycamore Creek east of Fort Worth, 24.6 feet; near the Tarrant-Johnson County line, 12 feet. The transitional zone from the ironstone to the prevailing clay facies occurs in northern Tarrant County; north of the Trinity there is much ironstone scattered over the outcrop, the residue of numerous thin ironstone ledges, such as are very conspicuous on Red River. South of the Trinity, these are reduced to thin seams or scattered nodules, and blackish clay makes up the bulk of the formation. From Johnson County southwards, the clay becomes decidedly marly, in transition to the limy southern section. From Riovista southwards the Pawpaw is entirely marl, with little clay and no ironstone; the fauna consists of echinoids in abundance, oysters, pelecypods, and gastropods, and the pyritic micromorphs are entirely missing. On Nolands River, 10 miles west of Cleburne, the Pawpaw consists of 10.8 feet of reddish clay containing fragments of pyritized *Turrilites* and *Arca* (Winton, in 10, p. 33). On the Waco road, one mile south of Riovista, the Pawpaw consists of calcareous yellow marl with a few ironstone and limestone fragments, and a mixture of the pyritic micromorphs of the geosynclinal facies (*Turrilites, Arca, Pervinquieria,* type locality of *Flickia bösei*) and neritic fossils (abundant *Heteraster, Holaster, Washitaster, Hemiaster calvini*).

At Fort Stockton and Kent, the Pawpaw, if represented, is sandy marl in the top of the Weno. At Cerro de Muleros, above the east end of the tunnel, is black clay with pyritic micromorphs (*Neokentroceras, Pervinquieria*), overlain by sandy clays with *Alectryonia quadriplicata* and other oysters. The sandy clays are probably Pawpaw; the lower black clays may be Pawpaw also, but it is just as probable that they are Weno, and that *Neokentroceras,* supposedly a Pawpaw marker, shows only its partial range at other localities where the upper Weno is limestone and where therefore the facies is unfavorable, and that here, where a favorable facies occurs in the Weno, its true range is exhibited.

Paleontology.—The three main facies of the Pawpaw each show a different aggregation of fossils. In the marl, the usual neritic, type, most of the fossils are widely ranging upper Washita types, with a premodinance of irregular echinoids. Near Riovista whole nests of these occur. No good markers have been proven in this facies. In the synclinal (black clay) facies there occurs one of the four striking interfingerings of the habitat favorable for pyritic micromorphs which are known in the Washita group. Therefore, as in the interfingerings of rudistid and neritic facies, care must be taken to avoid confusion between total range (given a favorable facies) and partial (local) range. Under these conditions, no zone markers for the Pawpaw are known, but dilligent and prolonged collecting has practically demonstrated that some fossils occur in the Pawpaw and not in the nearby Denton and Grayson pyritic micromorph zones. The known ranges of these micromorphic ammonites are as follows:

	Duck Creek	Denton	Pawpaw	Grayson	Eagle Ford
Wintonia	—	—	—	+	
Turrilites	—	—	+	+	
Scaphites	+		+	+	
Baculites			+	+	
Hamites	+		+		
Worthoceras	+		+		
aff. Nipponites	+				
Submantelliceras	—	—	+	+	
Pervinquieria	+	+	+	—	
Stoliczkaia	—	—	+	—	
Flickia	—	—	+	—	
Adkinsia	—	—	—	+	
Allocrioceras					+
Metaptychoceras					+
Prionocylus and Priontropis					+

The distribution of the pyritic micromorph faunas is significant for paleogeography: they are sparse in the Red River region, abundant in the Fort Worth-East Texas embayment (best Pawpaw in Tarrant and Johnson counties, best Grayson in McLennan and Bell), absent over the Austin high, and abundant again (facies permitting) in the Rio Grande embayment (as in the Grayson at Del Rio). They are absent on the Terrell arch, and again abundant in the Terlingua region, where, off the Quitman-Malone arm of the Kimmeridge-Valanginian sea, the Comanchean formations thickened enormously.

Even in the synclinal areas, the usual neritic limestones and marls interfingered, and their faunas of oysters, echinoids, and molluscs are present (as in the Pawpaw at Fort Worth).

In the Pawpaw, near Fort Worth, at a pyritic fossil locality, several large vertebrae and ribs of a plesiosaur were found.

Miss M. J. Rathbun has kindly identified the following Pawpaw crustacea from the collections of this Bureau:

Macrura	*Brachyura*
Linaupurus n. sp. 2	Actaea n. sp.
Nephrops n. sp.	Caloxanthus n. sp.
Ischnodactylus n. sp.	Fam. Portunidae, n. gen., n. sp.
Callianassa n. sp. 1	Fam. Calappidae, n. gen., n. sp.
	Necrocarcinus n. sp. 1
	Necrocarcinus ? n. sp. 3
	Xanthosia n. sp. 2

Foraminifera from Pawpaw formation

(Sycamore Creek, east of Katy Lake, Fort Worth)

Ammobaculites subcretacea Cushman and Alexander
Textularia washitensis Carsey
Textularia rioensis Carsey
Lenticulina washitensis (Carsey)
Vaginulina recta Reuss
Gümbelina globulosa (Ehrenberg)
Gyroidina nitida (Reuss)
Anomalina falcata (Reuss)
Globigerina lacera (Ehrenberg)
Globigerina washitensis Carsey
(numerous holothurians)

MAIN STREET FORMATION[41]

Nomenclature.—The formation was named by Hill (788, pp. 302–303, 330–331) in 1894, the type locality being on East Main Street, Denison, Texas. The formation is exposed in a cut at the St. Louis and San Francisco Railway station, and in cuts of Pawpaw Creek and of railways within the city limits. Synonyms: Choctaw limestone, (Cragin, 325)*; Bennington limestone (Taff, Atoka folio No. 79, p. 6, 1902); "*Exogyra arietina*" limestone (Taff, 1575).

Stratigraphic position and contacts.—Stephenson places an unconformity (?) at the base of the Main Street, and describes the basal stratum as follows: "Greenish-gray, sandy, calcareous, clay marl with scattered white clay pebbles and ferruginous concretionary clay nodules along the base, some of which suggest having been mechanically included . . . 1.25 to 1.5 feet." The Main Street-Grayson contact has not been well investigated, but is possibly conformable.

Facies.—Three main facies are known: (1) the usual marl-lime facies, in southern Oklahoma, and in Grayson and Cooke counties; (2) rudistid caprock, as near Fort Stockton; and (3) red sandstone-quartzite with fossils, at El Paso.

[41]*Literature.—North-central Texas:* Hill, 803; Stephenson, 1530; Winton, 1789. *South-central Texas:* Cuyler, 383; Hill, 803; Taff, 1575. *Trans-Pecos Texas:* Adkins, 12; Böse, 129. *Paleontology:* Roemer, 1331; Cragin, 325; Adkins and Winton, 9; Adkins, 13; Scott, 1389.

*Hand-written notation by Professor Cragin: date of publication, April 5, 1895. See also: Cragin, Am. Geol., 16: 165, footnote, September, 1895.

Areal outcrop; local sections.—Taff says that the Main Street is about 10 feet thick in Bryan and Marshall counties, Oklahoma. In Marshall County (174, p. 44) it is 10 to 20 feet thick, and consists of heavy-bedded, brown, hard, semi-crystalline limestone with subordinate interbedded layers of marl. There is almost as much marl as limestone in most sections. The limestone is more massive, and the marl more reduced, near the base of the formation. As farther south, *Kingena wacoensis* is common in the basal part, and *Exogyra arietina* is common in the upper part. In Grayson County it is 8 to 23 feet thick, and around Denison about 9 to 12 feet thick. In the railway cut, 3 miles west of the Union Station at Denison, Stephenson measured 8¾ to 9 feet of irregular layers of limestone underlain by a massive limestone ledge, which rests on a clay marl with apparently rolled pebbles at its base. In a headwaters branch of Pawpaw Creek, just east of the underpass under the Missouri, Kansas and Texas tracks south of the Union Station at Denison, Stephenson recorded 9.5 to 10 feet of Main Street, consisting of an upper 8 feet of irregular nodular limestone strata interbedded with soft yellow marl layers, and a lower 1.5 to 2 feet of gray, faintly laminated sandy marl with evidences of unconformity at its base. At the Choctaw Creek bridge on the Denison-Bonham road, the Main Street is 17 feet thick, all limestone. In the Pottsboro cut-off, about 4 miles west of Denison, it is 11 feet thick; 1 mile south of Fink it is 13¾ feet thick, and at another nearby locality, about 8 feet thick; in Rock Creek, northwestern Grayson County, it is 23 feet thick. The basal part contains *Alectryonia quadriplicata*, its highest occurrence. The Main Street is generally coarsely crystalline, bedded, brecciated white limestone, which because of its ferruginous content turns deep yellow or yellow-brown on oxidation and hydration. Both marls and limestones are locally somewhat sandy. In a railway cut in the eastern part of Denison, an excellent exposure of the topmost Main Street layer in contact with the Grayson, contains many fossils. On the trestles of the Missouri, Oklahoma and Gulf Railway across the small headwaters of Pawpaw Creek, about a mile east of Denison, there are fossiliferous Grayson exposures with the Main Street contact exposed. In the extreme northeastern corner of Cooke County, 2 miles west of Dexter, the Main Street is a bed of light-blue limestone 10 to 15 feet thick (803, p. 282).

On passing south, the Main Street changes in thickness and in lithology. In northern Denton County it is 14 to 15 feet thick, in the southern part of the county about 20 feet. In the Clear Creek section, 5 miles northeast of Denton, it is 17 feet thick. The heavily iron-stained, massive, thick ledges of the Red River section give way in Denton County to a limestone almost indistinguishable from the Fort Worth limestone: the limestone strata are thinner, more evenly bedded, whiter, and alternate with light-colored marls.

In Tarrant County the Main Street increases from 25 to about 50 feet from north to south; in Johnson County it is nearly 50 feet. From Denton County southwards, the Main Street forms conspicuous and extensive upland prairies, next in size to those of the Fort Worth limestone. Good and nearly complete sections of the formation occur in Buffalo Creek at Cleburne, along Deer Creek between Burleson and Crowley, and near Crowley.

From Hill County southwards, the Main Street becomes thinner, and past Bell County is consolidated with other members into the top of the Georgetown limestone. In southern Hill County, west of Aquilla, it is about 35 feet thick, in McLennan County about 25 feet, and in Bell County about 20 feet. A few feet is recorded at Austin. Its thickness in the lower Pecos Valley, where the Georgetown is thick, is unrecorded. Over its thinned southern extension, it maintains its typical facies and fauna: *Turrilites brazoensis, Exogyra arietina* (in the top), and *Kingena wacoensis.*

An important part of the Main Street is the upper few feet, which form the "transition zone" to the overlying Grayson. Some misunderstanding of this portion is evident in the literature. In Grayson County the Grayson is at many places badly overwashed, and the Main Street is full of *Exogyra arietina* from bottom to top; in Travis County the Main Street limestone is reduced in thickness and is inconspicuous, and the Grayson (Del Rio) is full of *Exogyra arietina.* Those writers who considered *Exogyra arietina* to be diagnostic of a single formation correlated the Main Street with the Del Rio (and as a further deduction, the Grayson with the Buda). Speculatively the Woodbine has also been correlated with the Buda. To establish a correlation between these formations, the best starting point is the "transition zone" at the Main Street-Grayson contact. This is well exposed at Shoal Creek and 18th Street, Austin; at the fault a mile east-northeast of Georgetown; on Lampasas River 4¾ miles east of south of Belton; at numerous places near South Bosque; at Grayson Bluff northeast of Roanoke; and in a railway cut a half-mile southeast of the Union Station at Denison. Persistent and abundant fossils in the zone are large. Typical specimens are *Turrilites brazoensis, Exogyra arietina, Kingena wacoensis* (basally), *Stoliczkaia* n. sp. (numerous fine ribs), and *Mantelliceras* two n. spp. ("*Acanthoceras* aff. *cunningtoni*" Böse). Study of this persistent level indicates that it is identical throughout its range. It everywhere overlies hard Main Street limestone and underlies Grayson marl or clay. This indicates that the Grayson and the Del Rio are at the same level at their base, and the pyritic micromorphs are the same, from Denton County to Del Rio and Terlingua.

The Main Street in the Fort Stockton area is a rudistid caprock, containing many of the reef-dwelling genera found in the middle caprock. At Kent it is neritic limestone, with banks of *Exogyra arietina.* At El Paso it is a thick, red-brown quartzite, evidently a marginal facies, containing in the upper part in thin, shaly layers, poorly preserved *Exogyra arietina, Exogyra whitneyi?* (juvenile), and *Hemiaster calvini.*

Paleontology.—The Grayson is one of the most distinctive Comanchean formations. As Hill and Cragin pointed out, it and the Main Street stand out from the lower and middle Washita faunally. The last quadrituberculate and compressed *Pervinquieria* occur in the Main Street; none is known from the Grayson. *Stoliczkaia,* already appearing in the Denton, has several species in the Main Street and Grayson. *Prohysteroceras* and *Macraster* have not been reported from above the Pawpaw. *Mantelliceras,* a Cenomanian genus, appears in the "transition zone." The dying out of Albian genera lends to this boundary the appearance of considerable change; the fact that the section is probably fuller here than at many localities published elsewhere makes the placing of the boundary more difficult; on the other hand all sections now require closer zonal study. *Turrilites brazoensis* is a practical marker for the Main Street.

Scott (1389) correlates the upper Washita, including the Main Street, with the Upper Albian in Europe, which he claims is greatly extended in Texas. It is possible that the Main Street contains a fuller development of zones than the Upper Albian in England and France, a situation which would make the Albian-Cenomanian boundary hazier in Texas than in western Europe.

It is significant that the highest "*Pervinquieria*" in Texas occur in the Main Street. However, the Buda and apparently the Grayson are distinctly Cenomanian in fauna. This correlation awaits more extensive and accurate zonal studies.

Foraminifera from Main Street member

(Mount Bonnell road, west of Austin)

Flabellammina alexanderi Cushman
Textularia washitensis Carsey
Textularia rioensis Carsey
Lenticulina washitensis Carsey
Saracenaria sp.
Vaginulina recta Reuss
Nodosaria obscura Reuss
Lagena sulcata (Walker and Jacob)
Frondicularia sp.
Dentalinopsis excavata (Reuss)
Patellina subcretacea Cushman and Alexander
Gyroidina nitida (Reuss)
Anomalina sp.
Globigerina washitensis Carsey

GRAYSON FORMATION[42]

Nomenclature.—The formation was first called Grayson by Cragin (325, pp. 40, 43) in 1895. In 1898 Hill and Vaughan (795, p. 236) applied the name Del Rio to its southward extension in the Rio Grande Valley near Del Rio.

Taff (1575, pp. 277–283), like some later writers, considered the scattered limy ledges in the upper Grayson in north Texas to be the equivalent of the Buda limestone farther south. Some earlier writers correlated the Del Rio clay in south Texas with the Main Street limestone in north Texas, and the Buda in south Texas with the Grayson marl in north Texas. These early correlations led to the separate naming of the Grayson and the Del Rio. However, both the basal Grayson flaggy zone, with "*Acanthoceras*" aff. *cunningtoni* Böse, *Stoliczkaia* spp., and abundant *Turrilites brazoensis,* and the overlying clay, seem essentially identical from Red River to the Rio Grande; and in this event Cragin's name has priority. Taff has expressed a similar opinion; in his reports the Grayson was called "Vola clay" and the Buda "Vola limestone."

Roemer, without describing the clay, had collected from it in southwestern Hill County west of Aquilla, and had described *Exogyra arietina* (1331, p. 68, pl. 8, figs. 10 a–e) from the Waco Indian camp west of New Braunfels. B. F. Shumard first described the "*Exogyra arietina* marl" (1464a, pp. 583, 586) from the base of Mount Bonnell near Austin, and correctly placed it beneath the Austin limestone with Eagle Ford at the base and above the

[42]*Literature.—Oklahoma:* Bullard, 174; Honess, 839, 840. *Central Texas:* Cragin, 325; Carpenter, 197; Hill, 772, 788, 803, 822; Winton, 1791; Roemer, 1330, 1331; Taff, 1575; Shumard, 1464a. *Rio Grande Embayment:* Hill and Vaughan, 795. *Trans-Pecos Texas:* Böse, 129; Hill, 722; Udden, 1626, 1648. *Paleontology:* Alexander, 31; Adkins and Winton, 9; Adkins, 10; Böse, 133, 134; Cragin, 325; Plummer, 1237, 1238; Roemer, 1331; Udden, 1628.

"Washita" (= Georgetown) limestone. Very curiously, he overlooked the Buda. In the older literature the Grayson is often called the *Exogyra arietina clay*" or "marl."

Synonyms.—Gelbliche Kalkmergeln, Roemer, 1331, p. 16; Roemer, 1330, p. 184. *Exogyra arietina* marl, Shumard, 1464a, pp. 583, 586; Marcou, 1042, pp. 86–97. *Exogyra arietina* clays: Hill, 755, p. xiv, xxiii; Hill, 772, p. 517. *Exogyra arietina* beds: Hill, 788, pp. 318, 319, 321–322. *Exogyra arietina subdivision:* Taff, 1575, pp. 275–277. *Vola* limestone and marl: Taff, 1575, pp. 277–283. Grayson marl: Cragin, 325, p. 43 (type locality: cuts of D. B. & N. O. Ry., in southeastern part of Denison); Hill, 803, pp. 245 (fig. 29), 246 (fig. 30), 247, 286–288. Del Rio clay: Hill and Vaughan, 795, p. 236 (type locality: a conical butte, Loma de la Cruz, and surrounding clay lowlands 2 miles south of Del Rio).

Stratigraphy and contacts.—Throughout Texas the Grayson is underlain, concordantly and apparently conformably, by the Main Street formation or member. In southeastern Oklahoma the thinned Grayson lies above the Main Street ("Bennington") limestone and below the Woodbine ("Silo"). Some confusion in correlation has arisen over the thin transitional zone, consisting of alternating marls and marly limestones, at the base of the Grayson in central Texas. These strata are paleontologically most like the underlying Main Street limestone, because of an abundance of *Kingena* and *Turrilites brazoensis* Roemer. They are also marked by *Stoliczkaia* spp., "*Acanthoceras*"[43] aff. *cunningtoni* Böse (a fossil practically restricted to this level), and *Exogyra arietina,* which is abundant in both Main Street and basal Grayson.

In north-central Texas, north of latitude 31° 30′, near Waco, the Grayson is overlain, apparently unconformably, by Woodbine. South of McLennan County, it is overlain by Buda, the nature of the contact being unknown. In McLennan and Bell counties, at the outcrop, the Buda is of intermittent occurrence, and, where it is absent, the black shales at the base of the Eagle Ford flags rest unconformably on the Grayson, with a pebble and phosphatic conglomerate at their base. At a locality near Cedar Mills, Grayson County, the Grayson has been reported absent and the Woodbine rests directly on the Main Street limestone. In southern Oklahoma, east of longitude 95° 30′, the Grayson is apparently absent, and the

[43]A new genus, to be described in a forthcoming paper.

Woodbine overlies a beveled Comanche surface ranging from Grayson down to Goodland.

In Trans-Pecos Texas and northern Coahuila, the Grayson is absent over a considerable area, in which the Buda rests directly on the Georgetown. In Reeves and western Pecos counties, the Grayson thins northwards and disappears. In the southern Edwards Plateau, between San Antonio and Del Rio it thins northward and disappears, as it probably does also in southern Oklahoma.

Throughout Texas, the Grayson is underlain, concordantly and apparently conformably, by the Main Street formation or member of the Georgetown limestone. The "*Acanthoceras*" *cunningtoni* zone appears to be transitional between the two formations.

Facies.—(1) Throughout its extent in southern Oklahoma, central Texas, and western Trans-Pecos, Texas, the Grayson is essentially of the clay facies, with subordinate amounts of friable sandstone flags and siltstone locally, especially near its top. (2) In western Val Verde and Terrell counties and in northern Coahuila, the Grayson (particularly in its upper part, on crossing the Terrell high axis) consists of interbedded, thin, calcareous flagstones and limy marl, containing ammonites and other fossils. In this region and in the Big Bend, many of these flags are siliceous, and contain vast numbers of the large arenaceous foraminifer, *Haplostiche texana.* Over the Terrell arch and southwards into northern Coahuila (as near Remolino, El Macho, La Babia), the Grayson is mostly fossiliferous limestone flags (compare also: 578, p. 1427).

Areal outcrops and local sections.—Honess (840, vol. III, p. 92) states that in Bryan and western Choctaw counties, Oklahoma, the Woodbine overlaps onto Comanchean formations, and is in unconformable contact with the Main Street ("Bennington") limestone and with the Goodland limestone at the eastern line of McCurtain County. The Grayson is therefore absent at the outcrop in southeastern Oklahoma. In Bryan County, Oklahoma (Taff, Atoka folio No. 79, 1902) the Grayson marl is present but thins to the east; but, at a complete exposure 1 mile north of Durant, it is 50 feet thick (1790, p. 28, footnote). It is exposed at localities 2 to 3 miles east and northeast of Woodville, Marshall County, Oklahoma (174, p. 47).

Red River valley.—The easternmost outcrop of the Grayson formation in Texas is in northeastern Grayson County. On Pawpaw

Branch, 3 miles east of Stillhouse Ferry, the Grayson, about 27 feet thick, consists of blue-gray marl alternating, particularly near the top, with thin seams of grayish nodular limestone (177). The topmost limestone seam is overlain by thin blue-gray marl, and black, bituminous clay, which grades into yellow weathering Woodbine sand. At the road crossings of Sandy Creek just east and north of Cedar Mills, Bullard records the Woodbine in direct contact with the Main Street limestone, the Grayson marl being completely missing. However about a half-mile upstream from Cedar Mills, on Sandy Creek, Bullard records a normal thickness (25 to 30 feet) of Grayson, with an irregular upper contact. In a branch of Little Mineral Creek about a mile south of Fink, Bullard records about 29 feet of Grayson, consisting basally of clay marl, and, at the top, marl with a few thin limestone seams. At a locality 1 mile south of Bloomfield, Cooke County, the Grayson is 32 feet thick and consists of gray and white marl with some thin strata of white chalky limestone (189, p. 40).

Red River to Brazos River.—The best Denton County exposure is in a tall bluff 3 miles northeast of Roanoke at the edge of Denton Creek valley, where the Grayson is complete with both contacts exposed (1789, p. 73; 1791, p. 30). The section consists of about 80 feet of gray or yellowish marl, containing in the top eleven limestone ledges each less than a foot thick. These upper ledges in the Grayson are correlated with the Buda by Winton, and at a locality only a few miles south of the Grayson bluff, the uppermost hard limestone ledge is called Buda by Hill (822). About 50 feet of middle and upper Grayson is exposed near the highway 2 miles southeast of Burleson; it consists of gray and yellowish marl. At the Aquilla Creek crossing 1.6 miles west of Peoria, the Grayson-Woodbine contact is exposed. Here the Grayson is a gray-blue clay with *Pecten* and *Gryphaea mucronata* Gabb, and the basal Woodbine is a lustrous black shale with ferruginous nodules, and, basally, a thin sand and iron layer. At the R. E. Finley well 1.5 miles west of Aquilla, southern Hill County, the complete Grayson, about 75 feet thick, is exposed as a clay containing pyritic micromorphs and, near its top, thin limy layers. In McLennan County, north of the Brazos, there are numerous exposures of the upper Grayson in contact with the basal black shale beneath the *Acanthoceras* flags of the Eagle Ford (11, pp. 52–58).

Brazos River to Colorado River.—Along the Bosque escarpment in southern McLennan County, there are several exposures of the Grayson-black shale contact. These show the upper half of the Grayson, with abundant fossils. At Bosqueville, and from the Bell-McLennan line southwards to a point east of Salado, the Buda is intermittently present at the outcrop between the Grayson and the basal Gulf black shale; in the intervening portions along the contact, the Buda is absent at the contact (11, pp. 58–67; 16, pp. 48–59). A significant locality 2 miles south-southwest of Moody shows rolled and decomposed Buda limestone boulders, but no solid strata of Buda, at this contact (16, p. 52); a short distance farther south, solid Buda appears. The intermittent Buda is clear evidence of unconformity at this level. In southern Bell County, about 75 feet of Grayson is exposed; a complete section exists on the south bank of Leon River, 2.5 miles southeast of Belton. On the east bank of Lampasas River, about 4¾ miles east of south of Belton, most of the Grayson, including the basal transition zone, is exposed. From Salado southwards, the main body of the Buda is present at the outcrop, overlying the Grayson. At localities along Smith Creek, 1 to 2 miles east to northeast of Georgetown, a complete section of Grayson is exposed. The entire formation is clay, with flaggy layers near the top. The clay contains ferruginous nodules, pyrite, gypsum, and some ironstone. A complete section is exposed at the concrete bridge just above the mouth of Barton Creek in South Austin. The upper part of the formation and the Grayson-Buda contact occur at several localities along Shoal Creek. In Travis County the Grayson practically lacks the pyrite micromorphs found in the Bell-McLennan county area and the *Haplostiche texana* which is abundant in West Texas, but has abundant *Exogyra arietina* in the basal transition zone and the lower half of the formation, and abundant *Gryphaea mucronata* in the upper part.

Colorado River to Del Rio.—In Bexar County (888, p. 770; 1402, p. 110) the thickness of the Grayson is 65 to 78 feet; in Medina County, 60 feet (992, p. 39); in Uvalde County (1686, p. 7; 1681, p. 253), 50 to 137 feet; in the Brackettville region, 75 feet; in Maverick County, up to 279 feet (1681, p. 253); and at Del Rio, about 200 feet (1324, p. 15). Near San Antonio the formation consists largely of clay; on drilling it caves badly, requires casing, and is therefore known to drillers as the "mud hole." Its basal part contains some thin limy flags. The clay also contains gypsum, pyrite, and ferruginous masses; it weathers to a narrow strip of mesquite-covered, hilly topography, or else to valleys.

Thinned Grayson in lower Pecos Valley.—From about 200 feet in the clay flats south and east of Del Rio, the Grayson thins rapidly in all directions. In the hills north of Del Rio it is 50 feet thick or less. To the west it thins to about 30 feet at Comstock, to 15 feet at localities southwest of Shumla, and to nothing at a railway cut 4 miles west of Shumla and in exposures near Langtry. North of Del Rio the Grayson thins rapidly, and in the Rock Springs area is represented by 15 feet or less of calcareous seams lying between the Georgetown and the thinned Buda limestones. Westward from Langtry the Grayson thickens.

From Del Rio it outcrops in a straight band running a little west of south for 45 miles to Tinaja Azul, about 6 miles south-southwest of Remolino, Coahuila, where it disappears. Over this area it gradually thins southward, until the Georgetown and Buda come to lie in concordant contact. The upper zone of the Grayson, marked by an abundance of *Exogyra cartledgei,* as seen near El Sauz, Goodwin Ranch, and Remolino, persists, and the basal zones drop out, whether by overlap or by change of facies is unknown. In Dumble's Zorro Creek section (480, p. 377), in Coahuila near the Rio Grande, the Grayson, about 110 to 140 feet thick and containing *Pecten, Exogyra arietina* Roemer, *Exogyra drakei* Cragin, and *Haplostiche texana* (Conrad) in blue, yellow, and red clays, with bands of sandy flagstones and concretionary limestones, is like that at Del Rio. The thinning is a result of the northwest-trending Terrell arch, which runs from the Burro Mountains uplift (dome) toward the Marathon basin. West of this high axis, in Brewster County, the Grayson rapidly thickens.

In the Grayson (Del Rio) of the Guajes Valley, east side of the Sierra de Encantada about 100 km. south-southeast of Boquillas in northern Coahuila, C. L. Baker and R. B. Campbell have collected abundant rhynchonellid brachiopods together with *Kingena* cf. *wacoensis, Exogyra arietina* (?), and limonitic *Turrilites.*

Big Bend.—In Dryden Canyon, just north of the town of Dryden, the Grayson, consisting of 9 feet of loose, brownish-yellow clay, full of *Exogyra arietina* Roemer, can be seen to pinch out to the east between the Georgetown and Buda limestones. Farther west, near

Nichols Pump, the Grayson consists of 25 to 30 feet of hard, calcareous sandstone flags with abundant *Haplostiche texana* and ripple marks, indicating shallow water deposition (248, pp. 13–14). Many *Haplostiche* in this district show orientation, presumably by current action. Between Dryden and Sanderson, the thinned Grayson contains *Exogyra whitneyi* and *Hemiaster calvini*. In eastern Brewster County, thin but typical Grayson is overlain by Buda. Along the Alpine-Terlingua road, exposures show less than 50 feet of Grayson. East of the Chisos Mountains it is about 20 feet thick. In the Terlingua district (1626, p. 27) it has thickened to 120 to 180 feet at different places. The formation is a clay, with laminated flags, siliceous flags, and calcareous nodules in its top. The basal and

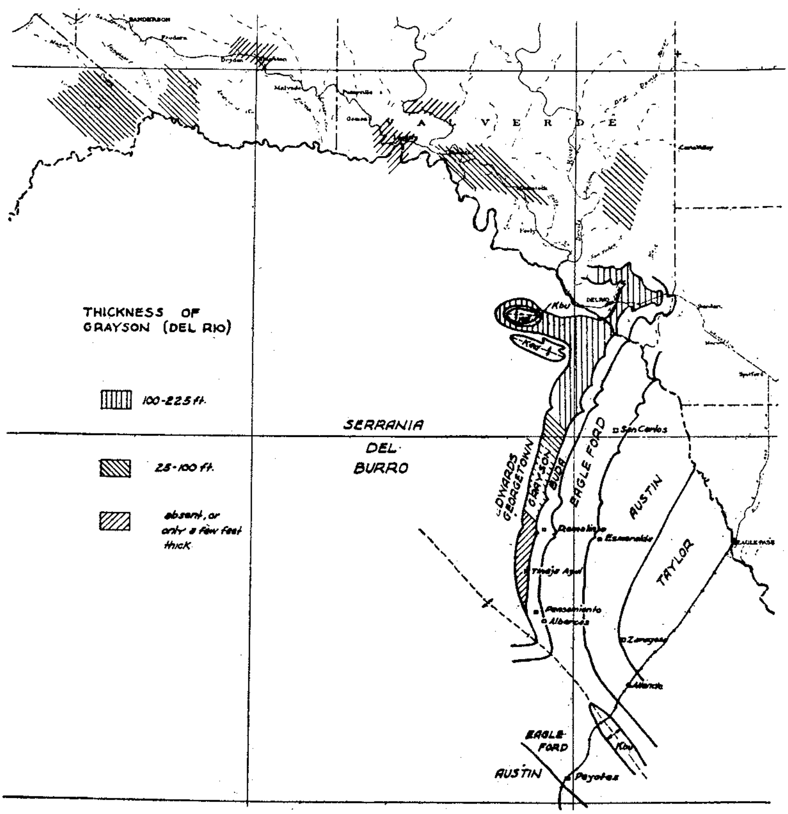

Fig. 21. Thinning of Grayson (= Del Rio) formation west and south of Del Rio. Approximate scale, 1 inch = 35 miles.

middle parts contain an abundance of echinoids (mostly *Heteraster*), *Gryphaea mucronata*, pyritized micromorphs (ammonites, gastropods), and *Haplostiche texana* in silicified flags. The top contains the zone of abundance of *Exogyra cartledgei* Böse. Excellent exposures are in the Mariposa and California Mountain district, and on the Reed Plateau south of Terlingua. In Cibolo Canyon south of Shafter, the Grayson has a thickness of 80 feet, and consists of clay with some thin ledges of fossiliferous limestone (1623, p. 39). The entire outer circumference of the Solitario dome includes a narrow outcrop of Grayson, about 125 feet thick, forming the cuesta face of the outwardly-dipping Buda limestone. This formation is a clay with a few limy seams, and has the same fossils as at Terlingua.

Near Chispa Summit, western Jeff Davis County, the Grayson is a clay with considerable nodular or flaggy limestone. In the southern Quitman Mountains, 300 feet of Grayson has been reported, consisting of ferruginous, laminated and flaggy calcareous sand, argillaceous limestone and clay, with *Haplostiche texana*. In the northwestern Eagle Mountains, near the east end of Devils Ridge, the Grayson with *Haplostiche* consists of less than 100 feet of sandy and somewhat marly limestone. Similar rock occurs in the small hills just southwest of Etholen station.

North of Southern Pacific Railway.—The Grayson rapidly thins northward, and disappears in western Pecos County. At a locality a mile north of Hovey, it is represented by about 5 feet of limy marl with *Exogyra arietina* (F. B. Plummer, personal comm.). A similar situation has been reported from a locality north of Strobel (J. A. Udden, personal comm.). It is absent beneath the Buda at the north end of the Davis Mountains. Likewise at Kent no Grayson has been reported, although thin limy banks carrying *Exogyra arietina* and referred to the Main Street occur here. Farther north there are no records of Grayson.

El Paso section.—The small ravines at the west end of the tunnel at Bowen, N. M., contain exposures of about 75 feet of Grayson, which are the No. 8 beds of Böse's Cerro de Muleros section, containing *Exogyra whitneyi* Böse and *Hemiaster calvini* Clark.

Subsurface extent.—The Grayson has not been definitely identified in most parts of the East Texas embayment. A clay at its stratigraphic position occurs in many wells in Red River, Lamar, and Fannin counties.

Mode of deposition.—The Grayson, as a whole, is a marl or clay, containing oysters and other shells. Its site of deposition was doubtless epicontinental and neritic, but at what depth or distance from the shore is not known.

Lithology; microscopic appearance; mineral content.—The formation contains gypsum, pyrite, and hydrated oxides of iron. The uppermost limestones, correlated by Winton and others with the Buda, are coarse-grained and contain foraminifera and other fossils. The lower limestones, on microscopic examination, are finer grained and less fossiliferous (1791, p. 73).

Thickness.—The following are some reported thicknesses of the Grayson:

	Feet
Oklahoma, Durant	50
Texas, Anderson County	51
Grayson County	25+
Cooke County	25
Denton County	82
Tarrant County	80+
Johnson County	100
Hill County	80–100
McLennan County	80
Bell County	105–114
Williamson County	80–125
Travis County	80–100
Mexia (969)	85–100; 55–65
Milam County	80–100
Luling (165)	80
Lytton Springs (188)	60–100
(267)	45–80
Caldwell County (728a)	50–60
Salt Flat field (1076)	50
Darst Creek field	52
Larremore field (1716a)	49
Bexar County outcrop	50–70

	Feet
S. W. Bexar County (888)	78
Medina County	60
Uvalde County (578)	75
(1681)	137
Maverick County (1681)	279
Rycade wells (578)	260
Indio ranch (578)	190
Rock Springs	20
Val Verde County	
Del Rio	200
Langtry	0
Dryden	0
Terrell County	
Comstock	40
Eastern Brewster County	25
Terlingua	120–180
Solitario	125
Presidio County, Shafter	80
Sierra Blanca	75
El Paso	60
Pecos County, Hovey	5

Paleontology.—*Exogyra arietina* F. Roemer and *Gryphaea mucronata* Gabb are currently stated to characterize the Grayson (Del Rio). *E. arietina* is present in much of the Main Street, and especially in the transition zone at its top, in association with *Kingena wacoensis* (Roemer); it is abundant in the lower part of the Grayson, where *G. mucronata* is rare; and rare in the upper Grayson where *G. mucronata* is abundant. *G. mucronata* also occurs in the basal Buda. The Grayson in the southern sections contains abundant *Haplostiche texana*, mostly in siliceous flagstones. There is a notable oyster zone in the Grayson. It comprises *Exogyra cartledgei* Böse, *Exogyra* n. sp. aff. *texana* Roemer, at least two new species of large *Exogyra* (one resembling *E. olisiponensis*, and the other smooth), and *Exogyra drakei* Cragin.

The Grayson contains the highest of five principal Washita zones of pyritic micromorphs. Its pyritic ammonites are somewhat similar to those in the Pawpaw, but show greater advancement, especially in the Mantelliceratidae. Grayson genera are: *Scaphites, Hamites, Wintonia, Baculites, Submantelliceras (Cottreauites), Adkinsia,* and several undescribed forms.

The foraminiferal fauna is distinctive, and includes the following species, which Mrs. Helen Jeanne Plummer has kindly listed:

Dentalinopsis excavata Reuss
Marginulina aequivoca Reuss
Vaginulina recta Reuss
Vaginulina intumescens Reuss
Vaginulina kockii Roemer
Lingulina nodosaria Reuss
Frondicularia denticulocarinata Chapman
Patellina subcretacea Cushman and Alexander
Gyrodina nitida (Reuss)
Anomalina falcata Reuss
Anomalina asterigerinoides Plummer
Globigerina bulloides d'Orbigny
Globigerina washitensis Carsey
Globorotalia delrioensis Plummer
Pyrulina cylindroides (Roemer)
Cristellaria (Astacolus) washitensis Carsey
Ramulina globulifera Brady
Gaudryinella delrioensis Plummer
Gaudryina sp. ("filiformis" Carsey)
Textularia washitensis Carsey
Textularia rioensis Carsey
Massalina sp.
Haplostiche texana (Conrad)—erroneously called "Nodosaria."

Foraminifera from Grayson (Del Rio) formation

(Grayson Bluff, Denton County; and Shoal Creek, Austin)

Haplostiche texana (Conrad)
Glomospira sp.
Ammobaculites subcretacea Cushman and Alexander
Textularia rioensis Carsey
Textularia washitensis Carsey
Gaudryina gradata Berthelin
Gaudryinella delrioensis Plummer
Valvulina sp. aff. trochoides (Reuss)
Lenticulina washitensis (Carsey)
Marginulina tenuissima Reuss
Vaginulina intumescens Reuss
Vaginulina recta Reuss
Dentalina communis d'Orbigny
Nodosaria obscura Reuss
Lagena sulcata (Walker and Jacob)
Massalina sp.
Gümbelina sp. aff. globifera (Reuss)
Dentalinopsis excavata (Reuss)
Valvulineria asterigerinoides Plummer
Gyroidina nitida (Reuss)
Anomalina falcata (Reuss)
Globigerina washitensis Carsey
Globigerina sp. cf. lacera (Ehrenberg)
Globorotalia delrioensis Plummer

The arenaceous foraminifer, "*Nodosaria*" *texana* Conrad, has been variously referred to "a new genus somewhat like *Cribrogenerina*" by the present writer (12, p. 47), to *Haplostiche* by Plummer (1238, p. 124), and to a new genus *Cribratina* by Sample (1362a, p. 319). It or closely similar species occurs in Trinity, Fredericksburg, and Washita formations, and is most abundant in the Weno in north Texas and in the Grayson in west Texas.

The following are the most characteristic Grayson ostracoda:

Cythereis burlesonensis Alexander
Cythereis roanokensis Alexander
Cytherelloidea obliquirugata (Jones)
Macrocypris graysonensis Alexander (lower Grayson only)

BUDA FORMATION[44]

Nomenclature. — Shumard, during his two years residence as State Geologist in Austin, missed this formation entirely. Hill's 1889 papers introduced the names "Shoal Creek limestone," "Burnt limestone," and "*Vola* limestone," referring respectively to Shoal Creek, Austin, Texas, to the oxidized glauconitic specks characteristic of the weathered limestone, and to *Pecten roemeri* Hill, a Buda guide fossil. The name Buda was first used, at Hill's suggestion, by Vaughan (1687, p. 18) in 1900 for the preoccupied name Shoal Creek (also: 803, p. 288). The type locality is on Shoal Creek at Austin.

Stratigraphy and contacts.—The Buda is a south Texas formation, both in central and in Trans-Pecos Texas; northwards it thins and disappears. The main body of its outcrop does not reach farther north than central Bell County, east of Salado. Thence northwards to Bosqueville, west of Waco, it has an intermittent outcrop. It passes underground in an east-northeast direction, and is known in wells at Axtell and near Kosse. A small thickness has been thrust up to the surface in the Palestine salt dome. In east Texas it has not been recorded. At a locality in southern Denton County, a hard limestone in the upper Grayson has the lithology of the Buda, and it has been considered of that age by Winton and by Hill; Buda zone fossils have so far not been recorded from it. In western Texas, Buda occurs at El Paso. At Bosqueville, Buda is overlain by Woodbine sandstone, elsewhere by Eagle Ford or by the lustrous black shale or clay at the base of the Eagle Ford flags. The Buda-Grayson contact has not been recorded, but is probably conformable.

Facies.—Several minor variations occur in Texas. (1) Marginal facies, as in Bell County. This rock consists of an impure, discolored, fragmental, organic, coralliferous limestone, containing

[44]*Literature.*—Vaughan, 1687, p. 18; Hill, 803, p. 288; Hill and Vaughan, 795, p. 237; 808; Adkins, 11; Adkins and Arick, 16; Lahee, 969; Udden, 1625, 1626; Getzendaner, 578, 578a. *Paleontology:* Böse, 134; Hill, 752; Hill and Vaughan, 796; Lasswitz, 976; Shattuck, 1447; Whitney, 1756, 1757; Vaughan, 1688.

much ground up shell fragments and debris and some whole shells, and locally resembling a coquina or coquina detritus. The limestone contains some sand and clay. Iron blotches and stains are common. The rock is porous, roughly nodular, and poorly bedded. It contains abundant stocks and heads of compound corals, and some simple corals. Locally this limestone is missing, and is probably marked by an unconformity above, although this has not been proved. (2) A submarginal facies of crystalline limestone with shells, shell fragments, glauconite specks, and red blotches, the typical "burnt limestone" phase so widespread in central Texas. (3) A compact, fine-grained, "porcellanous" facies, as at Chispa Summit, the Solitario, and southwards into Coahuila, a dense, light-colored limestone with pronounced conchoidal fracture, resembling the Ellenburger-like Edwards in central Texas or the Georgetown at Terlingua. (4) A rudistid limestone facies, as near Sierra Blanca and Del Rio.

Areal outcrop; local sections.—The Buda is a south Texas formation; it does not occur much north of Waco, the southern Edwards Plateau, San Martine, and El Paso.

It has been questionably identified from the southwest side of the Sabine uplift. A limestone referred to the Buda is the lowest outcropping formation on the Palestine salt dome.

> [The limestone] is a hard, dense white rock which can be fractured with difficulty and is very different from the brittle Austin chalk. It contains casts of fossils, a small smooth *Exogyra* sp. and an impression of an ammonite which appears to be a Lower Cretaceous form. According to Dr. L. W. Stephenson and Miss L. L. Lane (personal communication) it is probably Buda, the highest formation in the Washita group of the Lower Cretaceous. About 25 feet of limestone is exposed on the south side of the hill south of the Woodbine sand. Evidently it was formerly in contact with the salt, because nearby salt wells find salt at about 150 feet overlain by secondary deposits (1252, pp. 256–257).

In southeastern Denton County the uppermost, hard, crystalline limestone ledge in the Grayson has been considered Buda (822, 1791), and Winton states that the upper 12 feet (consisting of several limy ledges) or perhaps more, of the Grayson in Denton County is of Buda age. A collection of fossils from this locality, made by Dr. Hill and now in the Department of Geology of The University of Texas, consists of high Washita species, but lacks the usual Buda markers.

At various upper Grayson localities, one or two marly-chalky nodular limestone seams occur in the uppermost Grayson; these contain high Washita fossils, but, so far, nothing conclusively Buda has been reported from them.

In Keas' Branch at Bosqueville, McLennan County, there is a unique outcrop of 2.5 feet of Buda limestone, overlain by about 2 feet of thin-bedded, brown Woodbine sandstone, part of it with strong cross-bedding. The Buda contains *Pecten roemeri* Hill, *Gryphaea mucronata* Gabb, *Exogyra* n. sp. aff. *texana* Roemer, and weathered pelecypod casts. The Woodbine contains *Ostrea carica* Cragin, and, in loose blocks near China Springs, *Ostrea* aff. *soleniscus* Meek. The upper surface of the Buda is irregular and much corroded, and the Woodbine unconformably overlies it.

From Bosqueville south to the McLennan-Bell County line, the Buda is absent; rock in this area considered and mapped Buda by various geologists is the Eagle Ford flags. At the county line 2 miles southwest of Moody, solid Buda is absent, but its place is occupied by an iron-stained gypsiferous clay in which many rolled and decomposed Buda boulders are imbedded. This is underlain by a foot of light gray, sandy clay and typical Grayson clay; it is overlain by the lustrous black shale and clay at the base of the Eagle Ford flags. North and south of this locality, the Buda is absent on the outcrop. Southward to Salado the Buda is at some places present and at other places absent. To the Old Howard School, a distance of 8.8 miles from the county line, it is present; at Pepper Creek School it is present; a small outcrop occurs on the south bank of Leon River, about 2.5 miles southeast of Belton. Between these places it is absent. The main outcrop, extending south into south-central Texas, begins at a point 3 miles east of Salado. Throughout Bell County the Buda, where present, is 2 to 5 feet thick. This intermittent outcrop shows that the thin landward edge of the Buda rock sheet suffered erosion and partial destruction in the interval between the end of Buda deposition and the beginning of the black shale (Upper Cretaceous) deposition. This erosion was probably submarine. Across Williamson County the Buda increased in thickness from 5 to 20 feet, and, in wells, 30 to 59 feet is recorded. The thickness slowly increases down dip. In Travis County outcrops, it is 42 to 47 feet thick, and, in wells, 25 to 54 feet has been reported. The well at Axtell, McLennan County, had a small thickness of what appears to be Buda limestone. In wells near Mexia 55 to 70 feet is reported.

In Bexar County the Buda is 55 to 65 feet thick, in Medina County about 60 feet. In these counties it is a dense, hard, fine-grained, buff or light gray limestone, tinged with blue or yellow, and, on weathering, locally blotched with red. It has a smooth conchoidal fracture, and is generally distinctly nodular. Farther west the nodular feature is absent, and the limestone is a medium, even-bedded, dense, fine-grained limestone, of a "porcellanous" or semi-lithographic type, and is only sparsely fossiliferous. Some portions of the formation, in the Big Bend, however, remain more clayey and nodular. North of San Antonio the lithology is entirely different. The fresh rock is blackish to bluish gray, somewhat marly, slightly nodular, and contains innumerable small specks and fragments of lime and shell debris. These specks are ferruginous, perhaps originally from glauconite, and weather to brick-red or bright red spots. This is the "burnt" limestone of the early literature. The marginal facies in Bell County is this same texture exaggerated; in wells near the outcrop other somewhat intermediate varieties of this clastic type occur. Throughout south-central Texas, the Buda is a coralliferous formation, but near the margin in Bell County the corals are larger, more varied, and more abundant.

In the Uvalde area, 60 to 75 feet of Buda is reported; in Val Verde County, 50 feet or more; in Zorro Creek, in northern Coahuila, 80 feet of heavy-bedded semi-crystalline limestone of creamy-white color (480, p. 377). In the Solitario rim the Buda is 100 feet thick; in the Terlingua area, 80 to 90 feet; and in the Shafter district, about 70 feet thick. Near Rock Springs, the cap of the Edwards Plateau consists of thinned Buda overlying thin Grayson (1524, p. 407). Buda occurs around the northeastern edge of the Davis Mountains, in the San Martine area, and at El Paso. In this area the northward thinning of the Buda is less easily studied than in central Texas, because of lack of outcrops.

In microscopic section the Buda is rather easily recognized by its clastic, organic contents; with careful study it is distinguishable from the very similar limestones of the Eagle Ford flags.

Paleontology.—So far as known, *Budaiceras* (several species) and some undescribed ammonites, *Exogyra clarki, E.* n. sp. (like *texana*), *Pecten roemeri* Hill, *Codiopsis texana* Whitney, *Mantelliceras* *hoplitoides* (Lasswitz), and *Mantelliceras budaense* Adkins are restricted to the Buda. *Gryphaea mucronata* and *Exogyra arietina* range up into the basal Buda. Many upper Washita species occur in the Buda. So far as known, no megafossil is common to upper Comanche and basal Gulf series.

It seems definitely established that the Buda is of basal Cenomanian age, and correlates with a part of the Mantelliceratan division of Spath; the upper Cenomanian (Acanthoceratan) is represented in the upper Woodbine and the basal Eagle Ford.

GULF SERIES[45]

Nomenclature.—The Gulf series includes all sedimentary strata above the base of the Woodbine and below the base of the Midway. The name "Gulf Series" was first used by Hill (731, p. 298) in 1887 in essentially its present-day meaning, and since that time it has generally been recognized as a valid stratigraphic unit in Texas. Previously, Roemer (1330, 1331) had included mostly Gulf strata in his "Kreide am Fusse des Hochlandes," and Shumard's (1463) "Upper Cretaceous or Calcareous division" included the Austin, Eagle Ford and several Comanche formations. Marcou (1042) placed the Austin chalk and Eagle Ford in his "Upper Cretaceous or Senonian" and some of the Eagle Ford in his "Middle Cretaceous or Greensand and Turonian." Shumard (1474, 1475) announced the presence of Dakota strata with dicotyledonous leaves, and of Ripley in Texas. Papers of later writers who have given general

[45]*Literature.—Arkansas:* Dane, 392. *Louisiana:* Spooner, W. C., Interior salt domes of Louisiana, Bull. Amer. Asn. Petr. Geol., 10: 217–292, 1926. (See also bibliography on Trinity group.) *Northeast Texas:* Fohs, 543; Gordon, 608, 609; Hager, 640; Hill, 816; Levorsen, 987a; McFarland, 1079; Powers, 1248, 1252; Renick, 1298; Stephenson, 1530; Thomas, 1601a. *North-east Texas:* Adkins, 11, 16; Decker, 401; Hager, 637; Hill, 731, 732, 803; Lahee, 965, 969; Matson, 1059, 1060, 1062; Shuler, 1454; Stephenson, 1534, 1539. *Chalks:* Ellisor, 521; Gordon, 608; Hill, 816; Reiter, 1297; Taff, 1575a, 1578; Thomas, 1601a, 1601b. *South-central Texas:* Hill, 803, 808; Jones, 888; Liddle, 992; McCollum, 1076; Pace, 1168; Roemer, 1330; Sellards, 1402; Taff, 1574; Vaughan, 1685, 1686. *Rio Grande Embayment:* Böse, 135; Dumble, 468, 480; Getzendaner, 578, 578a; Udden, 1625; Hill, 795; Tatum, 1590. *Trans-Pecos Texas:* Baker, 44, 45, 46, 48, 55, 56; Udden, 1626, 1628; Vaughan, 1687; Cragin, 331; Stanton, 1521. *Gulf Coast:* Decker, 401; Deussen, 421; Fenneman, 537; Judson, 898; Hopkins, 843. *Mexico:* Tatum, J. L., General geology of northeast Mexico, Bull. Am. Asn. Petr. Geol., 15: 867–893, 1931. Böse, 135; Burckhardt, 181; Dumble, 480. *Western Interior:* Darton, 395; Reeside, 1291. *Paleontology:* Adkins, 13, 15, 20; Alexander, 30; Böse, 134; Carsey, 199; Clark, 253; Cragin, 324; Hill, 735, 755; Israelsky, 869; Meek, 1081a; Moreman, 1140; Plummer, 1238; Scott, 1389; Stanton, 1518; Stephenson, 1527, 1532, 1532a; Thomas, 1600; Wade, 1700; White, 1753. *Igneous rocks:* Hill, 765, 808; Kemp, 900; Lonsdale, 1009; Lord, 1014; Ross, 1353; Vaughan, 1686, 1687; Baker, 44.

or local accounts of the Upper Cretaceous in Texas are included in the bibliography and accompanying literature lists.

Synonyms: Upper Cretaceous (of most writers); Ojinaga (Burrows, 1910).

Definition.—The lower limit of the series is defined lithologically by the presence of the underlying Grayson or Buda at most places. Paleontologically no exact definition can be given at present. The basalmost Gulf strata are of Cenomanian age, like the underlying Grayson-Buda and the overlying flagstone (Tarrant) of the Eagle Ford. Some minor correlations, as the age of the Pepper shale, still remain in doubt. The upper contact is likewise debatable. At most places the Navarro-Midway contact is distinguishable, though various writers have debated the extent of the hiatus (1528, 1535a, 1389, 1390, 572).

Economic importance.—The Woodbine outcrop forms the sandy Eastern (Lower) Cross Timbers in northeast Texas, and underground the Woodbine sands form important reservoirs for artesian water, oil, and gas. The remaining Gulf formations in northeast Texas compose the Black Land belt (Black Prairie), an important cotton and agricultural country. Lime and clay products, volcanic ash, cinnabar (in the Eagle Ford near Terlingua), oil and gas, coal, and numerous minor resources, occur in Upper Cretaceous rock formations.

Stratigraphic position and contacts.—The Comanche-Gulf contact is generally if not everywhere unconformable. On the high structures in northwestern Louisiana, the beds of the Comanche series were uplifted and eroded before the deposition of the Gulf series. From Cerrogordo, Arkansas, westward to Grayson County, Texas, the Woodbine unconformably rests on a beveled surface of Comanche formations ranging upwards from Kiamichi to Grayson. Thence southwards to Bosqueville, McLennan County, the Buda is absent and the Gulf series rests on the Grayson marl. Thence south to Bexar County and west to El Paso the Woodbine sand is absent, and the Eagle Ford rests on Buda. The ravining at this contact mentioned by Dumble (506, p. 19) is caused by solution of underlying limestones and slump of the Eagle Ford into the solution cavities. Near Tucumcari, New Mexico, and in Cimarron County, Oklahoma, the Dakota unconformably overlies Duck Creek. Gulfwards from the outcrop in north Texas the Grayson, and in south Texas the Buda, underlie the Gulf series, apparently concordantly and possibly unconformably. On some interior salt domes, formations adjacent to this contact have been elevated to the surface or to a shallow depth. Thus on the Palestine dome, Woodbine and higher formations are reported at the surface, and on some other domes Gulf formations are reached at shallow depths. In the cap rock of the South Liberty salt dome between depths of 2022–2057 feet, Upper Cretaceous foraminiferal marls have been found (1142). The Upper Cretaceous-Eocene contact is generally distinct and is apparently represented by a break in sedimentation. Unfortunately the Upper Cretaceous and basal Midway zonation is too imperfectly known to establish the extent of the break between the two systems. The high zones of *Sphenodiscus* and *Parapachydiscus* aff. *colligatus* at Lampazos, Arroyo de Caballeros, and Eagle Pass indicate upper Maestrichtian age, but the lack of known sediments on the Gulf Coastal Plain filling the interval alleged to be missing prevents exact knowledge of the magnitude of the hiatus. The facts about the Cretaceous-Eocene contact are even less clear in Trans-Pecos Texas, where near-shore and apparently non-marine conditions intervene. The Tornillo clays, containing saurian bones and therefore supposedly Cretaceous, lack distinctive zone fossils. The overlying Chisos beds including volcanics are of undetermined age. The evidence on this problem is summarized in the discussion on the highest Cretaceous. At most places outside the Coastal Plain the highest Cretaceous has been subsequently removed.

Extent.—The Upper Cretaceous in Texas outcrops in seven main areas: (1) Northeast and central Texas: from the northeast corner of the state westward to Grayson County, thence southward to near San Antonio, thence westward to near Eagle Pass; small faulted inliers are located on the Palestine and other domes. (2) An area of Eagle Ford and Austin chalk in Val Verde and Terrell counties, identical with that along Zorro Creek and elsewhere between the Burro Mountains and the Rio Grande. (3) The Chisos-Terlingua area, Brewster County. (4) The Chispa Summit-San Carlos-Presidio and Van Horn Mountains area. (5) The Davis Mountains area. (6) The Quitman-Eagle Mountains area. (7) The Cerro de Muleros area (Eagle Ford) in Chihuahua and New Mexico just northwest of El Paso. In addition, in northeastern New Mexico and in Cimarron County, Oklahoma, near the Texas line, Upper Cretaceous occurs. Gulf formations extend underground for an unknown distance in the Gulf Coastal Plain and the Rio Grande embayment.

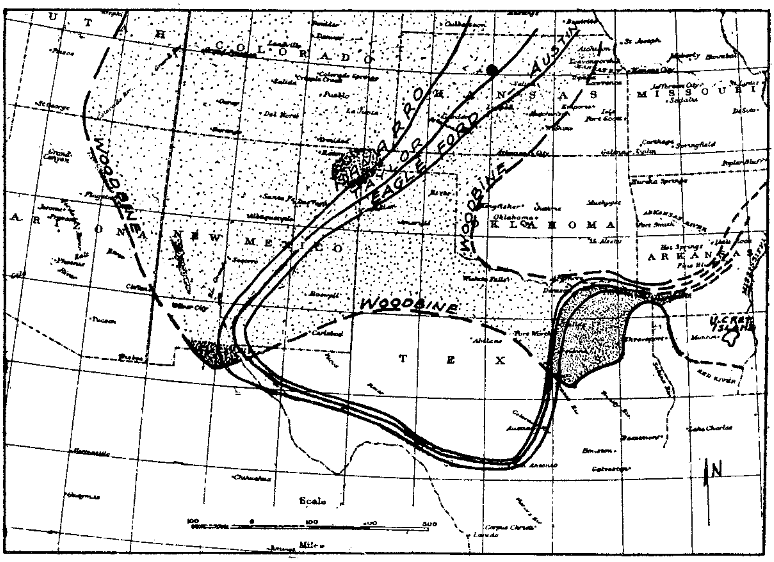

Fig. 22. Known extent of outcrops of the five groups of the Upper Cretaceous in and near Texas.

Stippled area in Texas is Woodbine (heavy dots = known Woodbine; open dots = Woodbine inferred but now absent through subsequent removal). The four remaining groups are absent over a large area in Oklahoma and north-central Texas but occur *exterior* to the lines shown. This is not a paleogeographic map.

Regional structure.—Gulf formations are present over the Sabine uplift and other structurally high areas in northern Lousiana. They pass through the East Texas embayment and the Fort Worth embayment and their thicknesses are reduced over the San Marcos Arch. They thicken extensively in the Rio Grande embayment, where their upper members become marginal or non-marine (Tulillo, Olmos, Aguja, Tornillo, Vieja). Numerous smaller structural features are discussed in their appropriate connections.

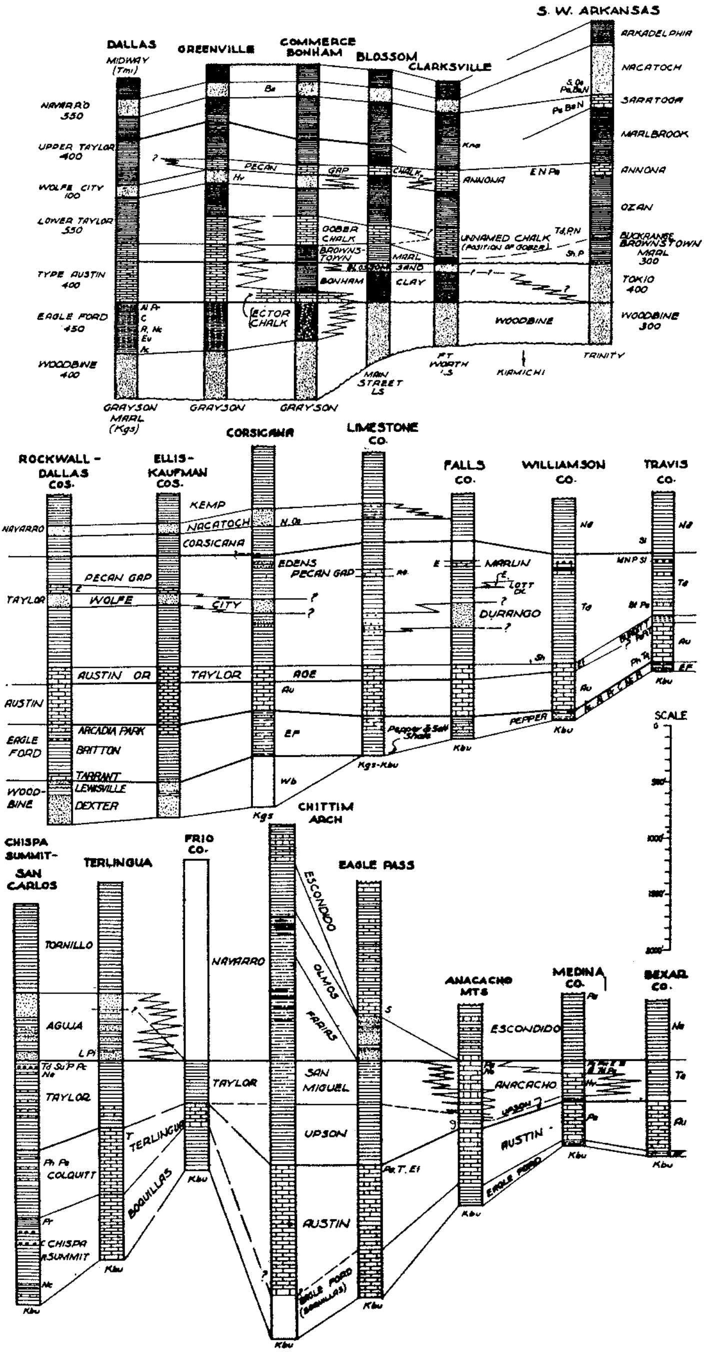

Fig. 23. Correlation of Upper Cretaceous in Texas.

Facies.—The most varied facies mark the Gulf series. It is impracticable to summarize them briefly. Various kinds of marginal sediments occur in the Woodbine, Taylor (Wolfe City), Navarro (Nacotoch, Tulillo), the uppermost Cretaceous (Aguja, Tornillo), and at other levels. Most of the series consists of normal, fossiliferous epicontinental (neritic) sedimentation. The series is notable for the large amount of argillaceous material, although extensive chalky limestones and some more crystalline limestones occur. From the Woodbine on, volcanic materials are prominent.

Igneous materials in Gulf series.—Bentonite is widespread at many Upper Cretaceous levels in Texas (1353, 578a). Basaltic plugs are numerous in a belt extending parallel to the Balcones fault zone from Austin to the Rio Grande (1009, 765, 808, 1686). Serpentine intrusives, many of them occupying a position near the base of the Taylor, occur in central Texas, and some of them contain commercial oil. The principal known ones (summarized in Sellards, 1444a) are: Thrall, Chapman, Yoast, Lytton Springs, Dale, Buchanan, Lytton Springs townsite, Schimmel-Batts, Zavala County (several wells), Kimbro, Darst Creek, and the Uvalde region. The main stratigraphic position of the serpentine is the basal Taylor, but it occurs also as stringers or otherwise at lower levels (1009, 187, 188, 1444a, 1641). In Trans-Pecos Texas, there is a great variety of intrusive

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Navarro:
- Ba Belemnitella americana
- Oo Ostrea owenana
- S Sphenodiscus
- Sl Sphenodiscus lenticularis
- N Nostoceras
- L Libycoceras (?)

Taylor:
- M Menuites
- B Bostrychoceras aff. polyplocum
- Pa Parapachydiscus
- Pw Parapachydiscus aff. wittekindi
- Pg Parapachydiscus aff. gollevillensis
- P Placenticeras
- Pm Placenticeras meeki
- Pi Placenticeras intercalare
- Hv Hoplitoplacenticeras aff. vari
- Pc Pseudoschloenbachia chispaense + spp.
- E Echinocorys texanus + spp.
- Td Texanites aff. delawarense
- Su Submortoniceras n. sp.
- Ne Neancyloceras
- Bt Baculites taylorensis
- Sh Scaphites hippocrepis

Austin:
- Et Exogyra tigrina
- T Texanites spp.
- Tq Texanites quattuornodosum
- Pc Puzosia aff. corbarica
- Ph Phlycticrioceras
- Pe Peroniceras

Eagle Ford:
- Al Alectryonia lugubris
- Pr Prionotropis
- C Coilopoceras
- Nc Neocardioceras
- R Romaniceras
- Eu Eucalycoceras
- Ac Acanthoceras

igneous bodies in both Lower and Upper Cretaceous rocks. Sills and dikes are common. A ring-sill of felsite encircles the Solitario rim at a basal Glen Rose level; and other felsite sills occur in the Comanche and Gulf rocks at higher levels. The bentonites are of various, mostly Upper, Cretaceous ages; the intrusives are mostly of post-Cretaceous age.

Topography; vegetation; soils.—In humid central Texas, the Upper Cretaceous forms generally either Cross Timbers with sandy soil and oak vegetation, as in the Woodbine and parts of the Taylor, or prairies with deep, fertile, chocolate to black soil, as in the more clayey formations. The harder members form landward facing cuesta scarps, such as the White Rock escarpment of the basal Austin chalk. Much of this prairie was primitively covered with mesquite and other small trees and with scattered motts of oak or elm. In the more arid and mountainous Trans-Pecos Texas the soil cover is often lacking; the soft formations produce flats and badlands.

Paleontology and zonation.—More detailed notes on fossils are given under the discussions of separate formations. The following tentative zonation of the Upper Cretaceous formations is presented, subject to revision when further details are known. The selection of a zone fossil from an assemblage restricted in vertical range is often arbitrary, and in general the one known to have the greatest horizontal range is chosen. In practice the best general markers are certain ammonite genera. For more detailed work, however, species are equally valid, provided they have sufficiently wide distribution. The following generic ranges are valuable: *Dufrenoya, Douvilleiceras, Parahoplites* in the Trinity; *Oxytropidoceras, Dipoloceras* and *Adkinsites* in the Fredericksburg and Kiamichi; "*Pervinquieria,*" *Prohysteroceras, Submantelliceras, Stoliczkaia,* in the Washita; *Metoicoceras, Eucalycoceras, Romaniceras, Neocardioceras, Thomasites, Fagesia* and others in the Eagle Ford; "*Mortoniceras*" in Austin and higher formations; *Placenticeras* in mostly Taylor equivalents; *Sphenodiscus* in Navarro equivalents.

PROVISIONAL ZONATION OF UPPER CRETACEOUS IN TEXAS[46]

Group and formation	*Zone fossil*	*Associated fossils*
Escondido-Navarro	4. Parapachydiscus aff. colligatus	Parapachydiscus spp.
	3. Coahuilites	
	2. Sphenodiscus pleurisepta	Sphenodiscus spp.
	1. Sphenodiscus lenticularis	
	7. Nostoceras spp.	Sphen. lenticularis Menuites stephensoni n. sp.
	6. Echinocorys texanus	Bostrychoceras aff. polyplocum Parapachydiscus aff. gollevillensis; P. aff. wittekindi
Taylor	5. Hoplitoplacenticeras aff. vari	Parapach. streckeri; Neancyloceras clinense
	4. Mortoniceras aff. delawarense	Pseudoschloenbachia; Plac. sancarlosense; Anisoceras
	3. Placenticeras guadalupae	
	2. ?Baculites taylorensis	Parapachydiscus travisi Scaphites verrucosus
	1. Scaphites hippocrepis	
Burditt chalk marl	10. Parapuzosia americana	Exogyra tigrina + spp. Ostrea centerensis
Upper Austin chalk	9. Texanites sp. 8. Barroisiceras dentatocarinatum	
Middle Austin chalk	7. Austinites n. gen. 6. Texanites minutum[46b] 5. Gauthiericeras sp.	
Lower Austin chalk	4. Barroisiceras dartoni 3. Peroniceras aff. westphalicum 2. Texanites quattuornodosum 1. Coilopoceras austinense	
EAGLE FORD:		
Arcadia Park	9. Alectryonia lugubris	
	8. Prionocyclus aff. wyomingense	
	7. Prionotropis spp.	Scaphites vermiculus

[46]These species and zones are more fully described in a forthcoming publication on ammonites.

[46b]Spath (1511b, p. 379) has restored the name *Mortoniceras* to the Washita ammonites formerly called "*Pervinquieria*," and has renamed the common Upper Cretaceous genus *Texanites* (genotype: *Amm. texanus* Roemer).

Group and formation	*Zone fossil*	*Associated fossils*
	6. Coilopoceras eaglefordense	C. chispaense + spp.
	5. Romaniceras-Metoicoceras	
Britton	4. Neocardioceras spp.	Pseudaspidoceras spp.
	3. Eucalycoceras bentonianum	Metoicoceras irwini
	2. Acanthoceras wintoni	
Tarrant	1. Acanthoceras tarrantense	
WOODBINE:		
Lewisville	4. Acanthoceras sp.	
	3. Aguilera cumminsi-Ostrea soleniscus	
Dexter	2. Plants	
Pepper?[46a]	1. Euhystrichoceras?-Metacalycoceras?	
COMANCHE SERIES:		
Buda	2. Pecten roemeri	
	1. Budaiceras	
Grayson (="Del Rio")	2. Adkinsia	Turrilites bosquensis
	1. Graysonites n. gen.	Exogyra arietina

WOODBINE GROUP

Nomenclature.—The first description of Woodbine[47] strata was published by B. F. Shumard (1474, p. 140) in 1863, when he announced the discovery of dicotyledonous leaves (*Salix, Ilex,* and *Laurus*) in yellowish sandstones and bluish shales in Lamar County, and correlated the beds with the Dakota of Meek and Hayden. He correctly placed these strata below his "Marly clay or Red River group" (Eagle Ford). The Lower (Eastern) Cross Timbers belt, underlain by the Woodbine formation, was noted by early travelers and was described by William Kennedy (902a) in 1841. It was mapped by R. H. Loughridge (1017) in 1884 for the tenth census.

[46a]The Woodbine age of the typical Pepper clay, as also the other basal Gulf clays beneath the Tarrant flaggy limestone, has not yet been definitely established.

[47]*Literature.—Arkansas:* Dane, 392. *East Texas:* Plummer, 1232; Bullard, 177; Stephenson, 1530. *North-central Texas:* Stanton, 1522e, 1523; Scott, 1391; Winton, 1789, 1791; Hill, 803; Adkins, 11, 16; Lahee, 969. *Trans-Pecos Texas:* Böse, 129. *Paleontology:* Hill, 803; Berry, 105; Adkins, 13; Plummer, 1234b; Scott, 1391; Cragin, 324. *Igneous rocks:* Getzendaner, 578, pp. 1428–1429; Ross, 1353. *Deposition:* Scott, 1391; Plummer, 1234b; Shuler and Millican, 1455b.

Hill in 1887 described the Lower and Upper Cross Timbers belts more minutely and gave the name "Timber Creek group" (731, pp. 296, 298, 300) to the formation now called Woodbine. In 1891 he pointed out the value of these beds as an artesian reservoir (780, pp. 69–70). The formation was first called "Woodbine" by Hill in 1902 (803, p. 292), the type locality being near Woodbine, eastern Cooke County, Texas. The Woodbine, formerly called a formation, is here considered as a group, and consequently units, as Lewisville and Dexter, formerly vaguely called "beds," are here considered formations.

Stratigraphy and contacts.—Both the lower and the upper contacts of the Woodbine are unconformable at many places, but further study is required before it can be stated that they are everywhere unconformable.

Basal contact.—On the outcrop north of Bosqueville, McLennan County, the Buda limestone is absent, and the Woodbine everywhere directly overlies the Grayson. At Bosqueville a thin remnant of Woodbine overlies about 2 feet of Buda limestone. South of this point the Woodbine is absent, unless it should prove to be represented by the thin Pepper shale lying beneath the Tarrant flaggy limestone and unconformably above the Grayson or Buda. In the El Paso district a sandstone in the position of the Woodbine (Dakota) overlies the Buda. Gulfwards from the outcrop, the formation underlying the Woodbine is reported as a clay of the stratigraphic position of the Grayson, in Fannin and Lamar County wells and in the East Texas embayment.

At certain places the upper formations of the Lower Cretaceous are removed, and the Woodbine rests on lower formations. This situation exists eastward from Grayson County. Thus at Cedar Mills, Grayson County (177, pp. 49–50; 1575, pp. 282, 295; 1391; 1539, p. 1327), a massive 10-foot stratum of Woodbine sand with a layer of hematite concretions in its base directly overlies Grayson marl, which is reduced to only 2 feet in thickness. This occurrence may represent the subsequent planation of the top of the Washita group, which becomes more pronounced farther east, for in passing down the Red River valley the Comanche series is beveled off and the Woodbine rests on successively lower formations. Thus at Cerrogordo, Arkansas, the Woodbine rests unconformably on

Kiamichi clay, and farther east, on Trinity sand. Scott (1820, p. 2) denies any visible unconformity at the base of the Woodbine from Red River southward to Hill County, but the contact at most localities is invisible because of overwash. A second area in which the Woodbine (Dakota) rests unconformably on lower Washita rocks is in Dallam County in the northern Llano Estacado. Here, as C. L. Baker has recently reported, sands lithologically referable to the Dakota directly overlie shales and sands of probable Purgatoire age. At localities in an adjoining county, Cimarron County, Oklahoma, the Purgatoire contains typical Duck Creek ammonites but lacks fossils known to be from any higher level.

Upper contact.—No discordance of dip at the Woodbine-Eagle Ford contact is suggested in sections made at Bear Creek, western Dallas County (1575, p. 292), Walnut Creek, Tarrant County (1575, p. 292) and Chambers Creek, Johnson County (1575, p. 302). However, Stephenson (1539, p. 1327) considers that at most places from Tarrant County southwards where the contact has been examined, an unconformity is indicated by the sharp lithologic change and by the presence of mechanically reworked material in the base of the Eagle Ford. He says: "At several localities in Johnson and Hill counties water-worn sandstone pebbles as much as 2 inches in their longest dimension were observed in this basal bed, and in a new road cut a mile northeast of Tarrant station, Tarrant County, the basal bed of the Eagle Ford beneath beds carrying *Acanthoceras* aff. *A. rotomagense* Defrance consists of a hard conglomerate containing many dark phosphatic pebbles and some fish bone fragments, resting on Woodbine sandstone."

Subdivisions.—The following are the more prominent subdivisions of the Woodbine at the outcrop between Brazos and Red rivers, particularly in the Denton-Tarrant county section:

Eagle Ford fish and shell layer

————*unconformity*————

D. Black, lustrous clays, containing *Ostrea carica* Cragin. These may be a brackish water deposit. They are provisionally included in the Lewisville formation.

C. Typical Lewisville clays, sandy clays, and sandstone, with marine fauna.

B. Non-marine sands with volcanic material and fossil plants; Dexter sands.

A. Basal clays. Taff (1575, p. 292) reports them at the Denton brick plant, where they are about 25 feet thick and are overlain by Dexter sands. Winton (1791, p. 36) reports the basal clay from the Sanger-Pilot Point road, and from cores of the Tarrant County Water Improvement District. It is local in occurrence and in lithology: Taff reports that at places it is sandy and lignitic. A basal Woodbine clay, thin and sporadic, has been reported in wells in the East Texas embayment. A clay in this stratigraphic position, outcropping from Bell County southward, is here called the Pepper formation. Its correlation with the basal Woodbine clay in Denton and Tarrant counties and in eastern Texas is still unsatisfactory.

————————*unconformity*————————

Grayson clay (Buda at Bosqueville, McLennan County).

Facies.—As will be pointed out in the discussion of the Wilcox group, Woodbine and Wilcox show many similarities in types of materials and in probable depositional history. The Woodbine group begins with a thin, fine grained, mostly non-calcareous clay, which is marine and fossiliferous at least in Tarrant, Bell, and Travis counties. The reservations must be made, however, that these clays have not all been proven contemporaneous with each other, nor has their Woodbine age been proved. The one in Bell County unconformably overlies Grayson clay. They are likely all near-shore deposits. They are succeeded by the Dexter sand. This formation consists of water-bearing pack sands and locally of indurated sandstone layers, some of which form the caps of the various Brushy Knobs along the Woodbine outcrop from Hill County northward to Grayson County. These sands are leaf-bearing and not typically marine, or at least no marine invertebrates have been recorded from them. Eastward from Hyatts Bluff, Fannin County, Woodbine clays contain much decomposed volcanic material (1113a, 1353), and may represent outwash on a rather flat depositional plain, but may be in part marine because they are closely associated with beds containing invertebrate fossils (*Ostrea soleniscus?*, *Metoicoceras*, *Metengonoceras*). These beds are suggested to be of upper Woodbine age (1353, p. 198). The Lewisville beds are a near-shore sandy deposit and contain marine fossils. The upper black, lustrous clays contain oysters, and are a near-shore, marine or brackish, deposit. The overlying Eagle Ford is a neritic marine deposit. On account of difficulties of correlation, the facies of the

Woodbine in the East Texas embayment is imperfectly known. The Dakota in western Texas is supposedly non-marine.

Areal outcrop; local sections.—The outcrop and subsurface occurrence of the Woodbine in Texas comprise a squarish sand-clay sheet about 120 by 180 miles in extent, occupying an area of about 21,000 square miles. The northern and western edges of this sheet are formed by the outcrop, from which the rocks dip gulfwards into the East Texas embayment. The sheet is roughly bounded on the north by the Red River valley; on the west by the interior margin of the Eastern Cross Timbers belt, which borders the interior edge of the Black Prairie and runs from near Gainesville to near Waco; on the south by an underground line passing roughly from Waco eastwards to Leon County, Palestine and Nacogdoches; and on the east by a line roughly paralleling the western edge of the Sabine uplift (see fig. 22).

The Woodbine outcrops along Red River valley in a narrow southward dipping strip from Cerrogordo, Arkansas, west to Orlena, Cooke County, Texas (mapped in 1353, pl. 20). Thence the outcrop runs south to near Aquilla, southern Hill County, near the Brazos (mapped in 803, Pl. LXVI). South and east of these outcrops it dips gulfwards and is buried beneath younger sediments (1232, 1234b). North and west of the outcrop the Woodbine has been removed by erosion over central Texas, but remains in the El Paso region (128a, 129), in Dallam County (615), in Cimarron County, Oklahoma (Rothrock, Okla. G. S. Bull. 34, 1925), and probably at other places in the Texas Panhandle. The Woodbine has been correlated with the Dakota by C. A. White and by later writers. It is possible that Dakota sediments covered most of the Llano Estacado, but whether all of north Texas east of the Llano and west of the central Texas outcrop was so covered is unknown. The extent of the various facies and the position of the shore lines of the Woodbine remain to be investigated.

Outcrop in Arkansas and Oklahoma.—Two features distinguish the Woodbine in Arkansas and Oklahoma from that in north Texas: in McCurtain County, Oklahoma, and eastwards in southern Arkansas, it contains much tuffaceous material; and in Arkansas it contains near the base considerable gravel deposits. In southwestern Arkansas the Woodbine consists of 300 feet or less chiefly of gravel and cross-bedded sand, a large part of which contains water-laid volcanic materials, and minor amounts of red, dark gray and brown clay (392, pp. 17–29; 1353). The base of the Woodbine is a gravel bed, with a maximum thickness of 60 feet, which thins and disappears to the west. In size the material ranges from small grains to cobbles 5 inches in diameter. The pebbles are subrounded or well rounded. Most of them are novaculite, some are quartzite or chert, a few are kaolinized, porphyritic igneous rock. The upper part of the formation consists typically of sand containing grains of novaculite and igneous rocks, and gravelly lenses and beds. The formation contains lenses and beds of calcite-cemented sandstone preserving microscopic tuff structure, and unconsolidated sand containing pockets of red clay, the product of oxidation and decomposition of volcanic material. Dark, leaf-bearing clays have been found in Arkansas, but no invertebrate fossils. The cross-bedded, assorted tuffaceous sands and gravels are a waterlaid deposit. Leaves and carbonized wood indicate the nearness of land. The occurrence of basal gravel, calcite, glauconite, and the wide, uniform distribution of the volcanic materials indicate marine deposition, according to Dane, though some of the materials, as the red clay and the coarser lenticular gravels may be subaerial deposits.

Red River valley.—In southern Bryan and Choctaw counties, Oklahoma, the Woodbine has a thickness of about 500 feet, and in Fannin County, Texas, an apparent thickness of 625 feet (1353, p. 178). In northeastern Texas and in Bryan and Choctaw counties, Oklahoma, the Woodbine consists of irregularly bedded quartz sand, which was deposited in shallow-marine and brackish water, and of films, lenses, and layers of clay, and cross-bedded, water-laid volcanic sands and tuffs. At Golden Bluff, 3 miles east of Arthur City, Lamar County, and at a locality 2 miles east of Kanawha, northwestern Red River County, *Ostrea soleniscus,* a Woodbine fossil, occurs. It is overlain by Eagle Ford west of Woodland, northwestern Red River County, and by Bonham clay east of that point. In northwestern Fannin County, as at Hyatts Bluff, tuffaceous sandstone occurs in the Woodbine.

Grayson-Cooke counties.—The basal Woodbine is of variable composition. At Cedar Mills, massive sand overlies the Grayson. On Rock Creek, northeastern Grayson County, the Grayson is overlain by 10 to 15 feet of lignitic clay containing thin seams of lignite, lignitic sand and lignitized wood debris; this is succeeded by massive beds of yellow and brown sand, interstratified with lenses of blue and black clays. At a locality 6 miles southeast of Gainesville, Taff observed the Woodbine sandstone resting directly on Grayson marl, without an intervening clay stratum. In a branch of Choctaw Creek about 7 miles east-southeast of Denison, Taff reports that above the Grayson there is about 20 feet of purplish-blue, lignitic clay, overlain by considerable cross-bedded Woodbine sandstone. North of Denton County, the Dexter sand makes a conspicuous outcrop, forming a sandy, timbered soil strewn with blocks of dark, ferruginous sandstone and siliceous ironstone concretions. This outcrop passes northwards through Woodbine, Callisburg, and Dexter, and at a point south of Orlena turns eastward down the Red River valley, and continues thence through Gordonville, Pottsboro, and Woodlake. The knobs of Iron Ore Ridge consist of Dexter clays and sands capped by hard, fossiliferous Lewisville sandstone. The Dexter sands in Grayson County reach a thickness of 250 feet, of which the basal 100 feet contains much dark brown indurated ferruginous sandstone and ironstone concretions. The bulk of the Dexter consists of sandstone, sand, and clay. The sandstone ranges from soft to hard, from massive to thin bedded, and in color from white or greenish to yellow, brown, and red. The grains are coarse and quartzose, the cementing material calcareous or siliceous. In Denison the basal part of the Dexter consists of free white sand and a small amount of mica flakes and glauconite specks. This portion of the Woodbine yields dicotyledonous leaves at localities near Denison (803, pp. 314–317).

The Lewisville beds become more clayey and less sandy northwards from Timber Creek, the type locality. Near Gordonville they consist of dark-blue clay, and brown sandy clay containing beds of impure lignite up to 3½ feet thick. Lignite outcrops in Walnut Creek north of Gordonville and near Big Mineral Creek between Gordonville and Pottsville. On Hickory and Big Mineral creeks the Lewisville has increased in thickness and consists of sandy clays (the proportion of sand having decreased) and several local seams of lignite up to 3 feet in thickness. Hill places the top of the Woodbine at a greenish-gray sandstone stratum containing *Exogyra columbella* Meek.

Denton-Tarrant counties.—The basal clay in this district consists of 5 to 25 feet of fine-grained, blue-black or purplish-black, practically non-calcareous clay, deposited in irregular sheets of different thicknesses, but devoid of shaly lamination and breaking with a conchoidal fracture. The clay is marine, and carries ammonites (*Mantelliceras* or *Submantelliceras*, Scott), pelecypoda, gastropoda, and foraminifera. It is exposed on the Sanger road west of Pilot Point, and has been found in core drills in Tarrant County, but at most localities on the outcrop it is badly overwashed by Woodbine sand. It is overlain by apparently non-marine sands and sandy clays. Scott considers the basal clay as having been deposited near the mouths of rivers draining lowlands (1820, p. 2).

Southeast of Denton the 10 to 15 feet of thin layers of ferruginous sand and sandy clay at the base of the Woodbine is succeeded by thick Dexter sands. At the Denton brickyards the basal Woodbine consists of dark blue to gray clay, some sandy clay, and thin seams of blue-gray, blackish and reddish sandstone.

The Dexter sand, which reaches a thickness of 100 feet or more in this region, is difficult to partition because of its inconsecutive exposures. It has at least two main sandstone members, the lower one, containing fossils, being exposed around Burleson and at localities 2 miles or more west of Tarrant station, the other being exposed in cuts just east of Tarrant station. The intervening strata are dark laminated clays and sandy clays.

The Lewisville in Tarrant County includes sandstones, sandy clays, and lustrous, black, oyster-bearing clays, as exposed around Tarrant station (1575, pp. 293–294). Taff published a section of 200 or more feet of Lewisville sands, sandstones, and clays at the type locality, Timber Creek south of Lewisville, southeastern Denton County.

Johnson-McLennan counties.—At the outcrop the Woodbine thins from 300 feet at the Tarrant-Johnson county line to nothing in northern McLennan County. Underground it thickens in a northeast direction toward the East Texas embayment. On North Chambers Creek, 6 miles southeast of Alvarado, the upper 68 feet of Woodbine consists of sandstone and clay, both the upper and the basal strata containing Lewisville fossils (1575, pp. 290–291). On South Chambers Creek north of Grandview, the upper 71 feet of Woodbine consists of sandstones and some clay, with Lewisville fossils. The Dexter sands and clays have a large outcrop to the west of these localities. On Cottonwood Creek south of Osceola, northern Hill County, the upper 86 feet of the Woodbine consists of sandstones, packsands, and clays, with Lewisville fossils in the upper part. Near Aquilla, southern Hill County, sands, sandstones, and clays form the middle and basal Woodbine, but no Lewisville fossils are recorded from this section (1575, p. 288). At the R. E. Finley well, 2 miles south of west of Aquilla, 13 feet of white and brown sandstone and blue shale represents the Woodbine (11, p. 39). Between this point and Bosqueville, west of Waco, any thinned Woodbine is represented in the black, lustrous shales beneath the Eagle Ford flags. At Bosqueville about 2 feet of Woodbine sandstone with *Ostrea* cf. *carica* Cragin overlies the Buda. Near China Springs limestone blocks contain *O. soleniscus* (11, p. 59). South of this locality the Woodbine, if present, is represented in the black, lustrous shales beneath the *Acanthoceras* flags.

The materials and mode of deposition of the Woodbine have been somewhat studied. The materials (Ross, Miser and Stephenson, 1353; Plummer, 1234b; Kelsey and Denton, 899b) consist of quartz (angular to rounded; clear, milky, gray, pink, purple), clay and silt, volcanic ash, bentonite, carbonaceous material, black chert, glauconite, marcasite, pyrite and other substances. In outcrop and well samples, and from all parts of the Woodbine, generally about 70% by weight of the grains falls in grade 3 (.295–.147 mm. diameter). In the Red River valley the Woodbine contains much volcanic material (1353). The deposition (Scott, 1391; Shuler and Millican, 1455b) is notably lenticular, and is stated to be regulated by current action. Shuler and Millican state that the Upper Woodbine (Lewisville) in south-central Denton County was marked by shallow, off-shore, lenticular deposition of "materials transported from the northeast for distances necessary for moderate sorting." The section shows several southwardly advancing lentils of sand, sandstone or sandy clay (one of them called the "Copperas Branch tongue," 1455b, p. 19).

Subsurface in outcrop-counties.—Wells in the northern tip of McLennan County passed through only a small thickness of Woodbine: in the F. & M. well at Leroy there was logged 5 feet (855–860) of hard sand rock, but in the Wirt Franklin, J. A. West No. 1 well sands bearing salt water were found for an interval of 118 feet (975–1093). Thence the subsurface margin of Woodbine as recorded in wells passes southeastward across Limestone County, and crosses the Mexia fault south of Groesbeck. The Woodbine isopachs run in a southeast direction, and between Hillsboro and Hubbard the formation is 100 to 150 feet thick.

Northwards across Johnson County, Woodbine in wells thickens from 160 feet to about 300 feet, in Tarrant County it is about 325 to 350 feet, in the Dallas wells reported by Shuler it is given as about 325 feet, and in Grayson County it probably reaches a thickness of 500 feet.

East Texas oil field. (Decker, 401; Gugelmeyer, 633a; Lahee, 971; Levorsen, 987a; McFarland, 1079; Moos, 1138c).—The principal production is from the Woodbine. On passing eastwards toward the East Texas oil field and up the west flank of the Sabine uplift, the Eagle Ford and Woodbine successively thin out and disappear. The Eagle Ford disappears in eastern Smith County, leaving the Austin overlying the Woodbine. Farther east, along the east edge of the field in central Gregg County and western Rusk County, the Woodbine disappears, leaving the Austin (Tokio) unconformably overlying the Lower Cretaceous (1079, pp. 845–846, figs. 1–2). This unconformity is stated to be an effect of uplift and subsequent erosion: during Eagle Ford times the area was elevated and the beds truncated, and in Austin time the sea again covered these truncated beds. The Austin (Tokio) is somewhat sandy, and its base is a conglomerate derived from earlier formations, consisting of rounded, water-worn pebbles one-quarter to one-half inch in diameter, of chert and chalk in a matrix of chalky silt (Plummer and Sargent, 1234b, p. 16).

Southern extension of the Woodbine.—From McLennan County southwards a purplish-black, non-calcareous clay, which lies above the Grayson (or the Buda) and below the *Acanthoceras* flags of the Eagle Ford, has been considered as the southern extension of the Woodbine by Stephenson and several other writers. This clay has been best studied in the Belton-Temple section. It is here called the Pepper formation.

PEPPER FORMATION

Nomenclature.—The basal, non-calcareous, blue-purplish clay-shale which extends southwards from the Woodbine outcrop proper in McLennan County and underlies the *Acanthoceras* flags of the Eagle Ford is a distinct stratigraphic unit. It is separated from the underlying Grayson (Del Rio) by an unconformity, represented by a pebble conglomerate. Its top is marked by a sharp break in the character of sedimentation, the overlying Tarrant formation being an arenaceous flaggy limestone containing much fish debris, phosphatic bodies and fossil wood, and showing many evidences of shallow water deposition. The Pepper shale has a distinct fauna, now being studied. In the past its categorical reference to either the Woodbine or the Eagle Ford has only added to the confusion regarding its age, and for these reasons it is here separately named. It may be a part of the Woodbine, a question still open for debate. Taff (1575, p. 299), and later Stephenson (1534, p. 3), have expressed the idea that the "basal Eagle Ford shale" south of the Brazos is of Woodbine age. They brought forward no fossil evidence to support the idea. Taff thought the Woodbine must be present because he thought there was continuous deposition from Buda to Eagle Ford times, and Stephenson's correlation was purely lithological. The type locality of the Pepper shale is taken to be an exposure on a small branch of Pepper Creek, just south of the Belton-Temple highway, Bell County, Texas, and 1.6 miles east of the easternmost of two underpasses of the highway under the Santa Fe Railway.

Outcrop.—The type locality of this shale was described in detail by Adkins and Arick (16, pp. 51–59). The basal reworked zone is about ½ foot thick at most places. It is succeeded by a clay, having a rough conchoidal fracture and no fine shale lamination but with horizontal bedding planes at intervals of a few inches. This clay is carbonaceous and blackish blue when wet, but dull purplish gray when dry, especially in its lower part. It contains a fauna of ammonites, pelecypods, gastropods, and other fossils, preserved as delicate impressions, often crushed, or as thin films of shelly material.

The member outcrops entirely across Bell County, and perhaps in McLennan County; however, much of the basal Gulf shale in McLennan County hitherto called "basal Eagle Ford shale" is different from the Pepper in fossils and lithology, and contains a large normal marine fauna, including the soft-shelled turtle, *Protostega gigas* Cope, other reptilian bones, various species of *Inoceramus*, one of them reaching 2 feet in diameter, and many other fossils (11, pp. 75–77). Nor is it certain that the intermittent, thin, purplish-black clays which underlie the base of the Woodbine sandstone in east Texas wells is the same as the Pepper, although the lithology is similar. Drs. Winton and Scott have studied cores from the basal part of the Gulf series in wells of the Tarrant County Water Improvement District. Some of this material is similar lithologically and paleontologically to typical Pepper shale, but other cores contain fossils not yet found in the Pepper (1791, p. 36). The "basal Eagle Ford shale" near Austin is somewhat similar in lithology and fossils to the typical Pepper shale. A shale in this stratigraphic position is recorded as far south as Medina County.

Paleontology.—At the type locality the Pepper contains a considerable fauna of gastropods, pelecypods, and a few ammonites preserved as delicate impressions. One ammonite suggests *Neocardioceras,* and another is a small *Scaphites* with nodes on the straight portion. Dr. Spath identified one ammonite as possibly a *Euhystrichoceras.* Other fossils from this locality are: *Plicatula* sp. aff. *arenaria* Meek, *Tapes* sp. aff. *cyprimeriformis* Stanton, *Avicula* sp. aff. *gastrodes* Meek, and *Anchura* sp. The pebble layer at the base of the formation contains reworked *Exogyra arietina, Gryphaea mucronata,* other oysters, fish remains, phosphatic and rounded quartz pebbles and other detritus. From the Tarrant County cores Dr. Spath identified an ammonite as possibly *Metacalycoceras,* and Dr. Scott identified a doubtful *Mantelliceras* (?) or *Submantelliceras* (?). From a basal sandstone core near Van, *Turritella* aff. *seriatim-granulosa* Gabb (not F. Roemer) is known. In Bouldin Creek, South Austin, many gastropods and pelecypods occur.

Dr. Spath states that "the largest specimen [from the cores of the Tarrant County Water Improvement District] probably is some "*Calycoceras,*" but determinations are suggested only because the Cenomanian age is known." Of the fossils from the type locality of the Pepper clay, he says that "it is just possible that one is a *Neocardioceras.* The best of all the specimens, a dwarf-form [desmoceratid] like *Flickia* or *Adkinsia,* but without suture line and also indeterminable, does not help in dating this assemblage" (Dr. L. F. Spath, personal communication). Another type Pepper species is an unrolled, tuberculate *Scaphites*-like form with long straight portion, which Dr. Spath says is "not like anything known"; still another resembles keeled, ribbed Schloenbachids, and seems closest to *Euhystrichoceras,* but is still unndetermined. The ammonites from this level are now being studied by the writer.

Mrs. Helen Jeanne Plummer has kindly washed and examined material from the ammonite-bearing purplish clays above the reworked layer and about 2 feet above the base of the formation at the type locality, and has made the following statement:

The thinly laminated, grey, and slightly variegated shale washes to a small concentrate in which small, white, and underdeveloped foraminiferal tests are very frequent. The most abundant form is a species of *Ammobaculites* in

which the initial coil is very conspicuous. More rare forms consist of a minute *Ammobaculites*, very small *Ammodiscus*, and a very delicate *Reophax*.
Though arenaceous forms obviously developed in somewhat adverse environment do not constitute final evidence of geologic age, these forms are much more closely related to Upper Cretaceous faunas than to those of the Lower Cretaceous. These species have no relation to those of the Grayson or Del Rio formations, but are similar to species in the Eagle Ford and other Upper Cretaceous faunal groups. I feel no hesitancy in referring this shale to the Upper Cretaceous series.

Age.—The exact age of the type Pepper clay is still unknown. It overlies the upper Grayson (Del Rio) and underlies the Tarrant flagstone at its type locality. The basal contact is an apparently concordant one and is marked by a detrital bed of quartz pebbles and other coarse material, and the exact nature of the upper contact is unsettled (apparently it is concordant). The shales at the base of the Gulf series in Travis and Tarrant counties and in east Texas may be equivalent to the Pepper shale, but their age is still unknown.

Mineral content.—Kelsey and Denton (899b) mention the following characteristics of the heavy mineral content of the Woodbine: titanite is rare; garnet is either absent or meager; zircon is not present in large amount.

Paleontology and zonation.—Knowledge of Woodbine zonation is so imperfect, the fossiliferous localities so scattered, and the fossiliferous levels in the formation so restricted, that only a general composite account of the paleontology is here outlined. Probably Woodbine time covers only a short interval of relatively rapid deposition, at least if judged by Spath's (1510) English zonation, where it would be practically limited to his *vectense* and *diadema* zones of the Upper Cenomanian, since the Buda (*q. v.*) is of Mantelliceratan age (Lower Cenomanian) and the basal *Acanthoceras* zone of the Eagle Ford is about the middle of the Upper Cenomanian (*rotomagense* zone). Subject to further confirmation of these correlations, the Woodbine would represent a lower portion of the Upper Cenomanian.

Woodbine paleontology has been most studied near Lewisville, Denton County, and Tarrant, Tarrant County. Here the fossils are partitioned as follows:

	Feet
5. Upper sandstone; hard to friable, ferruginous sandstone with shells and fish teeth; (zone of *Acanthoceras* n. sp., 2 miles north of Grandview); *Exogyra columbella* Meek, *Ostrea soleniscus* Meek, *Ostrea carica* Cragin, *Exogyra* sp., *Barbatia micronema*	20–30
4. Upper shales, blue-black, gypsiferous, some seams of sand, lignite and ironstone; *Ostrea carica* Cragin	80
3. Lewisville beds (zone of *Aguilera cumminsi*); *Aguilera cumminsi* White, *Ostrea carica* Cragin, *Ostrea soleniscus* Meek, *Exogyra ferox* Cragin, *Arca galliennei* var. *tramitensis* Cragin, *Trigonarca siouxensis* (Hall and Meek), *Barbatia micronema* Meek, *Pteria salinensis* White?, *Modiola filisculpta* Cragin, *Cytherea taffi* Cragin, *Cytherea leveretti* Cragin; *Turritella renauxiana* d'Orbigny?, *Cerithium tramitensis* Cragin, *Cerithium interlineatum* Cragin, *Natica humilis* Cragin, *Nerita* sp. Cragin; Timber Creek near Lewisville, Denton County; localities in Hill County; about	100
2. Dexter sands; yellow ferruginous sandstone and cross-bedded sands, and brown siliceous ironstone seams and nodules containing dicotyledonous leaves; about	100
1. Basal clays; dark laminated clays; *Mantelliceras* (?) or *Submantelliceras* (?) pelecypods, gastropods; exposed on Sanger-Pilot Point road	5–25

Between Denison and Sherman in the uppermost Woodbine, Hill records *Cyprimeria, Ostrea soleniscus, Arca,* and *Exogyra columbella.* In northwestern Fannin County in arenaceous marl of supposed Dakota age, Cragin records *Ostrea lyoni* Shumard, *Exogyra ferox* Cragin, and *Cytherea taffi* Cragin. Stephenson reports in a sand stated to be of either upper Woodbine or lower Eagle Ford age *Metengonoceras dumbli, Metoicoceras swallovi* Shumard and *Acanthoceras* sp. In a greensand at the top of the section (Woodbine?) at Pine Bluff, Lamar County, Hill records an ammonite *(Scaphites?)* and a crab attached to a log of lignite, and in the clays at the top of the bluff *Axinea* and *Scaphites.* From Johnson and Hill counties Taff (1575, pp. 288–291) records abundant Lewisville oysters, pelecypods, and gastropods. The Timber Creek locality is described by Taff (1575, pp. 287–288) and by Hill (801, pp. 309–310).

Woodbine invertebrates are listed by Hill (801, p. 314) and plants by Hill (801, p. 314) and by Berry (105).

From the Woodbine in Texas there have been recorded: Cephalopoda 3 species, Pelecypoda 15, Gastropoda 5, and plants 43 (2

Gymnosperms and 41 Dicotyledons). It must be kept in mind that Berry considers the Arthurs Bluff plant-bearing beds (called Dexter sands of Hill) as more probably the "time equivalent of what is called Eagle Ford in the Austin section."

EAGLE FORD GROUP

Nomenclature.—The first mention of Eagle Ford[48] equivalents in the geological literature on Texas was by Ferdinand Roemer, who in 1852 included in his "formations at the foot of the highland" in the New Braunfels region the black Eagle Ford shales with fish remains. These Upper Cretaceous rocks east of the Balcones fault he considered to be Lower Cretaceous and to be overlain by Edwards limestone, which he considered as of Turonian age. The next mention of Eagle Ford was in the writings of B. F. Shumard, who placed it at different places in his geological column, depending on what part of Texas he was describing. Relying on his brother's observations in Grayson County, he established for the Eagle Ford the "Marly Clay or Red River Group," which he placed correctly above the Woodbine sands but incorrectly at the base of the entire Cretaceous column. However, from his own observations near Austin, he placed the Eagle Ford fish bed with mososaur remains in its proper position below the Austin chalk; but at another place (1463, p. 587) he records the "blue marl with *Inoceramus problematicus*") as lying just below the Georgetown and just above the Glen Rose. Marcou in 1862 (1042) correctly placed the fish beds, the blue marl with *Inoceramus problematicus* and the Marly Clay or Red River Group all beneath the Austin chalk. In 1887 Hill (731, pp. 296, 298) placed these strata in the basal Gulf series above the Woodbine sands, and first applied to them the name "Eagle Ford shales." The type locality is at Eagle Ford, Dallas County, about 6 miles west of Dallas, where the uppermost part of the formation is exposed.

Stratigraphic position and contacts.—The Eagle Ford is everywhere overlain by the Austin chalk or its equivalents, such as the

[48]*Literature.—North-central Texas:* Bullard, 177; Scott, 1391; Hill, 803; Taff, 1574, 1575. *South-central Texas:* Hill, 803; Deussen, 421. *Rio Grande Embayment:* Udden, 1625, 1626; Christner, 248; Roberts, 1324. *Trans-Pecos Texas:* Adkins, 20; Baker, 46; Böse, 129; Hill, 722. *Paleontology:* Adkins, 20; Alexander, 30; Böhm, 126; Hyatt, 867; Moreman, 1141; Shumard, 1464a; Stanton, 1518; Stephenson, 1540. *Igneous rocks:* Ross, 1353.

Bonham clay in Fannin County. It is underlain generally by the Woodbine as far south as Brazos River, where the Woodbine disappears at the outcrop, and south of the Brazos by either the Pepper shale or the Buda limestone. In west Texas it is underlain by the Buda, except at El Paso and in parts of the Llano Estacado, where Dakota equivalents appear to be present. However, at a few localities the top of the Comanche series is missing, and the Eagle Ford there rests on lower formations. Thus at most places in Bell and McLennan counties Eagle Ford directly overlies the Grayson marl. Locally on the Sabine uplift, the Eagle Ford, if present, is in a marginal facies, and overlies either the Woodbine or the older uplifted and beveled rocks of the Trinity or Fredericksburg Cretaceous which compose the post-Washita erosion surface on which the Upper Cretaceous formations were deposited in this region.

Basal contact.—The Woodbine-Eagle Ford contact is unconformable at several localities north of the Brazos, but has not been investigated at most places. In a road cut a mile northeast of Tarrant station, Tarrant County, the basal bed of the Eagle Ford "consists of a hard conglomerate containing many dark phosphatic pebbles and some fish bone fragments, resting on Woodbine sandstone" (1539, p. 1327). At several localities in Johnson and Hill counties the basal bed of the Eagle Ford contains "water-worn sandstone pebbles as much as 2 inches in their longest dimension." In McLennan and Hill counties the Woodbine sand is absent and the Tarrant flaggy limestone, forming the base of the Eagle Ford, is concordantly underlain by Pepper shale, which in turn unconformably overlies the Grayson marl. This situation is observed as far south as Medina County. West of Brackettville the Eagle Ford is present in the form of limestone flags (Boquillas facies), which directly overlie the Buda limestone with a slightly undulating contact. These relations occur in many places in Trans-Pecos Texas in the Chisos and Terlingua quadrangles, in the lower Pecos Valley, in the Solitario rim, at the northern ends of the Eagle and Davis mountains, and elsewhere.

The Buda-Eagle Ford contact is unconformable at many places in south-central Texas. At Towne's Mill and other places in Williamson County the contact has been recorded as concordant (1574, p. 350), but Cragin (324, p. 243) records *Prionotropis* and fish debris in the basal layer of the Eagle Ford and considers that the Woodbine equivalents are totally absent and that the contact is unconformable. The contact is better known near Austin. In a cut made in October, 1930, at 19th and Nueces Streets, the upper surface of the Buda limestone was seen to be only slightly undulating, with an irregularity of as much as 6 inches vertically in 2 feet horizontally, and the basal stratum of the Eagle Ford is a layer of porous, ferruginous material, 1 to 3 inches thick, containing Buda limestone in the form of granules and small pebbles in an advanced stage of decomposition. This layer is overlain by 15 feet of blue-black shale containing sulphur yellow streaks, as was exposed in pits at the new fire station at the same street intersection. Above this basal shale is the Eagle Ford flaggy limestone (Tarrant?). The same sequence occurs in the diversion channel of Bouldin Creek at the crossing of the Barton Springs road in South Austin, and at other places near the city. At these places small fragments of Buda are included in the basal Eagle Ford. In Bear Creek west of Manchaca a large exposure of this contact reveals a slightly undulating surface and a thin basal ferruginous layer.

Upper contact.—The Eagle Ford-Austin contact is generally unconformable in central Texas. It is marked in northeast Texas by Taff's "fish-bed conglomerate," a layer up to a foot thick of reworked Eagle Ford material containing oysters, fish teeth and other fossils. This has been observed at several places in Grayson County. In the Texas Portland Cement Company's quarry 3 miles west of Dallas, Stephenson records phosphatic pebbles in the base of the Austin chalk just above the contact with the Eagle Ford shales. He traced it southward to Hays County, and in Hays and Travis counties recorded borings extending from the base of the Austin chalk for as much as 18 inches down into the Eagle Ford shale and filled with glauconitic chalk like the basal Austin chalk (1539, p. 1328). At several localities near Austin the basal 3 feet of the Austin chalk contains many rounded or irregular phosphatic pebbles up to 3 inches in diameter.

Subdivisions.—Dr. W. L. Moreman divides the Eagle Ford in central Texas into three units, the definitions here given being abstracted from a description which he kindly furnished. They are, in ascending order: Tarrant, Britton, and Arcadia Park formations of Moreman.

Tarrant sandy clay and limestone.—Type locality: one mile east of Tarrant station (Tarrant County), at crossing of St. Louis, San Francisco and Texas railway over a tributary of Bear Creek. Typical thickness: 15 feet. Lithology: gray and brownish-gray sandy clay and intermittent thin brownish limestone strata and calcareous concretions. The basal stratum, unconformably overlying the Woodbine sand, is a phosphatic pebble conglomerate, 1 to 6 inches thick. The top is a parting of limonitic material less than 1 inch thick. Fossils: *Acanthoceras tarrantense* (Adkins), *Metengonoceras dumbli* (Cragin), *Exogyra columbella* Meek. Areal extent: The typical lithology and fossils persist from southern Denton County to southeastern Tarrant County. Northwards the unit is represented at Slate Shoals, Lamar County, by sandy clay containing *Metengonoceras dumbli.* Southwards it is 1 foot thick on Mountain Creek, Johnson County, and on the Waco highway south of Alvarado, and 5 feet thick in central Bell County (16, pp. 49–61). In Williamson and Travis counties, the Eagle Ford flag is 10 to 20 feet thick. However, from Bell County southwards its fauna differs markedly from that at Tarrant, and it may not be of exactly the same age; and the lithology has changed from sandy clay with thin interbedded limestone, to thin limestone flags with subordinate interbedded clay and bentonite seams. Age: Upper Cenomanian.

Britton clay.—Type locality: Britton, northwestern Ellis County. Typical thickness: 250 feet; near Dallas, about 300 or more feet. Lithology: mostly blue clay; a few flaggy limestone seams and calcareous concretions, the latter becoming more abundant near the top of the unit. The lower one-third of the unit is blue clay, capped by a 10-foot bed of black shale having near its top a 3-inch bentonite seam; it is overlain by 20 feet of white or yellowish laminated marl. This basal third of the unit seems to disappear north of Denton County and south of Hill County, leaving the upper Britton in contact with the Grayson (or Pepper). The upper blue clay portion of the Britton is continuous from Red River to Austin. It is thickest in the latitude of Dallas, thinner to the north, being represented by 30 to 50 feet of blue sandy clay, and at Austin is reduced to a few feet mainly by thinning of the several beds. The Britton grades upward into the Arcadia Park. *Met. swallovi* occurs in the base of the Eagle Ford in Grayson County, and at Slate Shoals, Lamar County, in sandy clay.

Fossils: The Britton contains two zones: (a) basal one-third, zone of *Metoicoceras irwini* Moreman; (b) upper portion, zone of *Metoicoceras whitei* Hyatt. Other fossils in Britton formation: *Metoicoceras gibbosum* Hyatt, *Placenticeras pseudoplacenta* var. *occidentale* Hyatt, *Baculites gracilis* Shumard, *Inoceramus labiatus* Schlotheim, *Inoc. capulus* Shumard.

The type locality of the Britton clay may be taken as tributary of Newton Branch 3¾ miles south of Britton, on the Midlothian road.

Arcadia Park shale.—Type locality: Arcadia Park station, 7 miles west of Dallas, on the Fort Worth-Dallas interurban. Typical thickness: about 100 feet; thins to north and to south, about 10 feet thick at Austin. Lithology:

The type section consists of basally 20 feet of blue clay; then 1 to 3 feet of thin limestone flags forming escarpment and dip-slope; the upper part, 75 feet of blue shale containing numerous calcareous concretions of various sizes. On Red River the upper part is sandy and the lower part blue shaly clay with a few thin scattered sandstone seams. Southwards, in McLennan and Bell counties, the unit is laminated marl; at Austin the lower part is flaggy, laminated marl and the upper part blue shale. The Arcadia Park unit is unconformably overlain by the Austin chalk; the transition zone, Taff's "Fish Bed Conglomerate" (1575, pp. 299–304), is composed of clay containing gypsum, phosphatic pebbles and reworked pelecypods (many *Alectryonia lugubris*) and fish remains. At White Rock escarpment on the Dallas-Fort Worth road, it is about a foot thick. Fossils: the ammonites are typically prionotropid; *Prionotropis* aff. *woolgari* (Mantell) is abundant in the basal part, particularly in the limestone flags, associated with *Inoceramus dimidius* White. The upper part contains *Prionotropis, Prionocyclus,* and near the top a zone of abundance of *Alectryonia lugubris* (Conrad).

It may be noted that in the Waco area Prather (1256, 1257) applied the name "South Bosque marls" to the upper Eagle Ford.

Facies.—Five facies occur in Texas:

(1) Black shale facies (type): Lustrous shales, well laminated, black or locally pinkish-black when fresh but weathering gray to rusty-brown, compose the bulk of the formation in north-central Texas as far south as Waco, where a flag member is intercalated near the base. Above the flags in south-central Texas is a black shale with bentonitic streaks.

(2) Flag facies (Val Verde, 468, p. 221; Boquillas, 1626, pp. 29–33): From Waco southwards on the outcrop this member occupies increasingly more of the basal part of the Eagle Ford. Westwards from San Antonio the amount of black shale decreases, and in Val Verde, Terrell, Brewster, and Presidio counties, all of the Eagle Ford is of the flag facies. The transition takes place between Uvalde and Brackettville.

(3) Clay (Mancos) facies: The Eagle Ford equivalent in the Chispa Summit region, western Jeff Davis County, has almost entirely the clay facies, with a subordinate amount of thin platy layers and bands of septaria and concretions; it is here called the *Chispa Summit formation.*

(4) Chalky limestone seams, as at Chispa Summit. The upper Eagle Ford near the Val Verde-Maverick county line is reported to be chalky, somewhat like the overlying Austin.

(5) Marginal facies, composed of igneous detritus, as at King's Water Hole, Uvalde County (1009, 1686).

Throughout central and east Texas, the Eagle Ford, especially in its upper part, contains much bentonitic and similar clayey material in thin seams interbedded with the flagstones or shales.

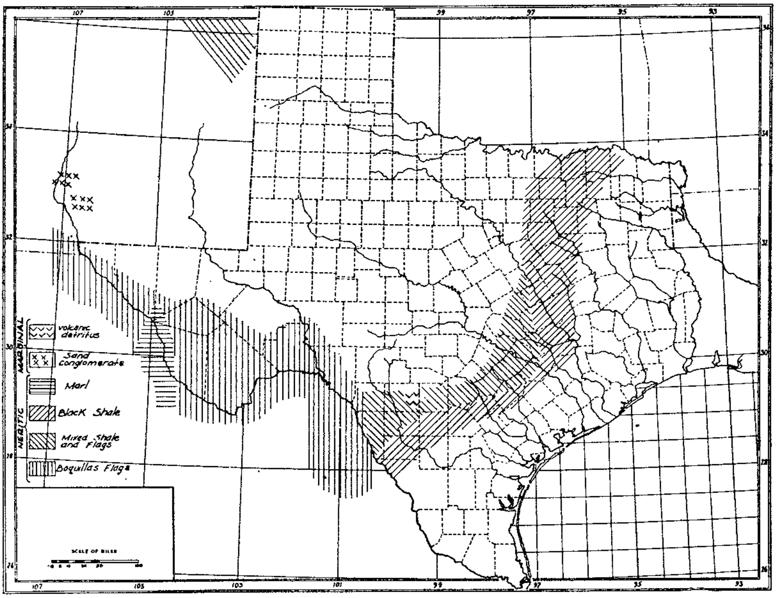

Fig. 24. Facies of Eagle Ford group in and near Texas.

Areal outcrop; local sections.—The Eagle Ford outcrop extends up Red River valley from northwestern Red River County to western Grayson County (1353, pl. 20). Thence it turns south and, passing west of Dallas and Waco and through Austin, extends to northern Bexar County, where it turns west, parallel to the Balcones fault. It extends west to beyond Brackettville, and then turns south through Maverick County and into the Rio Grande embayment. West of Devils River a prominent outcrop covers much of western Val Verde and southeastern Terrell counties. There are many scattered outcrops in Trans-Pecos Texas. The largest are in southern Brewster, northwestern Presidio and southern Hudspeth counties. Smaller ones are on the eastern and northern edges of the Davis Mountains, near Sierra Blanca, and in and west of El Paso. Benton outcrops near Clayton, New Mexico, within a few miles of the New Mexico-Texas state line.

An Eagle Ford outcrop occurs on the Palestine dome, and the group is reached in many wells in the Gulf Coastal Plain.

Red River counties.—The easternmost Eagle Ford mapped in Texas is in eastern Lamar and western Red River counties, extending a little east of Woodland (1353, p. 179, Pl. XX). These beds consist of 50 or 60 feet of fine to coarse marine sand, with a central band which contains a small percentage of water-laid volcanic material. At the base of this sand just north of Woodland there is a bed of conglomeratic sand, 1½ feet thick, containing many water-worn pebbles of novaculite reaching a diameter of 1 inch and reworked chunks of soft reddish sandstone. This material is not of the typical Eagle Ford lithology, and may represent basal Bonham clay (Austin chalk age).

In western Lamar County and in Fannin County, the Woodbine sand is overlain, probably unconformably, by the Eagle Ford clay, which consists typically of 300 to 400 feet of dark, more or less bituminous clay carrying calcium carbonate concretions, in part septarian, some of which are fossiliferous. In the Paris city well (844, p. 27) 520 feet (80–600) of Eagle Ford is recorded. In Fannin County, Garretts and Sowells bluffs contain exposures of fossiliferous, septaria-bearing Eagle Ford clay, and in wells about 400 feet of Eagle Ford is recorded. In the Celeste well (Hunt County) the record shows 292 feet (1243–1535) or more of Eagle Ford.

In Grayson County Stephenson records an estimated thickness of 300 to 400 feet of Eagle Ford. In the Fortuna Oil Company, H. M. Ryan well, 3 miles north-northwest of Tom Bean, 350 feet (555–905) of Eagle Ford was penetrated. The log of the Sherman city well shows 459 feet (32–491) of Eagle Ford. Stephenson reports from western Collin County 535 feet (1530, p. 147). At Sherman, about 10 feet below the base of the hard Austin chalk, there is a conglomeratic layer of gray sandstone, containing phosphatic pebbles, *Ostrea alifera* Cragin, and fish teeth, which Stephenson considers to be the basal layer of the Austin chalk deposit. This is the "fish-bed conglomerate" of Taff's reports, and is widespread in north-central Texas. The top of the Eagle Ford here consists of 20 feet or more of clay and considerable sand, with *Ostrea lugubris* Conrad (= *bellaplicata* Shumard). The upper part of the formation consists of blue clay, and some thin, platy sandstone and limestone layers containing *Prionotropis* and *Prionocyclus*. The upper Eagle Ford clays carry large limestone concretions and septaria, some of them fossiliferous. Eastward from Sherman the sandy strata at the top of the formation increase in thickness. In a creek a mile west of Bells, Stephenson records about 50 feet of ferruginous sandstone ("fish-bed"?), dark greenish-gray massive sand, and argillaceous fine sand with layers of soft yellow sandstone. This is underlain by dark, shaly, gypsiferous, septaria-bearing Eagle Ford clay.

The middle and basal parts of the Eagle Ford blue-black laminated clay are poorly exposed in this district. They contain concretions and nodules with ammonites and other fossils at localities about 4 miles east of Whitesboro.

On Panther Creek, northeast and southeast of Rock Hill, Collin County, Taff (1575, p. 303) records a fine siliceous conglomerate or grit, containing fish teeth, at a level 18 feet below the massive Austin chalk, and just below it is Eagle Ford clay with *Ostrea lugubris*. On Squirrel Creek, southern Grayson County, the conglomerate, 20 inches thick, containing *Ostrea lugubris* and fish teeth, occurs 10 feet below the top of the Eagle Ford, and in the clay beneath it large numbers of the *Ostrea* occur.

Tarrant-Dallas section.—Wells in Dallas penetrate 500 feet of Eagle Ford (1454, pl. 20). The White Rock escarpment southwest of Dallas exposes the upper part of the formation, which consists mostly of laminated blue clay; the uppermost part contains fossiliferous, laminated sandy limestone flags, as exposed near Arcadia Park, and lower in the section numerous large flattened limy concretions. *Ostrea lugubris*, exposed in the cut of the Dallas-Fort Worth highway, ranges down into the Eagle Ford for 50 to 75 feet. The concretions contain *Metoicoceras swallovi*, "*Placenticeras*" *syrtale* var. *cumminsi* and other ammonites. Taff (1575, p. 292) records the basal Eagle Ford on Bear Creek near the Dallas-Tarrant county line: it begins with finely laminated, arenaceous and calcareous clay, which contains clay segregations and fossiliferous concretions (*Metoicoceras inequiplicatum*), followed by laminated sand, sandy clay and hard, sandy flagstones. These strata overlie stratified sand and clay carrying Lewisville fossils. The basal Eagle Ford near Tarrant station is a clay and sandy clay with *Acanthoceras* and other fossils (1789, pp. 74–83). The middle Eagle Ford, exposed on Bear and Hackberry creeks, is a blue shale with numerous ammonites and other fossils. The middle and upper parts of the section near Britton and Midlothian, Ellis County, are very fossiliferous blue-black shales with concretions and, in the upper part, thin, flaggy layers (1141).

Hill-McLennan-Bell counties.—Wells in Hill County penetrate about 133 to 365 feet of Eagle Ford. The basal Eagle Ford is a black shale, above which a small thickness of limy flags is exposed in the area west of Hillsboro. The upper Eagle Ford is a lustrous black clay with *Inoceramus* aff. *labiatus* and ammonites (*Prionotropis*), well exposed in Chambers Creek near Maypearl. In McLennan County the Eagle Ford, 175 feet or less thick, is well exposed in the Bosque escarpment west and southwest of Waco. Here the basal, thin, black shale is fossiliferous. It is succeeded by a few feet of Eagle Ford flags. The upper shale is about 100 feet thick, and outcrops at Bosque Bridge, Potato Hill, South Bosque, near Moody, and elsewhere. Both the flags and the upper shales contain numerous bentonite seams, up to 18 inches thick. In Bell County (16, pp. 59–61), the Eagle Ford, exclusive of the Pepper shale, consists of about 5 feet of limestone flags overlain by about 50 feet of black or brown shale containing numerous bentonite seams. The upper Eagle Ford at many places, as near Maypearl and Waco, contains large flattened concretions and large septaria. In these counties the Eagle Ford outcrops in a west-facing escarpment, which, especially northwards, where the formations are thicker and the outcrop broader, expands into rolling hills, some of them locally capped by harder flagstone layers. These flagstones are well exposed near South Bosque and in the Blue Cut of the Santa Fe Railway south of McGregor. A similar isolated Eagle Ford exposure whose cap has been recently removed is Haunted Hill north of Moody.

Williamson-Travis-Hays counties.—At Prairiedell, Bell County, where the Buda is 5 feet thick (16, pp. 50, 56), Eagle Ford flags with *Acanthoceras* aff. *cornutum* occur. In wells in Williamson County 43 to 71 feet of Eagle Ford is recorded, with greater thicknesses down-dip. On the San Gabriel below Weir, about 50 feet is exposed, consisting of basal black shale, thick medial flags, and upper black shale. On Brushy Creek below Round Rock, a similar but thinner section occurs. The basal and upper contacts occur respectively 1 and 2 miles south of Round Rock; fossils are listed elsewhere. A complete section is exposed down Walnut Creek from Watters Park. The upper contact is well exposed in the headwaters of Shoal Creek, and shows phosphatic nodules and fossils in the upper 2 feet of the Eagle Ford and the basal 3 feet of the Austin chalk. An excellent section of the Austin-Eagle Ford unconformable contact, the upper shale and the middle flags was reached in excavations (March, 1932) on the west part of The University of Texas campus. The basal shale (Pepper?) was excellently exposed in building and sewer excavations at 19th and Nueces Streets, Austin. A diversion cut on Bouldin Creek, on the Barton Springs road in South Austin, exposes the Eagle Ford and its contact with the Buda. In Bear Creek west of Manchaca the entire Eagle Ford with both contacts is exposed. The formation is recorded as 24 to 45 feet thick in wells, and 42 to 47 feet on the surface, in Travis County. On the Blanco River southwest of Kyle the upper Eagle Ford and its contact with the Austin are well exposed.

Southwest Texas.—The interfingering transition from the black shale facies to the Boquillas (Val Verde) flag facies occurs between Uvalde and Brackettville. In Val Verde and Terrell counties the Boquillas is extensively exposed and is not sharply defined from the overlying Austin flaggy limestone. In Brewster and western Pecos counties the Boquillas overlies the Buda concordantly and with a wavy contact. This is well exposed around the outer part of the Solitario rim, and at the north end of the Davis Mountains. At Chispa Summit the Eagle Ford (Mancos) clays and thin flags overlie the Buda, apparently concordantly. At Cerro de Muleros west of El Paso, 350 feet of shales and flags with *Inoceramus labiatus* are recorded.

From the northern and eastern slopes of Gomez Peak, northern Jeff Davis County, Mr. A. H. Dunlap reports an Eagle Ford section consisting of (a) about 250 to 300 feet of beds, the base in undulating contact with the Buda limestone; their lower half consists of hard, ringing, thin-bedded, salmon colored Boquillas flagstones, their upper half of alternating flagstones and yellow shales which contain near the top *Scaphites, Prionotropis,* a three-foot ammonite, *Inoceramus* cf. *labiatus* and other fossils; and (b) about 240 feet of yellow to whitish-yellow clay. He reports the presence, at the Texas Pacific dam in Little Aguja canyon, northern Davis Mountains, of about 15 feet of sand of undetermined age, underlying what appears to be basal Eagle Ford shales.

Paleontology and zonation.—At present the Eagle Ford can be divided only tentatively into paleontological zones, which are summarized as follows:

Austin chalk

————*unconformity*————

8. Alectryonia lugubris zone
7. Prionocyclus-Prionotropis zone
6. Coilopoceras zone
5. Romaniceras-Metoicoceras whitei zone
4. Neocardioceras zone (Pseudaspidoceras)
3. Eucalycoceras bentonianum zone
2. Acanthoceras wintoni zone
1. Acanthoceras tarrantense zone

————*unconformity*————

A generally valid zonation, based on expansion and rectification of these zones, requires further detailed collections and comparisons between numerous localities.

Red River counties.—Shumard (1464a) Cragin (324), Taff (1575), Hyatt (867) and others record the following fossil partition in Grayson County:

	Feet
7. *Alectryonia lugubris (bellaplicata)* zone: shell aggregates, blue clays, shelly marl with sand and phosphatic grains; *Ammonites meekianus* Shumard, *Ostrea alifera* Cragin and its var. *pediformis, Alectryonia lugubris, Ostrea congesta, Cardium choctawense, Corbula graysonensis;* Post Oak Creek, near Sherman, and elsewhere; thickness, about	75+
6. *Prionotropis* zone; blue-black shale with large ironstone concretions and septaria; *Prionotropis graysonensis, Scaphites vermiculus, Metoicoceras swallovi, Alectryonia bellaplicata, Corbula tuomeyi, Venus sublamellosus;* 4–4½ miles north of Sherman; creek northeast of Sherman Junction; thickness	200+
4. *Metengonoceras dumbli, Metoicoceras swallovi, "Ancyloceras" annulatus* Shumard, *Baculites gracilis; Cytherea lamarensis, Turbinopsis septariana, Neritopsis biangulatus, Natica striaticostata* Cragin, *Fusus graysonensis* Cragin, *Anchura modesta* Cragin; 4 miles east of Whitesboro; estimated thickness	300+

2. Blue-black, gypsiferous clay with sand streaks and small concretions; thickness about 50—

In Fannin and Lamar counties the Eagle Ford contains *Metoicoceras swalloVi, Prionotropis graysonensis, Amm. inequiplicatus*, gastropods and pelecypods.

Tarrant-Dallas counties.—The Eagle Ford section, as studied by Taff (1574, 1575), Cummins, Winton, Scott (1391), Moreman (1141), the writer and others suggests the following zonation:

	Feet
7. *Alectryonia lugubris* zone: shale with sand, shells, bones, fish teeth, and *A. lugubris* (Conrad) in abundance; White Rock escarpment	15
6. *Prionotropis* zone: shale and thin flaggy limestone; *Prionotropis, Prionocyclus, Scaphites vermiculus* Shumard; Arcadia Park	60
5. *Coilopoceras* zone: shales; *C.* aff. *eaglefordense;* about	75
4. *Romaniceras-Metoicoceras whitei* zone: 3 miles NW of Midlothian	50
3. *Neocardioceras* zone: shales; Keenan's Crossing (*Neocardioceras septem-seriatim* holotype, *Metengonoceras dumbli*), Horton's Mill, California Crossing; thickness uncertain, possibly	50
2. *Eucalycoceras bentonianum-Borissiakoceras* zone: shales; *Borissiakoceras* n. sp., *Metoicoceras irwini* (Cottonwood Creek); *Bor.* n. sp., *Eucalycoceras* n. sp. (Walnut Creek); *Eucalycoceras bentonianum* (Cragin), *Metengonoceras dumbli* (Cragin), *Proplacenticeras syrtale* var. *cumminsi* (Cragin), *Baculites gracilis* Shumàrd, "*Ancyloceras*" *annulatum* Shumard, *Inoceramus* (Hackberry Creek); about	90
Zone undetermined: carbonaceous shales, with *Acanthoceras* (*Eucalycoceras?*) *wintoni* Adkins, *Ammonites inequiplicatus* Shumard; about	145
1. *Acanthoceras* zone; shale, sandstone; Tarrant station; about	15

The *Acanthoceras* zone is unconformably underlain by shelly Woodbine sandstone containing *Ostrea soleniscus* Meek, *Ostrea carica* Cragin, *Exogyra columbella* Meek, *Arca tramitensis* Cragin, *Neritopsis tramitensis* Cragin, fish teeth, and many other fossils.

Wells in Dallas show a thickness of 495 feet of Eagle Ford.

Western Ellis County (*Britton-Midlothian-Maypearl*).—South of the preceding section and in the same strike, along the White Rock escarpment, is a well-developed section of Eagle Ford, studied by Moreman (1141) and others. A more detailed zonation, with descriptions of numerous species, will be published by Moreman.

	Feet
8. Transition zone: blue marl, fish teeth	5
6. *Prionotropis* zone: shales and thin flaggy limestones; about	100
4. *Metoicoceras whitei* zone: shales with *M. whitei, M. whitei* var., *Neocardioceras septem-seriatim* (Cragin), *Romaniceras* sp., *Proplacenticeras pseudoplacenta* and its var. *occidentale* (Hyatt), *Scaphites* aff.	

warreni, *Baculites gracilis* Shumard, *Allocrioceras pariense* (White), *Inoceramus fragilis*, *Lunatia*, *Fasciolaria*, fish remains; about 100

2. *Eucalycoceras* zone; shales with *Metoicoceras irwini* Moreman (= aff. *pontieri*), *Metoicoceras* sp. A. (Moreman), *Pachydiscus* sp. A. Moreman, *Placenticeras* sp.; basally some limy flags; about 150

Zone undetermined; basal black shales; about 125

1. *Acanthoceras* zone; limestone with *A. tarrantense* (Adkins), *Meteng. planum* Hyatt, *Exogyra columbella* Meek; Mountain Creek; about 15

———*unconformity*———

Woodbine (Lewisville beds): shell aggregate of *Ostrea soleniscus*, fish remains and numerous Lewisville fossils.

Waco section.—The most reliable wells near Waco show about 200 feet of Eagle Ford; on the Bosque escarpment there is about 175 feet. The following fossils are known in this section:

Feet

3. Upper shales with bentonite seams; *Prionotropis* (normal and micromorph), *Inoceramus* spp., *Pachydiscus*, *Metaptychoceras* n. sp., *Allocrioceras* n. sp., *Hemiaster* sp., pelecypods and gastropods; *Clidastes*, *Ichthyodectes*, *Xiphactinus*, *Protosphyraena*, *Oxyrhina*, plesiosaurs; about 100

2. Middle flags; *Mantelliceras sellardsi* Adkins, *Eucalycoceras* sp., *Scaphites* aff. *aequalis*, *Inoceramus*, *Ostrea*, *Pecten*; about 35

1. Pepper clays (?): Basal shale; fish (*Portheus?*), turtle (*Protostega gigas* Cope), mososaurs and other vertebrata; *Inoceramus*, *Cardium*, *Turritella*, *Arca*; exposed at spillway below dam, Bosque Bridge, South Bosque and Bosque escarpment; about 40

Bell County.—Between Belton and Temple, and elsewhere in the county, the following summarized section occurs:

Feet

3. Upper shales with bentonite seams; *Inoceramus*; about 55

2. Middle flags (*Acanthoceras* zone); *Acanthoceras bellense*, *A. stephensoni*, *A. lonsdalei*, *Acanthoceras* (several other species), *Eucalycoceras leonense*, *Metacalycoceras* spp., *Heliococeras pariense* White, *Ancyloceras annulatum*, *Turrilites* aff. *costatus* Sowerby, *T.* aff. *desnoyersi* d'Orbigny, *Turrilites* spp., *Inoceramus fragilis*, pelecypods, gastropods, reptilia, fishes, carbonized wood; about 5

1. Pepper clays: Basal lustrous black shale; *Anchura*, *Yoldia*, other pelecypods; the age of this shale is not entirely clear; about 50

The basal shale rests unconformably on Del Rio (Grayson) at most places, on Buda at a few places.

Travis County.—At the outcrop near Austin there is 35 to 40 feet of Eagle Ford, in wells 24 to 45 feet, counting the basal black shale.

The following is a generalized section, compiled from Bear Creek near Manchaca, Bouldin Creek, excavations on The University of Texas campus, Watters Park, Round Rock, and the San Gabriel River south of Weir:

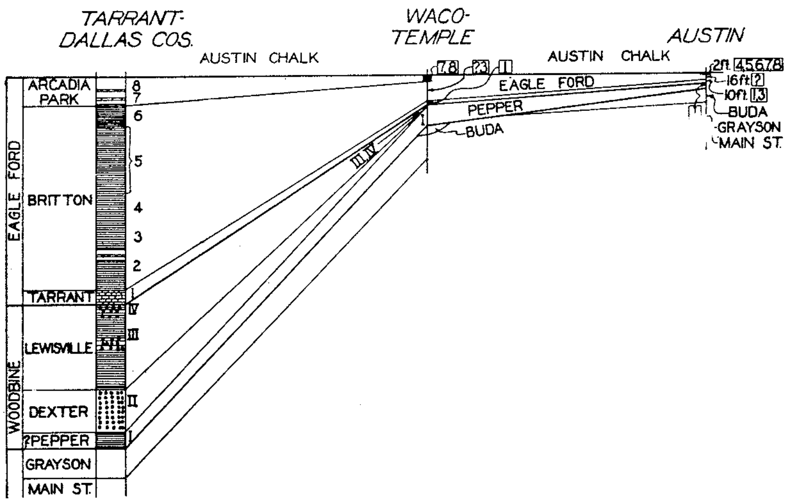

Fig. 25. Condensed zone in Eagle Ford group in south-central Texas.

Eagle Ford zones:
8. Alectryonia lugubris
7. Prionotropis
6. Coilopoceras
5. Romaniceras-Metoicoceras
4. Neocardioceras
3. Eucalycoceras bentonianum
2. Acanthoceras wintoni
1. Acanthoceras tarrantense

Woodbine zones:
IV. Acanthoceras n. sp.
III. Aguilera cumminsi-Ostrea soleniscus
II. Plants
I. Euhystrichoceras?-desmoceratids (indet).

Buda markers: Budaiceras, Pecten roemeri
Grayson markers: Graysonites n. gen., Adkinsia, Gryphaea mucronata
Main Street markers: Stoliczkaia sp., Turrilites brazoensis

Feet

(D) 8, 7, 6, 5, 4. Condensed zone;[48a] Eagle Ford clay containing angular boulders up to 18 inches long of both chalky limestone and laminated Eagle Ford limestone, corroded by ground water but not

[48a]*Omission* is a submarine condition in which neither sedimentation nor removal of sediments occurs. The zonal fossils representing several successive time units are preserved along the omission-surface, where they are found commingled in a single stratum so that the succession of the fossil zones of different ages is unrecognizable. This mixture of fossils of

rolled; some phosphatic pebbles; *Alectryonia lugubris* (Conrad), *Prionocyclus* sp., *Prionotropis* spp., *Coilopoceras chispaense, C. eaglefordense, C.* n. sp., *Romaniceras* sp., *Pseudaspidoceras* 2 spp., *Proplacenticeras* (?) n. sp., *Neocardioceras* spp., *Scaphites* n. sp., pelecypods, fish teeth; about 1.5

(C) Zone undetermined; laminated shale with thin bentonite seams, a 4–10 inch bentonite seam at base; color yellow from ground water; *Inoceramus* spp., pelecypods, fish teeth; about 16.5

(B) 3, 1. Black limestone flags and shale; *Exogyra columbella, Mantelliceras* n. sp. (compressed), *Acanthoceras* sp. (strongly cornute), *Eucalycoceras leonense* Adkins, *Austiniceras* n. sp., *Eucalycoceras bentonianum* Cragin (?); *Metoicoceras* sp. (?);[49] plants, fish; about 12

———*unconformity*———

(A) Pepper shale (?): Basal lustrous black shale; *Exogyra columbella* (?), gastropods, pelecypods, *Ammobaculites*; about 15

———*unconformity*———

Buda limestone.

The thin uppermost boulder bed of the Eagle Ford at Austin is here interpreted as a condensed zone, representing the upper five zones of the Eagle Ford in north Texas. If this boulder bed were a product of subaerial erosion, it would show (a) miscellaneous debris from various formations on the erosion surface, and (b) great wear of the soft fossils. Neither of these features appears to be present.

Trans-Pecos Texas.—In Val Verde, Terrell, Brewster, and southern Presidio counties the Eagle Ford occurs in the Boquillas flag

different ages in a single bed is a *condensed zone.* Thus in the topmost stratum of the Eagle Ford near Austin, apparently all zones from the *Pseudaspidoceras-Neocardioceras* zones of the lower Eagle Ford to the *Ostrea lugubris* zone at the top of the Eagle Ford are indiscriminately mixed together in a stratum less than 2 feet thick. These features are explained in Arnold Heim: Ueber submarine Denudation und chemische Sedimente. Geol. Rundschau, 15: 1–47, 1925.

[49]Scott (1391, p. 622) records a specimen of *Metoicoceras whitei* in float at the top of the Buda on Barton [probably Bouldin] Creek, south Austin. According to the writer's interpretation, this would represent layer B or C above. Cragin (324, p. 243) records *Prionotropis* [?] from immediately above the Buda limestone on the San Gabriel at Towne's Mill below Weir. Four individuals of *Coilopoceras* in the University of Bonn were collected by George Stolley in 1886–1887 from "Barton's [probably Bouldin] Creek, 6 miles von Austin, Texas." One is ribbed, the others smooth; one has a complicated suture with tall elements; and the others have simpler sutures with blunter lobes; two are thin-lenticular, the others fatter. They are probably identical with the several species which have been collected by the writer from the uppermost Eagle Ford condensed zone in Travis County. Among the species recently found at Austin is *C. colleti* Hyatt, the genotype, essentially identical with topotypes from Hyatt's type locality, Carthage, New Mexico, collected by Prof. H. B. Stenzel and kindly donated to the Bureau of Economic Geology. By far the most abundant genus in the condensed zone near Austin is *Coilopoceras,* then *Pseudaspidoceras.*

facies. A few ammonites, *Inoceramus*, fish remains and other fossils have been found; but the formation has not been zoned.

In the Chispa Summit area the Eagle Ford equivalents are in the marl facies, here called the *Chispa Summit formation.* The type locality is in the headwaters of Van Horn Creek on the Johnson and Colquitt ranches, in the neighborhood of Needle Peak (see 20, p. 36, fig. 7). The formation is here around 800 feet thick. It has been zoned as follows (20):

8. Upper thin limestone flags and interbedded marls. Fossils: *Prionotropis, Metoicoceras, Scaphites* aff. *aequalis*, belemnites; *Inoceramus* aff. *labiatus;* pelecypods.

7. Clays.

6. *Coilopoceras zone:* Clay with flat calcareous mudstone nodules; *Coilopoceras eaglefordense, C. chispaense, Coilopoceras* aff. *springeri* Hyatt, *Acanthoceras* sp., pyritic micromorphs *(Prionotropis, Metaptychoceras), Camptonectes.*

5. *Coilopoceras-Romaniceras transition zone:* clay with calcareous nodules; *Coilopoceras eaglefordense, Romaniceras cumminsi, Metacalycoceras* (?) n. sp., micromorphs (*Prionotropis*).

4. Interbedded limy flagstones and marl; few fossils.

3. *Romaniceras zone:* clay with septaria, concretions, conglomerate concretions, and nodules; *Romaniceras loboense*, probably *R. cumminsi, Pseudaspidoceras* (?) *chispaense, Prionotropis* aff. *papalis*, a new genus of Vascoceratidae, *Acanthoceras.*

2. Clay with subordinate thin flags; *Metoicoceras, Inoceramus.*

1 (b). *Pseudaspidoceras zone:* Thin limestone flags with some interbedded marl and a band of gray chalk. *Pseudaspidoceras* aff. *footeanum* + spp., *Metoicoceras, Acanthoceras, Prionotropis* aff., *hyatti, Allocrioceras pariense* White (?), *Scaphites.*

1 (a). Interbedded limestone flags and marls (*Neocardioceras zone*): *Neocardioceras septem-seriatim* (Cragin) + sp., "*Acanthoceras*" *coloradoense* Henderson, *Metoicoceras* spp., *Mantelliceras* aff. *couloni, Scaphites* aff. *africanus* Perv. + spp., *Baculites gracilis, Allocrioceras* n. sp., *Acanthoceras* sp., echinoids, gastropods.

Zone 1a is interpreted as Upper Cenomanian. It is noteworthy that in the English and French sections the Cenomanian-Turonian boundary is marked by a zone of *Neocardioceras* and *Metoicoceras pontieri* (= aff. *irwini* Moreman) (see Spath, 1510, table opp. p. 80). Zones 1b–2 are considered Lower Turonian (Salmurian); zones 3–8 are considered Upper Turonian. The principal *Acanthoceras* zone of the Eagle Ford flags (Tarrant; Upper Cenomanian) was not located at Chispa Summit. Salmurian with the ammonites

Fagesia texana Adkins, *Thomasites* n. sp., *Neoptychites* n. sp., and a new genus (= "*Hoplitoides mirabilis*" Böse, not Perv.), occurs in the Van Horn Mountains 8 miles west of Chispa Summit. In the Terlingua quadrangle the top of the Eagle Ford may be taken as a persistent limestone flag cap rock containing belemnites, *Crioceras* n. sp., and *Scaphites* aff. *vermiculus* Shumard (from near Woodlake, Grayson County, but larger).

Foraminifera of Eagle Ford Formation[50]

Haplophragmoides aff. calcula Cushman and Waters
Ammobaculites aff. subcretacea Cushman and Alexander
*Spiroplectammina terquemi (Berthelin)
*Verneuilina aff. propinqua H. B. Brady
Vaginulina webbervillensis Carsey
Vaginulina regina Plummer
Flabellina hebronensis Moreman
Frondicularia cordai Reuss
Guembelina globulosa (Ehrenberg)
Ventilabrella eggeri Cushman
Bulimina aff. elegans d'Orbigny
Bulimina aff. murchisoniana d'Orbigny
Loxostoma tegulatum (Reuss)
Gaudryina filiformis Berthelin
*Quinqueloculina stelligera Schlumberger
Trochammina diagonis (Carsey)
Lenticulina rotulata Lamarck
Marginulina elongata d'Orbigny
Dentalina communis d'Orbigny
Dentalina adolphina d'Orbigny
*Bolivina sp.
Entosolenia laevigata (Reuss)
Globigerina cretacea d'Orbigny
Globigerina voluta White
*Hasterigerinella moremani Cushman
Globotruncana arca (Cushman)
Gyroidina depressa (Alth)
Valvulineria aff. asterigerinoides Plummer
*Anomalina eaglefordensis Moreman

The following ostracoda are most distinctive of the Eagle Ford:

Cythereis eaglefordensis Alexander
Bairdia alexandrina Blake
Cytherella münsteri (Römer)
Cytheropteron n. sp. Alexander
Cythereis n. spp. Alexander

Ammonites known in Eagle Ford Equivalents in Texas

Lytoceratidae:
 Lytoceras (?) n. sp.
Baculitidae:
 Baculites gracilis Shumard
 Baculites spp.
Scaphitidae:
 Scaphites vermiculus Shumard
 Scaphites n. sp. Moreman
 Scaphites aff. africanus Perv.
 Scaphites n. spp.
Crioceratidae:
 Crioceras n. sp.
Hamitidae:
 Metaptychoceras n. sp.
Turrilitidae:
 Turrilites aff. costatus
 Turrilites aff. desnoyersi
 Turrilites spp.
Engonoceratidae:
 Metengonoceras dumbli (Cragin)
 Metengonoceras spp.
Prionotropidae:
 Prionotropis aff. woolgari
 Prionotropis aff. papalis
 Prionotropis hyatti Stanton
 Prionotropis graysonensis (Shumard)
 Prionotropis aff. bravaisi (Moreman)

[50]From six outcrops in Dallas and Denton counties; list by Helen Jeanne Plummer; asterisk indicates species thought to be characteristic of the formation.

Prionotropis spp.
Prionocyclus spp.
Neocardioceras septem-seriatum (Cragin)
Neocardioceras n. sp. Moreman
Neocardioceras n. sp. (?)
Watinoceras (?) aff. coloradoense (Henderson)

Acanthoceratidae:
Mantelliceras sellardsi Adkins
Mantelliceras spp.
Eucalycoceras n. sp.
Eucalycoceras bentonianum (Cragin)
Eucalycoceras leonense Adkins
Eucalycoceras spp.
Acanthoceras aff. cornutum
Acanthoceras stephensoni Adkins
Acanthoceras bellense Adkins
Acanthoceras lonsdalei Adkins
Acanthoceras tarrantense (Adkins)
Acanthoceras wintoni Adkins
Acanthoceras spp.
Romaniceras loboense Adkins
Romaniceras cumminsi Adkins
Romaniceras aff. deverianum
Protacanthoceras (?) sp.

Metoicoceratinae:
Metoicoceras swallovi (Shumard)
Metoicoceras whitei Hyatt
Metoicoceras gibbosum Hyatt
Metoicoceras irwini Moreman (= aff. pontieri
Metoicoceras (?) inequiplicatum (Shumard)
Metoicoceras spp. indet.

Mammitidae:
Pseudaspidoceras eaglense (Adkins)
Pseudaspidoceras aff. armatum Perv.
Pseudaspidoceras aff. pedroanum (White)
Pseudaspidoceras aff. footeanum (Stoliczka)
Pseudaspidoceras aff. footeanum (Petraschek)

Vascoceratidae:
Fagesia texana Adkins
Fagesia aff. haarmanni Böse
Thomasites n. sp.
Neoptychites n. sp.
Three new genera

Coilopoceratidae:
Coilopoceras colleti Hyatt
Coilopoceras eaglefordense Adkins
Coilopoceras chispaense Adkins
Coilopoceras n. spp.
Coilopoceras aff. springeri Hyatt

Placenticeratidae:
Proplacenticeras (?) pseudoplacenta Hyatt and var. occidentale Hyatt
Proplacenticeras (?) cumminsi (Hyatt)

Phlycticrioceratidae:
Phlycticrioceras n. spp.
Allocrioceras pariense (White)
Allocrioceras larvatum (Conrad)
Allocrioceras rotundatum (Conrad)
Allocrioceras n. sp.

Not placed:
Ancyloceras annulatum Shumard
Borissiakoceras 2 n. spp.

Other fossils are listed in Adkins, 13, p. 32.

AUSTIN GROUP[51]

Nomenclature.—The name Austin limestone was first used by B. F. Shumard (1463, pp. 583, 585) in 1860 for the limestone typically exposed at Austin, which was located by Shumard correctly above the thinned Eagle Ford (fish bed), but incorrectly below the Comanche Peak formation. Shumard says that the State House and several public buildings in Austin were made of the stone. The "Pinto" limestone of Dumble is a synonym.

[51]*Literature.—North-central Texas:* Alexander, 31b; Hill, 803; Shuler, 1454; Stephenson, 1530; Taff, 1575; Bullard, 177; Lahee, 969. *South-central Texas:* Adkins, 11, 16; Hill, 803, 808; Vaughan, 1686; Sellards, 1402; Liddle, 992; Taff, 1574. *Trans-Pecos Texas:* Udden, 1625, 1626. *Paleontology:* Böhm, 126; Heine, 702; Heinz, 703, 703a; Kniker, 947; Lasswitz, 976; Prather, 1256, 1257; Schlüter, 1372; Stanton, 1518; Stephenson, 1540; Adkins, 13; Roemer, 1331; Reeside, 1295a. *Igneous rocks:* Lonsdale, 1009; Ross, 1353.

Stratigraphic position and contacts.—East of Sherman a little below the base of the typical Austin there is a fish-bed conglomerate with associated sands and clays (thicker to the east) and pebbles of phosphate, chert and quartz. Stephenson regards this as evidence of an unconformity, and places the "fish bed conglomerate" at the base of the Austin chalk. Stephenson has traced Taff's Fish bed conglomerate from the Red River region southward to Hays County. It contains fossil material reworked from the underlying Eagle Ford, including several kinds of oyster shells and the teeth of several kinds of fish. In Travis and Hays counties small borings extend from the base of the Austin downward into the Eagle Ford clay to a depth of as much as 18 inches and these are filled with glauconitic chalk exactly like the basal chalk layer of the overlying Austin (1539, p. 1328). In McLennan County the Austin-Taylor contact is unconformable, and is marked by a thin but persistent phosphatic conglomerate. At a locality near Bynum, Hill County, the base of the Taylor cuts across bedding planes of the upper Austin chalk. The phosphatic conglomerate at the base of the Taylor has been traced across Hill, McLennan and Ellis counties to the Dallas County line, where it apparently dies out. According to Stephenson, a layer containing numerous specimens of *Inoceramus undulato-plicatus* Roemer lies at the top of the exposed Austin chalk at Waco but 250 feet below the top at Dallas and well down in the Austin chalk at a place 6 miles northeast of Austin, showing that the unconformity at Waco represents the removal of at least 250 feet of upper Austin chalk (1539, p. 1330). East of eastern Smith County, Austin rests on Woodbine, and east of Upshur-central Gregg counties where the Woodbine disappears, on Comanche rocks.

Facies.—The type Austin is an alternation of white chalky limestone and limy marl strata with some layers of shelly marl especially near the top. East of Grayson County on the outcrop, clay (Bonham) and sand (Blossom) appear. In the East Texas oil fields east of Smith County the Austin is sandy, and in southwestern Arkansas its partial equivalent, the Tokio, contains much sand interbedded with clay. Likewise in the northern Louisiana oil fields it contains sand. Two other intergrading facies occur in west Texas. From Val Verde-Terrell counties westward to beyond Terlingua, the Austin consists of thin limestone flags, chalkier to the east, more crystalline to the west. Near Terlingua these are thin and are interbedded with much marly material, so as to weather down to flats. To the northwest the formation becomes more marly until at Chispa Summit it consists of marl, with thin subordinate amounts of marly and platy limestone flags. This facies is here called the *Colquitt* formation.

Near Pilot Knob, Travis County, the Austin locally occurs in a reef facies, a rather pure white shelly limestone, in part coquina, containing interbedded serpentine at places, with echinoids, caprinids, oysters and various other mollusca.

Areal Geology.—Eastwards from the eastern line of Grayson County (roughly east of the axis of the Preston anticline) through Fannin, Lamar and Red River counties, the Austin is represented by four equivalents, in ascending order as follows: (1) "Fish bed conglomerate" and associated sands and clays; (2) Ector chalk; (3) Bonham clay; (4) Blossom sand. In the Black Prairie region the Austin is represented by the Austin chalk proper, overlain by the Burditt marl. In Trans-Pecos Texas it is represented by unnamed flags generally similar to the underlying Boquillas but less vividly colored, and farther northwest by an unnamed clay facies. In the Sabinas coal basin (northern Coahuila) a local marginal facies of coarse grits, sands and conglomerates appears.

Topography and vegetation.—In the humid region, where the Austin is composed mostly of limestone ("chalk"), and typically forms prairies, the central or inner portion of the black land belt, two general topographic types prevail: the canyon topography occurs along streams cutting across the Black Prairie, and the interstream areas are prairie land. Indurated limestone layers produce steep bluffs along streams, but the softer strata weather to more rounded forms, and the canyons are not intrenched. The uplands are widely but shallowly dissected by small headwaters, especially on cuesta slopes. The upland type of Austin is most typically shown on top the White Rock escarpment, as in Dallas and Ellis counties, where through-going drainage is eliminated and only small headwaters remain. Here a deep fertile soil is formed, and the topography is flattened. Near large streams, much soil is removed and bare patches of limestone rock may mark hill slopes. The most characteristic soil of the Austin is the "Houston" clay, typically a dark-brown or grayish-brown clay superficially, grading at a foot or more depth into grayish-yellow clay containing friable limy material, which deeper grades into the chalky marl or chalky limestone of the Austin. Where derived from the chalky limestone, the subsoil is a greenish-yellow, chalky, friable clay, grading into soft, white chalky material at depths of less than 3 feet. The dried soil may be crumbly, and in color light or dark ashy gray. The prairie white rock land originally supported a growth of mesquite grass, with occasional post oak, elm and hackberry. The bare Austin chalk, especially on escarpments, is covered with a thicket growth of small trees and shrubs, "cedar" (= juniper), oaks, elm, hackberry, box elder, red bud, honey locust, sumac, mesquite, smilax, prickly pear and bear grass. The main oaks are *Quercus brevilocata* (shin oak), and *Quercus texana.*

In the semi-arid region the Austin group is largely of a soft facies. At most places it consists of thin interbedded marls and flags and forms flats. In the Chispa Summit district, it is largely marls, and forms miniature bad lands.

NORTHEASTERN TEXAS

From Fannin County eastwards on the outcrop, the Austin consists of the four units described below. Southwards from Fannin County, these lose their identity, and the group consists of typical Austin limestone overlain by Burditt chalk marl.

FISH BED CONGLOMERATE

This bed, first described by B. F. Shumard (1463), was described by Taff from eastern Grayson County (1575, p. 303). On Squirrel Creek one mile below Trinity school house, at a level 10 feet below the top of the Eagle Ford, there is a 20-inch stratum of conglomerate or coarse grit containing fish teeth and a few *Ostrea lugubris.* On Choctaw Creek 1½ miles above the Sherman-Van Alstyne road, the conglomerate, 2.5 feet thick, is located 10 feet below the top of the Eagle Ford and it and the underlying Eagle Ford have many *O. lugubris.* In Post Oak Creek near Sherman, the 2-foot conglomerate is overlain by 20 feet of Eagle Ford shale. Near Ector and Ravenna the conglomerate is 35 feet below the base of the Austin chalk, the intervening material being mostly light greenish calcareous shaly and somewhat sandy clay, containing in the lower 10 feet lenses of sand and sandstone.

About 3 miles south of Ravenna the indurated conglomerate, about 10 inches thick, consists of coarse calcareous sand, grayish and brownish phosphatic pebbles, a few pebbles of quartz and chert, and scattered shark teeth (1530, p. 149).

ECTOR CHALK

This member was named by Stephenson in 1919 (1530, p. 149). It is the basalmost member having the chalk facies, in this section. From Dallas northwards the Austin chalk has thickened considerably, and in the Sherman-Leonard section in southwestern Fannin County its top includes chalk of Taylor age perhaps continuous eastward with the Gober chalk. East of the axis of the Preston anticline the Austin portion of the chalk changes facies, becoming the Bonham clay, except that its base retains the chalk facies and extends from a point south of Ector northeastwards to near Ivanhoe, Fannin County. This is the Ector chalk member, 50 feet or less thick near Ector. It is underlain by the shaly clay, thin sands and fish bed conglomerate previously mentioned. The shaly clay grades into the chalk through a transition zone only about one foot thick. The easternmost known locality of the Ector (1530, p. 150) is on the old Bonham-Ravenna road about 1½ miles southeast of Ravenna. The member contains *Gryphaea aucella* Roemer and "*Radiolites*" *austinensis* Roemer.

BONHAM CLAY

Southwest of Bonham the thick central portion of the Austin chalk changes in a northeast direction into the Bonham clay. It was named by Stephenson (1534, p. 8) in 1927, the type locality being at small exposures a short distance north of Bonham, Fannin County, Texas. It is a greenish-gray waxy clay, weathering yellowish green, about 400 feet thick. A little above the middle there is a stratum of calcareous and strongly glauconitic clay with fragments of *Inoceramus* large species, *Ostrea congesta* Conrad and *Ostrea plumosa* Morton, which Stephenson considers the westward extension of the Blossom sand. To a certain extent the transition from Austin chalk to Bonham clay has been observed in Grayson County east of Sherman. In the area between Luella, Bells and Whitewright, the basal half of the Austin is largely impure argillaceous chalk and chalky clay, and as far west as Luella, highly argillaceous, slightly bituminous shaly chalk or chalky clay. The Bonham clay is mapped eastward, across Fannin, Lamar and Red River counties, to Red River north of Clarksville, between Pecan Bayou and Silver City. In southern McCurtain County, Oklahoma, and in southwestern Arkansas the same member is called the Tokio. The Bonham clay has been traced as a narrow strip through southern Grayson and northern Collin counties as far south as McKinney (Alexander and Smith, 31b).

BLOSSOM SAND

This sand, first called by Veatch (1691, p. 25) "sub-Clarksville" sand from wells near Clarksville, was named Blossom by Gordon (609, p. 19), who correlated it with the sandy upper portion of the Eagle Ford at Sherman. The type locality is at Blossom, eastern Lamar County.

The upper part of the Bonham clay about halfway between Ector and Randolph, southwestern Fannin County, is calcareous and chalky and eastwards is distinctly glauconitic; this develops into brown, sandy, ferruginous glauconitic beds interlaminated with thin clay beds, outcropping as a sandy belt several miles wide. The Blossom outcrop passes eastward across central Fannin, Lamar and Red River counties, through Paris, Blossom, Detroit and Bagwell, and ending at the edge of Red River valley near the mouth of Pecan Bayou.

Stephenson states that the fossils from the Blossom indicate the equivalence of the Blossom with the upper part, perhaps the upper half, of the type Austin near Austin. At least 11 species are common to the type Austin, and the following indicate synchroneity with the upper part of the type Austin: *Inoceramus* aff. *I. deformis* Meek, *Ostrea congesta* Conrad, *Ostrea* aff. *O. diluviana* Linné, *Gryphaea aucella* Roemer, *Exogyra ponderosa* Roemer, *Liopistha elegantula* (Roemer)?, and *Baculites asper* Morton. No Eagle Ford species were found. The cephalopoda listed are: *Nautilus* sp., "*Hamites*" sp., *Baculites asper* Morton, *Placenticeras* sp., and *Prionotropis?*.

BLACK PRAIRIE REGION

TYPICAL AUSTIN CHALK

From eastern Grayson County southwards, the Austin is in general typical. It forms a wide, prominent and important outcrop, the substratum of a part of the fertile black land belt (Black

Prairie) devoted largely to cotton raising. On it are located many important towns: Sherman, McKinney, Dallas, Waxahachie, Midlothian, Waco, Temple, Austin and San Antonio. The total chalk in eastern Grayson County is probably as much as 1000 feet thick; near Dallas 700 feet; at Corsicana 425 feet; 480 feet in the Powell field and 440 feet in the Mexia-Richland area (969, p. 331); near Groesbeck, southern Limestone County, 350 feet; in Bell County 550-604 feet; in Milam County about 500 feet; in Williamson County, 325–342 feet; in Travis County, about 420 feet (275–400 in wells); in Medina County, about 350 feet; in eastern Uvalde County, 350 feet; western Uvalde County, about 350 feet [F. M. Getzendaner, personal communication].

Although the literature contains records of 350 to 400 feet of Austin in Bexar County, many geologists now consider that these thicknesses include some rocks of Taylor age. The Austin chalk is stated to be 110 feet thick in eastern Bexar County [L. W. MacNaughton, personal communication], and the 443 feet of Austin recorded (888) in southwestern Bexar County is stated to include the Anacacho. Likewise it is unknown how much, if any, of the upper part of the type Austin chalk in Travis County should be separated from the true Austin. These questions require extensive zonal work and a paleontological redefinition of the type sections.

At the type locality the lower two-thirds of Austin consists of irregular strata of variable thickness, from thin-bedded to massive, and with often indefinite limits, generally alternately harder and softer. They are composed of a gray-white chalky limestone in the harder layers, and a dark blue or blackish marly limestone or limy marl weathering dead white or light gray, and in texture unevenly flaky or laminated. A few of the limestones are indurated, some are shelly. Some contain much debris of oysters, inocerami and other shells. At certain levels considerable glauconite, dispersed as small specks, occurs; the formation contains imbedded balls, cylinders and irregular botryoidal masses of pyrite with radiating internal structure; and locally veins, seams and joint cracks filled with calcite. In youthful stream cuts vertical cliffs of alternately projecting and receding strata occur; on hillsides and upland prairies a rounded topography prevails. On many patches of upland, headwater erosion is sufficiently rapid to strip the outcrop of soil.

Generally harder and softer ledges are not topographically well expressed. The upper part of the formation has considerable calcareous marl, in beds up to 30 feet thick, and some very shelly marl (with *Exogyra*), generally in beds 5 feet or less thick. Such a marl in northern Travis County seems to be characterized by the presence of *Exogyra tigrina* Stephenson and "*Ostrea*" *centerensis* Stephenson, and contains other species listed below. A notable feature of this level is the presence of a wide range and variety of *Exogyra*, probably referable to several species.

The Austin consists of beds of impure chalky limestone, containing 85 per cent or more of calcium carbonate, interstratified with beds of softer marl. It is usually of an earthy texture, free from grit, and on fresh exposure softer, so that it can be cut with a hand saw, but on exposure more indurated. In thin slices the material shows calcite crystals, particles of amorphous calcite, finely crystalline calcareous material, foraminiferan shells and fragments, fragments of the prismatic layer of *Inoceramus* often in great abundance, debris of pelecypods, gastropods, echinoids, and other organic fragments. The material has the typical crystalline structure of limestone. Some slices show abundant glauconite specks; some show a sparse to medium amount of "spherical bodies" (see page 365); and some show a finely crystalline texture almost devoid of organic material. Typical analyses show calcium carbonate 82 per cent; silica and insoluble silicates 11 per cent; ferric oxide and alumina 3 per cent; magnesia 1 per cent.

The water-filled subterranean chalky limestone is usually of a blackish-blue to bluish-gray color, as in most cores. The air-dried material is generally glaring white and of a matte texture. The dried marls may be more blackish or bluish. They weather mostly into abrupt slopes capped by harder ledges. Some ledges become indurated and crystalline; others, less crystalline, weather into irregular small conchoidal flakes with an earthy fracture. The harder strata have an irregular, ragged conchoidal fracture. Locally in the more massive layers, there occurs a large conchoidal flaking, superficially resembling exfoliation. On prolonged disintegration, the Austin weathers into a black residual soil, characteristic of the Black Lands belt of east-central Texas. Locally as near Pilot Knob, the Austin is metamorphosed, and occurs as a porous, redeposited and recrystallized limestone in medium beds, soft enough on fresh exposure to be sawed, nearly pure, and producing an excellent building stone. The German Lutheran Church just north of the Capitol at Austin is built of this stone. Formerly the ordinary

Austin was somewhat used as a building stone, but its softness, marly partings and iron stain make it less desirable than other stones available in central Texas.

The outcrop covers the southeastern one-fourth or more of Grayson County. Marly lime is more prominent in the lower half of the formation, and medium bedded to thick massive chalky limestone in the upper half. In Dallas County the base of the chalk capping soft upper Eagle Ford shales, clays and flags, forms the prominent west-facing White Rock escarpment which proceeds southwards to the Brazos. It is well exposed in road cuts and cement plants on the Fort Worth road about 5 miles west of Dallas. In the quarry of the Texas Portland Cement Company 3 miles west of Dallas, the base of the Austin chalk, just above the Eagle Ford contact, is marked by a layer of phosphatic pebbles (1530, p. 148, and Pl. XXVII-A). The basal part, 150 feet of the formation, consists of heavy-bedded, massive chalk layers separated by thin shaly layers, the most resistant beds being contained in the basalmost 50 feet (1454, p. 19). The basal part contains an abundance of nodular, spherical or cylindrical masses of pyrite.

The middle part, about 250 feet thick, has fewer massive layers, and is characterized by thick, and often indurated shaly layers which show a fine lamination. This part does not show in stream cuts as marked expression of projecting and receding layers as does the basal part. The uppermost part contains more shaly limestone and less chalk. The colors are predominantly blue and yellow. Some sandy strata occur. At the Austin-Taylor boundary, there is a sharp transition from massive flaggy chalk (containing "large ammonites," most of them *Parapuzosia*) to gray shale, some of it calcareous.

In the Waco region the basal chalk is well exposed in Cameron Park. Here it consists of medium to thick massively bedded strata with some alternating receding ledges. By undercutting of Bosque River large blocks fall down the slopes and disintegrate. Flaking and exfoliation are extensive. In the cuts of Brazos River across the Austin chalk outcrop, considerable small scale faulting, with the development of V- and A-shaped grabens and horsts, is present. Such local faulting occurs in White Rock Creek near the Harrington well.

The base of the chalk, and locally the hard Eagle Ford flags, form the crest of the west-facing Bosque escarpment across McLennan County. The Bosque is deflected parallel to this scarp and follows it northward to the point where the Brazos cuts through the scarp. Along the scarp, there is considerable faulting in disconnected lines. The medial part of the chalk consists of medium bedded chalky limestone softer marly layers, weathering white. The Austin-Taylor contact occurs in and near the Baylor University Campus. Here the topmost chalk stratum is a massive chalky limestone containing *Inoceramus undulato-plicatus* and other species, and is followed with a sharp lithological break by blue-black Taylor shale. Stephenson considers that about the upper 250 feet of chalk is here absent by subsequent erosion. The top of the chalk occurs in several creeks just east of the Waco-Austin highway. In these creeks Dr. Pace has demonstrated a persistent line of faulting, possibly the eastern limit of the Balcones fault zone in this area.

Southward from Waco, the typical hard Austin chalk is overlain by a chalk marl of variable thickness, generally referred to the Taylor because of its foraminifera. In or near the base of this marl at many localities, large ammonites of the genera *Parapachydiscus* and *Parapuzosia* occur, and their zone of abundance marks approximately the top of the Austin chalk. Unfortunately their exact zonation has not yet been published. They occur in several localities southwest of Robinson and Rosenthal, and east of Temple, west of Holland in the branches of Darr's Creek, north of Austin in Big and Little Walnut creeks, on the Rio Grande at Tequesquite Creek between Del Rio and Eagle Pass, and near San Carlos, Coahuila. Some of these "cart-wheel" species reach large size; two of them have been described from Tequesquite Creek by Scott and Moore. The eastern border of the chalk is exposed near Garland, east of a line between Waco and Eddy, in Deer Creek, in northern Bell county near Little Flock Church east of Temple, in various creeks west of Holland, in Brushy Creek south of Hutto, and in various creeks in Travis County.

In San Antonio the excavations in Brackenridge Park represent the Austin chalk at levels between 100 and 150 feet above the base. The rock is evenly bedded in strata of from six inches to several feet in thickness. It is light gray, tinged with yellow. Oxidized pyrite nodules are present. Near the base of the quarry, a layer rich in *Gryphaea* shells occurs. In this county the upper 200 feet of the Austin is a soft bluish calcareous clay or mud. In these beds Stephenson found *Scaphites* sp., *Placenticeras* sp., and a large *Baculites.*

The Austin in Medina County (992, pp. 46–48) consists of alternations of soft chalky limestones and marls, argillaceous shales, or clays. Near the top the formation is mostly chalky limestone. The basal half of the Austin as far west as Hondo River contains ledges which are highly glauconitic. The upper part especially has vertical cylindrical concretions of pyrite with radiating structure. The basal 75 feet is quite highly indurated and lithologically somewhat resembles the Buda, but lacks the calcite veins characteristic of that formation. At a level about 275 above the base there is a layer of *Gryphaea aucella* shells, about 4 to 5 feet thick, which persists across Medina and Bexar counties, and is possibly the same as the prominent *Gryphaea* layer above the middle of the formation at Austin.

In the Uvalde area the Austin consists of soft, white and yellow chalky limestone and limy marl alternating. Two large exposures are on the east side of Nueces River opposite Soldiers Camp Spring, where the upper 150 feet is exposed; and a basal 200 feet in the high bluff on the west side of the Nueces between the Southern Pacific Railroad and the West Nueces. *Gryphaea aucella* Roemer, *Inoceramus* aff. *digitatus* Sowerby, and *Mortoniceras texanum* (Roemer) are recorded from the Austin in this area.

BURDITT MARL[52]

Nomenclature.—Hill included this chalk marl with the Austin chalk, and stated that the top is transitional to the Taylor. Taff (1574, p. 353) segregated the upper marly lime zone of the Austin chalk, and considered it lithologically transitional to the Taylor marl. This chalk marl is here called Burditt, from Burditt School, Travis County, and the type locality is along Little Walnut Creek downstream from the Austin-Cameron road.

Stratigraphy.—Stephenson states that the Taylor in McLennan County unconformably overlies the Austin, and that its base contains a phosphatic pebble zone. There appears to be no marked

[52]*Literature.—Areal:* Taff, 1574, p. 353; Adkins and Arick, 16, p. 64; Dane and Stephenson, 391. *Fossils:* Stephenson, 1540; Scott and Moore, 1393.

break in Travis County, although a prominent layer of phosphatic nodules and fossils occurs in the Burditt near the type locality.

Areal geology.—In south-central McLennan County above the solid Austin chalk, there are chalk marls some of which may be of the same age as the Burditt in Travis County. In Bell County the solid chalk is overlain by a chalk marl which contains many thick-shelled *Exogyra*, some *Ostrea centerensis*, *Parapuzosia*, and several other fossils. This chalk marl outcrops in Deer Creek, the head-waters of Little Elm Creek, in Cottonwood Creek, and in the branches of Darr's Creek west of Holland. Only about 35 feet has been recorded from The Pure Oil Company Hill core test west of Rogers, but it seems to be thicker on the outcrop. At many places in this zone in McLennan, Bell, and Travis counties large *Parapuzosia* occur, and seem to be distinctive of the level.

Taff records the zone from the high bluffs on San Gabriel River, between 1 and 2 miles below Jonah. Lithologically it is transitional to the Austin chalk. At least 20 feet of marly, chalky lime occurs, interbedded with marl, and with some thin seams of indurated sandy marl. Taff records that this marl contains "large *Exogyra ponderosa*, an oyster resembling *O. subovata*, and a small narrow-beaked oyster." A sandy flagstone layer above the marly lime is regarded by Taff as the top of the Austin.

At the type locality on Little Walnut Creek about 5 miles north-east of Austin, the Burditt marl is about 40 feet thick. It is a light-gray, somewhat shelly, calcareous clay overlying the hard chalk. Several species or varieties of *Exogyra* (*laeviuscula?*, *ponderosa*, *tigrina*, and costate, subcostate, imbricate, spinose, and subcancellate kinds), cart-wheel ammonites (mostly *Parapuzosia*), *Mortoniceras*, *Glyptoxoceras*, *Nautilus* (*Eutrephoceras*) and "*Ostrea*" *centerensis* occur here.

At the crossing of the new Del Rio-Eagle Pass road over Tequesquite Creek, *Exogyra tigrina* and various large ammonites including *Parapuzosia* similar to those in the Burditt marl occur in the limestone. At localities between San Carlos and El Moral, Coahuila, exceptionally large ammonites occur at this level.

A soft, thin member at the top of the Austin chalk in Medina and Bexar counties is likely equivalent to the Burditt.

This unit is distinguishable lithologically from McLennan County probably to Medina County. Paleontologically it is approximately the zone of large cart-wheel ammonites (*Parapuzosia*).

Paleontology.—This unit is the zone of abundance of *Parapuzosia* sp. and the oysters *Exogyra tigrina* Stephenson, *Exogyra* n. sp. (called the "Chalk Ponderosa"), and *"Ostrea" centerensis* Stephenson. In addition it contains fossils of undetermined range: *Nautilus* sp., *Mortoniceras* sp., a pachydiscid, *Neancycloceras?*, *Baculites*, *Exogyra ponderosa*, *E. laeviuscula?*, and several other mollusca. The foraminiferal fauna includes a large proportion of species common to Austin and Taylor, and apparently a few Austin markers, according to Mrs. Helen Jeanne Plummer.

TRANS-PECOS TEXAS

West of the Pecos, the Austin outcrops in four general areas. In Terrell County there is a considerable area of Austin chalk in thin to medium bedded white chalky limestone ledges along the Shumla-Dryden highway. These beds, perhaps 200 feet remaining, contain typical *Inoceramus* and other fossils.

In Brewster County, in the Chisos and Terlingua quadrangles the Austin is irregularly exposed, and forms the lower part of Udden's Terlingua formation. The Austin locally may be considered bounded below by a widespread caprock of siliceous limestone in medium or thin-bedded flags, containing *Crioceras* n. sp. (with short spines), a belemnite, one or two species of *Scaphites*, and some unidentified discoidal ammonites. It outcrops on the hill north of No. 16 head shaft of the Chisos Mining Company at Terlingua, at the south end of Grace Canyon, at many places between Terlingua and Hen Egg Mountain, on the north and west slopes of Mariscal Mountain, and elsewhere. The Austin extends up to and grades into typical Taylor clay. In lithology it is entirely different from type Austin, but somewhat similar to Val Verde or Boquillas flags. It consists of thin to medium bedded, laminated, slightly shaly limestone flags, blackish-blue to gray interiorly, weathering to whitish-gray in the more calcareous layers, blackish-blue in the more shaly and carbonaceous layers, brittle, jointed vertically, and breaking into diamond-shaped blocks of various sizes or in more indurated flags weathering to large, hard, ringing slabs. Near the top there is an alternation of softer shaly and harder limy strata, which on domes weather to circular benches with low infacing cuesta faces and long outdipping back slopes. The formation is less resistant, and forms less prominent hills, than the underlying Boquillas flags (Eagle Ford); it is more resistant than the Taylor, which weathers to clay flats and slides, bad lands and outlier topography. Among the fossils are: *Mortoniceras* several species, *Baculites, Inoceramus subquadratus* Schlüter, *Inoceramus* several species, *Durania* cf. *austinensis* (Roemer), and others.

A notable area of Austin is in the southeastern part of the Chisos quadrangle along the Rio Grande between San Vicente and the mouth of Tornillo Creek, where numerous *Inoceramus* cf. *digitatus* Sowerby occur. In the Tierra Vieja, Van Horn and Eagle Mountains, Austin formation outcrops. Between Chispa Summit and the abandoned San Carlos coal mine, it is in almost entirely a clay facies, with small intercalated bodies of thin limestone flags. This formation, about 1200 feet thick, bounded below by the Chispa Summit (Eagle Ford) and above by Taylor clays, is here called the *Colquitt formation.* The type locality is on the Colquitt ranch below Chispa Summit, western Jeff Davis County.

In northern Brewster and western Pecos counties, Austin chalky limestone occurs on the east slope of the Davis Mountains beneath the Taylor clay.

Paleontology.—But little progress has been made toward a zonation of the Austin chalk and its equivalents. The following are some fossils from the formation with their probable ranges. The earliest *Mortoniceras*[52a] occur in the Austin; the genus is represented by a complicated, as yet unpublished, flowering of species as in the Washita genus *Pervinquieria. M. minutum* Lasswitz is common; *M. quattuornodosum* Lasswitz and *M. texanum* (Roemer) are rare. The rudistids *Durania* and *Sauvagesia* are common in Austin and Taylor. *Inoceramus subquadratus* Schlüter (often misnamed *I. crippsi*) is perhaps the commonest Chalk *Inoceramus*. A rarer tall form is *I. subquadratus* var. *austinensis* Heinz (703a). Practically typical *I. digitatus* Sowerby occurs in the Big Bend. *I. undulato-plicatus* Roemer characterizes the upper part of the Austin

[52a]The ammonite genus *Mortoniceras* as applied to Austin chalk and higher species has been renamed *Texanites* by Spath (1511b), but for the convenience of readers the older name is retained in this discussion.

chalk, but its total range is unknown. At many levels both basal and upper, forms like *Haploscapha grandis* Conrad and *H. niobrarensis* Logan occur. Other rather characteristic species are *Pecten bensoni* Kniker, *Spondylus guadalupae* Roemer, *Liopistha elegantula* (Roemer), *Gryphaea aucella* Roemer, *Hemiaster texanus* (Roemer), *Exogyra laeviuscula* Roemer, *Exogyra* n. sp. Böse (so-called "Chalk Ponderosa," practically confined to the Austin chalk marl at the top of the formation), *Exogyra tigrina* Stephenson, *"Ostrea" centerensis* Stephenson, and others. In a lowermost portion in Travis County, no *Mortoniceras* have yet been reported; to this portion likely belong: *Phlycticrioceras* n. sp., *Parapuzosia* aff. *stobaei,* and *Coilopoceras austinense* Adkins. This portion contains large *Inoceramus* (up to 2 feet in diameter).

A middle portion of the chalk contains *Mortoniceras minutum* Lasswitz, and several species similar to it, *M. planatum* Lasswitz, *M. quattuornodosum* Lasswitz, *M. texanum* (Lasswitz), *M.* aff. *emschere,* and other species, *Parapachydiscus* (small sp.), *Parapuzosia* aff. *corbarica, Barroisiceras dentatocarinatum* (Roemer), pelecypods and echinoids, and a new ammonite genus closest related to *Mortoniceras.*

Near the top of the chalk there are found: *Parapuzosia* (large species), *Parapachydiscus* (large species), *"Hamites," Baculites,* and other ammonites. The overlying chalk marl with *Exogyra* n. sp. (Chalk Ponderosa), *Exogyra tigrina* and *"Ostrea" centerensis,* contains *Baculites, "Hamites"* and *Parapachydiscus* (small sp.).

The following species are on record from western Texas: (a) probably from the basal Austin equivalents, Coniacian = Spath's Gauthiericeratan age, *Peroniceras* aff. *czörnigi* (Reeside, from Seco Creek and Tequesquite Creek); *P.* aff. *czörnigi,* with very prominent alations (Arick; Capote Ranch), *P.* aff. *westphalicum* (Reeside; Uvalde County), *Gauthiericeras* aff. *margae* (Terlingua area). (b) From upper levels, Lower Santonian = Mortoniceratan, *Parapuzosia americana* Scott and Moore, *P. bösei* Scott and Moore (Tequesquite Creek). *Canadoceras flaccidicostum* (Roemer) and *Turrilites wysogorskii* Lasswitz also probably are Austin chalk species. Some of these ammonites were described by Reeside (1295a).

Of the rudistids, *Sauvagesia* aff. *degolyeri* Stanton, *S. acutocostata* Adkins, *S.* aff. *belti* Stephenson, and *Durania austinensis* (Roemer) occur in the chalk.

Fish and mososaur remains have been found in the Austin chalk.

The following are among the most distinctive Austin ostracoda:

Cythereis bicornis Israelsky (upper Austin)
Cythereis n. sp. aff. bicornis Alexander (lower Austin)
Cythere sphenoides (Reuss) (Austin; Taylor)
Cytheropteron pedatum Marsson (upper Austin; rare; Gober, common; Pecan Gap; Annona; Saratoga)
Cytheropteron n. sp. Alexander
Cythere n. sp. Alexander
Cythereis semiplicata (Reuss)
Cythereis ornatissima (Reuss)
Cythereis ornatissima (Reuss) (upper Austin; Gober)
Cythereis austinensis Alexander (upper Austin)
Cytherella parallela (Reuss)
Cytherella bullata Alexander (upper Austin to Pecan Gap)

Foraminifera do not in general afford an exact distinction of Austin from either Eagle Ford or basal Taylor; however, the following foraminifera are found in the Austin chalk in central Texas:

Austin Foraminifera[53]

Ammodiscus incertus (d'Orbigny)
Flabellamina rugosa Alexander and Smith
Flabellamina clava Alexander and Smith
Spiroplectammina anceps (Reuss)
Textularia agglutinans d'Orbigny
Gaudryina carinata Franke
Gaudryina pupoides d'Orbigny
Gaudryina stephensoni Cushman
Clavulina cf. communis d'Orbigny
Heterostomella sp.
Trixtaxilina (?) sp.
Valvulina inflata Franke
Arenobulimina cf. presli (Reuss)
Dorothia sp.
Lenticulina rotulata Lamarck
Lenticulina aff. pondi (Cushman)
Lenticulina spp.
Hemicristellaria trilobata (d'Orbigny)
Saracenaria italica Defrance
Vaginulina recta Reuss
Vaginulina regina Plummer
Flabellinella sp.
Dentalina alternata (Jones)
Dentalina communis d'Orbigny
Dentalina granti Plummer
Dentalina megapolitana Reuss
Dentalina spp.
Nodosaria affinis Reuss
Flabellina interpunctata von der Marck
Frondicularia archiaciana d'Orbigny
Frondicularia cordai Reuss
Frondicularia lanceola Reuss
Frondicularia verneuiliana d'Orbigny + var. bidentata Cushman
Frondicularia spp.
Ramulina aculeata (J. Wright)
Vitrewebbina cervicornis (Chapman)
Guembelina globulosa (Ehrenberg)
*Rectoguembelina texana Cushman
*Eouvigerina serrata (Chapman)
Pseudouvigerina plummerae Cushman
Pseudouvigerina sp.
Spiroplectoides rosula (Ehrenberg)
*Hantkenina multispinata Cushman and Wickenden
Bulimina murchisoniana d'Orbigny
Loxostoma tegulatum (Reuss)
Ellipsonodosaria rotundata (d' Orbigny)

[53]In this list, prepared by Helen Jeanne Plummer, the species marked (*) are thought to be most characteristic of the Austin.

Discorbis aff. correcta Carsey
Gyroidina depressa (Alth)
Gyroidina globosa (v. Hagenow)
Globigerina cretacea d'Orbigny
Globigerinella voluta (White)
*Hasterigerinella alexanderi Cushman
*Hasterigerinella watersi Cushman
Globotruncana arca (Cushman)
Globotruncana canaliculata (Reuss)
Globotruncana fornicata Plummer
Anomalina involuta (Reuss)
Anomalina ripleyensis W. Berry
Anomalina taylorensis Carsey

TAYLOR GROUP[54]

Nomenclature.—When this and many other Texas rock groups were named the conception of type locality did not exist. The name of the formation might be changed, because of preoccupation or convenience, and another name substituted without the notion that the conception of the formation was thereby altered. Towns were few, and often one was selected on the strip of the formation because it was the nearest available name, not because the town stood on a large or significant exposure.[55] It is here assumed that for certain names of long standing, change of name does not involve change of the type locality, so that the type locality of the Taylor is on the Colorado in Travis County, the type locality of the Buda on Shoal Creek at Austin, the type locality of the Edwards on Barton Creek near Austin.

The Taylor, first called the "Blue Bluffs division" (from Blue Bluff of the Colorado, 6 miles east of Austin) in Hill's 1889 papers, was named the Taylor marls by Hill (780, p. 73) in 1891. In many papers it had been called the "*Exogyra ponderosa* marls" or "clays." It changes facies rapidly along the outcrop across Texas, and the attempt to apply the system of formational and member names to these many types of lithology has resulted in a maze of local names. The following is a partial summary of the names so far applied to Taylor equivalents:

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[54]*Literature.—Arkansas:* Dane, 392; Stephenson, 1538; Israelsky, 870. *North-central Texas:* Dane, 391; Reiter, 1297; Spofford, 1511d; Stephenson, 1530, 1534; Shuler, 1454; Bullard, 177; Lahee, 969; Hill, 103. *South-central Texas:* Hill, 795, 803, 808; Stephenson, 1541; Vaughan, 1685; Baker, 49; Udden, 1625. *Trans-Pecos Texas:* Udden, 1626; Vaughan, 1687. *Paleontology:* Adkins, 15; Hyatt, 867; Vaughan, 1687; Stephenson, 1541; Udden, 1627. *Igneous rocks:* Lonsdale, 1009; Ross, 1353, 1353a; Udden, 1641. *Rockwall sandstone dike:* Burleson, 172, pp. 128–129; Hill, 803, p. 361; Kelsey, 899b; Paige, 1169; Patton, 1183; Stephenson, 1535; Fohs and Robinson, 543.

[55]R. T. Hill, personal communication.

Subdivisions of Taylor Group in Texas

Arkansas	*Northeast Texas*	*McLennan-Falls-Bell counties*	*Medina County*	*Maverick County*	*Presidio County*
Marlbrook	*unnamed upper marl*	*unnamed upper marl* Cooledge	*Strata at King's Water Hole*	San Miguel	San Carlos beds
Annona	Pecan Gap Wolfe City	Marlin Lott Rogers	Anacacho		
Ozan	*unnamed marl*	*unnamed sandy marl* ("Wolfe City")			
	Gober chalk	Durango sand		Upson	
Browns-town	Browns-town	*unnamed basal marl*	Upson		

Stratigraphic position and contacts.—As was previously stated, the Austin-Taylor contact is unconformable in south-central Texas. The contact has not been sufficiently studied in west Texas. The Taylor-Navarro contact, according to Stephenson, is represented by a large unconformity from Travis County southwards; at Kimbro, the two basal Navarro zones (*Exogyra cancellata* zone, and Nacatoch sand) are absent, and the succeeding chalky marl member rests on Taylor with only a thin phosphatic pebble zone intervening. In an exposure 8 miles west of Cameron, Milam County, the Nacatoch sand is absent, and the chalky marl member rests on the *Exogyra cancellata* zone of the basal Navarro. The unconformity, with the two basal Navarro members missing, "continues toward the southwest with as great or greater magnitude, nearly to the Rio Grande Valley, where, in the vicinity of Eagle Pass, Maverick County, the gap is only partly filled by the Olmos, a coal-bearing formation. How far this unconformity extends into Mexico has not been determined" (1539, p. 1332).

Facies.—Since the foregoing multiplicity of "formations" or members in the Taylor represents an attempt to designate different lithologic facies by individual names, the facies of the Taylor are evidently many. They can be classed mostly as chalks, clays or marls, and sands, but these types of sediments are interpenetrating at many places and at many levels. It is now practically useless to attempt broad generalities concerning the detailed location of each facies during all of Taylor time. At and above the middle of the Taylor in the central Texas outcrop, there was a widespread epoch of sand deposition, represented by the Wolfe City, Durango and unnamed sands. These are marginal, and indicate proximity to a shore. Some levels in the San Miguel in the Eagle Pass district are distinctly sandy. Elsewhere in central Texas and in Trans-Pecos Texas the Taylor is of the type facies, *i.e.*, marl or clay. In southern Arkansas the recorded Taylor equivalents are, in ascending order: Brownstown, dark gray, pure and slightly sandy marls; Ozan, dark gray sandy marl, chalky marl, glauconitic chalk, sandy marl and sands with black chert pebbles (sandier to east); Annona, white chalk; Marlbrook, dark gray pure and chalky marl. The Brownstown is lower Taylor; the middle Taylor is represented by the unconformity at the Brownstown-Ozan contact; and the Ozan, Annona and Marlbrook are upper Taylor. In the upper half of the Taylor the Annona-Pecan Gap-Marlin chalks, and at lower levels the Gober and the Lott, represent widespread conditions favorable to chalk deposition. The Anacacho is a near-shore limestone deposit of the reef facies.

The sandstone dikes near Rockwall were visited by Richard Burleson (172, pp. 128–129) in July, 1874, and were apparently considered as intrusive bodies. The dikes have been described by later writers (803, 899b, 1169, 1183, 1535). They are stated to represent cracks filled with sand, which may have been derived from nearby sand members in the Taylor. In this connection, earthquake cracks have been formed in recent years at various places in Trans-Pecos Texas.

Areal outcrop; local sections.—In Hunt, Fannin, Lamar and Red River counties, the Taylor is different from that in the type area in central Texas, and is subdivided into units which continue eastwards with some modification into southwestern Arkansas.

NORTHEAST TEXAS

BROWNSTOWN MARL

Nomenclature.—The Brownstown marl of Hill (753, pp. 86–87) was named from the vicinity of Brownstown, Sevier County, Arkansas. Veatch (1691, p. 25) restricted the term to the marls underlying the Annona chalk and overlying the Tokio (Veatch's Bingen). Dane (392, p. 46) later restricted the Brownstown to include only the lower part (on which the town Brownstown stands) of Veatch's Brownstown, the upper part being called Ozan.

Areal outcrop.—In Arkansas the Brownstown unconformably overlies the Tokio (392, p. 48). On the Ozan road 2.4 miles south of Nashville, Arkansas, there is exposed white Tokio clay containing poorly preserved fragments of plants. Overlying its slightly irregular surface there is a deposit of dark, calcareous Brownstown clay showing "borings" and irregularities filled with limy, sandy clay that extends down into the Tokio. In Arkansas, the thickness of the Brownstown is about 250 feet thick in Howard County, about 220 feet thick in Sevier County, and farther west it is thinner. In northeastern Texas it is 75 to 200 feet thick.

In Texas it extends from Red River County westward to near Bonham, overlying the Blossom sand, and in Lamar and eastern Fannin counties underlying the Gober chalk. It merges westwards into the top of the Bonham clay, which in southwestern Fannin County changes into the upper part of the Austin chalk (of Taylor age).

The oyster *Exogyra ponderosa* Roemer is so abundant in the Brownstown and in the overlying Ozan that the two formations together have been called *Exogyra ponderosa* marl. The Brownstown Exogyras include: (1) typical large, nearly smooth *ponderosa* with irregular and wide growth imbrications; (2) *E. ponderosa* var. *erraticostata* Stephenson, ornamented with irregular costae which become weaker toward the margin; (3) a form somewhat like the last, which has a relatively small and thin shell, and the left valve marked by numerous fine, narrow, bifurcating costae, the shell differing from *E. upatoiensis* in being larger and more coarsely ribbed. According to Stephenson a shell somewhat similar to the last, but narrower and higher, occurs in the Blossom sand in Texas. Ammonites found in the Brownstown include: *Baculites asper*, *Placenticeras*, and *Scaphites hippocrepis* (DeKay).

GOBER CHALK

Nomenclature.—This, the lower of the two main Taylor chalks in northeastern Texas and known previously under various names in the literature, was given the name Gober by Stephenson in 1927

(1534, p. 8). The type locality is the village Gober, south-central Fannin County, Texas.

Areal outcrop.—So far as is now known, the outcrop of the Gober is restricted to Fannin, Lamar and possibly western Red River counties, Texas. In the Clarksville section, there is a chalk in the position of the Gober, just above the Brownstown marl (392, fig. 3, page 81); this chalk, exposed at White Rock about 7 miles northeast of Clarksville, is stated by Stephenson (1534, p. 11) to have a lower stratigraphic position than the Pecan Gap (= upper Annona), being separated from it by a band of chalky clay or marl, but containing a similar micro-fauna. East of the Clarksville area the Gober is not recorded. Thomas and Rice (1601a, p. 964) state:

> The Gober chalk, occurring on the outcrop and in wells in northeast Texas, is a lower Taylor tongue and not a part of the true Austin chalk. In several respects it is more closely related to the lower Pecan Gap chalk than to the Austin and is intermediate in position.

The Gober chalk extends eastward from the upper part of the thickened body of Austin Taylor chalk outcropping in southwestern Fannin County. Where it connects with the main body of chalk overlying the Bonham clay it is as much as 400 feet thick, but to the east it thins, and in eastern Lamar County appears to pinch out entirely. According to Stephenson this eastward thinning of the Gober may be partly caused by basal strata of Gober changing into the marl facies of the underlying Brownstown and thus becoming indistinguishable from that member. In the area between Honey Grove, Fannin County and High, Lamar County, the lowest part of the Gober is in part composed of soft, more or less chalky clay or marl. The lowest layers of chalk, which are exposed in a cut about 1¼ miles west of High, are regarded as forming the base of the Gober. Eastward this chalk probably interfingers into and changes over into clay. The uppermost bed of Gober, from central Fannin County to eastern Lamar County, is a soft, tough limestone, 1 to 10 feet thick, which is suitable for building stone. Paleontological evidence indicates that the Gober is of younger age than the Austin type (1534, p. 8).

Above the Gober and below the Wolfe City sand, there is a considerable thickness of Taylor clay, continuous with the main body of type Taylor in south-central Texas and passing eastwards through northwestern Hunt County, southeastern Fannin County, southern

Lamar and Red River counties and into southwestern Arkansas. In Red River County in Stephenson's opinion the greatly expanded Annona chalk goes far enough down in the column to take in the equivalents "not only of the Pecan Gap chalk, but of the underlying Wolfe City sand member of the Taylor marl, and of most, if not all, of the still lower Taylor beds as they are developed in Lamar and Red River counties." (1534, p. 11.)

WOLFE CITY SAND

Nomenclature.—This member was described by Stephenson (1530, p. 155), the type locality being near Wolfe City, Hunt County. Good localities mentioned by Stephenson are a cut of the Gulf, Colorado and Santa Fe Railway, 1½ miles east by north of Wolfe City, and railway ditches ⅘ to 1 mile east of Pecan Gap, Delta County. Synonym: Corsicana sand (of various authors, not of R. T. Hill, 1901).

Areal outcrop.—The member consists of 75 to 100 feet of fine, calcareous gray sand or sandy marl with a few round, oval or irregular concretions of calcareous sandstone. The sand weathers to greenish-yellow. Near the middle of the member is a more or less persistent layer of highly fossiliferous calcareous sandstone of varying thickness, which contains a large molluscan fauna. Some beds of calcareous clay occur in the upper part of the member, between the indurated layer and the overlying Pecan Gap chalk member.

C. S. Ross (in 1535, p. 5) has described Wolfe City sand from near Wolfe City as follows:

> The mineral grains are predominantly quartz, but smaller amounts of feldspar, mica, and other minerals, are present. The grains are sharply angular for the most part. The cementing material is finely granular calcite. The sand grains average about 0.05 mm. in diameter.

Kelsey and Denton (899b) state that the Wolfe City sand "is characterized by a comparatively large amount of zircon and a moderate amount of garnet;" titanite is usually present in moderate amounts; staurolite and rutile are relatively unimportant.

In its type region the Wolfe City is 75 to 100 feet thick. It is not mapped farther southwest than central Rockwall County, though sands in its general stratigraphic position occur as far south as

Falls and Bell counties (page 464), nor east of northwestern Delta County.

The following fossils are known from the Wolfe City member: *Hoplitoplacenticeras* sp. aff. *H. vari, Baculites asper* Morton, *Scaphites* (2 or more species), *Inoceramus* aff. *barabini, Pecten* aff. *burlingtonensis, Liopistha (Cymella) bella* (Conrad), *Cardium (Criocardium)* sp., *Leptosolen biplicatus* Conrad, *Corbula crassiplica* Gabb, *Panope* cf. *decisa* Conrad, *Turritella trilira* Conrad, and others. Further notes on the Wolfe City are given by Dane and Stephenson (391, pp. 42–45).

PECAN GAP CHALK

Nomenclature.—This chalk was named by Stephenson (1530, p. 156) in 1919. The type locality is near Pecan Gap, Delta County, in a cut of the Gulf, Colorado and Santa Fe Railway ½ mile east of Pecan Gap. Other good localities are on the Cox place 3 miles east by south of Wolfe City; and on the Jim Burnett farm, one mile west of Kellog, Hunt County (see also 1511d).

Areal outcrop.—The Pecan Gap typically consists of about 50 feet of bluish-gray, slightly bituminous, more or less argillaceous and sandy chalk, weathering to a light gray and white. The lower 10 feet is a blue massive chalk, weathering light gray and white, becoming sandy and containing many phosphatic casts of mollusca in the lower 2 or 3 feet. At the type locality the basal chalk is glauconitic, contains numerous phosphatic nodules, and rests upon the somewhat irregular surface of the top of the Wolfe City sand, which is here a soft, fine-grained argillaceous sand. However at a locality ¾ mile north and ¾ mile west of Rockwall, the lowest 3 feet of the Pecan Gap, which consists of hard blue chalk weathering white and changing to calcareous clay at its base, rests without irregularity on dark argillaceous sand of the Wolfe City. The thickness of the Pecan Gap is here not more than 40 feet. Southwards the Pecan Gap thins. At a locality on the north side of Mustang Creek 3.1 miles N. 30° W. of Crandall, Kaufman County, the upper part of the Pecan Gap is a hard chalky marl, in part practically chalk (391, p. 44).

Cephalopods reported from the Pecan Gap in Delta and Hunt counties are: *Baculites asper* Morton?, *Baculites* spp., "*Turrilites*" (2 species), *Scaphites* (3 to 4 species), and *Nautilus* sp. Other fossils are: *Hemiaster* aff. *lacunosus* Slocum, *Gryphaea vesicularis* Lamarck var., *Ostrea plumosa* Morton, *Exogyra ponderosa* Roemer, *E. ponderosa* var. *erraticostata* Stephenson, *E. costata* Say (a small, non-typical form), *Anomia argentaria* Morton, *Pecten quinquecostatus* Sowerby, *Cardium spillmani* Conrad, *Liopistha protexta* Conrad?, "*Radiolites*" *austinensis* Roemer, and several others.

Fossils from the Annona and Pecan Gap chalks are listed by Thomas and Rice (1601c). Some Taylor and Austin chalk samples contain "spherical bodies" (p. 365).

The Pecan Gap-Wolfe City contact is unconformable in Hunt and Collin counties. At a locality 2.6 miles east-southeast of Kingston, Hunt County, the base of the Pecan Gap chalk is highly phosphatic, contains many phosphatic casts of fossils, and many borings filled with chalk extend to a depth of 2 feet into the underlying greenish-gray marine sand. In Bear Creek, ½ mile south of Lavon, Collin County, the base of the Pecan Gap chalk, marked by a thin line of phosphatic casts and nodules, cuts across the edges of the underlying Taylor clay strata (1539, pp. 1330–1331).

The base of the upper Taylor marl overlying the Pecan Gap chalk contains, at a locality 3¾ miles southwest of Clarksville, Red River County, a few smoothly water-worn quartz pebbles (1539, p. 1331). Additional Pecan Gap localities in Red River County are recorded by Spofford (1511d).

MARLBROOK MARL EQUIVALENTS

In Arkansas the restricted Marlbrook marl of Dane, consisting of the marl conformably overlying the Annona chalk and unconformably underlying the Saratoga chalk, contains in its upper part a few fairly typical *Exogyra cancellata* (of which the most typical forms occur in the base of the Saratoga), and a variety of *E. ponderosa* which is transitional between the typical *ponderosa* and *E. cancellata*. Stephenson regards the *Exogyra cancellata* zone (= Saratoga, in Arkansas) as the basal member of the Navarro, and considers as upper Taylor at least from Hunt County southward the 300 or more feet of marl overlying the Pecan Gap chalk (391, p. 44). In Kaufman County this marl has an estimated maximum thickness of 400 feet, and it thins eastwards. Apparently there is no distinct stratigraphic break between this marl and the underlying Pecan Gap from Collin County southward. The Pecan Gap grades upward into chalky marl containing locally thin chalk seams for at least 100 feet above the Pecan Gap. A single specimen of *Exogyra ponderosa* was found at this level at a locality on the Josephine road about 2 miles north by east of Nevada, Collin County. Above this level the marl is less chalky, and in places is a calcareous clay containing abundant fragments of *Inoceramus* and occasionally, poorly preserved, large, compressed *Baculites*, and other, unidentified fossils. East of Hunt County and specifically in central and eastern Red River County, the 500 feet of marl above the Pecan Gap chalk, though devoid of large fossils, may be of upper Taylor (Marlbrook) age (391, p. 47).

A high Taylor (?) sand in the Corsicana area has been called the Edens sand (1062, p. 228, pl. XX).

CENTRAL TEXAS

From east-central Dallas County southward to northern Limestone County the only member differentiated in the Taylor group is the revised and expanded southern extension of the Wolfe City sand, of Dane and Stephenson (391, p. 48), which lies above the middle of the Taylor. It is underlain by lower Taylor clay and overlain by upper Taylor clay.

In western Limestone and east-central Falls counties, at the approximate stratigraphic level of the Pecan Gap chalk, is a thin chalk called the Marlin chalk. At this latitude about the medial one-third of the Taylor is occupied by prevailingly sand strata, at least at its top and bottom, and these strata have been designated as the southern extension of the Wolfe City sand. However, southwards they become thin, and from about their middle there is a thin southward chalky bed, outcropping in south-central Falls County and eastern Bell County, called the Lott chalk. In eastern Bell County there are Taylor chalks at several levels, and one of these has been called the Rogers chalk. From Axtell, eastern McLennan County, southwards to near Theo, on the Bell-Falls county line, there is a thin sand member, called the Durango sand. The names so far given do not by any means exhaust all the seams of chalk, sand, clay, and other materials in the Taylor in this region, for well logs and cores indicate that the naming could continue to great lengths. In the latitude of Temple approximately the Taylor consists of the following known beds, in ascending order: (1) chalk marl; (2) unnamed clay-marl; (3) Durango sand; (4) unnamed clay; (5) Lott and possibly other chalks; (6) unnamed clay; (7) chalks, probably including the Marlin chalk; (8) unnamed clays.

From Bell County, where logs indicate the Taylor to be 1200 to 1400 feet thick, southward through the type locality east of Austin, to Hays County, the Taylor has not been subdivided. In Hays County the basal part of the Taylor is of the Austin chalk facies (Norman Thomas, personal communication).

"WOLFE CITY" SAND (southern extension)

This sand terrane has been traced and mapped by Dane and Stephenson (391, pp. 48–51). South of Trinity River sandy beds in the upper Taylor at and near the stratigraphic position of the Wolfe City sand are 250 feet thick. The upper part of this sand body they consider equivalent to the type Wolfe City and the lower part equivalent to the Taylor marl beneath the Wolfe City. This enlarged and emended Wolfe City of Dane and Stephenson includes all the conspicuously sandy beds near the center of the Taylor as far south as Hill County (391, p. 48). The "Corsicana sand" of various authors (not Hill, 803, p. 342) is a synonym.

Light and dark sand and clay composes the member as far south as Limestone County. About 0.3 mile north of Garrett, Ellis County, a lower 25 feet of the sand consists of bedded fine-grained dark, slightly argillaceous sand, alternating with sandy clay, and near the top of the exposure a 2-foot layer of thin-bedded hard gray slabby calcareous sandstone, brown on weathered exposure. Near the top of the Wolfe City 1½ miles east of Bristol, there is an even-bedded, fine-grained clean quartz sand which weathers yellowish red. The strata are ½ to 2 feet thick, and there are hard calcareous lenticular sandstone beds containing indistinct fossil impressions.

In Navarro County the basal part of the Wolfe City is characteristically well-bedded alternating sandy calcareous clay and soft, marly sand, in beds up to 2 inches thick, and thin beds of hard gray calcareous sandstone. The upper part contains soft, nearly massive, fine-grained, yellow-weathering sand and some hard irregular concretionary lenses of calcareous sandstone.

From Rockwall County southward to Limestone County no chalk was observed at the level of the Pecan Gap chalk. In this area, between the top of the Wolfe City sand and the base of the Navarro, there is about 400 feet of marl, locally chalky in the lower part, and apparently devoid of diagnostic fossils.

South of Hill County "the sandy calcareous clay below the Wolfe City sand of Hill County becomes increasingly sandy southward through McLennan and Falls counties. On the contrary, the 350-foot section included in the Wolfe City sand in southern Hill and southwestern Navarro counties becomes decreasingly sandy southward through McLennan and Falls counties. Characteristically it is a bedded sandy marl with regular even beds of either pure or slightly sandy marl ranging from ½ to 1 inch thick, with intervening thinner sheets and vermicular pockets of soft, clean sand. . . . Altogether there is probably a thickness of about 550 feet of this sandy marl, the upper part of which is equivalent to the Wolfe City sand of Hill and Navarro counties, and the lower part of which is equivalent to sandy marl in Hill County" (391, p. 50).

DURANGO SAND

One prominent lower Taylor sand was called Durango sand by Dane and Stephenson (391, pp. 43, 51), the type locality being Durango, western Falls County. It is located about 350 to 400 feet above the base of the Taylor and is of unknown thickness, but is the definite base of the Taylor sands in this section. It makes a distinct sandy strip a mile or more in width, and on the Lott road 1.2 miles south of Chilton has a recorded thickness of at least 65 feet.

LOTT CHALK

This middle Taylor chalk, named by Dane and Stephenson, with its type locality at Lott, central Falls County, outcrops in southern Falls and eastern Bell counties, is 50 or less feet thick, and makes irregular and inconsecutive exposures. Another chalk, apparently disconnected, so far as could be judged from poor outcrops, is the Rogers chalk, found in stream cuts just west and south of Rogers, southwestern Bell County (16, p. 65).

MARLIN CHALK

The chalk underlying the town of Marlin and occurring at the historic Falls of the Brazos has long been known by this name, and forms a prominent outcrop in western Limestone, the east corner of McLennan, and north-central Falls counties. The Cooledge chalk (1297) is a higher Taylor chalk. The point farthest northeast at which the chalk was observed is 3.2 miles north by west of Prairie Hill, where a few feet of white chalk occur (391, p. 54). At this point the beds beneath the Marlin chalk are sandy shale and calcareous sand like that in the upper Wolfe City; farther south they become marl. At localities on the edge of the bottom lands of the Brazos 0.4 and 0.9 mile south of the courthouse at Marlin, there is exposed in a small west-facing scarp about 4 feet of soft argillaceous creamy chalk with fossils, underlain by 5 feet of pure chalk. At the crossing of Big Creek 3.2 miles south by east of Mart there is a large 15-foot exposure of bedded marly and pure chalk containing *Gryphaea* sp., *Echinocorys* aff. *E. texanus* (Cragin) and other fossils. At the Falls of the Brazos at low water a large exposure of bedded chalk containing *Exogyra ponderosa* and other fossils is visible. In Limestone and Falls counties above the Marlin chalk is 250 feet (thinning to the south) of marl, chalky towards the base but gradually less calcareous above. South of Falls County the marl carries *Exogyra ponderosa*, and has some minor lithologic variations: concretionary limestone lenses several feet in length, some of which are mostly crystalline calcite; sandy marl with sandy concretionary lenses like the Navarro but with *E. ponderosa*. A high Taylor chalk exposed 3 miles northwest of Cooledge is called the Cooledge chalk (1297, p. 323).

The Taylor in eastern Williamson County has been very little studied and no lithologic members have been differentiated in this section. The similar section in eastern Travis County as at the Blue Bluff of the Colorado 6 miles east of Austin, from which the formation was first named, contains mostly blue calcareous, fossiliferous clay containing many *Inoceramus*, *Exogyra*, and other fossils. Helen Jeanne Plummer and Norman Thomas have studied the calcareous Taylor marl 2 miles west of Taylor on the south side of the Round Rock road, and have found it to contain a typical Pecan Gap microfauna.

In Travis County the type locality (S. O. Burford, unpublished MS.), the following is the general partition of the Taylor: (1) At the base there is 100 feet or more of massive blue marl containing *Ostrea falcata, G. vomer* (lowest) and *Exogyra ponderosa* (massive round form). (2) A phosphatic *Baculites* zone, one foot thick (some fossils described in 15). (3) About 275 feet of massive blue marl with ferruginous seams. (4) A 4-foot layer of clayey chalk, the upper 1 foot hard and fossiliferous: *Exogyra costata* var., "*Lituola nautiloidea*" [= *L. taylorensis*]; exposed in the Del Valle bluffs. (5) About 100 feet of massive blue marl, with *Gryphaea vesicularis* in the lower half. (6) About 20 feet of unctuous clay and nodular limestone, with "*Helicoceras navarroense*" abundant. (7) About 40 feet of bentonitic clay, the upper 10 feet very bentonitic; contains *Exogyra ponderosa,* and *Exogyra cancellata.*

As already noted, near Kimbro the upper Taylor is a marl containing *Exogyra ponderosa, Menuites* n. sp., *Placenticeras, Nostoceras* and *Ptychoceras* of the same general groups as in the Navarro at Chatfield, and many other fossils. It is overlain by Navarro with *Exogyra costata;* there is some faulting at the contact.

SOUTH AND WEST TEXAS

The Upper Cretaceous beds, on passing into the Rio Grande embayment, thicken and in their medial and upper parts take on shallow water facies. C. A. White had early called certain of these brackish water beds "Laramie," and the first attempt to crystallize the succession into formations was by Dumble (468, pp. 224–228), who established the following classification for the Taylor and Navarro equivalents in this district:

Eagle Pass division	Escondido beds	Navarro equivalents
	Coal Series (Olmos of Stephenson and Dane)	
	San Miguel beds	
	Upson clays	Taylor equivalents

C. A. White had earlier proposed the name "Eagle Pass beds" for the Upper Cretaceous coal-bearing strata of this district, and Dumble (468, p. 224) revised and extended this name to include all Cretaceous strata above the "Pinto" limestone (Austin chalk).

In eastern Kinney, Uvalde, Medina, and western Bexar counties, the basal Taylor is represented by the Anacacho limestone, and the upper Taylor marls overlie the eastwardly thinning edge of the Anacacho. According to Stephenson the Upson and San Miguel in the Eagle Pass district represent the Taylor, and the overlying Olmos (Coal Series) represents the near-shore facies of the basal Navarro, of which the *Exogyra cancellata* zone and the Nacatoch sand are apparently missing here.

ANACACHO LIMESTONE[55a]

Nomenclature.—The member was named by Hill and Vaughan (795, p. 240), the type locality being the Anacacho Mountains, Kinney County, Texas.

Areal outcrop.—In western Uvalde and eastern Kinney counties the topographically prominent Anacacho Mountains are composed mostly of this limestone, which overlies the Austin chalk and underlies the uppermost Cretaceous sandstones and clays called "Pulliam formation" (Navarro) by Vaughan. The thickness of the Anacacho is as much as 500 feet locally. The Anacacho limestone as typically developed occurs in the Anacacho Mountains, where it is about 500 feet thick. It is underlain by Austin chalk and overlain by Navarro (Vaughan's "Pulliam" beds), and therefore is at this point co-extensive with the Taylor. In the west end of the mountains it is underlain by a small thickness of Upson (basal Taylor) clay; at the west end of the Anacacho Mountains the Anacacho limestone ends abruptly, and farther west the formation is presumably represented by the Upson and the San Miguel, and the limestone facies is represented, if at all, only by thin stringers in the basal San Miguel.

The Anacacho typically consists of yellow, usually argillaceous but locally arenaceous, limestones with beds of yellow marl or clay. The limestones are more developed toward the west end of the Anacacho Mountains and farther east the clays are more prominent. But in the mountains some marl beds are as much as 40 feet thick. The limestones are medium to thick-bedded, clayey or sandy, generally bluish or blue-gray on fresh exposure, weathering yellowish from hydrated iron oxides. The texture is generally coarse, and much of the limestone consists of ground-up fragments of fossil shells with, however, many whole shells. It has been supposed that

[55a]*Literature.*—Adkins, 15; Baker, 49; Getzendaner, 578, 578a; Hill and Vaughan, 795; Liddle, 992; Udden, 1625; Vaughan, 1685, 1686.

this type of material represents a bar, a reef, or a very near-shore calcareous deposit. Siliceous concretions or segregations are present, but well-formed flints appear to be missing. The limestones are very fossiliferous and contain, besides *Exogyra, Inoceramus,* and many other pelecypods and gastropods, both ammonites (*Hamites, Parapachydiscus*) and rudistids (*Radiolites, Sphaerulites*) (1686, p. 7).

Farther east in Medina County, Liddle (992, p. 58) records that the Taylor consists of a thin basal Upson clay in wells, followed by about 200 feet representing the thinned eastward extension of the Anacacho limestone. Stephenson states that "in eastern Medina County and in western Bexar County the westward-thinning body of Taylor marl overlaps the eastward-thinning tongue-like extension of the Anacacho limestone. Still farther west, in Kinney and Maverick counties, the Anacacho is represented by the Upson clay and the San Miguel formation" (1534, p. 9).

Some fossils in the Anacacho are: *Parapachydiscus streckeri* Adkins, *Hamites* (?) *clinensis* Adkins, *Baculites, Inoceramus* aff. *barabini, Exogyra laeviuscula* Roemer, *Exogyra ponderosa* Roemer, *Gryphaea vesicularis, "Radiolites," "Sphaerulites,"* and others.

UPSON CLAY

Nomenclature.—The member was named by E. T. Dumble (468, p. 224) in 1892, the type locality being the now abandoned Upson post office in Maverick County.

Upson post office was in the Lehman ranch house, which is now in the village of Quemado on the Eagle Pass-Del Rio highway (note by L. W. MacNaughton).

Areal outcrop.—This is a more purely argillaceous and less calcareous phase of the Taylor marl. In Maverick County (578, p. 1431) it is about 550 feet thick, and on approaching the west end of the Anacacho Mountains it becomes rapidly thinner, only a reduced basal part remaining beneath the Anacacho limestone along the north face of the mountain (1625, p. 69). The Anacacho is therefore considered contemporaneous to the Upson and part at least of the overlying San Miguel beds in Maverick County.

The San Miguel lacks about 8 or 9 miles of reaching the Anacacho Mountains. It begins at a point about 7 miles south of Spofford Junction and thence extends southward; to the north of that point in lenses out, between the Upson clay and the Escondido, and disappears (note by F. M. Getzendaner).

On fresh exposure it is a dark gray or greenish-gray clay; on weathered exposure it usually is yellowish. Locally it contains small flakes, thin horizontal seams, and crystals of gypsum. Barite crystals and concretions formed around *Exogyra ponderosa* and other nuclei, occur. It is interesting that barite concretions, some surrounding ammonites and other fossils, occur in the upper Taylor at Kimbro, Travis County, and at San Carlos, Presidio County. A cycad, *Cycadeoidea uddeni* Wieland, was found in these clays near Paloma station. Other fossils are *Exogyra ponderosa* (typical), *Exogyra* (costate species), *Ostrea larva,* and others.

SAN MIGUEL FORMATION

Nomenclature.—The member was named by Dumble (468, p. 224) from the old San Miguel ranch on the Rio Grande above Eagle Pass.

San Miguel was a ranch (old stone house) on Elm (or La Posta) Creek, in the southeast portion of the present J. K. Burr ranch, Maverick County (note by F. M. Getzendaner).

Areal outcrop.—The member is mapped only as extending southwards from near the western end of the Anacacho Mountains, being deflected gulfwards in a long reëntrant on crossing the Chittim structure, and crossing the Rio Grande into Coahuila along a stretch 4 to 13 miles above Eagle Pass. Its equivalents extend southwards into Mexico for a short distance, but have not been closely mapped, and are soon lost in the extensive facies changes in the Gulf beds in the Sabinas Basin.

The San Miguel consists of fossiliferous sands and sandy limestones, and unfossiliferous clays superficially like the Upson. The member is about 400 feet thick. Good exposures occur, near the type locality, on the Rio Grande from 2 to 6 miles below the mouth of Hackberry Creek (Canyon Chiquito). Here sandstones are interbedded with clays and shales, which increase in number and thickness in the upper part of the beds. On Elm Creek, Udden gives the thickness of the San Miguel as not over 400 feet.

From the larger fossils the age of the San Miguel has been considered upper Taylor (1541, pp. 793–800). Dumble, although he correlated the San Miguel with the "glauconitic beds" (*i.e.*, Navarro), stated clearly that he found *Exogyra ponderosa* in the upper San Miguel (468, p. 225). Stephenson finds in the member large, smooth *E. ponderosa* and the var. *spinosa* Stephenson. The latter variety has a range from upper *E. ponderosa* (Upper Taylor) to lower *E. costata* (Lower Navarro). Stephenson gives the following list of fossils from the San Miguel, an asterisk marking those which he considers as indicating the Taylor age of the member:

*Nemodon aff. N. punctus Stephenson
Ostrea plumosa Morton
Ostrea saltillensis Böse (numerous)
*Ostrea n. sp.
*Exogyra ponderosa Roemer (large and numerous in places)
Pecten simplicius Conrad
Pecten aff. P. mississippiensis Conrad
Anomia sp. (numerous)
Lioptistha (Cymella) bella (Conrad)
Cardium (Pachycardium) spillmani Conrad
*Cardium aff. C. carolinensis Conrad
Cardium (Ethmocardium) n. sp.
Veniella conradi (Morton)
Cyprimeria depressa Conrad
*Turritella aff. T. quadrilira Johnson (numerous)
Pugnellus n. sp. (numerous)
Placenticeras sp.

Vanderpool describes the microscopic features of the San Miguel: it is gray and yellow, calcareous sandstones and sandy clays, with glauconite, selenite, pyrite and mica. The sand consists for the most part of small subrounded, clear and smoky quartz grains, with dark colored chert and magnetite. The beds of this formation are quite fossiliferous. The clays contain:

Anomalina sp.
Cibicides sp.
Lenticulina velascoensis White n. var.
Lenticulina cf. reniformis (d'Orbigny)
Lenticulina sp.
Nodosaria sp.
Textularia sp. (?)
Vaginulina cf. lineara (Carsey) n. var.
Ostracoda:
  Bairdia sp.
  Bythocypris sp.
  Cythereis sp.

Vanderpool (1681, p. 978) inclines to the Navarro age of the San Miguel, because of the microfauna and because of a stratigraphic break between the San Miguel and the underlying Upson clay. Stephenson bases the Taylor age of the San Miguel on the fossils listed above, particularly the large, smooth forms of *Exogyra ponderosa,* and on the large break in the marine succession beneath the base of the Escondido, a gap partly filled by the mostly non-marine lower Navarro Olmos beds. Unfortunately other markers such as ammonites have not been studied in sufficient detail to justify exact stratigraphic conclusions.

The Taylor outcrops in Trans-Pecos Texas in four general areas: (1) the east side of the Davis Mountains, where it is typical clay with *Gryphaea* aff. *G. newberryi* Stanton; (2) the Terlingua-Chisos area; (3) Tierra Vieja Mountains; and (4) southern Quitman Mountains. In the Terlingua area the Taylor is a typical marl, weathering into steep clay ridges, outliers and bad lands; it contains many fossils, principally *Inoceramus*, oysters, *Exogyra*, ammonites, rudistids and a few echinoids. In the Tierra Vieja-San Carlos area the Taylor attains a considerable thickness, of marl, sandy marl and shelly nodular limestones, with many ammonites and other fossils.

Paleontology.—Some more notable zonal features of the Taylor are: (1) the genus *Texanites*, already present in the Austin chalk continues with several Taylor species; (2) in the upper Taylor there is an extensive development of the genera *Placenticeras* and *Pseudoschloenbachia;* (3) the genus *Parapachydiscus* is present in several species; (4) uncoiling forms are abundant ("*Hamites,*" *Bostrychoceras, Nostoceras*). The presence of such genera as *Parapachydiscus, Menuites, Bostrychoceras,* and *Pseudoschloenbachia* gives a strongly Campanian cast to the ammonite assemblage, but pending more extensive zonal studies, no statements concerning this correlation are made at present.[56]

Available information shows that no adequate detailed zonation of the Taylor is possible with the present information, and that therefore a final correlation of the Taylor is now impossible. However, some important features of both zonation and correlation are known, and are reviewed below. The information comes mainly from five areas: San Carlos, Terlingua, Anacacho-Medina, Austin (type area), and northeast Texas.

No complete stratigraphic section of the Taylor near San Carlos is available; it is mostly shale or clay, and the upper part contains a prominent member composed of fossiliferous limestone concretions imbedded in marl. This level contains an abundance of

[56]Spath (Pal. Zentr., I, 53, 1932) states that a middle Taylor fauna "cannot be earlier than late Campanian."

Placenticeras sancarlosense, P. guadalupae, P. spp., *Pseudoschloenbachia chispaense, P.* spp., *Mortoniceras, Glyptoxoceras, Neancyloceras, Anisoceras, Scaphites, Baculites,* many other mollusca and reptilian bones. These ammonites occur in the upper 150 feet of the Taylor, and the remainder has not yet been studied.

In the Uvalde-Medina area the asphaltic Anacacho coquina limestone contains *Neancyloceras clinense, Parapachydiscus streckeri* and *Hoplitoplacenticeras* aff. *vari.* It is overlain by fossiliferous clayey and limy material, the basal part of which contains *Placenticeras* sp. indet. (from below King's Water Hole), *Scaphites* sp., *Baculites* sp., *Parapachydiscus* sp.; and the upper part contains *Echinocorys texanus* (type), *Mortoniceras* aff. *delawarense, Bostrychoceras* aff. *polyplocum, Parapachydiscus* aff. *wittekindi, Parapachydiscus* aff. *gollevillensis,* and other ammonites. The zones of the Anacacho and Upson are still unknown.

In the Austin area, a phosphatic ammonite zone lies at a level 100 feet or more above the base of the Taylor; it contains *Baculites taylorensis, Parapachydiscus travisi, Scaphites aricki, Scaphites porchi, "Hamites" (?Anisoceras) taylorensis,* rudistids and numerous other mollusca. An upper Taylor zone, exposed at several places in eastern Travis County carries many ammonites, some of them in barite nodules (as at San Carlos), including: *Nostoceras* spp., *Ptychoceras* (?) sp., *Menuites stephensoni* n. sp. (MS.), *Placenticeras* spp., *Sphenodiscus lenticularis* (reported by Burford), *Baculites* sp. (large), rudistids and other mollusca.

In northeastern Texas or southwestern Arkansas, the Wolfe City sand (about Mid-Taylor) contains *Baculites* spp. *(asper, anceps), Scaphites* spp. and *Hoplitoplacenticeras* aff. *vari.* From the Pecan Gap chalk *Scaphites, Baculites* and *"Turrilites"* are recorded. The lowest *Sphenodiscus* occurs in the Nacatoch sand. *Nostoceras* is recorded from the Buckrange sand (basal Ozan) up to the Nacatoch. *Placenticeras* is recorded in the Brownstown and Ozan. The following ammonites are recorded from the Brownstown: *Scaphites hippocrepis, Placenticeras, Baculites.* From the Buckrange sand (Ozan): *Mortoniceras* aff. *delawarense, Placenticeras, "Pachydiscus," Nostoceras, Baculites asper, B. ovatus.* From the Annona chalk: *Echinocorys* cf. *texanus, Nostoceras, "Pachydiscus," "Hamites," Baculites.* From the Saratoga chalk: *Nostoceras helicinum, "Pachydiscus," Baculites, Scaphites, Belemnitella americana.*

From the Nacatoch: *Nostoceras, "Pachydiscus," Scaphites, Baculites, Belemnitella americana.*

The following is a compiled list of known Taylor ammonites:

Pachydiscinae:
- Menuites stephensoni n. sp. MS.
- Parapachydiscus travisi Adkins
- Parapachydiscus streckeri Adkins
- Parapachydiscus spp.
- Parapachydiscus aff. gollevillensis
- Parapachydiscus aff. wittekindi
- "Pachydiscus" spp. Auctt.
- Madrasites (?) sp.

Scaphitidae:
- Scaphites verrucosus Shumard
- Scaphites aricki Adkins
- Scaphites porchi Adkins
- Scaphites hippocrepis DeKay
- Scaphites spp.

Baculitidae:
- Baculites taylorensis Adkins
- Baculites anceps
- Baculites asper
- Baculites afr. aquilasensis
- Baculites compressus
- Baculites ovatus + vars.

Prionotropidae:
- Pseudoschloenbachia chispaensis Adkins
- Pseudoschloenbachia n. spp.

"Mortoniceratidae":
- Mortoniceras delawarense (Meek)
- Mortoniceras aff. shoshonense (Meek)
- Mortoniceras n. spp.

Placenticeratidae:
- Placenticeras guadalupae Roemer
- Placenticeras sancarlosense Hyatt
- Placenticeras planum Hyatt
- Placenticeras spp.
- Hoplitoplacenticeras aff. vari

Diplomoceratidae:
- ?Diplomoceras sp.
- Neancyloceras clinense (Adkins)
- Neancyloceras n. sp.
- Glyptoxceras 2 spp.
- "Hamites" spp. Auctt.

Nostoceratidae:
- Nostoceras spp.
- ?Oxybeloceras sp.
- ?Hyphantoceras n. sp.
- Bostrychoceras aff. polyplocum
- "Turrilites" spp. Auctt.
- "Ancyloceras" aff. tricarinatum Whitfield
- "Heteroceras" spp. Auctt.

Anisoceratidae:
- Anisoceras aff. perarmatum
- Anisoceras spp.

Nautiloidea:
- Eutrephoceras spp.

Certain pelecypoda and other fossils are apparently reliable for broad zonation in the Taylor, as are certain foraminifera; lists of these more restricted fossils are given below.

Zonation.—The following tentative zonation is proposed, pending better ammonite collections:

	Big Bend	Travis County	N. E. Texas	S. W. Arkansas
7. Nostoceras		Upper Kta (Kimbro)		
6. Echinocorys texanus				
5. Hoplitoplacenticeras aff. vari	Basal Aguja		Pecan Gap	Annona
			Wolfe City	Ozan
4. Mortoniceras aff. delawarense	Taylor clays	Middle Kta		Buck-range
3. Placenticeras guadalupae				
2. ?Baculites taylorensis		Lower Kta	Browns-town	Browns-town
1. Scaphites hippocrepis				

The uppermost Taylor is likely of different ages at different places. *Sphenodiscus lenticularis* has been reported from it in eastern Travis County by Burford (in MS.), and it is known from the basal portion of Taylor clay overlying the asphaltic Anacacho coquina below King's Water Hole in Medina County. The Kimbro nodule zone, about 40 to 60 feet below the top of the Taylor, contains: *Sphenodiscus,*[57] *Nostoceras, "Ptychoceras," "Helicoceras" navarroense, Menuites stephensoni* n. sp. (MS.), *Baculites* (large), *Placenticeras,* and other ammonites. The Medina County uppermost Taylor may include still higher zones. In its basal 25 feet, immediately overlying the Anacacho limestone proper, there are reported: *Sphenodiscus lenticularis, Parapachydiscus* n. sp., and a *Scaphites.* At 50 to 75 feet above the Anacacho limestone are reported: *Echinocorys texanus, Mortoniceras* aff. *delawarense* (?), *Bostrychoceras* aff. *polyplocum, Parapachydiscus* aff. *wittekindi,* and *Parapachydiscus* aff. *gollevillensis.* The *Bostrychoceras, Menuites,* and *Parapachydiscus* are regarded[58] as indicating a high level, uppermost Campanian or even basal Maestrichtian, thus confirming Scott's view (1389, p. 118) as to the high age of the Taylor.

The fauna of the limestone nodule zone northeast and north of San Carlos is equally puzzling. Judging by Spath's European zonation alone, it may represent a condensed zone extending from the zone of *Placenticeras guadalupae* up to the *Pseudoschloenbachia* zone. This interpretation would make it comprise the entire Campanian, but further collecting is necessary to resolve the difficulty. In the Terlingua area it is notable that the range of *Placenticeras* extends well up into the Aguja sandstone, and that to date *Sphenodiscus* has not been found either near Terlingua or San Carlos. However, an ammonite resembling *Libycoceras* occurs at Cuesta Blanca just southeast of Terlingua.

The large echinoid *Echinocorys texanus* (Cragin) and related forms mark a general level above the middle of the Taylor, and occur in the upper part of the Annona chalk, the Pecan Gap chalk, the Marlin, Rogers and Lott chalks, the Taylor marl above the Wolfe City sand, and the Taylor above the Anacacho asphaltic limestone.

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[57]Discovered and reported by Dr. F. L. Whitney.

[58]Dr. L. F. Spath, personal communication; see also: Spath, 1510, p. 80 (table).

Hoplitoplacenticeras aff. *vari* has so far been found only in the Anacacho and the Wolfe City. It marks about middle Campanian in the standard zonation.

Mortoniceras aff. *delawarense* and related forms compose a variable group found at several different levels, mostly high in the Taylor. The lowest record is in the Buckrange sand (392, Pl. X). Probably the highest reported level is the upper Taylor clays in Medina County. The genus is abundant in the Austin chalk and other species occur in the Taylor and Aguja.

Placenticeras guadalupae was originally found low in the Taylor at the falls of the Guadalupe below New Braunfels. It forms a prominent zone near the top of the Taylor around San Carlos. This apparent discrepancy will likely be mostly eliminated by the discovery of further basal Taylor zones in both areas.

The two remaining zones appear generally to characterize basal Taylor. It may be noted that Böse (134, p. 269) cites *Gaudryceras kayei* (Forbes) from the Taylor near Vallecillo, Nuevo Leon, but the affinity of his species is too uncertain to afford an exact correlation.

The following are among the more distinctive Taylor ostracoda:

Cythereis plummeri (?) Israelsky
Cytheridea plummeri Alexander (upper Taylor; usually common)
Cythereis bicornis Israelsky (lower Taylor; Gober; Brownstown; upper Austin)
Cythereis ozanana Israelsky (middle and upper Taylor)
Cythereis foersteriana (Bosquet) (lower Taylor)
Cythere sphenoides (Reuss) (see Austin)
Cythereis semiplicata (Reuss) (Austin; lower Taylor)
Bairdia rotunda Alexander
Cythereis ornatissima (Reuss) (Upper Austin; lower Taylor)
Cytherella bullata Alexander (upper Austin; lower Taylor to and including Pecan Gap)
Cythereis quadrilatera (F. A. Roemer) (lower Taylor in south and central Texas)
Cythereis karsteni (Reuss) (lower Taylor; Brownstown; Gober)

An orbitoid foraminifer *Pseudorbitoides israelskii* Vaughan and Cole has been found (1688b, p. 615) in the Taylor in Texas Gas Utilities well No. 2, Pryor, Zavala County; in the Anacacho limestone from Humble Kincaid No. 4, Uvalde County; and from the Upson clay one-half mile south of the Southern Pacific Railway on Elm Creek, Kinney County.

The following are among the most distinctive Taylor foraminifera, according to lists kindly furnished by Helen Jeanne Plummer:

Reophax texana Cushman and Waters
Ammodiscus incertus (d'Orbigny)
Haplophragmoides excavata Cushman and Waters
Haplophragmoides fontinensis (Terquem)
Haplophragmoides sp.
*Lituola taylorensis Cushman and Waters
*Flabellammina compressa (Beissel)
*Frankeina taylorensis Cushman and Waters
Spiroplectammina anceps (Reuss)
Textularia concinna Reuss
Textularia ripleyensis W. Berry
Gaudryina carinata Franke
Gaudryina chapmani Franke
Gaudryina filiformis Berthelin
Gaudryina minima Egger
Gaudryina oxycona Reuss
Gaudryina pupoides d'Orbigny
Gaudryina aff. baccata Stache
Gaudryina aff. rugosa d'Orbigny
Clavulina amorpha Cushman
Clavulina insignis Plummer
Clavulina trilatera Cushman
Clavulina aff. communis d'Orbigny
Heterostomella foveolata (Marsson)
Heterostomella stephensoni (Cushman)
Heterostomella sp.
Tritaxilina (?)
Valvulina inflata Franke
Dorothia cf. bulletta (Carsey)
Spiroloculina sp.
Trochammina diagonis (Carsey)
Lenticulina navarroensis (Plummer)
Lenticulina pondi (Cushman)
Lenticulina rotulata Lamarck
Astacolus nuda (Reuss)
*Astacolus taylorensis (Plummer)
Hemicristellaria ensis (Reuss)
Saracenaria italica Defrance
Vaginulina regina Plummer
Vaginulina strigillata (Reuss)
Vaginulina aff. robusta Plummer
Flabellinella sp.
Marginulina bullata Reuss
Marginulina elongata d'Orbigny
Marginulina aff. foeda (Reuss)
Marginulina aff. tenuissima Reuss
Dentalina alternata (Jones)
Dentalina communis d'Orbigny
Dentalina confluens Reuss
Dentalina crinita Plummer
Dentalina fontannesi Berthelin
Dentalina granti (Plummer)
Dentalina megapolitana Reuss
Dentalina plebia Reuss
Dentalina raristriata (Chapman)
Dentalina reussi Neugeboren
Dentalina soluta Reuss
Dentalina spinescens (Reuss)
Nodosaria affinis Reuss
Nodosaria radicula (Linné)
Nodosaria cf. adolphina (d'Orbigny)
Nodosaria aff. hirsuta d'Orbigny
Lagena acuticostata Reuss
Lagena hispida Reuss
Lagena vulgaris Williamson
*Kyphopyxa christneri (Carsey)
Flabellina interpunctata von der Marck
Flabellina projecta (Carsey)
Flabellina rugosa d'Orbigny
Frondicularia archiaciana d'Orbigny
Frondicularia cordai Reuss
Frondicularia decheni Reuss
Frondicularia goldfussi Reuss
Frondicularia gracilis Franke
Frondicularia lanceola Reuss
Frondicularia microdisca Reuss
Frondicularia verneuiliana d'Orbigny
Frondicularia verneuiliana d'Orbigny var. fossata Cushman
Ramulina aculeata (J. Wright)
Vitrewebbina cervicornis (Chapman)
Nonionella aff. robusta Plummer
Guembelina globulosa (Ehrenberg)
Guembelina striata (Ehrenberg)
Guembelina spp.
Pseudotextularia varians Rzehak
Planoglobulina acervulinoides (Egger)
Ventilabrella eggeri Cushman
Eouvigerina americana Cushman
Eouvigerina gracilis Cushman
Pseudouvigerina plummerae Cushman
Spiroplectoides rosula (Ehrenberg)
Buliminella carseyae Plummer
Bulimina obtusa d'Orbigny
Bulimina murchisoniana d'Orbigny
Bolivina clavata Cushman
Bolivina gemma Cushman
Bolivina incrassata Reuss
*Bolivinoides decorata (Jones)
Loxostoma plaitum (Carsey)
Loxostoma tegulatum (Reuss)
Entosolenia aff. orbignyana (Seguenza)
Pleurostomella subnodosa Reuss
Ellipsonodosaria rotundata (d'Orbigny)

Valvulineria allomorphinoides (Reuss)
Gyroidina depressa (Alth)
Gyroidina globosa (von Hagenow)
*Gyroidina micheliniana (d'Orbigny)
Siphonina prima Plummer
Globigerina cretacea d'Orbigny
Globigerinella voluta (White)
Globotruncana arca (Cushman)
Globotruncana canaliculata (Reuss)
Globotruncana canaliculata (Reuss) var. ventricosa White
Globotruncana fornicata Plummer
*Cibicides excolata (Cushman)
Anomalina complanata Reuss
Anomalina grosserugosa (Gumbel)
Anomalina involuta (Reuss)
Anomalina ripleyensis (W. Berry)
*Clavulina disjuncta Cushman, 1933

PECAN GAP

Flabellammina compressa (Biessel)
Spiroplectammina anceps (Reuss)
Heterostomella stephensoni (Cushman)
Heterostomella sp.
Arenobulimina presli (Reuss)
Lenticulina rotulata Lamarck
Vaginulina strigillata (Reuss)
Lingulina furcillata Berthelin
Marginulina elongata d'Orbigny
Dentalina communis d'Orbigny
Dentalina consobrina d'Orbigny
Dentalina megapolitana Reuss
Dentalina spinescens (Reuss)
Nodosaria amphioxys Reuss
Nodosaria affinis Reuss
Nodosaria radicula (Linné)
Nodosaria cf. adolphina d'Orbigny
Lagena hispida Reuss
Lagena substriata Williamson
Lagena sulcata (Walker and Jacob)
Lagena sulcata (Walker and Jacob) var. semiinterrupta W. Berry
Lagena vulgaris Williamson
Flabellina interpunctata von der Marck
Frondicularia lanceola Reuss
Nonionella sp.
Guembellina excolata Cushman
Guembellina globulosa (Ehrenberg)
Guembellina striata (Ehrenberg)
Guembellina spp.
Ventilabrella carseyae Plummer
Ventilabrella eggeri Cushman
Eouvigerina americana Cushman
Eouvigerina gracilis Cushman
Bulimina sp.
Buliminella carseyae Plummer
Bolivinoides decorata (Jones) var. delicatula Cushman
Loxostoma clavata (Cushman)
Loxostoma tegulatum (Reuss)
Bolivinita eleyi Cushman
*Bolivinita planata Cushman
Spiroplectoides rosula (Ehrenberg)
Pseudouvigerina plummerae Cushman
Pleurostomella subnodosa Reuss
Ellipsonodosaria rotundata (d'Orbigny)
Entosolenia orbignyana (Seguenza)
Gyroidina globosa (von Hagenow)
*Gyroidina micheliniana (d'Orbigny)
Globigerina cretacea d'Orbigny
Globigerinella voluta (White)
Globotruncana arca (Cushman)
Globotruncana calcarata Cushman
Globotruncana canaliculata (Reuss)
Globotruncana fornicata Plummer
*Cibicides excolata (Cushman)
Anomalina taylorensis Carsey

ROGERS CHALK

Sta. 1255—7 miles NE. of Rogers, Bell County, Texas (Coll. Arick).

Flabellammina saratogaensis Cushman
Spiroplectammina anceps (Reuss)
Textularia ripleyensis W. Berry
Gaudryina indentata Cushman and Jarvis
Clavulina amorpha Cushman
Clavulina trilatera Cushman
Heterostomella foveolata (Marsson)
Heterostomella sp.
Arenobulimina presli (Reuss)
Dorothia sp.
Valvulina inflata Franke
Lenticulina rotulata Lamarck
Hemicristellaria ensis (Reuss)
Saracenaria italica Defrance
Marginulina bullata Reuss
Dentalina alternata (Jones)
Dentalina megapolitana Reuss
Dentalina soluta Reuss

Nodosaria affinis Reuss
Lagena aff. sulcata (Walker and Jacob)
Flabellina interpunctata von der Marck
Flabellina oldhami (Plummer)
Frondicularia archiaciana d'Orbigny
Frondicularia gracilis Franke
Frondicularia verneuiliana d'Orbigny var. bidentata Cuchman
Ramulina aculeata J. Wright
Buliminella carseyae Plummer
Bolivinoides decorata (Jones)
Valvulineria allomorphinoides (Reuss)
Gyroidina depressa (Alth)
Gyroidina globosa (v. Hagenow)
Gyroidina micheliniana (d'Orbigny)
Globotruncana arca (Cushman)
Globotruncana fornicata Plummer
Anomalina grosserugosa (Gümbel)
Anomalina ripleyensis (W. Berry)
Anomalina taylorensis Carsey

GOBER

(From three outcrops in Lamar and Fannin counties.)

Dr. Charles Ivan Alexander, Collector.

Ammodiscus incertus (d'Orbigny)
Flabellammina saratogaensis Cushman
Gaudryina carinata Franke
Gaudryina oxycona Reuss
Gaudryinella sp.
Clavulina cf. amorpha Cushman
Heterostomella sp.
Arenobulimina (?)
Dorothia sp.
Lenticulina rotulata Lamarck
Lenticulina aff. navarroensis (Plummer)
Lenticulina spp.
Astacolus cf. taylorensis Plummer
Marginulina bullata Reuss
Vaginulina regina Plummer
Vaginulina texana Cushman
Flabellinella sp.
Dentalina alternata (Jones)
Nodosaria affinis Reuss
Kyphopyxa christneri (Carsey)
Flabellina interpunctata von der Marck
Flabellina rugosa d'Orbigny
Frondicularia cordai Reuss
Frondicularia goldfussi Reuss
Frondicularia gracilis Franke
Frondicularia mucronata Reuss
Frondicularia verneuiliana d'Orbigny
Frondicularia verneuiliana d'Orbigny var. bidentata Cushman
Frondicularia spp.
Ramulina aculeata (J. Wright)
Guembelina globulosa (Ehrenberg)
Eouvigerina americana Cushman
Eouvigerina gracilis Cushman
Spiroplectoides rosula (Ehrenberg)
Buliminella carseyae Plummer
Loxostoma clavata (Cushman)
Loxostoma tegulatum (Reuss)
Gyroidina depressa (Alth)
Gyroidina globosa (v. Hagenow)
Gyroidina micheliniana (d'Orbigny)
Globigerina cretacea d'Orbigny
Globotruncana arca (Cushman)
Globotruncana fornicata Plummer
Globotruncana canaliculata (Reuss) var. ventricosa White
Anomalina involuta (Reuss)
Anomalina taylorensis Carsey

Economic geology.—Materials from the Taylor are extensively used for brick. The basal Taylor carries commercial oil locally. The Anacacho limestone near Cline, on account of its virtual sealing by the surrounding and superimposed clay facies, is an oil structure, and had it not been unroofed, would doubtless have produced commercial oil. It is a porous limestone, saturated locally with heavy oil residue, and the tar-limestone mixture is ground up and used for street and road paving.

NAVARRO GROUP[59]

Nomenclature.—The existence of Ripley strata in Texas was announced by Shumard (1475, p. 152) in 1861 (printed in 1863), and the name "Navarro beds" was first used by him in 1861 (1469, p. 189). Shumard's type area was Navarro County, but he had in mind no specific type locality, except that Chatfield Point and Corsicana are frequently mentioned as fossil localities in his text. Other synonyms of Navarro in the literature are: Glauconitic or Greensand division; Ripley group; *Exogyra costata* clays; Webberville formation (Hill and Vaughan, 795, p. 241; Hill and Vaughan, 808); Pulliam formation (Vaughan, 1686, p. 2).

Equivalents of the Navarro in Arkansas were early named Saratoga, Nacatoch, and Arkadelphia, and there the Navarro is by implication treated as a group, as it should be also in Texas. The formations of the Navarro have not all been named in Texas. Hill in 1901 (803, pp. 342–343) gave the name "Corsicana[60] beds" to a basal, more sandy portion, apparently including the Nacatoch sand, in Navarro County; and the upper Navarro he called the "Kemp beds." The medial Navarro sand is now generally correlated with the Nacatoch of Veatch, 1906 (1691, p. 27). Stephenson (391, 1534, 1536, 1539) treats the Navarro in the central Texas outcrop as consisting of the following units in ascending order: (1) *Exogyra cancellata* marls; (2) Nacatoch sand; (3) unnamed chalky marl; and (4) unnamed clay. He states that south of about the latitude of Cameron the two basal units are absent and the chalky marl rests on Taylor. For formations of Navarro, see p. 516.

Stratigraphy and contacts.—The Navarro is the uppermost group of the Upper Cretaceous in the Texas-Arkansas-Louisiana region, and is unconformably overlain by various overlapping Tertiary formations of Midway or Wilcox age. The amount of hiatus between

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[59]*Literature.—Arkansas:* Dane, 392. *Louisiana:* Howe, 850, 850a. *Northeast Texas:* Fohs and Robinson, 543; Matson, 1059, 1060, 1062; Thomas and Rice, 1601b; Powers, 1248; Hull and Spooner, 859; Sellards, 1408; Hammill, 643a. *North-central Texas:* Hill, 803; Lahee, 969; Matson, 1062; Powers, 1252; Stephenson, 1528, 1530, 1534. *South Texas:* Böse, 135; Morrison, 1132; Getzendaner, 578, 578a; McCollum, 1076; Udden, 1625; White, 1744. *Trans-Pecos Texas:* Udden, 1626; Vaughan, 1687. *Paleontology:* Alexander, 30; Böse, 134; Hoffmeister, 837; Hyatt, 866; Israelsky, 869; Plummer, 1235, 1238, 1238a; Shumard, 1469; Stephenson, 1527; Wade, 1700; White, 1743. *Igneous rocks:* Ross, 1353.

[60]The name Corsicana has also been erroneously used by several writers for a Taylor sand, probably the Wolfe City, located about 600 to 700 feet below the Nacatoch.

the uppermost known Navarro or Escondido and the overlying Tertiary has been much discussed, but is unknown because (a) the intervening zonation is unknown, and (b) the missing strata are nowhere filled in, so far as yet discovered, in the region. The question is further discussed under "Midway group." The upper Navarro unconformity is widely reported (803; 1193, p. 414; 969, p. 327).

In southern Arkansas the lower Navarro contact (Marlbrook-Saratoga) is lithologically sharp but is unconformable, and shows an irregularity of a few inches vertically in the base of the Saratoga. The basalmost Saratoga is marked by glauconite, phosphatic nodules and fossil casts, and small borings filled with this Saratoga material extend down into the underlying Marlbrook (392, p. 99). Stephenson (1539, p. 13) indicates a questionable unconformity at the base of the Navarro as far south as Cameron, and he states that from Cameron southwards the basal Navarro (*Exogyra cancellata* clays, and Nacatoch equivalent) is absent, only the upper Navarro being left. In Maverick County the non-marine Olmos beds are supposed to represent a break in sedimentation in the lower Navarro. In the Big Bend the basal Navarro contact has not been precisely located, but lies probably somewhere within the Aguja formation.[60a]

The following are the subdivisions of the Navarro group, as outlined in the literature on Texas and Arkansas:

Arkansas-Louisiana	*Northeast Texas*	*Travis County*	*Eagle Pass*	*Terlingua-San Carlos*
Arkadelphia	Kemp	Upper Navarro *according to Stephenson*	Escondido Farias	Upper
Nacatoch	Nacatoch	*Absent according to Stephenson*	Olmos?	Aguja?
Saratoga[61]	Neylandville (=*Exogyra cancellata* marl of Stephenson)			
Marlbrook	Upper Taylor	Upper Taylor	San Miguel[61a]	Lower Aguja?

[60a]Taliaferro (Jour. Geol., 41: 12–37, 1933) records sediments which indicate the nearness of Upper Cretaceous shore lines in northeastern Sonora (Cabullona district, southwest of Douglas, Ariz.).

[61]Thomas and Rice (1601b) state that the Saratoga fauna is more closely similar to the underlying Taylor than to the overlying faunas.

[61a]Vanderpool considers that the San Miguel foraminifera ally the formation more closely with the Navarro than with the Taylor.

SOUTHWESTERN ARKANSAS

The following formations have been recognized in the recent literature:

	Feet
3. Arkadelphia clay	120–160
2. Nacatoch sand	150–400
1. Saratoga chalk	50

SARATOGA FORMATION

Nomenclature.—The formation was first named by Branner in 1898 (Trans. Amer. Inst. Min. Eng., 27: 53). Variations in the stratigraphic application of the term are outlined by Dane (392, p. 98). The type localities are a short distance north, east and west of Saratoga, southern Howard County, Arkansas.

Areal outcrop.—The Saratoga unconformably overlies the Marlbrook marl and unconformably underlies the Nacatoch sand. It consists of sandy and marly chalk, more glauconitic phosphatic and fossiliferous near the base. Toward the east the upper Saratoga contains much chalky sand and abundant small carbonaceous plant fragments. The Marlbrook-Saratoga boundary suggests omission and the presence of a condensed zone.

Paleontology and zonation.—The recorded cephalopoda are: *Scaphites* sp., *Baculites* sp., *Eutrephoceras* sp., *Nostoceras helicinum* (Shumard)?, *Pachydiscus* sp., *Belemnitella americana* (Morton). *Sauvagesia* (?) occurs in the formation. The following oysters have been used as markers:

(1) *Exogyra costata* Say. It occurs in the Marlbrook as an "exotic variant" (392, p. 95). *E. costata* var. (with broad costae) is rare in the basal Saratoga (392, Pl. XX, fig. 2), abundant in upper Saratoga (where *E. cancellata* is generally absent) and abundant in the Nacatoch (392, p. 135, Pl. XXVI, fig. 1), *E. costata* with narrow costae (392, p. 149, Pl. XXVI, fig. 2) characterizes the Arkadelphia clay.

(2) *Exogyra cancellata* Stephenson. The upper Marlbrook contains (a) "*Exogyra ponderosa* var. with beginnings of cancellate ornamentation near the beak, regarded as ancestral to the typical *E. cancellata*" (392, p. 95); (b) others with more cancellation, referred to *E. cancellata* (392, p. 95, Pl. XVIII, fig. 2). In the Saratoga, *E. cancellata* with strong, cancellated costae (392, p. 106, Pl. XX, fig. 1) has its lower limit at the base of the formation, and its upper limit ranges from the middle to the top of the Saratoga.

(3) *Exogyra ponderosa* Roemer. In the Ozan and Annona, and up to top of Marlbrook, forms with less convex left valve and more closely spaced growth lines prevail. In the Marlbrook, some otherwise smooth *Exogyra* have costate ornamentation near the beak (392, p. 95).

From the preceding, it is evident that the Saratoga is scarcely or not at all represented as a chalk in northeastern Texas, and that the *Exogyra cancellata* zone is there present as a marl. Dane is impressed with the magnitude of the break in the geologic column at the base of the Saratoga. He says:

If the evolutionary change in the genus *Exogyra* could be taken as even a rude measure of the time that elapsed, the break between the Marlbrook and the Saratoga might represent as much time as was required for the deposition of the Brownstown, Ozan, Annona and Marlbrook. The establishment of the costate tendency shown in the uppermost Marlbrook probably required more time than that required for its progression to completion, and presumably also the evolution was accelerated in the lost interval by changing conditions.

However, Thomas and Rice (1601a, p. 966) state that:

The microfauna of the type Saratoga chalk is more closely related to the Taylor (Marlbrook) underneath than it is to the Navarro (Arkadelphia) above if the presence of common characteristic Taylor (Marlbrook) foraminifera and the lack of the common characteristic Navarro (Arkadelphia) foraminifera are sufficient criteria. The persistent Nacatoch sand above the Saratoga seems to represent a greater faunal break than the thin glauconite at the base of the Saratoga. This chalk extends from south-central Arkansas, through northwestern Louisiana, into the east side of the East Texas embayment. It is more widespread as found in wells than outcrops suggest.

NACATOCH FORMATION

Nomenclature.—The Nacatoch sand was defined by Veatch (1691, p. 27) as a series of sandy beds above the Marlbrook marl. The type locality is the 50-foot sand exposure in Nacatoch Bluff on the east bank of Little Missouri River, SW. ¼ sect. 36, T. 9 S., R. 22 W., Clark County, Arkansas.

Outcrop and lithology.—In Arkansas the Nacatoch consists of 400 feet or less of fine-grained, soft quartz sand with laminae and beds of gray clay, and some hard, calcareous, fossiliferous lenses and beds. Its top and bottom are marked by unconformities.

Paleontology and zonation.—The cephalopoda recorded from the Nacatoch include the following: *"Nautilus," "Pachydiscus," Baculites, Scaphites, Nostoceras, Belemitella americana* (Morton). *Ostrea owenana* Shumard and *Crenella serica* are stated to be Nacatoch markers, and *Liopistha protexta* is stated to occur in the Saratoga and Nacatoch. A list of Nacatoch fossils is given in Dane (392, pp. 132–135).

ARKADELPHIA FORMATION

Nomenclature.—The name, established by Hill in 1888, has been somewhat modified in meaning, and the type localities of the formation, as understood by Dane (392, pp. 144–145), are taken to be at localities 2 to 3 miles northwest of Fulton, at many places 5 to 7 miles north and northwest of Hope, and possibly at Arkadelphia.

Outcrop and lithology.—Unconformably overlying the Nacatoch sand is 160 feet or less of dark gray or black marl, weathering light gray, containing some beds of hard, calcareous gray sandstone, gray sandy clay, sandy limestone, dense concretionary limestone, and white impure chalk. The marl appears laminated when fresh, massive when weathered, and has a hackly, irregular or conchoidal fracture.

Paleontology.—The Arkadelphia is the highest Cretaceous outcrop formation in Arkansas, but, because of overlap, not necessarily the highest Cretaceous deposited. Recorded mollusca are: *Scaphites* sp., *Baculites* sp., *Exogyra* *costata* (with narrow costae), *Gryphaeostrea vomer* (Morton), *Gryphaea* sp., *Turritella* cf. *quadrilira* Johnson. A few other mollusca are reported from the formation.

NORTHERN LOUISIANA

In the Homer field, the Saratoga consists of 80 to 100 feet of white and gray chalk with interbedded thin strata of chalky shale. In the Bellevue field the Saratoga is a thin, light gray, sandy marl or impure chalk containing fossils. In some other fields the Saratoga is not usually distinguished, though it forms a part of the "chalk rock" beneath the Nacatoch sand. In the Caddo field this "chalk rock," comprising the Annona, Marlbrook and Saratoga, is 475 to 500 feet thick. In the Pine Island field, the combined Saratoga and Marlbrook have a thickness of about 260 feet, in Cotton Valley about 200 feet.

The Nacatoch is the main producing sand at Homer and Bellevue, produces oil at Pine Island and Caddo, gas at De Soto and Red River, and water in the Cotton Valley field. Its approximate average thicknesses are: Bellevue, 325 feet; Caddo, 200 to 300 feet; Cotton Valley, 370 feet; De Soto, 50 to 150 feet (average 125 feet); Homer, 225 to 275 feet; Pine Island, 200 feet. In the Cotton Valley field, the upper half of the Nacatoch is composed of limestone and sand, and the lower half of sandy shale. In De Soto Parish, it consists of gas rock, pack sand, and some sandy clay. In the Homer field, it consists of an upper sand and sandy limestone, ranging from 150 to 175 feet in thickness, and a lower shale ranging from 75 to 100 feet in thickness. The main oil-producing horizon is the upper 50 feet of the Nacotoch, which is a medium-to fine-textured sand commonly described as salt-and-pepper sand, poorly cemented, calcareous, slightly argillaceous, and in part glauconitic. Most of the grains are angular, and practically none are rounded. At Bellevue the Nacatoch consists of calcareous, medium-grained sand and sandstone, which changes in short distances from pure sand to a very sandy and locally very porous lime. These sands contain some indurated streaks. The basal Nacatoch contains breaks of shale or gumbo.

The Arkadelphia formation overlies the Nacatoch, forms a seal for it in oil and gas fields, and is the uppermost Cretaceous formation known in this area. Its approximate recorded thicknesses are: Bellevue, 40 feet; Caddo, 80 to 100 feet; Cotton Valley, 100 feet; Homer, 90 to 125 feet; Pine Island, 100 feet.

NORTHEAST TEXAS

The outcrop of the Navarro group between Red River and Brazos River is divisible into three formations, the medial Nacatoch sand being used as a recognizable marker to separate the basal marl from the upper marl. The Nacatoch sand strip runs about as follows: in Hopkins County, near Sulphur Bluff; in southeastern Hunt County, at Campbell, Dixon, Cash (faulted), and Quinlan (good

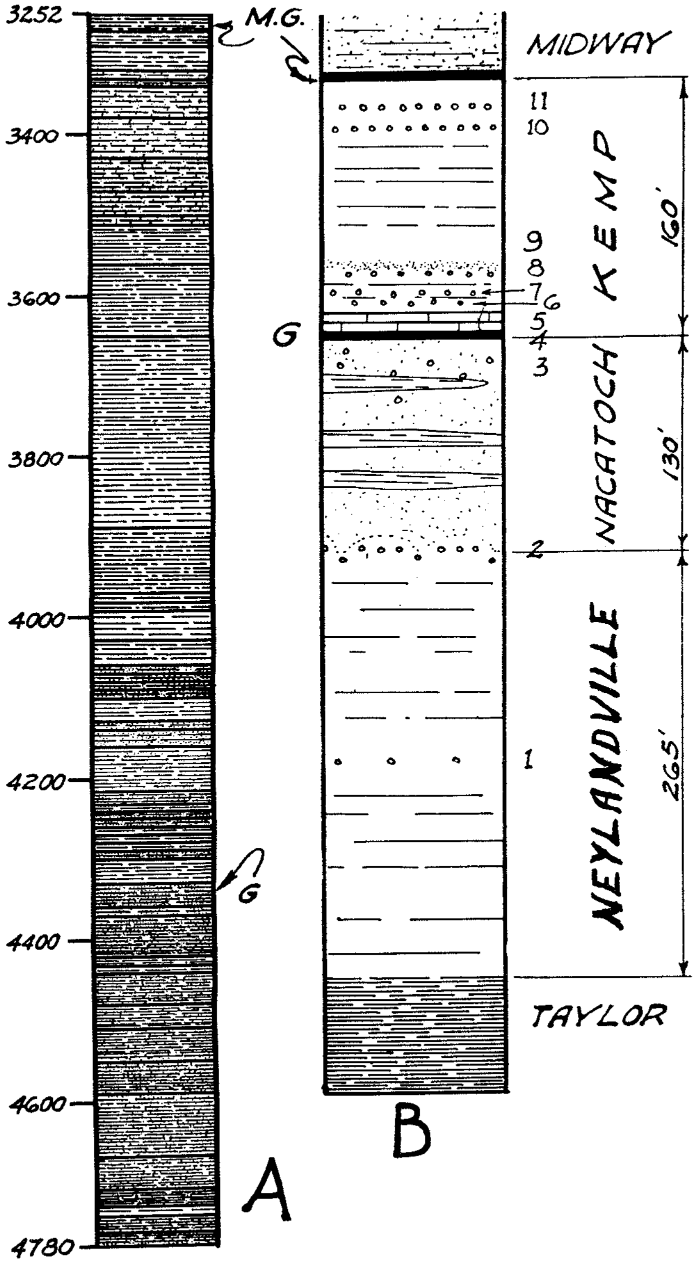

Fig. 26. Navarro group in (A) Amerada Rycade Oppenheimer well, Frio County; (B) outcrop in north-central Texas (by David J. Crawford).
G = glauconite; M. G. = basal Midway glauconite.

exposure); in Kaufman County, just west of Terrell and Kaufman; in Navarro County, just west of Chatfield (good exposures), west of Corsicana, near Corbet and west of Pursley; in northern Limestone County, east of Cooledge, where it is thin, and where Stephenson reports its southernmost exposure.

In northeast Texas the formations of the Navarro are:

Kemp formation (803, p. 343), including Stephenson's unnamed chalky marl member and unnamed upper clay member (1539, p. 1331).

Nacatoch formation (1691, p. 27).

Neylandville formation (restricted), comprising the basal part of the "Corsicana beds" of Hill (803, p. 342), and probably the "*Exogyra cancellata* beds" of Stephenson. See p. 516.

Below the Nacatoch, as thus defined, is the basal (Neylandville) marl of the Navarro; and above the Nacatoch, all the beds up to the basal greensand of the Midway are included under Hill's Kemp formation. It is to be noted that part at least of the basal marl is equivalent to the Saratoga in age, and that Thomas and Rice (1601b) would consider this part as more probably of Taylor age, thus placing the base of the Navarro group in, or at the base of, the Nacatoch.

Composite section of Navarro group from Franklin to Falls counties, Texas, with average thicknesses, by David J. Crawford

Midway group (Eocene):

Midway clay — Feet

Basal Midway glauconite layer

Navarro group:

Kemp formation: Upper Navarro clay — 160

Sandy clay, thickness 16 to 20 feet.

11. Concretion layer, located in Navarro below Midway greensand; dense compact concretions, well rounded, with many calcite partings.
    Clay, locally slightly sandy.
10. Concretion layer, located on tops and flanks of first Navarro scarp below Midway greensand, 30 to 40 feet below the Navarro-Midway contact; the best Upper Navarro bed for detailing.
    Sandy clay.
9. Concretion layer, in flat topography, 100+ feet below the Midway greensand.
    Clay, thin.

Feet

8. Sand, thin, about 15 feet, contains a concretion layer at base; located about 15 feet below No. 9, and 115+ feet below the basal Midway greensand. This is a stray sandstone in this upper 15-foot sand break; it appears in Limestone County and probably continues southward to Milam County, where it may be the Minerva-Rockdale producing horizon.

   Sandy clay.

7. Concretion layer, 120+ feet below Midway greensand, occurs in low places, field draws, washed from typical Navarro shales.

   Sandy clay, thin.

6. Concretion layer, located 10 to 15 feet above Navarro chalk. It is not persistent or continuous over any great distance and is a poor marker.

   Sandy clay, thin.

5. Navarro chalk stratum, immediately overlies the thin Nacatoch glauconitic fossil bed; locally almost pure chalk, grading elsewhere into marl; thickness 1 inch to 10 feet.

4. Glauconitic fossil bed, marks top of Nacatoch sand; thickness 4– feet.

   Nacatoch formation: sand, sandy shale, and some concretions, about 130

   Upper sand.

3. Fossiliferous Nacatoch boulder horizon; in upper 30 feet of Nacatoch sand, occurs down east face of Nacatoch dip slope. It is formed of well-defined boulders. To the north, in Hopkins and Hunt counties, these are of sandstone, but farther south as the Nacatoch becomes shalier across Limestone County, the boulders, although retaining sand characteristics, become very calcareous.

   Medial sand with shale lenses and scattered boulders.

   Basal sand layer, its basal contact irregular or undulating.

   Neylandville formation; marl, containing an upper and a medial concretion bed; approximate thickness........ 265

2. Upper Corsicana concretion bed: persistent, calcareous, very hard, brittle, easily shattered, locally fossiliferous concretions. The base of the Nacatoch is at most places poorly defined, and this bed is useful as a check on that contact.

   Upper clays.

1. Medial concretion layer, located about 150 feet below the base of the Nacàtoch, and tops basal scarp of Navarro. Thin, persistent, fossiliferous, very calcareous concretions.

   Basal clays.

Taylor group.

Features of concretion layers and other markers in the above Navarro section (David J. Crawford)

Bed	Color	Thickness	Hardness	Fossils	Reliability	Fracture	Range (feet)
11	grayish to white	3±′	5–6	Rare	Very good	Angular	5±
10	deep yellow	1′–3′	4	Rare to many	Excellent	Argillaceous	15?
9	red	1″	2	None	Good	Angular	20±
8	dark gray	2″–6″	Very hard	None	Undet.	True ss. fracture	2
7	brownish to reddish brown	3″–1′	6–7	None	Good	Subangular	15±
6	chrome	1′	1	None	Very	Argillac.	1–3
5	(chalk)	1″–10′			Poor		
4	(glauconite)						
3	white to gray	1′±	4+	Many	Fair	Irreg.	10–50
2	gray to yellow	½′–′	Very hard	None to many	Good	Subangular	20
1	white	4″–1′	3±	Present	Good	Argillac. irreg.	10±

NEYLANDVILLE FORMATION

Nomenclature.—The lower Navarro clays were apparently included, with the Nacatoch, in Hill's Corsicana beds (803, p. 342). They comprise most or all of Stephenson's "*Exogyra cancellata* subzone" (391, Pl. II; 1534, Pl. I), and are, in part at least, correlated with the Saratoga chalk in southwestern Arkansas (392, p. 111; 1534, p. 15). Although not entirely a satisfactory arrangement, it is considered best here to restrict and redefine the "Corsicana" of Hill to include all beds in the Navarro County section above the top of the Nacatoch sand and below the base of the upper clay of Stephenson, *i.e.*, the "chalk marl" of Stephenson. The beds between the top of the Taylor and the base of the Nacatoch are here called *Neylandville* formation. This terminology follows suggestions recently made by Dr. L. W. Stephenson (see p. 516).

The type localities of the Neylandville are taken as the first cut of the Texas Midland Railway west of Neylandville station, and exposures along the Bankhead highway between Liberty School and Neylandville, 3 to 6 miles in an air line northeast of Greenville, Texas.

Outcrop.—The basal Navarro consists generally of marls, with the scattered concretion layers described above. In some of the older literature it is not distinguished from the Marlbrook.

Caddo field, Louisiana-Texas.—The "Marlbrook" has been described (1059) as consisting of 325 to 375 feet of shale, gumbo, and some chalk and boulders, part of which is probably basal Navarro.

Hunt County.—Stephenson (1530, p. 157) describes the basal Navarro as follows:

> The lower 300 or 400 feet of the formation consists of gray calcareous shaly clay or marl that produces a dark gray or black soil and carries a distinctive fauna, the most significant species of which are *Exogyra cancellata* Stephenson, found at several localities near Cooper and Greenville, and *Anomia tellinoides,* Morton, found at one locality near the Texas & Midland Railroad 2 miles west of Cooper. This is the *Exogyra cancellata* subzone, which forms the basal part of the *E. costata* zone and which has been traced throughout the Atlantic and Gulf Coastal Plain from New Jersey to Kaufman County, Texas, and has been recognized at Ciudad del Maiz, San Luis Potosi, Mexico, about 440 miles south of Eagle Pass, Texas. This subzone is represented in southwestern Arkansas by the upper half or more of the Marlbrook marl with the exception of approximately the upper half of the "Saratoga" chalk member, which forms the upper 20 or 25 feet of the Marlbrook.

Dane and Stephenson (391, p. 47) give certain details regarding the *Exogyra cancellata* subzone northwards and eastwards from Rockwall County. In this direction the sandy constituent at the base of the Navarro disappears, and here the Navarro beds are typically less calcareous than the Taylor. At several localities along the Greenville road within 3 miles of Royce City, *Exogyra cancellata* occurs in calcareous clay or marl; at a point on this road 2.8 miles from Royce City *Exogyra cancellata, Placenticeras?*, and *Baculites* (large, smooth species) occur; at 2.5 miles from Royce City, *E. cancellata, Placenticeras?, Anomia tellinoides* Morton and *Gyrodes* occur; at the Greenville fair grounds, *E. cancellata* is abundant. The same zone occurs on the Josephine road 2 miles north by east of Nevada, Collin County, with the Taylor marl containing *E. ponderosa* only a short distance below it.

Rockwall and Kaufman counties.—Dane and Stephenson state (391, p. 46) that from a point 2.5 miles southeast of Chisholm, southeastern Rockwall County, south by west through Kaufman

County, the Taylor is overlain by gray, sandy calcareous clay or marl of unquestionable Navarro age. The clay contains *E. cancellata* and a "variety of that species in which the surface of the shell tends to be smooth instead of cancellated": in this zone the typical *E. ponderosa* has not been found, and *E. costata,* which elsewhere in the Coastal Plain is associated with *E. cancellata,* seems also to be rare or wanting. At localities 4.25 to 4.65 miles west of Kaufman, the basal Navarro is supposed to be represented by a 2-foot bed of strongly glauconitic marl containing poorly preserved fossils and nodules of phosphatic material. This bed is overlain by sandy marl. In the *Exogyra cancellata* zone in a cut 1½ miles east of Gastonia, *Ostrea panda* Morton and *Exogyra cancellata* were found; and in a cut 1 mile east of Gastonia there were found *Exogyra cancellata, E. costata, Anomia argentaria, Ostrea panda, O. tecticosta* and *Gryphaea* sp. (large).

Navarro County.—In wells near Corsicana the basal Navarro marl consists of about 140 feet of mostly dark gray or greenish-gray calcareous clay, some of which is sandy, glauconitic and fossiliferous. At most places two concretionary beds exist, one at the top and one near the middle of the formation. The lower Navarro is exposed in a roadside ditch east of Cedar Creek on the Corbet highway 5.7 miles southwest of the Corsicana railway station, and consists of sandy marl with large concretions. On the Emhouse road 1.8 miles northwest of the Corsicana airport there is a road cut with 2 to 3 feet of yellow-gray sandy clay containing pelecypods and other fossils.

Limestone County.—The basal Navarro in wells consists of about 265 feet of sandy marls with some sand streaks, some of them gas-bearing (543, Pl. XIII). The best published descriptions of the lower Navarro outcrops between the Trinity and the Brazos are by Dane and Stephenson (391, pp. 55–57). They state that from Navarro County southward to at least the latitude of Cameron, the lower Navarro is mostly a sandy marl, which generally can be recognized by its less calcareous nature and by the presence of large dense gray limestone concretions. Basal sandy Navarro marl is exposed in western Limestone County southwestward from a point 4.2 miles east of Prairie Hill, and on the Groesbeck road 5 miles east-southeast of Mart. The lower Navarro is stated to thin southwards from about 200 feet in Kaufman and Navarro counties to not more than 50 feet in Milam County.

Falls County.—The *Exogyra cancellata* zone was recognized by Dane and Stephenson (391, p. 56) in an outcrop of sandy marl with large concretionary limestone lenses weathering white, at a locality 6.1 miles northeast of McClanahan, Falls County. Stephenson has not recognized this zone anywhere in Texas south of Little River, Milam County (391, p. 57).

Salt domes in Gulf Coastal Plain.—The only known Navarro inliers in the Texas Gulf Coastal Plain are on the Brooks, Butler, Bullard, Keechi, Marquez, and Palestine domes (p. 262). From the Brooks dome Hill (709, p. 223, footnote) collected *Gryphaea vesicularis, Ostrea* sp., *Plicatula* sp., and *Inoceramus* sp., which he referred to the Marlbrook, and Harris (1250, p. 194) collected *Exogyra costata, Gryphaea vesicularis* and *Ostrea larva,* which indicate Navarro age. Probably Navarro is indicated by fossils collected on the Butler dome (1252, p. 265). On the Keechi dome lower Navarro with *Exogyra cancellata,* a microfauna stated by Selig to be of the approximate age of the Nacatoch, and upper Navarro with *Belemnitella americana,* are known (1252, pp. 247–248). On the Palestine dome the *Exogyra cancellata* zone has been found. Navarro is known in wells over a wide area in the East Texas embayment. Renick (1298, p. 533) described it as follows:

> In the East Texas geosyncline the Navarro, including the Nacatoch, consists of 375 to 1000 feet of dark and light gray and bluish-gray marine shale and clay, generally slightly calcareous with thin beds of gray limestone and brownish, ferruginous limestone. Some lime beds contain siderite concretions. It is about 1000 feet thick in Freestone County, but thins eastward to 400 feet or less in eastern Cherokee County. Near the top in eastern Anderson and Cherokee counties, but apparently somewhat higher in the Navarro section in Freestone County where this formation is thicker, there is a horizon possibly equivalent to the Nacatoch sand in Louisiana. This Nacatoch (?) horizon in some places is sandy shale, sand, and thin non-calcareous sandstone; in others, interbedded thin limestone and shale.

NACATOCH FORMATION

Nomenclature.—The type locality of the Nacatoch[62] sand, described by Veatch (1691, p. 27) is Nacatoch Bluff, on Little Missouri River, Clark County, Arkansas, where a 50-foot section is exposed. Synonyms in Texas are: Powell sand, Campbell sand, and probably Minerva sand; and from Hill's description (803, p. 342), the Nacatoch sand appears to compose the upper part of his "Corsicana beds." Synonyms in Louisiana are: Caddo sand, Vivian sand, Shreveport sands.

Outcrop.—The Nacatoch outcrop extends westward across the northern tier of Texas counties, Bowie, Red River, northern Delta, and turning southward with other Gulf outcrops in eastern Hunt County, passes through Kaufman and Navarro counties to northern Limestone County.

Underground the Nacatoch is widespread in northern Louisiana and in the East Texas embayment, though its exact subsurface extent is not yet securely known. In northwestern Louisiana it is an extensive gas-bearing horizon. The upper sand in the Bethany gas field, the sand in Eldorado, the producing sand in the Mexia-Groesbeck gas field, the oil sand in the Powell field, the heavy oil sand in the Corsicana field, and the Minerva sand in northern Milam County, are supposed to be nearly or exactly equivalent to the Nacatoch. The fields along the Mexia fault zone where the Nacatoch has produced oil or gas are listed by Lahee (969, p. 360).

Red River County to Hunt County.—In the Caddo oil field the thickness of the Nacatoch ranges from 100 to 200 feet, part of the difference being caused by the northward and westward thickening of the formation (1059, pp. 23–25). It is composed of light gray to greenish fine sand, alternating with layers of indurated sandstone and thin layers of clay. Locally the formation contains glauconite or calcareous filling or cement. Shale, gumbo, and indurated fine sand occur in lenses. The Nacatoch here bears gas and salt water. Westward across Panola County (859, p. 190; 1408, fig. 1) the Nacatoch thickens from a small amount to about 225 feet.

Stephenson records in northeastern Texas about 100 feet of Nacatoch, consisting of fine gray sands and more or less sandy clays

[62]*Literature.—Arkansas:* Dane, 392; Veatch, 1691, p. 27. *Louisiana:* Howe, 850 (bibliography); Veatch, 1691. *Northeast Texas:* Dane and Stephenson, 391; Lahee, 969; Matson, 1059, 1060, 1062; Powers, 1248, 1252; Stephenson, 1530, 1534; Fohs and Robinson, 543; Shumard, 1469; Hyatt, 866; Sellards, 1408; Hull and Spooner, 859.

(1530, p. 157). Fohs and Robinson (543, Pl. XIII) record the following sections of Nacatoch: in the Paris-Ripley-Sulphur Springs area, 140 feet of hard sandstone and muddy sands; in the Terrell-Wills Point section, 150 feet of hard, water-bearing sands, each 5 to 35 feet thick, and sandy shales; in the Bethany field, 150 feet of gas sand; near Corsicana, 270 feet of sand and sandy shale, some of it glauconitic. In Anderson County (1298, p. 542) from 350 feet above the top of the Pecan Gap chalk down to near the top of that chalk, there occur sand, sandstone, and sandy shale, and locally interbedded thin limestones and shales, which have been correlated with the Nacatoch, and which in Cherokee County give good showings of gas.

In Hunt County the Nacatoch strip passes west of Campbell and Dixon and near Cash and Quinlan. In a stream cut on the M. K. & T. Ry. about 3 miles east of Greenville the writer has collected, in a sand and sandy clay, abundant middle Navarro fossils, including *Exogyra costata* (narrow, elevated ribs), *Pycnodonta* aff. *vesicularis, Trigonia, Pecten, Eutrephoceras* and gastropods. In Kaufman County the Nacatoch outcrop passes just west of Terrell and Kaufman.

Navarro County.—The narrow Nacatoch outcrop passes through Chatfield, the western edge of Corsicana, near Pursley, east of Corbet and thence to a point east of Cooledge, northern Limestone County. The thickness in wells near Corsicana is about 200 feet. Matson and Hopkins (1062, p. 218) state that locally the sand is firmly cemented by lime to form hard, dense, calcareous sandstones or irregular shaped concretions. The sand ranges from medium grained to very fine grained and contains glauconite, which is more abundant in some beds than in others. Most samples of the sand are described as fine grained or very fine grained, greenish gray or dark gray, calcareous or argillaceous, and glauconitic; some are hard; a few levels in the formation are fossiliferous. A subordinate amount of dark gray, sandy, calcareous clay is present, apparently in lenses.

B. F. Shumard (1469) named the Navarro formation and described many fossils collected near Chatfield and Corsicana. Dr. T. W. Stanton collected in the same area about 1890, and some of his fossils were described by Hyatt (866). In recent years the region has been extensively but unsystematically collected. The Nacatoch outcrop crosses the Rice-Dallas Federal highway No. 75 about 2.75 miles north of the T. & B. V. Ry. underpass in Corsicana, and here there occur sands containing large concretions with fossils (*Baculites, Inoceramus, Turritella*). In northern Navarro County there are many Nacatoch outcrops; fossils occur at the Negro cemetery 1 mile north-northwest of Chatfield, and in concretions on the Hervey Lake road 2.1 miles northeast of Chatfield. From these localities Miss Gene Ross and others have collected numerous *Nostoceras, Helicoceras, Oxybeloceras, Baculites, Inoceramus* and gastropods.

Limestone County.—On the outcrop the Nacatoch is thin or absent; it has been reported to be thin near Cooledge. Passing underground down-dip it thickens considerably. Matson (1060, pp. 81, 89, 92) states that in the Mexia-Groesbeck area the Nacatoch has a thickness of 40 to 65 feet, and averages 40 feet, excluding the cap rock. The sand contains locally partings or lenses of shale, most of them 3 to 4 feet thick but some as thick as 10 feet. The sand is mostly fine grained, light gray quartz sand containing many grains of glauconite. Its top is generally cemented into a denser, firm sandstone, which forms a cap rock 1 to 10 feet (average 5 feet) thick. Beneath the cap rock the sand is porous except for layers and lenses of clay. The amount of pore space in samples tested ranges from 16.6 per cent to 34.2 per cent, and averages 25.5 per cent. From the uniform decline in pressure throughout the field it is assumed that the amount of porosity is maintained over a wide area. Lahee (969, p. 327) states that "a few hundred feet below the disconformity (top of the eroded Navarro) is a zone of shaly sands and true sands, more or less glauconitic, forming the Nacatoch sand member of the Navarro. In some localities, notably near Richland, the upper Navarro clays become progressively more marly downward, changing into a thin, hard limestone layer which caps the Nacatoch sand zone. This sandy zone ranges from 150 to 250 feet in thickness. It is not the same in all places, but as a rule contains one or more distinct sands, which may carry water or, on favorable structure, oil or gas." The Edens sand (1062, Pl. XX) lies near the Taylor-Navarro contact, and is thought to be the same as the Chatfield gas sand. As explained earlier, the "Corsicana" sand in the Taylor of this area is probably the Wolfe City sand.

Specimens of *Ostrea owenana* Shumard were identified by Stephenson from the glauconitic gas sand in the Mackey well near Mexia, and it is stated that the sand "probably corresponds in age to and may be physically continuous with the Nacatoch sand" (1060, p. 80).

Milam County.—The Minerva sand, lying about 110 to 120 feet below the local top of the Navarro, consists of rounded quartz grains, and is generally 3 to 10 feet thick with a maximum thickness of about 15 feet.

KEMP FORMATION

Nomenclature.—The upper part of the Navarro in the Navarro-Kaufman County area was called Kemp beds by Hill. The presumable type locality is the faulted inlier near Kemp.

Fossiliferous upper Navarro is exposed at many nearby places, as Quinlan and the Corsicana clay pits. Stephenson suggests that the chalk marl above the Nacatoch sand receive the name *Corsicana* formation (of Hill, but restricted); see p. 517.

Outcrop.—At various places in Texas unknown amounts of section have been subsequently removed from the top of the Navarro column, or else an unknown amount was never deposited, or exists down-dip but is overlapped nearer the outcrop by Midway. The Kemp formation has been in part correlated by many writers with the Arkadelphia clays in Arkansas.

Northeastern Texas.—In the Caddo oil field the upper Navarro clay is 300 to 400 feet thick (1059, pp. 25–26). It is a dark gumbo or shale, with thin layers of sand and sandstone near the base. In Panola County 600 feet of Arkadelphia has been recorded (Hammill, 643a; Sellards, 1408, p. 7). In the Paris-Sulphur Springs area the upper Navarro shale containing some sand is stated (543) to be about 535 feet thick; and in the Terrell-Wills Point section it consists of 590 to 620 feet of blue to black shales with some lime concretions near the top, and with some sandy shales and thin sands. In the Bethany area it consists of 500 feet, chiefly of shales with lime beds in the lower half.

Navarro County.—The upper Navarro clays are described (1062, pp. 218–219) as being slightly sandy and glauconitic, calcareous, and locally gypsiferous. The clay is dark blue when fresh, and weathers to greenish yellow, then to dark olive gray, and finally to black, waxy soil. It contains calcareous concretions, some composed of hard, dense limestone, some with septarian form, and some with cone-in-cone structure.

Limestone County.—The upper Navarro clay is described (1060, p. 89; 969, p. 327) as a compact to finely laminated gray clay, with a marked conchoidal fracture. The contact with the Midway is disconformable, and the Navarro surface contained inequalities over which various members of the Midway were deposited; locally the Tehuacana limestone is nearly in contact with Navarro, and at other places the two are separated by as much as 100 feet of sandy clay. In some localities, notably near Richland, the upper Navarro clays become progressively more marly downward, changing into a thin, hard limestone layer which caps the Nacatoch sand.

Salt domes in Coastal Plain.—On the Keechi dome fossils were collected which Stephenson (1252, pp. 247–248) considered as "probably very near to the top of the Navarro"; they included *Belemnitella americana, Baculites,* and *Pachydiscus.*

SOUTH-CENTRAL TEXAS

From near the Brazos (Milam County) southwards along the outcrop, the Navarro is considerably thinner than farther north, and the width of outcrop is correspondingly reduced. This situation persists as far south as Bexar County, where the Cretaceous outcrops swing westward parallel to the Balcones fault, and thence to northern Maverick County, where the Navarro section becomes greatly thickened on entering the Rio Grande embayment.

Stephenson, using *Exogyra* zones and lithology, has explained this regional thinning of the Navarro group as caused by the absence at the outcrop of certain basal Navarro beds. He states that from Falls County to Bexar County, a distance of 150 miles or more, the *Exogyra cancellata* zone is totally absent at the outcrop (1534, pp. 13–14), and that "the stratigraphic break between the Taylor marl and the upper Navarro, which in Travis County accounts for the absence of the *Exogyra cancellata* zone and the Nacatoch sand member, continues toward the southwest with as great or greater magnitude nearly to the Rio Grande Valley, where, in the vicinity of Eagle Pass, Maverick County, the gap is only partly filled by the Olmos, a coal-bearing formation" (1539, p. 1332).

In the following paragraphs it will appear that the Navarro beds in this area consist in part of sandy strata, which by some geologists have been identified as Nacatoch, and that down-dip the Navarro thickens enormously, so that even if some basal Navarro is locally missing at the outcrop it may be present down-dip.

So far, the only proposed subdivisions of the Navarro in this area are (a) an unnamed chalky marl member, and (b) an unnamed upper clay member, of Stephenson (1539, p. 1331).

Milam County.—The basal zone of the Navarro, consisting of sandy marl with both *Exogyra cancellata* and its smooth variety, occurs at a point 1.7 miles south of Burlington on the Cameron road, and at a point 7.4 miles northwest of Cameron on the Buckholts road. At a road exposure .4 mile southeast of the last-named locality there is a suggestion of an unconformity above the *E. cancellata* beds, which would cut these beds out farther south: at this place "gray sandy marl of typical lower Navarro lithology, such as outcrops only 0.4 mile farther northwest with a typical fauna, is overlain on a somewhat irregular contact by a 2-foot bed of richly glauconitic green, marly sand which carries typical *Exogyra costata* in association with strongly noded *Exogyra cancellata*, identical with the forms found in the Saratoga chalk of Arkansas" (391, p. 56).

Williamson and Travis counties.—On the outcrop from northern Williamson County southwards, the upper Navarro and the upper Taylor are so near to each other as to leave no room for lower Navarro outcrops (391, p. 57). However, the situation is still somewhat obscured by two factors: (a) faulting at or near the contact; and (b) the question of whether zonation can be based on the distinction between a variety of *E. ponderosa* characterized by cancellated sculpture on the umbonal portion of the shell, an upper Taylor form which is ancestral to, and probably prophetic of, the more typical *E. cancellata* of the lower Navarro (391, p. 57); and a nearly smooth variety of *E. cancellata* which occurs in the lower Navarro (391, p. 56).

Near Kimbro, northeastern Travis County (391, pp. 57–58; 1539, p. 1331), the upper part of the Taylor is a non-chalky marl containing *Exogyra ponderosa* (var. with cancellated beak region), various Taylor megafossils, and according to Mrs. Helen Jeanne Plummer, typical Taylor foraminifera. At a somewhat lower level is a nodule zone, containing many ammonites, among them *Sphenodiscus* cf.. *lenticularis* (found by Dr. F. L. Whitney), *Heliococeras?*, *Placenticeras* cfr. *intercalare, Menuites, Nostoceras, Oxybeloceras* and *Baculites*. Taff (1574, p. 356) records the fossiliferous nodule bed from Rice's Crossing. The Taylor marl is directly overlain by Stephenson's "chalky marl carrying a micro- and macro-fauna such as is characteristic of the chalky marl above the Nacatoch sand in Navarro and Limestone counties." In the base of this chalky marl there are a few small, dark phosphatic nodules. Thus, according to Stephenson, both the *Exogyra cancellata* zone and the Nacatoch are absent at Kimbro. At a road cut 8 miles west of Cameron, Milam County, he states that the chalky marl member of the Navarro rests, with a sharp, somewhat irregular contact upon the lower Navarro *Exogyra cancellata* zone, only the Nacatoch sand being absent.

In Travis County the Navarro, consisting of sandy clay and some black carbonaceous shales, was called "Webberville" by Hill and Vaughan (795, pp. 241–242; 808). The thickness recorded (1429) in wells is about 600 feet.

Bastrop and Caldwell counties.—In Bastrop County wells the Navarro is recorded (1422) as about 550 feet thick. It consists in the Larremore area in Caldwell County, where it is exposed as the lowest outcropping formation, of bedded gray clay shale and beds of yellow to gray, fine-grained, limy sandstone (1716). In the Salt Flat field (1076) it consists of about 500 feet of massively stratified marls. The upper part of the Navarro contains much sand in strata of blue-gray, fine-grained sandstone, some of which are as much as 12 inches in thickness, interbedded with gray marl and some sandy shale. The lower half of the Navarro is principally gray marl. Brucks (165) records the combined Taylor-Navarro thickness in the Luling field as about 1350 feet. At Lytton Springs the Navarro is given (188) as 550 feet of light bluish to dark clay and marls with thin sandstone layers and limestone concretions; the middle and upper Navarro contain numerous hard ledges. In the San Marcos area Brucks (164, p. 831) records 500 to 600 feet of Navarro, most of it bluish-gray calcareous clays, but the uppermost beds consisting of similar clays interbedded with cross-bedded and evenly bedded, very fine grained, variably indurated, calcareous sandstone, light blue when fresh, weathering to a grayish-yellow color. The formation has a rolling-plain topography, forms heavy black clay soils, and bears predominantly mesquite timber. Mr. R.

L. Cannon has kindly furnished the following notes concerning Navarro sands in the San Marcos area:

There are two zones in the Navarro formation carrying sand in the San Marcos quadrangle. The lower of these is the *Exogyra costata* zone.[63] I personally believe that this horizon is the equivalent of the Nacatoch member. At the time of working in this part of the section, having seen it from this area to southern Arkansas, I felt convinced that the same fossil assemblages were represented generally throughout the area.

A higher sand member may be seen in isolated places in the area between the San Marcos River and San Antonio. A locality is on the southwest bank of the San Marcos River about a mile north of Staples. Three other localities occur in about a straight line at distances 5 to 7 miles southwest of Staples, the middle one being about a mile west of Wade School. In places, if my memory serves me right, there is as much as 30 or 40 feet of fine sandstone in this member.

The clay pit of Blumberg's Brick Company, south of McQueeny and west of the Guadalupe River, has thin sandstone members in the upper part of the exposed section.

Bexar County to Uvalde County.—In Bexar County (1402, p. 50), a thickness of about 450 feet has been assigned to the Navarro. An upper 100 to 150 feet is locally sandy and oil-bearing. In Medina County about 580 feet is considered Navarro, excluding beds from which *Exogyra ponderosa, Echinocorys texanus* and *Bostrychoceras* n. sp. aff. *polyplocum* have been collected (992, p. 71).

On the Castroville road about 17.3 miles west of the Missouri Pacific station at San Antonio, there is exposed in a prominent road cut Navarro limy marl and limestone nodules with abundant *Exogyra costata* (prominent, narrow and elevated ribs), *Pycnodonta* aff. *vesicularis, Hemiaster bexari* Clark and several other fossils.

In Medina County the D'Hanis brick pit level consists of about 65 feet of soft yellow clay with a few thin limestone ledges near the top. This is followed by about 400 feet of soft, yellow arenaceous clays containing thin ledges of hard, brown arenaceous limestones up to 2 feet in thickness. These two layers contain shark teeth, oysters, pelecypods and gastropods. There follows about 65 feet of fine-grained very fossiliferous, hard, yellow, arenaceous limestones, with interbedded, soft calcareous shaly clay. This is the

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[63]Exposures occur at about the following distances and directions from Staples: 1 mile east; 3 miles north of west; 3 miles north-northwest; 4 miles northeast; 3 miles south-southwest. Another road locality is 4 miles northwest of Lockhart.

Sphenodiscus pleurisepta horizon; associated fossils are *Ostrea cortex. Nucula*, pelecypods and gastropods. The upper part of the formation consists of very fossiliferous, hard, light to dark brown limestone strata up to 2 feet thick, interbedded with thin clay shale strata (992, p. 71). This level contains *Ostrea cortex*.

The stratigraphic facts about the Navarro-Tertiary contact from Medina County to the Rio Grande have been excellently detailed by Stephenson (1528), and are briefly discussed on a later page.

In Uvalde County the Pulliam formation of Vaughan is only about 100 to 200 feet thick, and although it has not been zoned, comparison with the Escondido farther south indicates that a considerable thickness has been removed from its top; in Uvalde County wells the Escondido has a recorded thickness of 550 feet; and passing southwards into Maverick County this formation thickens rapidly.

RIO GRANDE EMBAYMENT

In the Rio Grande embayment the Navarro section thickens greatly on passing underground and down-dip. Part of this thickening represents beds intercalated down-dip but not present at the outcrop, and part represents thickened offshore extensions of beds present at the outcrop. Some of the thickening may be caused by the appearance down-dip of younger beds at the top of the section, which are covered nearer the outcrop by the overlapping Carrizo and other Tertiary formations. An additional important feature of the Navarro in the Rio Grande embayment is that, on the outcrop, certain levels (notably Olmos, Tulillo, and Aguja) are in the marginal facies, whereas down-dip most levels have assumed the marine neritic facies. The sections in the Amerada-Rycade No. 1 Oppenheimer well, Frio County, and those on the Chittim anticline east of Eagle Pass, noted in the following paragraphs, illustrate the features just mentioned. The corresponding sections on the Mexican side of the Rio Grande have been described by Böse and Cavins (134, 135).

The thickening of the Navarro group southward from Uvalde is notable: in Uvalde County wells the Escondido is 550 feet thick; in central Maverick County the Olmos is 434 feet thick, and the Escondido 1675 feet thick (1681, p. 253); in the Sullivan No. 1 well, southeastern Maverick County, the total Navarro is 2830 feet thick; and in the City National Bank well No. 1, in western Dimmit County, the Navarro is 2437 feet thick.

The general section on the Chittim structure follows (578, pp. 1432–1433):

	Feet
Escondido: Marine limestones and shales	750
Marine Navarro beds, older than Escondido	330–420
Olmos: Non-marine, sandy, lignitic, coal-bearing shales	400–600
Farias beds:	
Marine Navarro, glauconitic, sandy shales and impure sandstones; containing *Inoceramus* and other fossils	200
Marine Navarro, lignitic muddy sandstones and sandy shales	400
Marine Navarro: very micaceous, calcareous, sandy shales with a prolific basal Navarro microfauna	325

For comparison, another Rio Grande embayment section, in the Amerada-Rycade No. 1 Oppenheimer well, Frio County, is summarized, through the courtesy of Mr. L. W. MacNaughton. In this well the upper Navarro is supposed to be 815 feet thick (3252–4067) and the lower Navarro about 993 feet (4067–5060).

From microscopic examinations of cores and cuttings, the following depths have been stated for the Upper Cretaceous groups in this well:

Navarro	3252–5060	1808 feet
Taylor	5060–5435	375
Austin	5435–5650	225
Eagle Ford	5650–6039?	389?

The Buda has been reported at about 6039 feet, and the Edwards at 6302 feet. In the basal part of the Navarro some limestone and considerable sandstone were cored.

OLMOS FORMATION

Nomenclature.—The Olmos beds were called "Coal Series" by Dumble (468, p. 225), who extended White's use of the term "Eagle Pass division," and by later writers. Stephenson (1534, pp. 10, 14) in 1927 named the beds the Olmos, from the station Olmos, Maverick County, and from Olmos Creek, the type locality. Olmos (Elm) Creek follows the strike of the beds from about 7 or

8 miles north of Eagle Pass to the Rio Grande about 2 miles above Eagle Pass.

Areal outcrop.—The Olmos formation is largely non-marine sands and clays, on the outcrop 400–500 feet thick, and in wells 400–600 feet thick. It consists of clays, shales, and sandstones, with seams of coal and fireclay. Only one of the coal seams is thick enough to be profitably mined. Along Olmos (Elm) Creek irregularly stratified sandstones and clays containing ferruginous concretions and silicified wood are exposed. There is no constancy in the small beds of sand and clay; they are simply interlocking lenses (1687, p. 23). At several mines in the district the workable coal seam is about 6 feet thick, as in the old Hartz mine near Eagle Pass. In the clays above the coal a Laramie palm, *Geonomites tenuirachis* Lesquereux was found. The Eagle Pass coal is present at Fuente and in other mines near Piedras Negras, Coahuila, and coals of the same age, extend for 140 km. southwards into the coal basins of Sabinas and Barroterán. Udden measured the coal and adjacent strata on the Mexican and the American sides near Eagle Pass, and concluded that, although the total thickness of coal is relatively constant, toward the northeast the coal seams are broken up by clays, and that the coals become more impure (1625, p. 77). Sections in the Sabinas basin show that the facies of the formations has changed and the local divisions established at Eagle Pass are replaced by other local beds. Aguilera[64] lists fossils from the well-known locality near Las Esperanzas: *Exogyra costata* Say, *Ostrea arizpensis* Böse, *Placenticeras stantoni* var. *bolli*, *P. intercalare* Meek, *P. placenta* (Dekay), and *Sphenodiscus lenticularis* (Owen). From doubtful Olmos near Eagle Pass, Vaughan lists several marine fossils. Silicified wood is noted by various writers.

ESCONDIDO FORMATION

Nomenclature.—The highest Navarro formation, the Escondido, was named by Dumble (468, p. 227) in 1892. The type locality is near the mouth of Rio Escondido, which empties into the Rio Grande about 2 miles below Piedras Negras. Dumble says that a mile below the mouth of this river the top of the coal series (Olmos)

[64]Aguilera, J. G., Les gisements carbonifères de Coahuila, 10th Int. Geol. Cong., Livret-Guide No. XXVII, 1906. E. Ludlow, Les gisements carbonifères de Coahuila, *ibid.*, No. XXVIII, 1906.

crosses the Rio Grande and is capped by the basal hard ledge of Escondido, the same that caps the hills in the eastern part of Eagle Pass. The exposure of Escondido, a mile long, consists of clays and ripple-marked sandstones dipping down stream about 2°. It is sometimes stated that the type locality is on the Arroyo de Caballero, 35 miles down the Rio Grande from Piedras Negras. The topmost Escondido is exposed at this locality which is opposite the bluffs on the American side in which Stephenson (1528, Pl. XVI) figured the Cretaceous-Tertiary contact. On the Mexican side on the Blessé Ranch is Loma Prieta, a small conical hill containing the contact. At Arroyo Caballero are found: *Sphenodiscus pleurisepta, Parapachydiscus* aff. *colligatus, Cassidulus* cf. *subquadratus, Ostrea glabra,* and crustacea.

Areal outcrop.—In Maverick County, the Escondido, 550 to 750 feet thick, covers a wide outcrop on account of its superior resistance to erosion, and is subdivided by more prominent hard ledges into three parts. Northward these parts lose their identity by overlap and change of facies. The base is excellently exposed capping the cliffs just east and north of Eagle Pass, where on the first backslope *Exogyra costata* and *Sphenodiscus* occur in the softer layers. The Escondido consists of dark clays and marls, interbedded with more or less extensive strata of sandstone, limestone and shelly ledges. If the basal hard layers just mentioned are taken as the base of the Escondido, then the upper part of the Olmos is fossiliferous, and consists of 35 feet of purplish, sandy or silty clay and sandstone, containing several species of marine pelecypods and gastropoda. Hard Escondido members form prominent cuesta faces 2 to 3 and 7.5 to 8 miles east of Eagle Pass. Udden divides the Escondido into (1) basal sandstone followed by basal clay; (2) medial sandstone and clay; (3) upper sandstone and clay. The sandstone and clay strata and especially the oyster shell ledges are very lenticular and erratic in outcrop. All of these units show a marked down-dip deflection on crossing the Chittim plunging anticline, as do the Upson, San Miguel and Olmos beds (578, p. 1430, fig. 1).

The basal sandstone consists of medium to thick-bedded ledges separated by clay strata, and locally broken up into two or three units. In composition it ranges from a siliceous sand to a fairly pure limestone composed of considerable shell fragments. It is mostly of fine texture, but contains some gravel seams. Ripple marks, fragments of reptilian bones, and barite occur. It is recorded as unconformably overlying the Olmos beds. Udden gives its thickness as 30 to 100 feet. The lower clay, about 275 feet thick, makes a prominent back-slope and shelf down-dip, south and east, from the sandstone. The clay contains fibrous barite.

The bottom of the medial sandstone unit forms a range of hills extending from north to south about 3 miles east of Eagle Pass. It is more lenticular, more porous, and coarser grained than the basal sandstones. Locally shell breccias of *Ostrea cortex* reach a thickness of 40 feet. The entire unit is about 130 feet thick. The medial clay is light gray and contains small flakes of gypsum, and in its upper part large yellow limestone concretions, many with *Sphenodiscus pleurisepta.* The clay contains frequent *Ostrea cortex* throughout, and locally ledges of shell aggregate.

The fine-grained upper sandstone is persistent but thin, 5 to 30 feet thick. The upper clay consists of 100 or more feet mostly of clay with fibrous barite, oyster aggregates, and thin sandstones. Udden reports *Ostrea iridensis* in this unit. Some fossils recorded from the lower part of the Escondido are: *Inoceramus barabinai* Morton, *Turritella* cf. *saffordi* Gabb, *Trigonarca cuneata* Gabb, *Cardium* cf. *eufalense* Conrad, *Sphenodiscus pleurisepta* (Conrad) var. From the Upper Escondido the following are recorded: *Ostrea cortex* Conrad, *Cardium* cf. *eufalense* Conrad, *Mactra* cf. *warreneana* M. and H., *Eutrephoceras dekayi* (Morton), *Sphenodiscus pleurisepta* (Conrad).

Böse and Cavins have investigated and zoned the Escondido in the neighborhood of Lampazos, Nuevo Leon, in Las Mesillas and the Mesa de Cartujanos. It is entirely possible that in this district higher beds are present than at Eagle Pass, because of removal of the overlapping Tertiary beds. At any rate, characteristic ammonites, *Coahuilites* and certain species of *Sphenodiscus,* have not yet been reported from the American side. These ammonites Böse considers to indicate Maestrichtian age, a conclusion already reached by others from the occurrence of the supposed *Parapachydiscus* aff. *colligatus* at the Arroyo de Caballero. From their ammonite collections Böse and Cavins established the following Escondido zones, in ascending order: (1) *Coahuilites sheltoni;* (2) *Sphenodiscus lenticularis;* (3) *Sphenodiscus intermedius;* (4) *Coahuilites cavinsi;* (5) *Sphenodiscus pleurisepta.* It will be noted that in Las Mesillas and the Mesa de Cartujanos they consider *Exogyra costata* to underlie their *Coahuilites* zones, and that they record two species of *Sphenodiscus* well known from Texas. Another feature of importance is that they describe a Navarro facies of non-marine sandstone containing brackish-water pelecypods, the Tulillo facies.

BIG BEND

The formations of the Navarro group in Brewster and Presidio counties are, in ascending order, the Aguja (upper part), and the Tornillo. Ammonites indicate that the lower part of the Aguja is of Taylor age.

AGUJA FORMATION

Nomenclature.—When in 1907 Dr. Udden described his "Rattlesnake" formation, the name had already been used for a formation in the Oregon Pliocene.[65] Accordingly the name Aguja is here substituted for Udden's name. The type locality is Sierra Aguja (Needle Peak), in the flat in front of the Santa Helena fault scarp, 6 miles south of Terlingua, Brewster County, Texas. The slopes and surrounding flats contain a practically complete section of the beds, overlain by the Tornillo clay, and situated close to Udden's original type locality.

Areal outcrop.—Navarro equivalents outcrop in only two areas in Trans-Pecos Texas: (1) in the Terlingua-Chisos area; and (2) in the San Carlos-Candelaria-Presidio area, southern Presidio County. Lithologically and paleontologically the outcrops are very similar in the two areas and in both places may be referred to the Aguja and Tornillo formations.

The Aguja makes a narrow belt of outcrop encircling the Chisos Mountains except on the south. East of the Chisos at many places the outcrop is badly overwashed by bolson fill controlled by local levels, but nearer the Rio Grande and along large creeks, such as Tornillo Creek, good exposures occur. Such exposures are at San Vicente, and along Tornillo Creek 2 or 3 miles north of Hot Springs. Exposures occur north of Burro Mesa at Chisos Pen, along the headwaters of Cottonwood Creek. In the Terlingua quadrangle the

[65]Merriam, J. C., A contribution to the geology of the John Day Basin: Calif. Univ., Dept. Geol., Bull. 2: 269–314. 1901; also in Calkins 1902, *ibid.*, Bull. 3: 114. Apparently the name Rattlesnake has also been used for a granite intruding probably Triassic, by F. E. Hudson, Calif. Univ., Publ. Dept. Geol., Sci. Bull., Vol. 13, No. 6, pp. 181, 207–208, 1922.

Aguja has outcrops in two general areas. It enters the eastern edge of the quadrangle just south of Maverick Mountain and Study Butte, and in the lowlands of Rough Run and Dawson Creek it is exposed in a series of south-dipping parallel cuestas. From the Taylor outcrop near Study Butte south to the Tornillo purple and vari-colored clays south of Dawson Creek, the entire Aguja is well exposed. Thence the formation makes a large outcrop south of Cuesta Blanca, and extends southward covering the area between Willow (Sauz) and Terlingua creeks. The beds here dip eastwards under the Tornillo and higher formations of the Chisos Mountains. It is notable that just south of the Rio Grande the Aguja disappears and the Tornillo is in fault-contact with Fredericksburg along the Santa Helena fault. From a point north of Terlingua Abaja northwest to near Comanche Spring, the Aguja and Tornillo lie in a downfaulted block in which the igneous-capped Sierra Aguja (the type locality) is situated.

A second general area of Aguja is in the northeast quarter of the Terlingua quadrangle, east of Terlingua Creek. Good outcrops occur south of the fault scarp which crosses the Alpine-Terlingua road east of Hen Egg Mountain, in the flats encircling the dome at Payne's water hole, and in the flats north of Leon and Bee mountains.

Three widespread types of sediments compose the Aguja: (1) rather coarse grained fossiliferous sandstones, weathering to dark brown, tan, yellowish-brown, and blue-gray shades; (2) lustrous to dull black, non-marine, carbonaceous, lignite-bearing shales, and especially near the top of the formation some purplish, vermilion or greenish-gray shales, like those typical of the overlying Tornillo; (3) massive shelly clays, somewhat like those in the Taylor but generally weathering more yellowish-brown, and generally more sandy or silty. Udden states that the formation consists of sandstones, muddy and peaty clays and silts, a little limestone in thin strata, and a few thin beds of gravel. In the sandstone layers locally there are numerous casts of *Inoceramus cumminsi*, Cragin, and other species, and locally spherical, sandy, "cannonball" concretions up to a foot in diameter. At most contact localities the basal heavy shelly sandstones are distinct, but locally they appear to be absent, and in those places the basal Aguja sandy clays are distinguishable with some difficulty from the Taylor. In most areas where the beds are inclined, the topographic differentiation between sandstone ridges and shale valleys is striking. Udden states that the basal 100 feet of Aguja is transitional to the underlying Taylor, and has very similar clays, but contains the following fossils: *Volutomorpha* cf. *ponderosa* Whitfield, *Camptonectes burlingtonensis* Gabb (?), *Thracia* sp., *Gyrodes* (?), *Natica* (?), "*Rostellites*" [*Volutoderma*] *texana* Conrad (?), *Dentalium*, *Baculites*, fish teeth, and others (1626, p. 42).

Single beds of the sandstones are as much as 60 feet thick. They are well sorted. The grains are generally less than ½ mm. in diameter, and are free from gravel or mica; they consist of quartz. some chert (in the larger sizes), some magnetite, organic fragments, and calcareous material. The sandstones locally grade into thin limestones. Secondary calcareous cement from action of ground water is quite generally present. In sandstones 300 feet above the base of the Aguja, Udden (1626, p. 44) reports *Halymenites*. This alga (?) is a conspicuous marker in the Nacatoch sand in Arkansas, a fact probably significant for correlation. The finer sediments in the Aguja consist mostly of silts below, and of finer-textured clays above. The silts are locally marly, the calcareous material being present to an extent sufficient to form irregular concretions. Some original calcareous matter is present in the form of thin limestone seams containing organic fragments, and poorly assorted calcareous sand and mud. Thin limonite layers are present. Locally the iron concretions are circular disks, and some are thinly laminated and on weathering split into thin leaves.

Paleontology.—One of the commonest Aguja markers is *Ostrea* sp. aff. *pratti* Stephenson (sometimes called *O. subspatulata* Forbes, thicker than *O. owenana* Shumard). This conspicuous and durable oyster is abundant and widespread in the lower Aguja sandstones and sandy clays. Here also occurs a zone of abundance of *Exogyra* sp. (with fine, numerous costulations), and *Exogyra* aff. *cancellata;* apparently typical *E. costata* (with narrow, elevated costae) has not been reported. *Ostrea glabra* and another very long oyster, found at Chisos Pen and elsewhere, characterize the Aguja. Casts of *Inoceramus cumminsi* are abundant in the Aguja sandstones. Rudistids include *Durania* cfr. *maxima* Logan and *Durania* n. sp. A striking feature of the Aguja is the local abundance of a large gastropod fauna, consisting of many species like those described from the Ripley (1700). Locally an extensive bryozoan reef occurs near the base of the formation. Among the cephalopoda identified from the Aguja are: *Placenticeras intercalare* Meek, *P. meeki* Böhm, *Mortoniceras* cfr. *delawarense* (Morton), *Submortoniceras* n. sp. aff. *woodsi* Spath, *Libycoceras* (?) n. sp. *Baculites* spp., and *Eutrephoceras* sp.

The Aguja near Newman Springs and San Carlos is lithologically similar, and contains *Mortoniceras, Submortoniceras, Placenticeras, Baculites* and other ammonites, and the same *Exogyra* as near Terlingua.

Extensive reptilian beds occur in the Aguja. Those near Terlingua were studied briefly by Williston and by Udden (1626). They occur in the lustrous and dull carbonaceous beds above the basal Aguja sandstones in the Terlingua and Chisos quadrangles. Above the ammonite beds about 3 miles northwest of Vieja Pass dinosaur beds occur in a brownish silt. Tracks also occur on the Quinn (Means) ranch at the spring about 3 miles north-northwest of Newman Spring, San Carlos sheet.

TORNILLO FORMATION

Nomenclature.—The highest part of the Aguja is largely clays, free from sandstones, and grades upwards into the Tornillo clays, apparently without a sedimentary break. The Tornillo is probably Cretaceous (Udden reports saurian bones), and may or may not be marine. It is similar in lithology to some of the upper Aguja clays. The name was given by Udden (1626, p. 54) in 1907. The type locality is along upper Tornillo Creek, north of the Chisos Mountains and Burro Mesa (Chisos quadrangle).

Areal outcrop.—Udden states that at least 600 feet of these clays overlie the Aguja. They are gray, dull olive-green, dull blue, dull red, dull yellow, dull purple, dirty brown, and locally black and white; the prevailing colors are bluish-black with a somewhat rusty tinge, and with locally thick seams of dull purple. The Tornillo in general has a more rounded weathering than the Taylor, and lacks the steep and even vertical clay ridges, undercut slopes and clay slides of the Taylor. It is generally less calcareous and more laminated. It contains local thin lentils of tough, cemented sandstone. The clays have a very fine texture, and consist of particles mostly less than 1/64 mm. in diameter. Calcareous material is rare; it is associated with thin seams of sand, gravel, or iron carbonate; ironstone and other small residual concretions cover much of the weathered clay surface. Two features of weathering characterize the Tornillo, creeping, and clay balls. The Tornillo, in contrast to the underlying Aguja, is so impervious to water that after rains only a thin surface layer is moistened. This layer on drying cracks off and breaks into angular and round lumps which cover and roll down the slopes. The lack of moisture prevents any vegetation which might impede the clay slides. The Tornillo clay contains in most levels considerable bentonite, and some parts of it are largely composed of bentonitic minerals.

Similar outcrops occur over considerable areas in southern Presidio County west of the Rim Rock. An irregular, locally faulted outcrop extends from south of Newman Spring (San Carlos quadrangle) west almost to the Rio Grande, and another extends south and west for some miles from the Empire-Phillips Tootle well.

The formation has considerable fossiliferous outcrops of shale and sandstone in the Rio Grande Valley near Presidio, and in the basins surrounding the mountains near the lower Conchos Valley along the Kansas City, Mexico & Orient Railway south and west of Ojinaga, Chihuahua.

Paleontology.—The only fossils recorded are saurian bones, reptilian (?) tracks, and fossil wood.

Paleontology of Navarro group.—The lower limit of the Navarro coincides essentially with the junction between the ranges of *Placenticeras* and *Sphenodiscus.* In Medina and Travis counties, *Sphenodiscus lenticularis* is reported from strata currently called highest Taylor (highest typical *Exogyra ponderosa*), and Stephenson reports that in the Arkansas formations the lowest *Sphenodiscus* found is from the Nacatoch sand. In Medina County the Taylor has arbitrarily been extended about 75 feet above the top of the asphaltic Anacacho coquina, apparently to include all beds carrying *Exogyra ponderosa.* This throws *Bostrychoceras* aff. *polyplocum, Parapachydiscus* aff. *wittekindi, Parapachydiscus* aff. *gollevillensis, Sphenodiscus lenticularis* (besides *Hoplitoplacenticeras* aff. *vari, Menuites* and *Pseudoschloenbachia*) into the Taylor. In the face of such an assemblage, it would be difficult to place the age of the upper

Taylor, as thus construed, much lower than the Campanian-Maestrichtian boundary (see Spath, 1510, table opp. p. 80; also 1505, 1506). In the Aguja sandstones and shales, *Placenticeras*, but no *Sphenodiscus*, are known, and the upper Taylor ammonites just beneath the Aguja at San Carlos demonstrate a lower level than the top of the Taylor in Medina and Travis counties. How much Navarro is present in the Aguja remains to be discovered.

Among the most distinctive Navarro ostracoda are:

Cytheridea fabaformis (Berry)
Cytheridea micropunctata Alexander
Cythere alata (Bosquet)
Cythereis communis Israelsky (common; good marker)
Cythere rhomboidalis Berry (common; good marker)
Cythere ovata Berry
Cythereis parallelopora (Alexander)
Cytheridea everetti Berry
Cytheropteron hannai (Israelsky)
Cytheropteron saratogana (Israelsky)
Bairdia magna Alexander
Cytherella ovata (F. A. Roemer)
Cytherella tuberculifera Alexander
Cytherelloidea williamsoniana (Jones)

The following list of foraminifera known from the Navarro has been kindly supplied by Helen Jeanne Plummer, the most characteristic species being marked by asterisks:

Proteonina diffulgiformis (H. B. Brady)
Reophax texana Cushman and Waters
Ammodiscus incertus (dOrbigny)
Haplophragmoides calcula Cushman and Waters
Haplophragmoides excavata Cushman and Waters
*Haplophragmoides glabra Cushman and Waters
*Haplophragmoides rugosa Cushman and Waters
*Ammobaculoides navarroensis Plummer
Spiroplectammina anceps (Reuss)
*Verneuilina bronni Reuss
Gaudryina rugosa d'Orbigny
Gaudryinella spp.
Clauvulina insignis Plummer
Dorothia bulletta (Carsey)
Quinqueloculina sp.
Massalina cretacea (Reuss)
Trochammina diagonis (Carsey)
*Trochammina gyroides Cushman and Waters
*Trochammina texana Cushman and Waters
Lenticulina navarroensis (Plummer)
Lenticulina spp.
*Astacolus dissonus Plummer
Hemicristellaria ensis (Reuss)
*Hemicristellaria silicula Plummer
Saracenaria italica Defrance
*Vaginulina gracilis Plummer var. cretacea Plummer
Vaginulina multicostata Cushman
*Vaginulina simondsi Carsey
Vaginulina strigillata (Reuss)
Vaginulina webbervillensis Carsey
Vaginulina aff. cristellarioides Reuss
Marginulina elongata d'Orbigny
Dentalina communis d'Orbigny
Dentalina crinita Plummer
Dentalina granti Plummer
Dentalina megapolitana Reuss
Dentalina obliqua (Linné)
Dentalina reussi Neugeboren
Dentalina spinescens (Reuss)
Dentalina spinulosa (Montagu)
Nodosaria affinis Reuss
Nodosaria radicula (Linné)
Nodosaria vertebralis (Batsch)
Nodosaria cf. adolphina (d'Orbigny)
Nodosaria spp.
Pseudoglandulina sp.
Lagena hispida Reuss
Lagena sulcata (Walker and Jacob)
Flabellina interpunctata von der Marck

*Flabellina reticulata Reuss
Frondicularia archiaciana d'Orbigny
*Frondicularia clarki Bagg
Frondicularia cf. gracilis Franke
*Globulina lacrima Reuss
*Globulina lacrima Reuss var. subsphaerica (Berthelin)
*Globulina lacrima Reuss var. horrida Reuss
Guttulina problema d'Orbigny
*Pseudopolymorphina cuyleri Plummer
*Pseudopolymorphina mendezensis (White)
Nonionella robusta Plummer
*Heterohelix spp.
Guembelina excolata Cushman
Guembelina globulosa (Ehrenberg)
Guembelina striata (Ehrenberg)
Guembelina spp.
Pseudotextularia varians Rzehak
Ventilabrella eggeri Cushman
Ventilabrella carseyae Plummer
Planoglobulina sp.
Eouvigerina hispida Cushman
*Turrilina sp.
Bulimina obtusa d'Orbigny
*Bulimina aculeata d'Orbigny (Midway)
*Neobulimina cf. canadensis Cushman and Wickenden
*Bolivina decurrens (Ehrenberg)
*Bolivina watersi Cushman
*Loxostoma eleganta (Plummer) (Midway)
Loxostoma plaitum (Carsey)
Loxostoma plaitum (Carsey) var. limbosum Cushman
Loxostoma tegulatum (Reuss)
*Siphogenerinoides plummeri Cushman
*Uvigerina seligi Cushman
Reussia sp.
Pleurostomella subnodosa Reuss
Discorbis correcta Carsey
*Epistomina caracolla (Roemer)
*Epistomina aff. reticulata (Reuss)
Siphonina prima Plummer
Gyroidina depressa (Alth)
Gyroidina girardana (Reuss)
*Ceratobulimina cretacea Cushman and Harris
*Pulvinulinella aff. subperuviana Cushman
Allomorphina trigona Reuss
Pullenia quinqueloba (Reuss)
*Globigerina lacera (Ehrenberg)
*Globigerina rugosa Plummer
Globigerinella voluta (White)
Globotruncana arca (Cushman)
Globotruncana canaliculata (Reuss) var. ventricosa White
Globotruncana fornicata Plummer
Anomalina grosserugosa (Gümbel)
Anomalina pseudopapillosa Carsey
*Cibicides aff. ungeriana (d'Orbigny)

Cushman (Contr. Cushman Lab. Foram. Res., 8:89, 1932) states that *Gaudryina navarroana* Cushman and *Gaudryinella pseudoserrata* Cushman are excellent markers for the Navarro clay above the Nacatoch sand.

Records of common Navarro fossils

	Arkansas			East and Central Texas			Escondido				
	Saratoga	Nacatoch	Arkadelphia	Neylandville	Nacatoch	Kemp	L	M	U	Northern Mexico	Aguja formation
Sphenodiscus lenticularis							?				
S. pleurisepta							*		*		
S. beecheri									*		
S. aberrans										*	
S. lobatus									*		
S. prepleurisepta									*	*	
S. intermedius							*			*	
S. n. sp.								?			
S. stantoni									*		
Libycoceras (?) n. sp.											*
Coahuilites cavinsi										*	
C. orynskii										*	

	Arkansas			East and Central Texas			Escondido				
	Saratoga	Nacatoch	Arkadelphia	Neylandville	Nacatoch	Kemp	L	M	U	Northern Mexico	Aguja formation
C. sheltoni										*	
Parapachydiscus n. sp. 1									*		
P. n. sp. 2									*		
P. aff. colligatus									*		
Nostoceras spp.	*	*			*						
Oxybeloceras spp.				*	*						
"Pachydiscus" spp.	*	*									
Baculites spp.	*	*	*		*						*
Scaphites spp.	*	*	*								
Placenticeras spp.											*
Belemnitella americana	*	*									
Nautilus spp.	*	*			*						*
Sauvagesia	?										
Pycnodonta vesicularis	*	*									
Exogyra costata Say	*	*			*		*				
E. costata (narrow costae)			*		*	*					
E. spinosa Stephenson											
E. cancellata Stephenson	*			*							
Gryphaeostrea vomer			*								
Ostrea falcata		*									
Ostrea owenana		*			*						
Ostrea tecticosta		*									
Pecten argillensis Conrad			*		*						
Pecten simplicius Conrad		*	*								
Crenella serica		*				*					
Inoceramus aff. barabini		*									
Inoceramus spp.				*	*						
Veniella conradi Morton	*	*	*								
Cyprimeria depressa Conrad			?								
Paranomia scabra	*	*									
Liopistha protexta	*	*									
Anatimya antiradiata	*										
Turritella trilira	*	*									
Turr. cf. quadrilirata			*								
Liopistha (Cymella) bella		*									
Cardium (Pachyc.) spillmani	*										
Pecten mississippiensis		*									
Ostrea aff. pratti											*
Ostrea plumosa		*									
Ostrea mesenterica		*									
Cyprimeria densata	*										
Trigonia aff. eufalensis		*									
Anomia argentaria		*									

Stephenson states (1535a, p. 493) that the following are among the more conspicuous and useful of the species present in the upper Navarro but absent or rare in the *Exogyra cancellata* subzone (basal Navarro clays):

Trigonia eufaulensis Gabb
Pulvinites argentea Conrad
Crenella serica Conrad
Pholadomya littlei Gabb
Dreissensia tippana Conrad
Liopistha protexta Conrad
Crassatellites subplana (Conrad)
Cardium stantoni Wade

Cardium tippanum Conrad	Morea cancellaria Conrad
Cardium dumosum Conrad	Liopeplum liodermum (Conrad)
Cardium kummeli Weller	Ringicula pulchella Shumard
Aphrodina tippana Conrad	Scaphites conradi Morton + vars.
Turritella vertebroides Morton	Sphenodiscus (several species)
Sargana stantoni (Weller)	Belemnitella americana (Morton)

EXTRUSIVES ABOVE TORNILLO CLAY[66]

Above the Tornillo, extrusives outcrop in two areas: the Chisos Mountains, and the Rim Rock near San Carlos. The age of the basal part of the extrusives is unknown, but there is no evidence that it is Cretaceous. Certain volcanic beds in the Trans-Pecos region are dated as Cenozoic, on the evidence furnished by teeth, bones, plants, and gastropods.

Chisos Mountains area.—Udden (1626) described as "Chisos beds" about 2000 feet mostly of tuffaceous sediments, which occur in persistent thin, evenly bedded strata. Accessory materials are thin strata of clay, conglomerate, and cross-bedded, ripple-marked sandstone. No fossils are known from the Chisos beds. They are capped by the Crown conglomerate (1626, p. 66), consisting of three heavy ledges of conglomerate totaling about 60 feet thick, composed of well-rounded pebbles and boulders of trap rock, lava, and Comanche limestones, interbedded with materials like Chisos tuffs. In both Tornillo and Chisos beds, considerable bentonite results from decomposition.

Rim Rock area.—Vaughan (1687, p. 77), has included the volcanics above the San Carlos coals in his "Vieja series." It consists of about 1925 feet of extrusives up to and including the pantellerite. Baker (44, 46) has suggested the following sequence in Trans-Pecos Texas:

(5) Basalts (interbedded with, or later than, the "Santa Fe" lake beds; Pliocene?)
(4) Andesites
(3) Trachytes
(2) Pantellerite-paisanite } Vieja series of Vaughan (1687). Hyracodon (Oligocene) on Casey ranch; Wilcox (?) plants in Barilla Mountains (Berry, 104).
(1) Rhyolites }

[66]*Literature.*—Streeruwitz, 1560, 1561, 1564, 1566; Osann, 1160, 1161, 1162; Lord, 1014; Vaughan, 1687; Dumble, 480; Udden, 1626; Baker, 44, 46, 53; Mansfield, 1035c; Phillips, 1208; Turner, 1618, 1619; Hill, 722; Berry, 104.

Non-marine gastropoda have been collected from points west of the Mount Ord range southeast of Alpine and from the Fletcher (02) Ranch south of Alpine, in Tertiary felsites and conglomerates. Dr. Junius Henderson examined material consisting of large and small gastropods of more than one species, from the latter locality, and reported as follows:[67]

The large snails are certainly congeneric and almost certainly specifically identical with the snail that Prof. Cockerell described as *Helix hesperarche.*[68] . . . The fossil was labelled "either Puerco or Torrejon, probably Torrejon," to which Cockerell added, in brackets, ["New Mexico"]. He informs me that it was assumed to be from New Mexico because it is from the Cope collection and Cope was known to have fossil mammals from the Torrejon or Puerco. I do not know whether the label was in Cope's writing or was written by someone else, because the matrix resembled early Tertiary from New Mexico. . . . Cockerell says your specimens look exactly like the American Museum material. . . The difficulty is that Cope's specimen may have come from your locality instead of from New Mexico, [as] Sternberg, who did much collecting for Cope, obtained rich collections from Texas red beds and may have visited other localities.

Non-marine gastropods like *Planorbis* occur at the Casey ranch, at the northeastern foot of the Davis Mountains, within 200 feet of the base of the volcanics.

IGNEOUS ROCKS IN TEXAS CRETACEOUS[69]

The igneous occurrences within Cretaceous rocks in Texas are grouped mostly in two areas, Trans-Pecos Texas, and the Coastal Plain south and east of the Balcones fault. No igneous rocks of Cretaceous age have been reported from Trans-Pecos Texas except, doubtfully, some ultra-basic lavas in a large syncline southeast of the Marathon Basin (C. L. Baker), and the age of these rocks is still unknown. Other extrusives and intrusives (flows, stocks, plugs, sills, dikes) in Cretaceous formations in this area are thought to be of Tertiary age, and are discussed later in this paper.

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[67]Letter, to the writer, July 11, 1929.

[68]Cockrell, T. D. A., Tertiary mollusca from New Mexico and Wyoming: Bull. Am. Mus. Nat. Hist., 33: 104, pl. 10, figs. 1-3, 1914. *Helix* is used in the broad sense.

[69]*Literature.—Basaltic rocks:* Getzendaner, 578, 578a; Hill, 757, 765, 793; Hill and Vaughan, 795, 808; Lonsdale, 1009; Sellards, 1429. *Dikes:* Dawson, Hanna and Kirby, 398; Lonsdale, 1009; Sellards, 1429. *Sills:* Lonsdale, 1009, pp. 39-41. *Ash, tuff and bentonite:* Ross, Miser and Stephenson, 1353; Ross and Kerr, 1353a; Getzendaner, 578. *Serpentines:* Bybee, 187; Bybee and Short, 188; Collingwood, 268; Collingwood and Retger, 267; Getzendaner, 578; Lahee, 971; Lonsdale, 1009; Sellards, 1422, 1444a; Schoch, 1376; Schoch and Reed, 1377; Udden, 1638, 1639a; Udden and Bybee, 1641.

In south and central Texas, the known igneous bodies occur along the Cretaceous outcrop gulfwards from the Balcones fault zone. However, the Upper Cretaceous in northeastern Texas and southwestern Arkansas contains volcanic ash and bentonites (1353); and other igneous bodies will likely be found with further drilling in the Coastal plain. The known occurrences in the Cretaceous may be grouped as follows:

1. *Intrusive basaltic rocks:* Stocks or plugs of basalts (olivine-basalt, nephelite-melilite-basalt, limburgitic rocks, gabbro) and of phonolitic rocks (phonolite, nephelinite, Uvalde phonolite) occur in a narrow belt from Austin to near Brackettville, along and gulfwards from the Balcones fault zone (1009). The youngest formation cut by them is Pulliam, and Lonsdale is of the opinion that the age of the massive intrusions in this belt is Tertiary (1009, p. 44). Some such bodies, however, were exposed and weathered in Eagle Ford, Austin and Taylor times, and left sedimentary serpentines in those formations.

2. *Dikes and sills:* A few dikes are known in Glen Rose or Edwards outcrops in Travis, Comal, Bandera, Medina and possibly Uvalde counties. Lonsdale thinks these bodies may also be of Tertiary age (1009, p. 42). Surface sills occur in Kinney and Uvalde counties, and sills are known in wells in Travis and Zavala counties. Dikes in Bandera County were described (636) in 1888.

3. *Volcanic ash and bentonite:* Clays of volcanic origin occur as interbedded sedimentary deposits in the Woodbine (1353), Eagle Ford, Austin, Taylor and Navarro (1009, p. 46) groups.

4. *Serpentine:* Lonsdale (1009, pp. 139–149) divides the serpentines of the Balcones fault area into three classes. They are:

a. Weathering residues of basaltic rocks. Examples are the serpentines at Knippa, Uvalde County, at Pilot Knob, Travis County, and at the locality three-fourths mile upstream from Black Waterhole, Uvalde County.

b. Sedimentary serpentine. This is interbedded with other sedimentary rocks, of Eagle Ford, Austin, and perhaps other Upper Cretaceous ages. Examples are Pilot Knob and Black Waterhole. On Onion Creek north of Pilot Knob, this sedimentary igneous material contains *Inoceramus* and other Austin fossils. The tops of some serpentine "plugs" in the oil fields mentioned later contain foraminifera, and appear to be sedimentary; this conclusion however does not apply to the entire body of such "plugs."

c. Volcanic serpentine. These bodies, as found in Lytton Springs, Thrall, and other Coastal plain oil fields, are low cones of large size. Many writers have considered these bodies as extrusive, either onto the floors of Upper Cretaceous seas or onto low-lying emerged areas. Serpentine of this type occurs at *Buchanan, *Chapman, *Dale, *Lytton Springs, *Lytton Springs townsite, *Schimmel-Batts, *Thrall, *Yoast, Kimbro, Darst Creek and in Uvalde, Medina, Zavala and Travis counties (578, 1009, 1444a).

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*Asterisks indicate oil fields producing from serpentine.

NOTE ON SUBDIVISIONS OF NAVARRO GROUP

Dr. Stephenson suggests that the basal Navarro clays (*Exogyra cancellata* zone) below the Nacatoch be called *Neylandville* formation, and that if the name Kemp beds of Hill is retained, as in this paper, for the portion of the Navarro above the Nacatoch sand, the lower part (chalky marl) of the Kemp be separated as the *Corsicana* formation (restricted). It appears from Hill's description that he included in his "Corsicana beds" the Navarro clays below the Nacatoch, the Nacatoch, and a portion at least of the chalky marl. Dr. Stephenson says:[70]

"The name *Neylandville* would be an appropriate one to apply to the unit which I have heretofore called *Exogyra cancellata* zone. This zone includes all the beds between the Taylor marl below and the Nacatoch sand above. Exposures of the materials comprising the zone occur in washes in a field just south of the fair grounds at the southeast edge of Greenville, and in ditches along the Dixon road for a mile or more southeast of the fair grounds. Type exposures occur along the Bankhead highway between Liberty School and Neylandville, 3 to 6 miles in an air line northeast of Greenville, and in the first cut of the Texas Midland Railway west of Neylandville station.

"The Kemp formation, as used by the Bureau of Economic Geology in this report, includes the units which I have called the chalky marl member and the upper clay member. Since the chalky marl member underlies the city of Corsicana, it would be appropriate to restrict the name *Corsicana* to the chalky marl unit. As Hill originally used it, the "Corsicana" probably included the *Exogyra cancellata* zone, the Nacatoch sand, and the chalky marl. The pit of the Corsicana Brick Company 2 miles south of the court house at Corsicana, might appropriately be regarded as the type locality. If the name Kemp is retained, it should be restricted to the upper clay member, but exposures of this are rare in the vicinity of Kemp, and the desirability of applying the name to this unit has not been fully considered.

"The names Neylandville, and Corsicana (restricted) have not as yet been formally adopted by the United States Geological Survey."

CLOSE OF CRETACEOUS IN TEXAS

Most writers on the Navarro have mentioned that a hiatus or unconformity of unknown magnitude marks its top. Locally various Tertiary formations as high as the Indio overlap onto the Navarro, and the extent of highest Cretaceous strata which these overlaps conceal is unknown. It is stated that at different places beneath the Tertiary overlap Navarro of differing ages appears on the outcrop. Thus Stephenson indicates that about the upper half of the Escondido is younger than any Navarro in central Texas (1534, Pl. I), a view expressed also by other writers. At the pres-

[70]Personal communication, March 6, 1933.

ent time, lack of an adequate zonation of the Navarro, surface and underground, prevents a clear answer to this question. The Escondido in Nuevo Leon contains *Coahuilites* and other ammonites not yet found on the American side of the Rio Grande, but whether this lack represents a difference of age, of facies, or insufficient collecting, remains unknown.

Scott (1389, 1390) has attempted to correlate the basal Midway with Danian, and therefore add it to the Texas Cretaceous. This correlation depends on the affinities of *Hercoglossa vaughani, Venericardia bulla* and other Midway species, and is discussed later under the "Midway group." (See Plummer, Jour. Pal., 4:207, 1930; and Gardner, 572.)

Late Cretaceous time was marked by elevation of the land and retreat of the sea in central Texas, and early Tertiary by a new transgression of the sea. The interval between Cretaceous and Tertiary is therefore marked, on the outcrop, by an unconformity, which may extend down-dip a great distance, by various physical signs, and by a practically complete break in the megafauna. It is possible that down-dip and underground this gap is partly or entirely filled, but so far no such place is known.

The top of the Navarro is not of the same age at different places for two reasons. The sea retreated earlier in some areas than in others: in Trans-Pecos Texas, where the sandy and near-shore Aguja formation represents upper Taylor and probably Navarro; in northern Mexico, where Böse and Cavins described brackish (Tulillo) sandstones in the Navarro; in northeastern Sonora, where various Upper Cretaceous shore lines are in evidence. Furthermore, differing amounts of material have been removed from the top of the Cretaceous at various places near the outcrop, although it is probable that higher beds are preserved down-dip.

The amount of retreat of the uppermost Cretaceous sea is unknown, but it is improbable that the Taylor and Navarro seas extended much farther inland than the present Balcones fault zone. If they had deposited soft sediments over a large area of the Edwards Plateau and Osage Plains, and subsequently retreated, the basal Tertiary beds should contain great amounts of relatively fresh Upper Cretaceous materials and fossils; yet this feature is inconspicuous earlier than the Lissie. A less conclusive argument is that the Anacacho limestone is a near-shore Taylor reef. The physical evidences of unconformity, the locally deep leaching, the break in the fauna, and the fact that the basal Midway is different at different places (clay locally, Lone Oak limestone locally) argue for a distinct period of probably subaerial erosion.

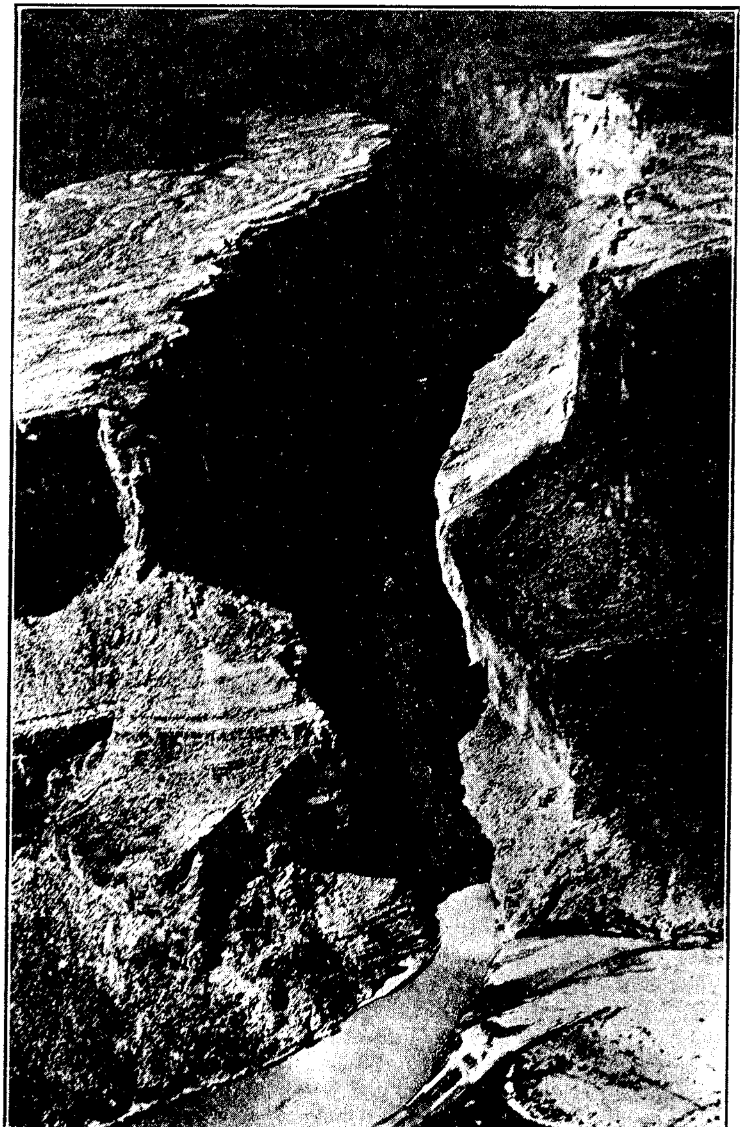

Fig. 27. Mouth of Santa Helena canyon of Rio Grande, 10 miles south of Terlingua. The wall is 1700 feet high, and is composed mostly of Fredericksburg limestone.

Part 3

CENOZOIC SYSTEMS IN TEXAS

F. B. Plummer

INTRODUCTION

ECONOMIC IMPORTANCE OF CENOZOIC STRATA

Cenozoic rocks furnish a large proportion of the natural resources of Texas. The soils developed from these strata support extensive forests of pine and hardwood timber, which constitute the chief supply of lumber. The clays make a good quality of brick and tile. Salt plugs, which have reserves of salt estimated by Barton (69, p. 49, 1928) to be 1,170,000,000 long tons above a depth of 2500 feet, occur within the area covered by Cenozoic strata. More than 700,000,000 barrels of oil have been produced from sands of Cenozoic age along the Gulf Coast and in south Texas. Barton (69, p. 23, 1928) estimates that over 500,000,000 barrels of known recoverable oil are still in the ground, and that three times as much is yet to be discovered. Available sulphur deposits in strata of Texas and Louisiana Gulf Coast amount to at least 90,000,000 tons. Lignite occurs in many places also. Baker (MS.) estimates that these reserves amount to 30,000,000,000 tons and points out that the lignite is the cheapest and most abundant source of future electric power in the state. Lignite is capable, by the process of hydrogenation, of furnishing an almost inexhaustible supply of gasolene and lubricating oils. The low-grade iron ore occurs in great abundance in the middle Eocene strata of east Texas. Cenozoic strata contain high-grade clay for the manufacture of brick, tile, and pottery, and volcanic ash altered to fuller's earth, which is extensively used as a filtrant for oils. The shallow sands furnish water supply for thousands of homes, and in certain areas in south Texas underground water is present in sufficient quantities to irrigate thousands of acres of truck gardens and valuable agricultural land. The U. S. Geological Survey estimates that more than four-fifths of the people of east and south Texas are supplied with drinking water from wells. The supplies of lumber, oil, lignite, salt, sulphur, and underground water are more than sufficient to give these formations first place in natural reserves among the major geologic groups.

GEOLOGIC INVESTIGATIONS

The first published announcement in American literature of the presence in Texas of strata belonging to the later geologic periods appears to have been by William Maclure,[1] who compiled a geologic map of the United States. In his observations that accompanied the map he referred to the unconsolidated sediments of the coastal province as alluvial rocks. In 1824 John Finch[2] suggested that Maclure's alluvial formation was identical with the Tertiary formations of Europe.

The first fossils from the Cenozoic strata of the Gulf Coast were described by Say,[3] Conrad,[4] and Lea.[5] Featherstonhaugh,[6] in his report of an examination of the country between the Missouri and Red rivers, was one of the first geologists to describe strata of Cenozoic age on the west side of the Mississippi embayment. During 1845, 1846, and 1847 Ferdinand Roemer, a German geologist, visited Texas in the interest of German colonization and published nine papers between 1847 and 1889 giving an account of his geological observations (**1327**, pp. 358–365, 1846; **1328**, pp. 21–28, 1848; **1330**, pp. 1–464, 1849; **1331**, pp. 1–100, 1852; **1335**, pp. 281–296, 1888). Roemer (**1330**, 1849) prepared the first map to show the Cretaceous-Eocene contact in Texas. He[7] noted also fossiliferous Eocene rocks in Robertson and Caldwell counties. In 1857 Schott (**1380**, pp. 28–48, 1857) published an account of the geology of the formations along the lower Rio Grande and illustrated a few Eocene fossils. Gabb (**555a**, pp. 375–406, 1860) published a paper

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[1]Maclure, Wm., **1031a**, pp. 411–428, 1809.

[2]Finch, John, Geological essay on the Tertiary formations in America: Amer. Jour. Sci., first ser., vol. 7, pp. 31–43, 1824.

[3]Say, Thomas, An account of some of the fossil shells of Maryland: Acad. Nat. Sci. Philadelphia Jour., vol. 4, pp. 124–155, pls. 7–13, 1828.

[4]Conrad, T. A., Fossil shells of the Tertiary formations of North America, pp. 1–121, pls. 1–20, Philadelphia, 1832, 1835.

[5]Lea, Isaac, Contributions to geology; Tertiary formation of Alabama, pp. 1–208, pls. 1–6, 1833. (Lea received his first Tertiary fossils from Judge Tllt of Claiborne, Alabama, in January, 1829.)

[6]Featherstonhaugh, G. W., Geological report of an examination made in 1834, of the elevated country between the Missouri and Red rivers, pp. 1–97, Washington, 1835.

[7]An interesting account of Roemer's travels in America has been published recently by S. W. Geiser (**572c**, pp. 421–460, 1932).

on a collection of Eocene fossils obtained near Wheelock, Robertson County.

From 1861 through the seventies, due to the Civil War and its effects, no noteworthy contributions to Cenozoic geology were made except by Hilgard. In 1860 Hilgard[8] completed a publication on the geology of Mississippi, in which he devoted 86 pages to the description of the Cenozoic strata, and published new sections and many lists of fossils. In 1869 he (**721a**, pp. 331–346, 1869) visited Louisiana and published the results of his observations in which he reviewed the geology of the younger formations of the state. In 1871 he published[9] a paper on the geological history of the Gulf of Mexico. In 1873 he[10] completed his final report on the geology of Louisiana, which was the most complete report of the Cenozoic geology published up to that time. Other noteworthy articles by Hilgard concern lignite beds and their under clays, the later Tertiary of the Gulf of Mexico, and an account of the old Tertiary of the Southwest. Altogether Hilgard dominated geological investigations on the Cenozoic formations between 1860 and 1885.

Beginning about 1885, however, interest in the coastal section was renewed by a number of new accounts of the geology. Noteworthy among these are those by Loughridge (**1017**, pp. 669–806, 1884), who published the first account of the occurrence of older Eocene (Midway) fossils in the Tehuacana Hills, Limestone County; Heilprin (**701**, pp. 393–406, 1891), who published descriptions of Eocene mollusca of Texas; and Hill (**734**, pp. 1–95, 1887), who presented a summary of all that was known at the time concerning the geology of the state. The first detailed accounts of the younger strata of Texas came in 1890 and succeeding years, as a result of the work of the Dumble Survey in Texas and the Smith Survey in Alabama. Penrose (**1189**, pp. 3–100, 1890) published a report on the geology of the Gulf Tertiary of Texas, and Kennedy published several reports dealing with Tertiary strata (**903**, pp. 65–203, 1891; **904**, pp. 3–40, 1892; **905**, pp. 41–125, 1892; and **906**, pp. 1–84,

[8]Hilgard, E. W., Geology and agriculture of the State of Mississippi, pp. 1–391, Jackson, Mississippi, 1860.

[9]Hilgard, E. W., On the geological history of the Gulf of Mexico: Am. Jour. Sci., 3rd ser., vol. 2, pp. 391–404, 1871.

[10]Hilgard, E. W., Supplementary and final report of a geological reconnaissance of the State of Louisiana, 44 pp., 1873.

1893). In 1894 Smith, Johnson, and Langdon[11] published the most complete account of the geology of the southern Gulf Coast.

During the same epoch Dumble, as director of the Geological Survey of Texas and later as chief geologist for the Southern Pacific Railroad, took much interest in Cenozoic geology and deserves much credit for his own researches as well as those carried on by his assistants. His numerous publications have contributed much to the knowledge of Cenozoic stratigraphy and have had much influence on later geologic work. He published a report (**470**, pp. 1–243, 1892) on the brown coal and lignites of the Eocene formations; an account (**478**, pp. 549–567, 1894) of the Cenozoic deposits of Texas; notes (**481**, pp. 23–27, 1895) on Texas Tertiaries; a treatise (**487**, vol. 2, pp. 471–516, 1898) on the geography, geology, and natural resources of Texas, in which much space was devoted to the younger formations; an account (**494**, pp. 913–987, 1903) of the geology of southwest Texas; two papers (**497**, pp. 50–51, 1911; **498**, pp. 52–53, 1911) dealing with Eocene beds; a discussion (**501**, pp. 447–476, 1915) of the Texas Tertiary sands, and a comparison (**502**, pp. 481–498, 1915) of the geology and stratigraphy of northern Mexico with southern Texas; another summary (**503**, pp. 125–204, 1916) of the geology of Texas; a bulletin (**506**, pp. 1–388, 1918) on the geology of east Texas containing a new map of the Cretaceous and Cenozoic formations; and finally, a revision (**510**, pp. 424–444, 1924) of the Texas Tertiary geologic section with special reference to the subsurface strata revealed in oil wells. Altogether Dumble contributed more to the Texas Cenozoic literature than any other geologist.

The first paper dealing exclusively with Texas Tertiary fossils was written by Heilprin (**701**, pp. 393–406, 1891). This good beginning was followed soon by a series of notable papers on Tertiary paleontology by Harris: Tertiary Geology of Southern Arkansas (**660**, pp. 1–206, 1894); Neocene Mollusca of Texas (**661**, pp. 83–114, 1895); Midway Stage (**662**, pp. 115–270, 1896); New and Otherwise Interesting Tertiary Mollusca from Texas (**663**, pp. 45–88, 1896); Lignitic Stage, part I (**664**, pp. 193–294, 1897); Lignitic Stage, part II (**664a**, pp. 1–128, 1899); Pelecypoda of the

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[11]Smith, E. A., Johnson, L. C., and Langdon, D. W., Jr., Report on the geology of the Coastal Plain of Alabama: Geol. Survey Alabama, pt. I, pp. 1-445, 24 pls.. 1894.

St. Maurice and Claiborne Stages (**668a**, pp. 1–268, 1919). During this interval Aldrich (**23**, p. 25, 1890; **24**, pp. 53–82, 1895; **26**, pp. 1–26, 1911), DeGregorio (**406b**, pp. 1–316, 1890), W. B. Clark (**251a**, pp. 1–173, 1891), Otto Meyer,[12] and Dall (**387**, pp. 1–200, 1890) added notable contributions to the paleontology of the southern Gulf Coast Tertiary formations.

Since the work of Harris and his contemporaries, most of the publications on the Cenozoic of Texas, except those of Dumble already mentioned, have come from the pens of geologists of the United States Geological Survey in the form of Water-Supply and Professional Papers. Thus, Veatch (**1691**, pp. 1–422, 1906) has described the underground waters and geology of east Texas, northern Louisiana, and southern Arkansas. Deussen (**415**, pp. 1–365, 1914; **421**, pp. 1–145, 1924); Deussen and Dole (**416**, pp. 141–177, 1916); Gordon (**609**, pp. 1–78, 1911), and Trowbridge (**1610**, pp. 85–107, 1923) have described the geology and underground waters of southeast, southwest, and northeast Texas. Berry has described the fossil floras (**101**, pp. 227–251, 1916; **103**, pp. 1–481, 1916; **109**, pp. 87–92, 1924; and **112**, pp. 1–196, 1930). Stephenson (**1528**, pp. 155–182, 1915) described the Cretaceous-Eocene contact in Texas, and Julia Gardner (**565**, pp. 109–115, 1923; **566**, pp. 141–145, 1924; **567**, pp. 134–138, 1925; **569**, pp. 245–251, 1927; **570**, pp. 362–383, 1927; **572**, pp. 149–160, 1931; **572a**, p. 470, discussion, 967–970, 1931) in connection with her work on a new geological map of Texas has studied the stratigraphy and paleontology of the Cenozoic strata and deserves much credit for completing a large task in a very difficult field. She has untangled a mass of conflicting ideas and has placed Texas stratigraphy on a firmer foundation.

The recent work of the paleontologists of the southwest in advancing the science of micropaleontology must be mentioned as an important item in any review of Cenozoic stratigraphic research. The knowledge gained from a study of the foraminiferal faunas has furnished a new, accurate, and very important tool to aid in the mapping and the correlation of formations. Esther Applin, Alva Ellisor, and Hedwig Kniker (**32**, pp. 79–122, 1925) in a

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[12]Meyer, Otto, Species in the southern old Tertiary: Am. Jour. Sci., vol. 30, pp. 270–275, Oct., 1885.

paper on the subsurface stratigraphy of the Coastal Plain proved the value of microfossils as a means of identifying and correlating underground strata in Texas. Helen Jeanne Plummer (**1235**, pp. 1–206, 1927) in a paper on the foraminifera of the Midway has shown the value of these fossils for zonation of Cenozoic formations and their value in surface mapping. Cushman and Applin (**352**, pp. 154–189, 1926) and Cushman and Thomas (**374**, pp. 176–184, 1929, and **379**, pp. 33–41, 1930) have described the foraminifera of the Jackson and Claiborne (Eocene) groups. Other recent helpful contributors to Texas Cenozoic stratigraphy are Bailey (**40**, pp. 1–187, 1926), who described excellently the volcanic tuffs of south Texas; Alva Ellisor (**522**, pp. 976–985, 1926), who wrote on Oligocene coral reefs, and (**523**, pp. 1335–1346, 1929) on the correlation of the Claiborne; Wendlandt and Knebel (**1728**, pp. 1347–1375, 1929), who have given the best account of the lower Claiborne of east Texas; Renick and Stenzel (**1299**, pp. 73–108, 1931), who described the lower Claiborne along Brazos River Valley; and Ball (**58**, pp. 1–173, 1931), who has added to the knowledge of the paleobotany of the Eocene formations.

GEOGRAPHIC EXTENT

Cenozoic formations are widespread in Texas. The outcrop covers a broad belt of territory along the Gulf of Mexico from Florida to Mexico. These formations outcrop along the Coastal Plain in an irregularly shaped belt, which includes most of the eastern part of Texas. The northern limit is a line drawn through points located 210 miles up Rio Grande Valley, 190 miles up Colorado River, and nearly 300 miles up Sabine River and its tributaries.

A few small patches of nonmarine Cenozoic strata have been identified in west Texas. West of the Pecos there are extensive intrusions of Cenozoic igneous rocks, ancient flows of Cenozoic lava, and beds of volcanic ash. Clays that contain leaves of Cenozoic plants, fossilized snail shells, and bones of animals are found interstratified with the ash beds in a few places.

Cenozoic strata cover more than one-third of the surface of the state and are developed in a wide and diverse variety of facies and structure, exceedingly interesting scientifically and very important economically.

RELATION OF REGIONAL STRUCTURE TO DISTRIBUTION OF OUTCROPS[13]

Regional structure has had two marked effects on the extent and character of Cenozoic formations. First, the uplifts and basins determined the facies of the sediments and lithology of the formations. The waters were deepest and the sea remained longest in the synclinal areas. Most formations in the middle of the troughs are made up of fine-grained marine muds and silts. Traced laterally

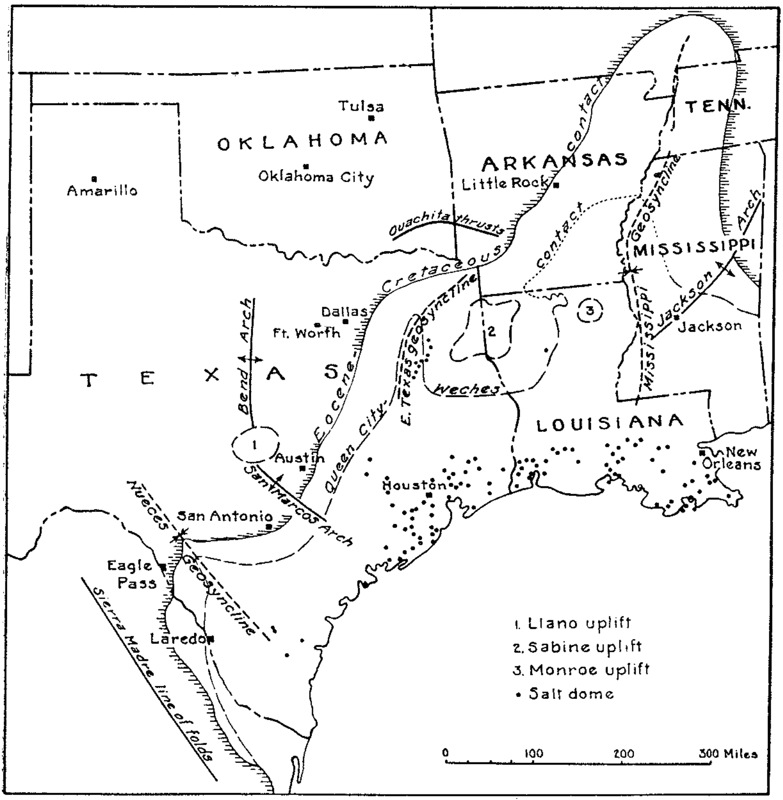

Fig. 28. Structural features in the Gulf Coast province of Texas and adjoining states.

[13]LITERATURE—Veatch, A. C., **1691**, pp. 66–69, 1906. Fohs, F. Julius, **543**, pp. 709–721, 1923. Pratt, Wallace E., and Lahee, F. H., **1263**, pp. 226–236, 1923. Powers, S., **1252**, pp. 209–268, 1926. Lahee, F. H., **969**, pp. 303–388, 1929. Wendlandt, E. A., **1728**, pp. 1347–1376, 1929. Heath, F. E., and Waters, J. A., **696**, pp. 43–60, 1931. Moody, C. L., **1125**, pp. 531–551, 1931.

toward an uplift, the same strata change to coarser sediments of littoral origin and merge with continental sediments having so different an aspect that geologists have assigned in some cases two names to the same formation. Second, the shape of the trough in which the sediments were deposited and the shape of the local abnormal structures in the basin controlled the shape of the shoreline and extent of the deposits. The outcrops of nearly all the formations broaden and extend landward in the basin areas, narrow and bend gulfward around the arches and uplifts, are repeated or widened by the faults having upthrow sides on the southeast, and are displaced, punctured, and broken by the salt plugs.

The Gulf Coast structural features that have had most effect on Cenozoic geology are as follows:

1. Mississippi embayment
2. Sabine uplift
3. East Texas basin
4. East Texas salt domes
5. Northeast Texas fault system:
   a. Balcones or Cretaceous group of faults
   b. Mexia-Powell or Midway group of faults
   c. Mt. Enterprise or Claiborne group of faults
6. Gulf Coast salt domes
7. San Marcos arch of the Llano uplift
8. South Texas fault system:
   a. Balcones or Cretaceous faults
   b. Midway group of faults
   c. Pettus or Claiborne group of faults
9. South Texas salt domes
10. Nueces valley trough
11. Chittim arch
12. Sierra Madre line of folds.

The location and extent of these features is shown on the map, figure 28, and their effect on the width and trend of the outcrops can be studied on the geologic map of Texas and on detailed maps of the faults and salt domes.

HISTORY OF SEDIMENTATION

The outstanding feature in the history of Cenozoic sedimentation in Texas is a continuous and relentless struggle between the encroaching waters of the Gulf and heavily loaded, large streams.

The sea endeavored to advance over the land, and the rivers constantly tried to build seaward a newly deposited land in the form of a deltaic plain.[14] In some epochs the water forces prevailed, in others the land-building processes predominated. During the Midway stage, for example, an advance of the sea brought far inland a marine sedimentary facies and marine fossils. During the Wilcox stage, river-laid sands were extended far seaward, and a continental facies of sediments containing land plants and a fresh-water fauna was superimposed over the marine strata. The present time appears to mark the end of a long epoch of land building in which the strand line has been pushed seaward to its limit. Drowned valleys, numerous bays, and long tidal areas in the lower stretches of the coastal rivers show a very recent change and indicate a beginning of another sea transgression.

The history of the Cenozoic era is a history of the transgressions and regressions of the marine waters, and the correct interpretation of the geology depends upon a knowledge of the remarkable intergrading and interbedding of the two types of sediments, the continental and the marine, as well as the recognition of intermediate types, the littoral and lagoonal sediments. Not only does one type of sediment replace the other vertically, as the Wilcox land deposits replace the Midway marine strata, but also, if some formational units are traced laterally far enough, one facies may grade or change abruptly into another. Thus the lower Miocene strata exhibit a typical land facies on the outcrop in east Texas; followed gulfward beneath younger strata they change to littoral deposits; still deeper they assume a typical deep-water marine facies. The same strata traced southwestward into southern Mexico exhibit the marine facies in outcrop.

The complicated intergradations of sediments make Cenozoic stratigraphy difficult and correlation of formations uncertain in some places. The relationships of the various facies of the formations during the epochs of the Cenozoic era are shown by the diagram, figure 29, which depicts transgressions and regressions of the strand line during Cenozoic history. It will be noted by referring to the figure that at least nine maximum transgressions of

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[14]Barton, D. C., (70, pp. 359–382, 1930) in his excellent account of recent deltaic sedimentation along the Coastal Plain has given the best description of the building-out process.

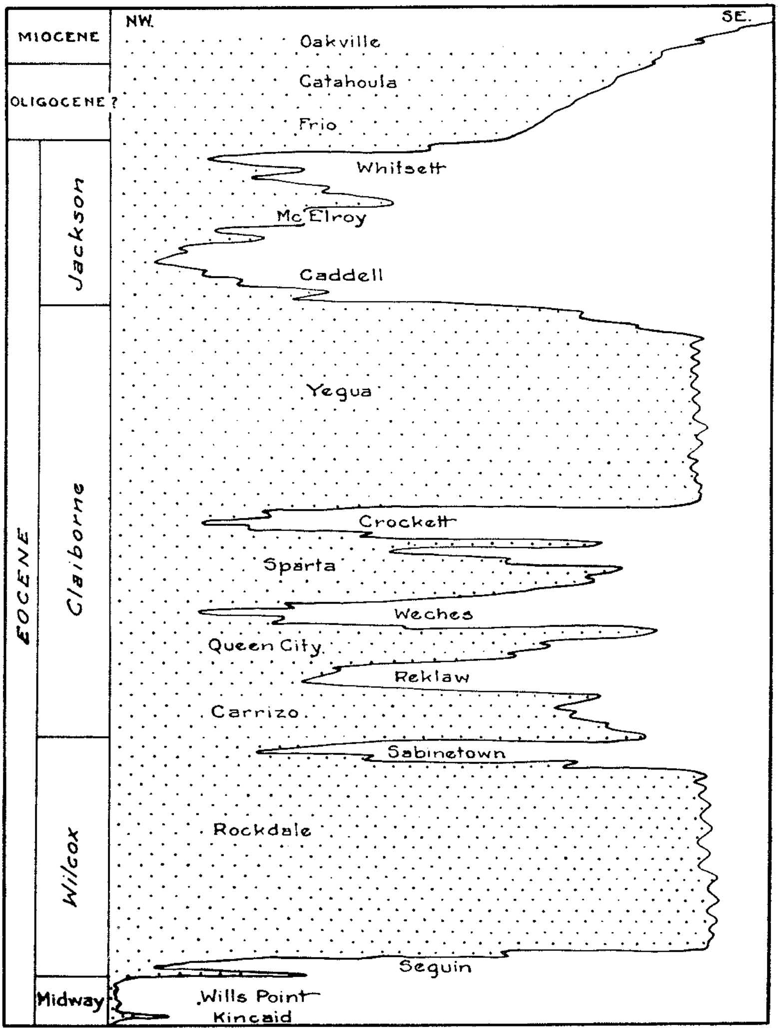

Fig. 29. Diagrammatic representation of the changes in strand lines during the Cenozoic era. The stippled portion represents land; the blank portion sea. Extension of blank areas to northwest shows advances of seas. Extension of stipled areas to the southeast indicates retreat of the sea. (Modified from diagram by H. B. Stenzel, 58, p. 6, 1931.)

the sea occurred, and that each transgression was followed by a maximum regression, and that during these major changes numerous oscillations of the strand line of greater or less extent took place. These major transgressions divide Cenozoic time into natural divisions which form a basis for the classification of the strata into formations. Thus the Wills Point, Reklaw, Weches, Crockett, lower Jackson and marine Miocene mark stages of advancement of the sea and of widespread marine deposits. The Carrizo, Queen City, Sparta, Yegua, Catahoula, Oakville, Goliad, and Lissie mark stages of major withdrawal of the sea and widespread land deposits. These major strand-line changes were most marked in the Mississippi embayment area of Texas, Louisiana, Mississippi, and Alabama and were much less persistent outside the embayment. In Mexico and Florida the marginal strips were narrow and have been removed. The succession of strand-line changes with their recurrent sediments have been interpreted as sedimentary cycles by Weller,[15] or as rhythms by Hudson.[16] These rhythms have been explained by some geologists as due to periodic isostatic adjustments in a geosyncline or embayment following heavy loading with sediments and corresponding removal of material from adjacent land masses; and by others as due to periodic compaction of clays by dehydration of colloids at depth following long epochs of deposition, the compaction requiring less time than the deposition and bringing about a transgression of water after each long period of filling and water displacement. Whatever the cause, these periodic major strand-line changes have played a very important rôle in Cenozoic sedimentary history of the Texas region and have brought about the complicated interfingering of the continental and marine facies in the geologic section.

CLASSIFICATION

The Cenozoic rocks in Texas have been divided into eight groups, and these divisions subdivided into formations and members as follows:

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[15]Weller, J. Marvin, Cyclical sedimentation of the Pennsylvanian period and its significance: Jour. Geol., vol. 38, pp. 97–135, 1930.

[16]Hudson, R. G., On the rhythmic succession of the Yoredale series in Wensleydale: Proc. Yorkshire Geol. Soc., n. ser., vol. 20, pt. 1, pp. 125–154, 1924.

Classification of stratigraphic divisions in Texas

Age	Group		Formation	Members Northeast Texas	Members Southwest Texas
Pleistocene	Houston		Beaumont	Undivided	Undivided
			Lissie	Undivided	Undivided
Pliocene	Citronelle		Goliad	Undivided	Labahia Lagarto Creek beds Lapara
Pliocene and Miocene	Fleming		Lagarto	Undivided	Undivided
			Oakville	Undivided	Undivided
Oligocene?	Gueydan		Catahoula	Onalaska Chita	Chusa Soledad Fant
Oligocene			Subsurface strata	Discorbis zone Heterostegina zone Marginulina zone	Discorbis zone Heterostegina zone Marginulina zone
			Frio	Absent east of Brazos	Undivided
			Subsurface strata	Undivided	Undivided
Eocene	Jackson		Fayette	Whitsett McElroy Caddell	Whitsett Lipan
	Claiborne		Yegua	Undivided	Undivided
		Cook Mt.*	Crockett	Undivided	Undifferentiated south of Atascosa County
			Sparta	Undivided	
		Mt. Selman*	Weches	Undivided	Undifferentiated south of Atascosa County
			Queen City	Undivided	
			Reklaw	Undivided	
			Carrizo	Undivided	Undivided
	Wilcox		Sabinetown	Undivided	Undivided
			Rockdale	Calvert Bluff Simsboro Butler	Undivided
			Seguin	Caldwell Knob Solomon Creek	Caldwell Knob Solomon Creek
	Midway		Wills Point	Kerens Wortham Mexia	Absent for most part
			Kincaid	Pisgah Littig	Pisgah Littig

*According to United States Geological Survey usage in 1932.

EOCENE SYSTEM

MIDWAY GROUP[17]

DEFINITION

The name Midway was first applied by Smith and Johnson[18] in 1887 to designate the oldest Eocene strata in Alabama. Harris (**660**, p. 12. 1894) used the term in his report on the Tertiary geology of southern Arkansas and again (**662**, p. 126, 1896) in his bulletin on the Midway stage in which he showed that it was a stratigraphic and paleontologic unit of first rank. In describing the formational divisions of the Austin quadrangle, Hill and Vaughan (**808**, p. 6, 1902) used the new name Lytton for the lowermost Eocene strata. The term Midway has been adopted generally by all geologists describing the lower part of the Eocene section, so that it is now well established. The type locality is at Midway Landing on Alabama River in Alabama.

The Midway includes all the strata between the Upper Cretaceous (Navarro and Escondido marls) and the sands of the Wilcox group. The contact with the underlying Cretaceous marls is unconformable and is marked in most places by a layer of glauconite, or a line of small black cobble-shaped phosphatic nodules, or a thin stratum of glauconitic sand containing polished pebbles and shark's teeth. The unconformable relationship shows plainly in the Rio Grande area and in northern Mexico, where, according to C. L. Baker, the contact is marked by water-worn boulders and pebbles and where the underlying Cretaceous beds dip more steeply than the Midway strata.

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[17]SELECTED LITERATURE—Smith, E. A., and Johnson, L. C., Tertiary and Cretaceous strata of the Tuscaloosa. Tombigbee, and Alabama rivers: U. S. Geol. Survey Bull. 43, p. 62, 1887. Penrose, R. A. F., **1189**, pp. 19–22, 1890. Kennedy, W., **905**, pp. 47–50, 1892. Harris, G. D., **660**. pp. 22–54, 1894; **662**, pp. 115–270, 1896. Smith, E. A., Johnson, L. C., and Langdon, D. W., Report of the geology of the coastal plain of Alabama: Geol. Survey Alabama, pt. 1, pp. 1–445, 1894. Kennedy, W., **911**, pp. 144–149, 1896. Veatch, A. C., **1691**, pp. 33, 34, 1906. Hill, R. T., and Vaughan, T. W., **808**, p. 6, 1902. Deussen, A., **415**, pp. 29–37, 1914; **421**, pp. 40–47, 1924. Dumble, E. T., **502**, pp. 485–486, 1915; **502a**, pp. 171–181, 1915; **506**, pp. 30–37, 1918. Liddle, R. A., **992**, pp. 74–81, 1918. Sellards, E. H., **1402**, pp. 54–57, 1919. Trowbridge, A. C., **1610**, pp. 88–89, 1923. Hull, J. P. D., Guide notes on the Midway in southwestern Arkansas: Am. Assoc. Pet. Geol. Bull., vol. 9, pp. 167–170, 1925. Cook, Wythe, The Cenozoic formation of Alabama: Geol. Survey Alabama Bull. 14, pp. 253–356, 1926. Plummer, Helen Jeanne, **1235**, pp. 1–206, pls. 1–15, 1927. Gardner, Julia A., **570**, pp. 362–383, 1927. Semmes, Douglas, Oil and gas in Alabama: Geol. Survey Alabama Special Rpt. 15, pp. 232–239, 1929.

[18]Smith, E. A., and Johnson, L. C., Tertiary and Cretaceous strata of the Tuscaloosa, Tombigbee, and Alabama rivers: U. S. Geol. Survey Bull. 43, p. 18, 1887.

The contact of Midway strata with the overlying basal sand of the Wilcox group is not so sharp as the lower contact, but in most places where exposures are good, it is easily recognized. It is the line where the thick, irregularly bedded, medium-grained sand of the basal Wilcox succeeds abruptly the evenly laminated silt and silty clay of the Midway. In places the contact is uneven, due to an abrupt change in sedimentation without an intervening period of erosion. The coarse, stream-deposited sand of the Wilcox tended to settle unevenly into the soft, fine, marine silt of the uppermost Midway.

SUBDIVISIONS

The Midway group has been divided on a basis of differences in facies and faunas into two divisions: Kincaid formation at the base, and Wills Point formation above.

KINCAID FORMATION[19]

Definition.—The identity of the lower portion of the Midway as a separate, easily distinguishable unit was first recognized in 1924 by oil geologists mapping the structure of the Mexia-Powell fault line. It was named Barrows member of the Midway by F. B. Plummer (MS., 1924), basal Midway by H. J. Plummer (**1235**, p. 14, 1927), and Tehuacana formation by the United States Geological Survey on the preliminary edition of the geologic map of Texas (**396c**, 1932).

The name Tehuacana was given by Harris (**662**, p. 155, 1896) to designate the Midway limestone at Tehuacana, and was used in the same significance by H. J. Plummer (**1235**, pp. 12, 13, fig. 1, 1927). The name is now in good usage among geologists for the limestone lentil. It therefore seems best to apply a new name to the basal strata of the Midway group in order to avoid confusion. Julia Gardner has proposed the name Kincaid from Kincaid ranch in

[19]SELECTED LITERATURE—Penrose, R. A. F., **1189**, pp. 19–22, 1889. Kennedy, W., **911**, p. 146, 1896. Harris, G. D., **662**, pp. 127–130, 1896. Deussen, A., **415**, pp. 33–36, 1914. Liddle, R. A., **992**, pp. 74–81, 1918. Dumble, E. T., **506**, pp. 34–37, 1918. Thompson, W. C., **1604**, pp. 323–332, 1922. Trowbridge, A. C., **1610**, pp. 88–89, 1923. Deussen, A., **421**, pp. 40–46, 1924. Cooke, W., The Cenozoic formations of Alabama: Geol. Survey Alabama Spec. Rept. 14, pp. 253–257, 1926. Plummer, Helen Jeanne, **1235**, p. 14 and pp. 20–24, 1927. Semmes, D. R., Oil and Gas in Alabama: Geol. Survey Alabama Spec. Rpt. 15, pp. 232–239, 1929. Chadwick, Geo. H., **237**, p. 117, 1929.

Uvalde County, and the United States Geological Survey has approved this term. Since both Wilcox and basal Midway strata occur in the vicinity of the Kincaid ranch, it seems best to select a type locality more accessable to geologists and where the entire section is exposed. Miss Gardner selected Tehuacana bluff as typical of the Tehuacana formation, the name used in the preliminary edition of the Texas geologic map, and this is the best possible type locality for the basal Midway division. Tehuacana bluff is the steep hill just west of the town of Tehuacana in Limestone County. Other typical localities are the bluff on the right bank of Colorado River on Caldwell ranch[20] 4 miles by river below Webberville and 2½ miles north of Caldwell village in Bastrop County, the exposures along Texas Highway No. 1 between the Terrell reservoir and Cobb, and especially the outcrops along the stream valleys in the vicinity of Ola and on both sides of the town of Elmo, Kaufman County.

Regional geology.—The outcrop of the Kincaid formation in most areas is characterized by a prominent northwestward-facing cuesta, which is conspicuous where indurated ledges mark the top of the formation. At Pisgah Ridge and at Tehuacana, for example, the limestone caps the top of the ridge, and the glauconitic sands and clays form the slopes.

The Kincaid formation has been mapped from central Delta County southwestward to the southern boundary of Kaufman County and from Richland Creek in Navarro County southwest to the center of Guadalupe County. It outcrops in western Bexar County, extends across Medina into eastern Uvalde County, and is exposed for a short distance in Rio Grande Valley 18 miles southeast of Eagle Pass. Its absence on geologic maps northeast of central Delta County is thought to be due to a change in facies at the outcrop from shallow marine to deltaic nonfossiliferous strata. Some geologists have suggested that the Kincaid strata were overlapped northeast of Delta County by younger nonfossiliferous beds. The absence of the outcrop of the Kincaid formation from just south of Corsicana northeastward across Navarro County is due in part to a large normal fault, which brings upper Wills Point beds in contact with the Navarro and in part to a thinning and an absence of

[20]Deussen, Alexander, 421, pp. 43, 44, fig. 11. Sta. 213. 1924.

the limestone. Its absence in Guadalupe County is due to an overlap of the Wills Point clay. In northeastern Maverick and western Zavala counties the Kincaid is overlapped by Carrizo sand.

The Kincaid formation extends beneath the surface south of its outcrop throughout the entire east and central Texas area. Characteristic fossils have been obtained from it in wells as far south as the Boggy Creek oil field in Cherokee County and from the Gay Hill salt dome in Washington County. Strata containing a typical Kincaid fauna outcrop on the Keechi salt dome in Anderson County.

The Kincaid formation has an average thickness of 150 feet along the outcrop. The strata dip southeastward beneath younger formations at the rate of 60 to 75 feet per mile. The formation thickens as the depth increases, and in some deep wells it is twice as thick as in outcrop. Measurements of sections of the outcrop and thicknesses in wells, in which formational contacts have been determined from reliable well samples, are included in the following table:

LOCATION	COUNTY	DEPTH *Feet*	AUTHORITY
Long-Bell No. 1, Shaffer Oil & Rfg. Co., sec. 35, T. 5 S., R. 12 W.	Grant (Ark.)	93	H. J. Plummer
Outcrop, 2 mi. N. of Cumby	Hopkins (Tex.)	118	F. B. Plummer
Outcrop, 2 mi. NE. of Cedar Grove	Kaufman (Tex.)	100	F. B. Plummer
Outcrop, W. of Tehuacana	Limestone (Tex.)	158	F. B. Plummer
Outcrop, Brazos River valley	Milam (Tex.)	40	A. C. Wright
Outcrop	Medina (Tex.)	75–100	R. A. Liddle
Price No. 1	Uvalde (Tex.)	287	F. M. Getzendaner
L. E. Hanchett No. 1	Dimmit (Tex.)	216	A. C. Trowbridge
Black No. 1, Texas Co.	Maverick (Tex.)	250	F. M. Getzendaner
Oppenheimer No. 1, S.W. of Pearsall	Frio (Tex.)	152	L. W. MacNaughton

Stratigraphy.—The Kincaid formation comprises the lower portion of the Midway group from the Cretaceous contact to the base of the Wills Point formation. The lower contact is everywhere unconformable. The upper contact is drawn in northeast Texas at the plane between the Tehuacana limestone and overlying glauconitic sand. Where the Tehuacana limestone is absent, the contact is drawn at the top of the clays carrying characteristic lower Midway fossils and below a glauconite commonly referred to as the second persistent glauconite, which occurs at the base of the Wills Point formation and in places contains the very characteristic zone fossil, *Venericardia bulla* Dall. In south Texas the Wills Point formation in most places is overlapped by the Carrizo sand so that the contact is not well exposed. The upper contact of the Kincaid is known to be, in most places at least, unconformable.

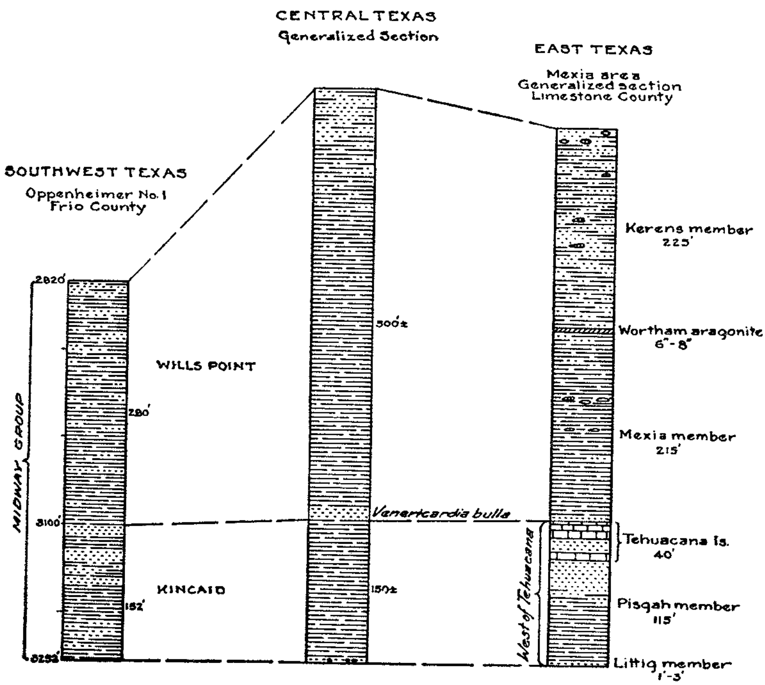

Fig. 30. Graphic sections of the Kincaid formation.

Some geologists place the upper glauconite of the Midway group in the Kincaid formation and draw the dividing line between the Wills Point and Kincaid at the top of this glauconite. The upper glauconite is now placed in the base of the Wills Point formation for the following reasons: (1) Glauconitic sands containing phosphatic nodules, and pebbles mark commonly basal layers of divisions. (2 The unconformity appears to be at the base of the glauconite and not at the top. (3) Although the glauconite layer has large fossils which occur both in the formations above and below, yet it has certain significant ones like *Venericardia bulla* Dall that appear for the first time. This fossil occurs in the Wills Point above the Tehuacana limestone at Mexia, and a closely related form occurs in the upper Midway (Naheola) formation of Alabama. No similar forms are found in the Kincaid. (4) A large percentage of the foraminifera in the glauconite are similar to species in the upper or Wills Point clay.

The Kincaid formation has been divided into the following subdivisions:

2. Pisgah member
1. Littig glauconite member

The Littig glauconite consists of a bed of glauconitic sand from 8 inches to 15 feet or more thick at the base of the Kincaid formation. It is named for the town of Littig in the eastern edge of Travis County. The type locality is the exposure[21] of the sand in the road 1½ miles by road south-southwest of Littig on the south side of Wilbarger Creek. The bed consists of greenish-black calcareous glauconite weathering to yellowish-green or buff color and containing phosphate nodules, small pebbles, shark's teeth, casts of fossils, and spherical, calcareous concretions. It is a very persistent layer that constitutes a good marker in stratigraphic and structural mapping.

The Pisgah member consists of clay, glauconitic clay, and glauconitic sand containing lentils of limestone. The member extends from the top of the Littig glauconite to the bottom of the basal glaucorite of the Wills Point formation. It contains in northeast Texas the Lone Oak, Rocky Cedar Creek, and Tehuacana limestone lentils. The outcrop of the Pisgah member and its limestone lentils in northeast Texas from Limestone County to Hopkins County are shown in figures 31 and 32 ,and the stratigraphic positions of the lentils are shown in the graphic sections, figure 30. The lentils are characterized as follows:

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[21]Plummer, Helen Jeanne, 1235, p. 58, Sta. 61, 1927.

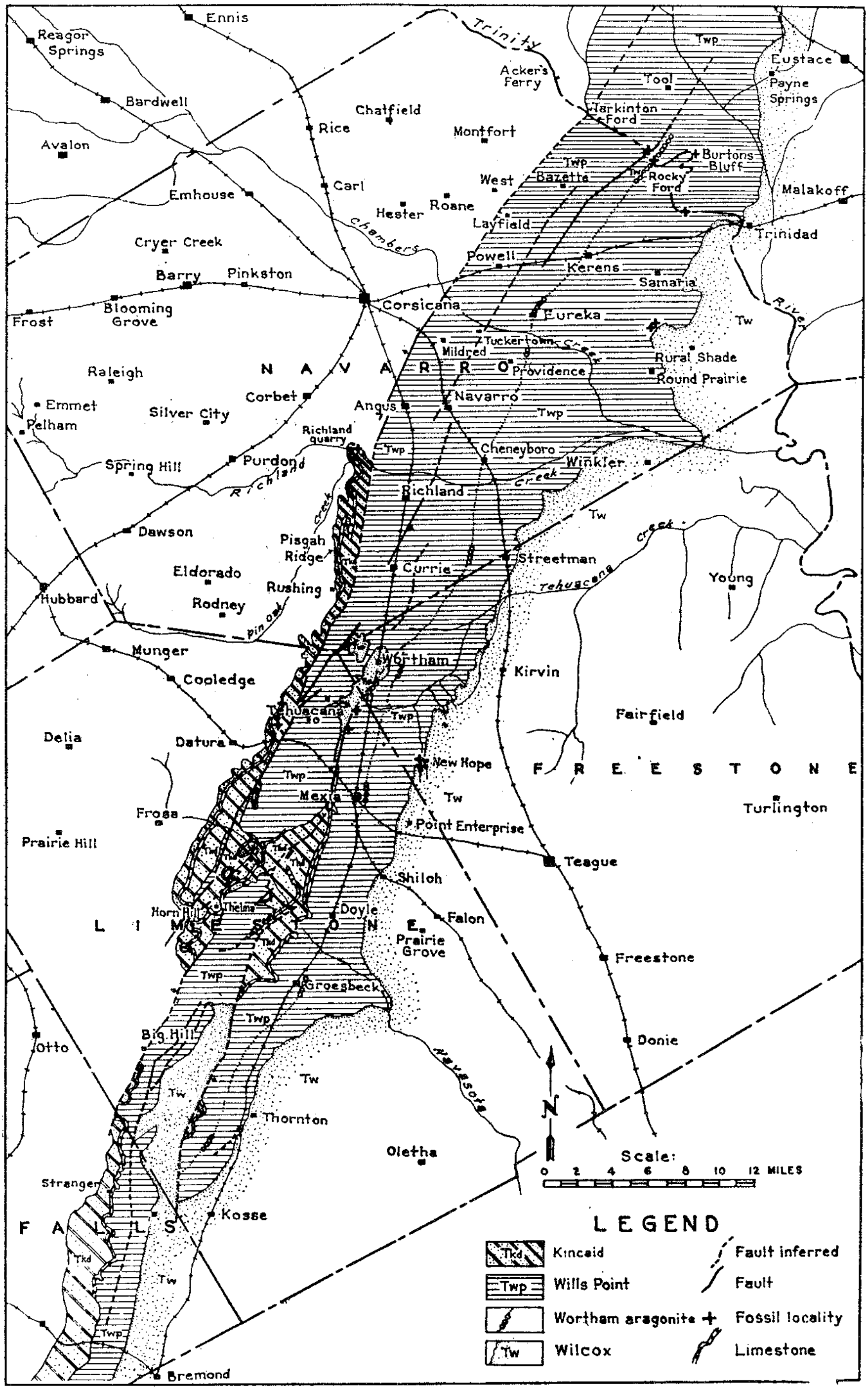

Fig. 31. Midway outcrop from eastern Falls County northeastward into western Henderson County.

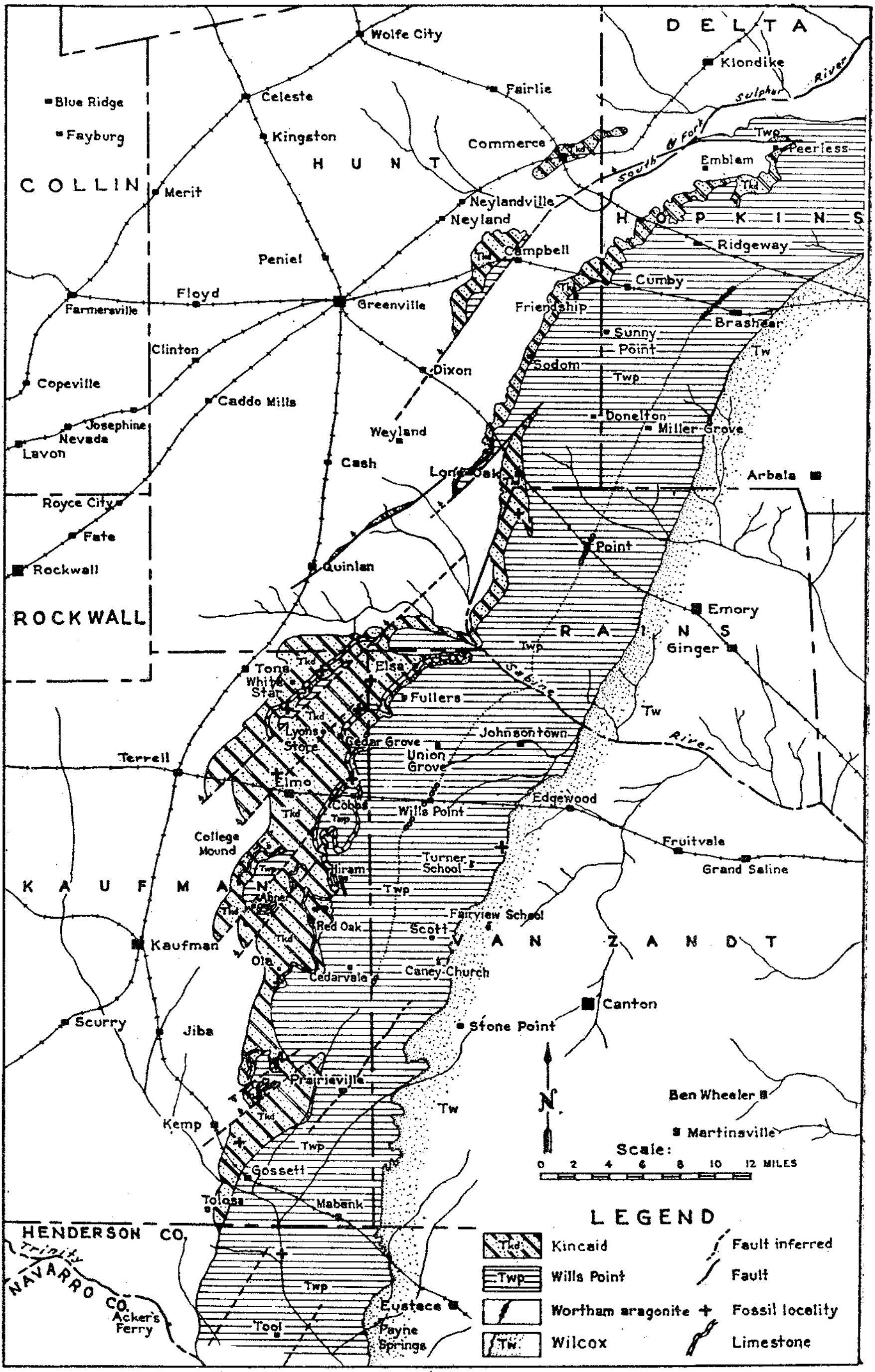

Fig. 32. Midway outcrop from western Henderson County northeastward into Hopkins County.

3. Tehuacana limestone lentil. The name Tehuacana was first applied by Harris (662, p. 155, 1896) for the Midway limestone at Tehuacana, which was described by Thompson (1604, p. 323, 1932). It consists of a deposit from 4 to 30 feet thick made up of coquina, oolite, and compact, indurated shell marl. It extends through Limestone, Navarro, and Kaufman counties. The type locality is the abandoned quarry at Tehuacana, Limestone County.
2. Rocky Cedar Creek limestone lentil. This lentil named by Harris (662, p. 155, 1896) is a local, thin bed of gray, fossiliferous limestone similar to the Tehuacana limestones but occurring slightly lower in the section. It is typically exposed in Ola quarry 1 mile south of Ola, and along Rocky Cedar Creek between Ola and Wills Point, Kaufman County.
1. Lone Oak limestone lentil. This lentil is an impure, oolitic limestone containing a few fossils and is typically exposed at Lone Oak quarry west of Lone Oak, Hunt County. It occurs near the base of the Pisgah member and can be traced for some distance northeast and southwest of Lone Oak.

The Pisgah member in southwest Texas is somewhat different from the typical exposures described in the northeastern part of the state. In Medina County the clay is thinner, the basal glauconite bed is thicker, and the gray limestone that occurs near its top is more persistent than are the lentils in northeast-central Texas.

The Elstone limestone was named by Liddle (922, p. 75, 1918). It is a white, hard, massive, fossiliferous limestone at the top of the Pisgah member in south Texas. It is typically exposed near Elstone in Medina County.

The following sections show the stratigraphic position, the thicknesses, and lithologic characteristics of the Kincaid formation in various districts.

Section of Kincaid formation[22] measured along the bank of a small creek 2.3 miles north of Cumby, on Paris road, Hopkins County.

	Thickness Ft.	in.
Wills Point formation—		
12. Clay, dark gray, compact, contains oval-shaped calcareous concretions with rough, fretted, and veined surfaces and smooth, egg-shaped, limonitic concretions	10	

[22]Plummer, Helen Jeanne, 1235, p. 43, fig. 6, Sta. 2A-G, 1927. Sample H at the top of the exposed strata is now included in the Wills Point formation, No. 12 in measured section here presented.

	Thickness Feet	
Kincaid formation—		
11. Clay, green, glauconitic, calcareous, containing irregularly shaped, black, phosphatic nodules, 1 inch or more in diameter	5	
10. Clay, dark gray, nearly black, thinly bedded, containing a large number of microscopic fossils	5	6
9. Nodules, thin layer, black, phosphatic, ¼ to 1 inch in diameter and etched with narrow white lines 1/32 of an inch wide		1
8. Clay, dark gray, dense, thick bedded, containing a rich microfauna	1	
7. Sand, grayish brown, cemented with calcite into a hard ledge, nonfossiliferous	1	2
6. Clay, dark grayish brown, soft, containing microfossils and a few large fossils	7	6
5. Limestone, dark gray, hard, impure, nonfossiliferous	1	
4. Clay, gray, silty, fossiliferous	7	
3. Clay, gray, silty, poorly bedded, fossiliferous and characterized by large, round concretions	10	
2. Clay, gray, silty, poorly bedded, breaks with conchoidal fracture and contains large calcareous concretions	5	
1. Clay, gray, obscured by stream alluvium and soil, so that its base is not exposed; thickness estimated	25	
Total thickness measured	78	3

Section of Kincaid formation measured at northeast end of ridge 1 mile northeast of White's Prairie schoolhouse on south side of Sabine River, southeast corner of Hunt County.

Pisgah member—	
4. *Rocky Cedar Creek limestone lentil.* Limestone, gray, impure, weathers to large pitted boulders, in places fossiliferous	12
3. Sand, yellowish buff, coarse grained, weathering light yellowish gray	22
2. Clay, yellow or greenish yellow, soft, silt, containing fine white specks of selenite and white nodules of amorphous gypsum. The upper layers are sandy	18
1. Clay, yellowish gray, calcareous, colloidal joint clay, breaks with conchoidal fracture and contains near its base hard, flat claystone concretions about 6 inches thick and several feet in diameter	10
Total thickness measured	62

The exact contact of the Kincaid formation with the underlying Cretaceous strata in this section has not been determined definitely.

The layer of flat concretions is thought to be at or near this plane of contact.

Section of the Kincaid formation exposed along a deep gully north of Ellison's house 2 miles northeast of Cedar Grove and 2½ miles southeast of McCoy, Kaufman County.

	Thickness *Feet*
Pisgah member—	
7. *Rocky Cedar Creek limestone lentil*—	
b. Limestone, white, hard, containing many specimens of *Turritella mortoni* Conrad var. and a few other fossils	1
a. Clay, yellowish gray, sandy, poorly exposed	15
6. Sand, buff to yellowish gray, fine grained, silty, poorly laminated	30
5. Sand, grayish yellow, fine grained, glauconitic, containing small, hard, nodular, calcareous concretions, some of which contain fairly well preserved fossils	15
5. Sand, yellowish green, and glauconite interbedded with thin seams a fraction of an inch in thickness of white and blue clay, and containing numerous, round, nodular, calcareous concretions from 3 to 20 inches in diameter, some of which have septarian structure	6
3. Sand, buff and yellow, glauconitic, fossiliferous, containing large, calcareous, hard, sandstone concretions. The freshly exposed layers near the bottom of the bank contain beautiful fossils, which are very soft and break into small fragments even when removed from the sand carefully	3
2. Sand, buff and variegated, mostly yellow, tinted with greenish and grayish hues, glauconitic and ferruginous and fairly well bedded. The sand grades downward into silty clay	14
1. Clay, yellowish gray, silty, bottom not exposed	10+
Total thickness exposed	94+

Section of Tehuacana limestone at Richland quarry 4 miles northwest of Richland, Navarro County.

Tehuacana limestone lentil—		
12. Limestone, gray, oolitic, foraminiferal, made up of a mass of minute oolites and minute fragments of firmly cemented limestone	4	
11. Marl, gray, with small lentils and concretionary masses of consolidated limestone	1	8
10. Limestone, gray, hard, crystalline	1	6
9. Marl, gray		4
8. Limestone, gray, hard, crystalline	1	

	Thickness Ft.	in.
7. Marl, gray, soft, containing small, white, soft nodules of amorphous gypsum	3	
6. Limestone, gray, oolitic, fragmental		8
5. Marl, gray, soft, containing foraminifera		6
4. Limestone, gray, soft		6
3. Limestone, oolitic, fragmental, containing aragonite crystals on its surface		7
2. Marl, yellowish gray, soft, unconsolidated	8	
1. Marl, yellowish gray, containing thin seams and nodules of aragonite	8	
(Base of section unexposed)		
Total thickness measured	29	7

Section of the Kincaid formation at its type locality northwest side of Tehuacana Hill, just west of Tehaucana on the Tehuacana-Waco road, Limestone County.

	Thickness Ft.	in.
Pisgah member—		
6. Tehuacana limestone lentil—		
c. Limestone, grayish white, in places stained yellow and in other spots brown by water saturated by ferruginous matter. The rock is composed of a great mass of small and highly fragmental shell material cemented by calcite to form a coquina. Many of the shells are microscopic, so that the rock viewed from a distance of a few feet has the appearance of a rather solid and nonfossiliferous ledge. Viewed under the hand lens the small fragments comprise a mixture of finely broken shells, small ostracods, minute pelecypods, foraminifera, and other material. In places the ledge is much jointed, the joint lines running N. 55° E. and N. 35°W. and the planes being nearly vertical	20	
b. Sand, greenish yellow, fine graned, not well exposed	20	
a. Limestone, light yellowish gray, fossiliferous, the lower ledge containing many large specimens of *Ostrea crenulimarginata* Gabb	10	
5. Sand, grayish yellow, glauconitic, medium grained, fossiliferous. Contains large spherical concretions and in places lenticular ledges of consolidated sand	28	
4. Clay, blue gray to black, weathering yellowish gray, very silty, in places sandy and fossiliferous, especially rich in microscopic forms	30	

	Thickness Ft.	in.
3. Clay, bluish gray to black, weathering yellow, contains less silt than overlying strata and breaks with conchoidal fracture. Contains seams and numerous nodules of white, soft, amorphous gypsum. Contains many fragments of fossils and a rich foraminiferal faunule (Univ. Texas Bull. 2644, pp. 53, 54, fig. 11, Sta. 40)	25	
2. Clay, bluish gray, very soft, in some layers very thinly laminated, in others massively bedded. Very fossiliferous, contains both large and microscopic fossils. The larger shells are exceedingly fragile	25	
Littig member—		
1. Sand, yellowish gray, very fine, glauconitic in places, contains a few pebbles and black phosphatic nodules. Covered by soil except in one freshly eroded gully		8
Total thickness measured	158	8

Section[23] *of Kincaid formation in northwest-facing slope of Elm Creek near the Schuddemagen ranch house 11 miles south of Sabinal, Uvalde County.*

	Thickness Feet
3. Sand, fine, greenish gray, slightly calcareous, with numerous interbedded layers of sandstone, the whole poorly exposed. At one place the basal 2 or 3 feet is replete with *Ostrea* sp.	50
2. Limestone, massive, sandy, prominently exposed along the hill slope; contains the following poorly preserved fossils as identified by Messrs. Vaughan and Cooke: *Glycymeris* sp., *Ostrea* sp., *Venericardia perantiqua* Conrad var. *smithii* Aldrich, *Cytherea ripleyana* Gabb, *Natica* sp., *Calyptraphorus velatus* Conrad var., *Pseudoliva* cf. *P. unilineata* Aldrich, Phos (?) sp., *Pleurotoma* sp.	10
1. Sand, fine, greenish gray, calcareous, poorly exposed	45
(The exact Cretaceous-Eocene contact was not determined by Stephenson. It lies probably near the base of the last bed measured.)	
Total thickness measured	105

Section[24] *of Kincaid formation on the Rio Grande about 9 miles above the Maverick-Webb county line.*

2. Clay, greenish, sandy, with indurated layers a few feet apart, weathered and poorly exposed 20
1. Limestone, hard, gray, in layers 1 to 2 feet thick, with interbedded thinner layers of greenish, fine, slightly indurated

[23]Measured by L. W. Stephenson, 1528, p. 177, 1915.
[24]Measured by L. W. Stephenson, 1528, p. 174, 1915.

	Thickness *Feet*
sand. The limestone is replete with *Venericardia* sp., *Cucullaea* sp., and other Eocene fossils. A costate *Anomia* derived mechanically from the underlying Cretaceous strata was found in the base of the limestone	13
Total thickness measured	33

Sedimentology.—The Kincaid formation has a marine facies throughout its extent. The basal strata are littoral in origin and record the transgression of the lower Eocene sea over the Cretaceous base-leveled plain. Its upper lentils indicate shallow waters at least locally. The Tehuacana limestone is a thin lentil of coquina consisting of minute shells and shell fragments cemented together. It suggests a shallow-water reef where animal life was very abundant and shells were broken and rolled by the waves. In places it carries reworked Cretaceous shells.

Lithology.—The strata of the Kincaid formation consist of glauconitic sands, soft gypsiferous clays, and hard indurated limestone lentils deposited in the following proportions: limestone, 10 per cent; clay and silty clay, 50 per cent; and sand, 40 per cent. The limestones and glauconitic layers thin eastward and southward beneath the surface, and the limestone lentils disappear a few miles southeast of the outcrop. The thickness of the clay remains about the same or increases slightly. The clays are everywhere calcareous and weather to produce rich, black, or olive-yellow soils. The color depends on the amount of iron present. The marls contain, in addition to calcareous matter, glauconite up to 20 per cent by weight and seams and minute crystals of selenite. In places the selenite particles can be seen on the surface of nearly every parting of the strata, so that Dumble called the basal beds "selenitic clays."

Small, black, phosphatic nodules occurring in certain thin zones at, or near, the base constitute one of the most characteristic features of the Kincaid formation. These nodules range from ¼ of an inch to 1½ inches in diameter and are dull black on the surface and grayish black inside. In many places the surfaces of these nodules are etched with narrow, gray bands about one-sixteenth of an inch wide.

Calcareous concretions composed of fine silt, sand, and glauconite firmly cemented into more or less rounded cannon-ball shapes are common. Limonitic concretions are present in some places but are rarer in this formation than in the overlying beds of the Wills Point formation.

The clays of the Kincaid formation contain much silica, alumina, and lime. The amount of iron varies considerably. In most places it is much more concentrated in the basal strata than in samples taken from the Navarro below or the Wills Point clays above.

The limestone lentils, except for glauconite and a few sand grains, are fairly pure shell rock having the chemical composition shown by the following analysis:

Percentage composition[a] *of limestone from Tehuacana, Limestone County.*

COMPOUNDS	SAMPLE NUMBERS			
	1005	1006	1007.	1008
SiO_2	4.80	5.50	3.96	5.40
Al_2O_3	1.29	1.67	5.36	7.33
Fe_2O_3	1.35	1.53	.....	1.67
CaO	50.02	48.69	50.65	44.79
MgO	0.00	0.00	Trace	0.00
CO_2	39.40	37.00	40.27	39.60

[a]Analyses by Schoch, 1378, p. 180, 1918.

The glauconite layers consist of dark, greenish-black glauconite grains mixed with some quartz grains, a little gypsum, selenite, and fossil fragments. The chemical composition is shown in the following analysis:

Analysis[a] *of glauconite from basal strata of Kincaid formation on Leon Creek near Castroville road about 7 miles west of San Antonio, Bexar County.*

	Per cent
SiO_2	35.18
Al_2O_3	5.30
CaO	16.00
Iron oxide	17.25
MgO	Trace
Na_2O	1.39
K_2O	1.69
CO_2	8.00
Phosphoric acid	3.30
Loss on ignition	10.10
	98.21

[a]Analysis made by Wm. B. Phillips, 1219, p. 69, 1914.

Distinctive characteristics.—The Kincaid formation is distinguished easily from the adjacent formations by the following criteria:

1. Topography. In many places the outcrop is along the back slope of a ridge capped by a limestone or by a glauconitic layer. The Upper Cretaceous marls below and the Wills Point formation above have commonly a flat, featureless, or gently rolling topography.
2. Soils. The soils are lighter, more silty, and yellower than those of the underlying Cretaceous. Navarro soils are thick, black, and waxy. The Kincaid soils, except where they are in close contact with the Cretaceous, are yellowish green at the base and grade upward into black at the surface. They contain more sand and more iron than Navarro soils. They are yellower, darker, and more calcareous than the Wills Point and terrace soils. The Wills Point soils are noncalcareous, silty, grayish black loams.
3. Phosphatic nodules. Small black nodules streaked with gray lines characterize certain parts of the Kincaid beds and do not occur in adjacent beds.
4. Concretions. The concretions of the Kincaid formation are most commonly large, well-rounded, rough-surfaced forms well cemented by calcium carbonate. Many contain fossils. The concretions of the Navarro are similar in shape but have smoother surfaces, more veins of crystalline calcite, more dendrite, and no fossils. The concretions of the Wills Point formation are of three types: (a) very numerous small ironstone concretions, (b) large flattened concretions with fretted, fine-veined surfaces, and (c) large elongate sandstone boulders from 3 to 15 feet long, which occur in the sandy beds at the top of the formation and in the base of the Wilcox.
5. Fossils. The Kincaid formation contains a very characteristic group of both megascopic and microscopic fossils, which clearly distinguish it from all other formations. These are listed and discussed in the paragraphs on paleontology.

Paleontology.—The fauna of the Kincaid formation, although abundant, varied, and represented by fairly well-preserved fossils, is not so large as that in the Upper Cretaceous strata from which Wade[25] has identified 333 species belonging to 199 genera. Nor is it so large as the fauna of the Crockett formation from which 118 genera and 250 species have been collected. It is, nevertheless, very

[25]Wade, Bruce, Fauna of the Ripley formation on Coon Creek, Tennessee: U. S. Geol. Survey Prof. Paper 137, p. 12, 1926.

distinctive and is of special interest to geologists, since it represents the earliest Eocene life in the Gulf Coast province and furnishes a means of studying the development of animals in the nearshore, sandy, somewhat restricted waters of the early Cenozoic sea, and demonstrates the evolution in animal life that took place in changing from the cosmopolitan associations and highly calcareous environment of the Cretaceous ocean to the littoral waters of the Cenozoic embayments.

Differences between the late Cretaceous and early Cenozoic faunas in Texas are apparent even in a cursory comparison of small suites of fossils, and they are striking when large collections are considered. The foraminifera from the Kincaid formation comprise several genera and many species, of which only a few are common to the Navarro formation. The collections of large fossils in the museum of the Bureau of Economic Geology contain 20 genera and 40 species from the Kincaid formation. The most representative forms are included in the following list:

- Ostrea crenulimarginata Gabb
- *Ostrea pulaskensis Harris
- Venericardia hesperia Gardner
- Venericardia smithii Aldrich
- Venericardia eoa Gardner n. sp. (MS.)
- Venericardia whitei Gardner
- Callocardia biborensis Gardner n. sp. (MS.)
- Callocardia kempae Gardner n. sp. (MS.)
- Callocardia pteleina Gardner n. sp. (MS.)
- Protocardia quihi Gardner, n. sp. (MS.)
- Limopsis quihi Gardner n. sp. (MS.)
- Phacoides albaripa Gardner n. sp. (MS.)
- Crassatellites gabbi (Safford)
- Crassatellites sepulcollis (Harris)
- Yoldia eborea (Conrad)
- Leda elongatoidea alaeformis Conrad
- Cucullaea saffordi ? (Gabb)
- Cucullaea kaufmanensis Gardner n. sp. (MS.)
- Cucullaea texana Gardner
- Corbula aldrichi Meyer
- Aporrhais gracilis Aldrich
- Turritella aff. T. saffordi Gabb
- Turritella mortoni Conrad var.
- Turitella aff. T. alabamiensis Whitfield
- Turritella ola Plummer n. sp. (MS.)
- Turritella humerosa Conrad
- *Natica alabamensis Whitfield ?
- Fasciolaria plummeri Gardner n. sp. (MS.)
- Latirus stephensi Gardner n. sp. (MS.)
- *Hercoglossa vaughani Gardner
- *Actaeon (Tornatellaea) quercollis Harris
- *Volutocorbis aff. V. limopsis (Conrad)
- *Fusus ostrarupis Harris
- *Dentalium mediaviense Harris

Not a single species of all this assemblage is known to occur in the Upper Cretaceous. The ammonoids, *Nostoceras, Oxybeloceras, Parapachydiscus, Sphenodiscus,* so common and highly developed during the Cretaceous, disappeared entirely at the end of that

*Occurs also in the Wills Point formation of the Midway group.

period. Coiled cephalopods are represented in the Midway by only one genus, *Hercoglossa*. The large oysters, exemplified by *Trigonia*, *Gryphaea*, *Exogyra*, and others so common in the Cretaceous disappeared or became insignificant before Midway times. In their places appeared an assemblage of new forms. The most noteworthy of these is the genus *Venericardia*. This pelecypod appeared for the first time in America and passed through an interesting development during the Midway stage. The interesting *Calyptraphorus*[26] also appeared for the first time in the Gulf Coast.

Notable changes in foraminiferal life took place also between the Cretaceous and Cenozoic periods as represented in outcrops.[27] In the deeper waters of the later Cretaceous seas rich in calcium carbonate, numerous forms of the family Heterohelicidae, especially those of the subfamily Gümbelininae, thrived in large numbers of species and of individuals. Pelagic forms of the genera *Globigerina* and *Globotruncana* crowded the faunal assemblages, which included also many representatives of the families Textulariidae, Verneuilinidae, Buliminidae, Lagenidae, and Rotaliidae. The striking changes in environmental conditions at the beginning of Cenozoic times, when the shallower waters held a lower content of calcium carbonate, are reflected in the Midway faunal assemblage, which marks the extinction of all forms of *Globotruncana* and of almost all forms of the Gümbelininae. The genus *Gümbelina* is represented in the Midway fauna by only one rare species, which is wholly unlike any that existed in Cretaceous times. Globigerine forms are frequent and even common in Midway strata, but the species are different from any Cretaceous species in this geologic section, their tests are small and thin shelled, and the group is by no means conspicuous.

The foraminiferal faunas of the Midway group bear no very striking general characteristics. The families Lagenidae and Rotaliidae are best represented, and some of the Cretaceous species in these groups lived over the period of erosion represented by the unconformity between the Navarro and Midway strata in outcrop and are found as frequent members of the Midway fauna. Most of

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[26]*Calyptraphorus* is also reported from the Cannon Ball formation of North Dakota associated with an interior fauna that appears to be very late Cretaceous in age. With this exception, it is known only from the Eocene.

[27]The information on the microfossils is furnished by Helen Jeanne Plummer.

the Midway species, however, are diagnostic, but the genera and families are for the most part long ranging and represent the common, moderately shallow-water assemblages, which persisted through the Eocene seas in this state.

Several species of foraminifera are diagnostic of the Kincaid formation. The three following species are especially valuable in identifying this unit: *Lenticulina pseudo-costata* (H. J. Plummer), *Vaginulina gracilis* H. J. Plummer, and *Eponides elevatus* (H. J. Plummer). The first-named species became extinct at the end of Kincaid times; the second developed rapidly during the deposition of the basal glauconite of the Wills Point formation into *Vaginulina robusta* H. J. Plummer, a diagnostic species of that formation; and the last has no analogue in the Wills Point formation but was probably the ancestor of the many forms of *Eponides* in the Claiborne, Jackson, and Oligocene strata of this area.

The species of foraminifera found most commonly in the Kincaid formation are as follows:

Clavulina aff. angularis d'Orbigny
Lenticulina midwayensis (Plummer)
Lenticulina midwayensis var. carinata (Plummer)
Lenticulina pseudo-mamilligera (Plummer)
Lenticulina pseudo-costata (Plummer)
Dentalina gardnerae (Plummer)
Dentalina pseudo-obliquestriata (Plummer)
Nodosaria affinis d'Orbigny
Pseudoglandulina comata (Batsch)
Vaginulina gracilis Plummer
Vaginulina plumoides Plummer
Flabellina rugosa d'Orbigny
Globulina gibba (d'Orbigny)
Discorbis newmanae Plummer
Eponides elevatus (Plummer)
Eponides exiguus var. limbatus (Plummer)
Globigerina pseudo-bulloides Plummer
Anomalina ammonoides var. acuta Plummer
Anomalina midwayensis (Plummer)
Anomalina midwayensis var. trochoidea (Plummer)
Anomalina vulgaris (Plummer)
Cibicides alleni (Plummer)

The contrast between the Upper Cretaceous floras and those of the early Cenozoic, although not so great as the contrast between the faunas of the two periods, is also noteworthy. Berry (**112**, p. 12, 1930) found that of 71 genera identified from the Ripley group only 28 are known to occur in the lower Eocene (Wilcox). He points out that the most noticeable differences in the floras are: (1) survival in the Ripley of many Mesozoic types that became extinct before the Wilcox, (2) appearance in the Eocene of such genera as *Salix, Fagus, Liriodendron, Cornophyllum,* and others, which, although they have an ancient history, for some reason are absent entirely from the Ripley and appear in the Wilcox. In general the terrestrial floras throughout the world exhibit, except perhaps in the western interior, where breaks in sedimentation were of less magnitude, strong biotic contrasts. The Eocene especially is characterized by a decided modernization of the floras as compared with those of the Cretaceous. Berry (**112**, p. 13, 1930) lists 83 genera of upper Eocene plants of modern aspect which are not present in the Upper Cretaceous sediments anywhere.

The following fossil zones have been recognized in the Kincaid formation:

1. *Venericardia eoa* zone. This zone is located in the Littig member and possibly also in the basal part of the Pisgah clay. This zone extends from Hopkins County to Brazos River and is probably present in the basal part of the section in south Texas. The following fossils are common in this zone:

Calyptraphorus velatus var. compressus Aldrich
Aporrhais gracilis Aldrich
Turritella n. sp.
Yoldia eborea (Conrad)
Cucullaea texana Gardner
Ostrea pulaskensis Harris
Crassatellites gabbi (Safford)
Venericardia eoa Gardner n. sp. (MS.)

2. *Venericardia hesperia* zone. This zone is located in the Elstone limestone lentil and can be traced through Medina and Uvalde counties and along the Rio Grande in Webb County. It is thought to be about 50 feet above the Midway-Cretaceous contact. The following fossils have been identified from this zone:

Turritella aff. T. saffordi Gabb
Turritella cf. humerosa Conrad
Natica sp.
Lucina sp.
Yoldia eborea (Conrad)
Ostrea pulaskensis Harris
Ostrea crenulimarginata Gabb
Cucullaea texana Gardner
Venericardia hesperia Gardner

3. *Venericardia smithii* zone. This zone occurs near the top of the Kincaid formation in Limestone, Kaufman, and Van Zandt counties, Texas. The fossil occurs associated with a similar fauna in Arkansas and Alabama. The following fossils have been identified from this zone:

Ostrea crenulimarginata Gabb
Ostrea pulaskensis Harris
Leda sp.
Lucina sp.
Venericardia smithii Aldrich
Callocardia kempae Gardner n. sp. (MS.)
Turritella aff. T. alabamiensis Whitfield
Turritella humerosa Conrad

Correlation.—The fauna of the Kincaid formation, the oldest of the Eocene fossil groups in America, appears to have no exact counterpart in Europe. It is for the most part a subtropical warm-water fauna that lived in Gulf Coast waters, ranged northward to Georgia, and extended southward into Mexico and South America

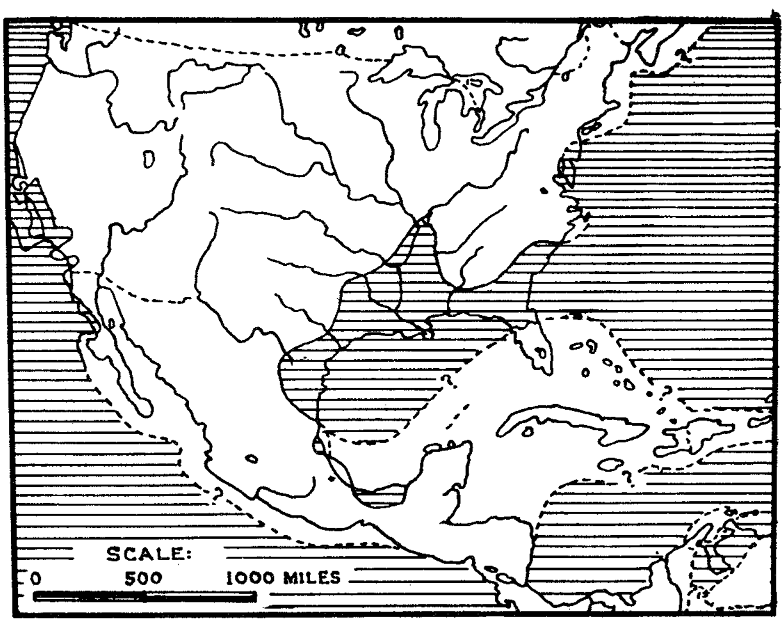

Fig. 33. Extent of the Kincaid sea in the Caribbean area and North America. (Adapted from Walther Staub, Eclog. geol. Helv., vol. 24, p. 71, 1931.)

(fig. 33). It has relationships with early Eocene faunas in India, Persia, and western Africa. It is not known on the Pacific Coast of America, in England, nor in the Paris and Vienna basins. For these reasons it is easier to make comparisons with the Indian, African, and South American strata than with the European. Scott (**1390**, p. 160, 1926) suggested that the *Venericardia smithii* zone may possibly be correlated with the Danian of northern Europe on a basis of the similarity of the nautiloid *Hercoglossa ulrichi* (C. A. White) from the Midway limestone of Arkansas with *Hercoglossa danica* (Schlotheim) from Denmark. Julia Gardner (**572**, pp. 149–160, 1931) has pointed out, however, that the nautiloids similar to *H. danica* (Schlotheim)[28] have a rather long range in India from the Danian into lower Eocene. Since glacial erratics in Sweden carry gastropods that have the aspect of *Turritella mortoni* Conrad and *T. hermosa* Conrad, and since "*Pleurotoma*" *johnstrupi* and *Voluta nodifera* resemble closely "*Pleurotoma*" *mediavia* Harris and *Volutocorbis texana* Gardner n. sp. (MS.) of the lower Midway of Texas, she believes that the lower Midway correlates better with the Seelandian group, which overlies the Danian in Scandinavia, than with the upper Danian itself. The relations are shown in the following tables:

TEXAS	NORTH EUROPE (SWEDEN AND DENMARK)		NORTH INDIA	
Wills Point	Karteminde		——	
Kincaid	Seelandian	Vestre Gasvaerk beds	Montian	——
		Klagsman and Skania beds		Hangu beds
——	Upper Danian		Tethyan (*Cardita beaumonti* beds)	
	Lower Danian			
Navarro	Maestrichian			

TEXAS	DENMARK		BELGIUM	ENGLAND
Wills Point	Karteminde		Landenian	Thanet sands
Kincaid	Seelandian	Vastre Gasvaerk beds	Montian	(Hiatus)
		Klagsman and Skania beds		

The Midway faunas seem to have developed out of an upper Danian (Tethyan) group of animals which lived in India and

[28] *Hercoglossa danica* (Schlotheim) is confined to the Danian of northern Europe.

Africa during latest Cretaceous, but which were absent in most of Europe and North America. The lower Midway fossils, therefore, have closer relationships with forms from the upper Danian of India and Africa than with the Cretaceous of this country.

The correlation of the Kincaid formation with the lower Eocene of America is more certain. The waters were directly connected, and environment and facies were similar, as shown on the map, figure 33. Fossils like those in the Kincaid formation occur in the Clayton beds of Mississippi and Alabama, Sucarnooche beds of Alabama, and the basal Midway beds of Arkansas. The Kincaid formation is correlated questionably with the lower Chicontepec group in Mexico, with bed No. 2 of the Soldado formation in Trinidad, and with the Pernambuco beds in Brazil.

Economic resources.—The chief resources of the Kincaid formation are its rich soils for agriculture, and its limestone lentils for road ballast, and its glauconite. The clay areas are adapted especially to growing cotton, corn, and grain. The glauconite areas constitute a belt adapted to growing fruit. According to Beck and Templin[29] the soils are chiefly clay loams. The surface consists of 2 to 6 inches of yellowish-brown or black clay. This is underlain by yellowish-green or greenish-yellow, heavy clay. The surface soil and subsoil contain an abundance of calcium carbonate. About one-quarter of the soil area is cultivated to cotton, which yields about one-third to one-half a bale to the acre. The remainder of the soil is used for pasture, which will support one head of cattle on each two acres. The soil is well adapted to raising pecans and peaches where moisture is sufficient.

The limestone lentils of the formation are of some importance. Since the Tehuacana, Rocky Cedar Creek, and Lone Oak limestones are the only hard rock in their respective provinces, the ledges are the source of crushed rock for building material, road ballast, and concrete. Quarries are located west of Richland, west of Groesbeck, and at Tehuacana. The sand layers in the basal part of the section furnish good water in wells throughout the northeastern part of Kaufman and northwestern Van Zandt counties and in the Mexia district.

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[29]Beck, M. W., and Templin, E. H., Soil survey of Navarro County, Texas: U. S. Dept. of Agriculture, No. 20, p. 9, 1926.

The glauconite itself has some value as a fertilizer[30] for enriching worn-out soils. The glauconite deposits of New Jersey in the past have been used extensively as fertilizers. Recently the basal strata of the Kincaid formation along the west bluff of Leon River west of San Antonio, Bexar County, have been subjected to experiments for this purpose. The fertilizing value of greensand depends upon its phosphoric acid and its soluble potash content. The New Jersey greensand contains from 2 to 3 per cent of phosphoric acid and from 1 to 6 per cent of potash. Samples from the basal greensand of the Kincaid formation west of San Antonio in Bexar County contain in most places over 4 per cent of potash, as shown by the following analyses:[31]

Percentage composition of Littig greensands in Bexar County.

Sample No.	Total-phosphoric acid	Total potash	Potash soluble in acid	Potash soluble in water	Insoluble in acid
24144	5.04	2.12	0.89	0.03	44.03
29210	5.70	4.24	4.23	——	41.15
29220	3.18	4.39	4.38	0.03	48.75
29320	4.39	4.71	4.44	-------	39.90
29321	2.82	4.51	4.20	-------	46.75
24409	4.97	5.05	5.00	-------	43.27

G. S. Fraps carried on a series of potash experiments with plants to determine the value of this greensand to plants. He concluded that greensand having the maximum amount of water-soluble potash shown by the chemical analyses to be present, when compared with a valuation of $0.06 a pound for commercial fertilizer, would have a value of $3.12 a ton. He determined further that ordinary greensand having a 10 per cent availability of phosphoric acid and 8 per cent availability of potash would have a value of $1.08 per ton. Greensand when applied at the rate of ten to forty tons per acre will increase the growth of crops on soils that need potash and phosphoric acid, and the good effect of the application will last longer than the ordinary fertilizer, since glauconite releases its potash slowly. Fraps concluded, however, that the fertilization value of glauconite is too low to compete with commercial fertilizers at present prices.

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[30]Blair, A. W., The agricultural value of greensand: New Jersey Agric. Exper. Sta. Circ. 61, 1916. Shreve, R. N., Greensand bibliography to 1930: U. S. Bureau Mines Bull. 328, 1930.
[31]Fraps, G. S., 546d, p. 7, 1931.

3. Kerens member
2. Wortham aragonite lentil
1. Mexia member

The Mexia member consists of dark, thinly laminated or compact fossiliferous clays 50 to 75 feet or more thick, of a fairly deep-water, marine facies and having a thin, glauconitic sand layer at its base (*Venericardia bulla* zone). The member is limited at the base by the Kincaid formation and bounded at the top by the Wortham aragonite layer. The type locality is the clay pit at the brick yard in the west edge of the town of Mexia, Limestone County.

The Wortham aragonite lentil is an impure, concretionary, persistent stratum of limestone 8 to 10 inches in thickness and having a crystalline structure in which many of the crystals are aragonite arranged in the form of rosettes. This peculiar and characteristic appearance has suggested to field geologists the name "rosette bed" to designate it. It occurs at the top of the Mexia marls about 75 feet above the base of the Wills Point formation and has been traced along the outcrop from Brazos River northeastward through Limestone, Freestone, Navarro, Henderson, Kaufman, Van Zandt, Hunt, and Hopkins counties (figs. 31 and 32). It is a thin, nonresistant, inconspicuous, persistent layer that forms a very helpful key bed in structural mapping. A typical exposure of the bed is that in the town of Eureka in Navarro County. It occurs also in the railroad cut just west of the station at Wills Point, Van Zandt County, and in a stream valley 1 mile east of Wortham, Freestone County.

The Kerens member consists of dark gray, silty or sandy clay. It occupies the upper two-thirds of the Wills Point formation and is overlain by the basal beds of the Wilcox group. The member is of variable thickness. In Brazos River valley it is about 300 feet thick. In Trinity River valley it is estimated to have a maximum thickness of 450 or possibly 500 feet. The type locality comprises the exposures[36] along Trinity River north of the St. Louis and Southwestern Railroad east of the town of Kerens in Navarro County. An especially good exposure is at the old Humble Oil and Refining Company pumping plant on Trinity River about one mile north of the new highway east from Kerens.

[36]Plummer, Helen Jeanne, 1235, p. 49, fig. 9, 1927. Stations 16, 17, 19, 20, 21, and an exposure at the abandoned pumping plant of the Humble Oil and Refining Company are shown on this map and constitute the type sections of the Kerens member.

The following described sections of the Wills Point formation show the essential characteristics of its strata in east-central Texas:

Section of middle part of Wills Point formation, west bluff Trinity River along old Athens-Kerens road, 5½ miles east of Kerens, Navarro County.[37] (Measured from a point 1¼ miles west of the river to the level of the water beneath the bridge.)

	Thickness *Feet*
10. Clay, dark, bluish gray, poorly stratified. The stratification lines contain silt grains and minute selenite crystals. Numerous small limonite concretions and a few shell fragments occur in the clay	7
9. Clay ?, obscured by river alluvium	20
8. Clay ?, obscured by gentle, grass-covered slope 1 mile long	54
7. Clay, bluish gray, obscurely bedded, siltless, breaks with a conchoidal fracture, and contains numerous limonite concretions, fragments of shells, and many foraminifera	15
6. Clay, bluish gray, unstratified, containing a few fragments of shells, foraminifera, and numerous iron concretions, which average 6 inches in diameter	10
5. Clay, dark gray, slightly silty, poorly bedded and breaking with a conchoidal fracture	10
4. Clay, obscured by grass-covered slope	40
3. Clay, gray, laminated. The layers are 2 to 3 inches thick separated by wavy partings of silt stained with limonite	5
2. Clay, silty, obscured by grass-covered slope	21
1. Clay, bluish gray, weathering yellowish gray, well stratified. The layers are about 1 inch thick and are interbedded with thin partings of silt	10
Total thickness of section measured	192

Descriptions of a series of isolated outcrops in stratigraphic sequence along the Mexia-Teague road from the clay pit in Mexia to the east line of Limestone County. (See figure 34.)

Wilcox group—
  Seguin formation—
    6. Sand, gray, medium grained, containing thin seams of limonite 25
Midway group—
  Wills Point formation—
    5. Sand, light grayish yellow, silty, thinly and uniformly bedded, soft, micaceous, breaks readily along bedding planes to form

[37]Plummer, Helen Jeanne, 1235, p. 49, fig. 9, 1927. The old road is shown crossing Trinity River at Station 17, and the measured section here given lies along this road from the road exposure shown in this figure to the bridge at Station 17.

	Thickness *Feet*
small, thin, smooth plates of sand. Exposed in a ditch near the town of Cotton Gin	18
4. Silt or silty clay, grayish black, weathering to yellowish gray, poorly laminated, containing large, rounded, rough-surfaced concretions, and a few poorly preserved large fossils: the nautiloid *Hercoglossa vaughani* (Gardner), the ornamented gastropod *Volutocorbis texana* Gardner n. sp. (MS.), a smooth naticoid, other very thin fragments of shells and foraminifera. The silty clay grades upward into fine and more evenly bedded sand. Exposed along creek near New Hope near eastern line of Limestone County	15
3. Clay, light gray, stiff, breaks with an uneven and conchoidal fracture, poorly bedded. The partings along the bedding planes show thin streaks of fine micaceous silt. The silt runs through the clay in uneven wavy bedding lines. The clay weathers to form light sandy soils. Exposed in ditch 1½ miles east of Mexia	15
2. Clay, dark bluish gray, compact, breaks with conchoidal fracture and contains numerous small egg-shaped limonitic concretions and a layer of rock about a foot thick, made up of a large number of botryoidal bunches of impure aragonite crystals. Exposed in ditch on Mexia-Wortham road	?
1. Clay, dark bluish gray, breaks with conchoidal fracture and contains poorly preserved shells and shell fragments and a few hard oval-shaped concretions from 8 to 11 inches in thickness. The concretions are greenish yellow, extremely hard, and break with conchoidal fracture. The freshly broken surfaces show fine dendritic patches of black manganese. Thickness in Mexia clay pit	25
(The total thickness of the section that includes these described exposures is estimated to be about 500 feet.)	
Clay, not exposed.	

Sedimentology.—The Mexia strata represent deep-water, off-shore sediments. The clays contain large numbers of corals belonging to the genera, *Flabellum, Trochocyathus,* and *Balanophyllia.* These corals according to Vaughan (1687a, p. 23, 1900) live at depths ranging from 100 fathoms to 1500 fathoms (600 to 9000 feet). The gastropods associated with them are small and have exceedingly fragile shells. They could not have lived on shores where strong waves and currents prevailed, nor could they have lived at depths where water pressure was high. It is probable that the waters were between 300 and 1000 feet deep.

The Kerens beds represent a transition from deep to shallower water in which there was a gradual increase in silt, culminating in sand deposition in some areas at the end of the Midway epoch. The silts contain arenaceous foraminifera, thicker shelled gastropods, and larger numbers of pelecypods, all of which lived in shallower waters, probably less than 300 feet deep.

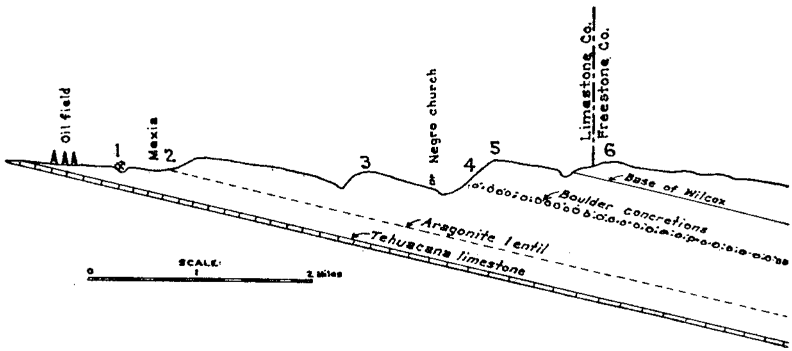

Fig. 34. Relationship of the Wills Point strata east of Mexia.

Lithology.—The Wills Point formation is made up of a little glauconite or glauconitic clay at the base, above which is compact, fossiliferous clay (Mexia member), grading upward into sparsely fossiliferous layers of silty clay (Kerens member) at the top.

The lower 50 to 75 feet of the formation consists of 1 to 10 feet of glauconite succeeded abruptly by almost pure, dark-blue clay containing fossils and small concretions. The concretions in the lower beds are of two kinds: small, rounded egg-shaped limonite and siderite nodules 1 to 6 inches in size, and large, more or less spherical, brittle, calcareous concretions. The surface of some of the calcareous concretions is smooth; in others it is covered with calcite veinlets arranged in intricate patterns, which give to the surface an embossed and fretted appearance. The middle 200 feet of the formation contains some silt deposited between the laminae of the clay. The amount of silt increases upward; the upper 100 feet of the formation contains more than 10 per cent of silt and in some places as much as 25 per cent. The grains of silt are less than 0.1 mm. in diameter and are angular in shape. About 90 per cent of them consist of quartz; the remaining 10 per cent are made

LOCATION	COUNTY	THICKNESS *Feet*	AUTHORITY
Long-Bell No. 1, Shaffer Oil & Rfg. Co., Sec. 36, T. 5 S., R. 12 W.	Grant (Ark.)	466	H. J. Plummer
Wise No. 1, Reiter & Foster, 6 mi. NE. of Cameron	Milam (Tex.)	565	A. C. Wright
Well section at Sulphur Springs	Hopkins (Tex.)	700	Do
Ott No. 1, ¼ mi. SW. of String Prairie	Bastrop (Tex.)	525	E. H. Sellards
Oppenheimer No. 1	Frio (Tex.)	387	L. W. MacNaughton
Pratt No. 1, 5 mi. SW. of Encinal	Webb (Tex.)	355	R. A. Jones

Stratigraphy.—The Wills Point formation overlies the Kincaid formation unconformably. The contact in most places is the plane between the yellowish, glauconitic sands of the basal Wills Point and the soft, calcareous, fossiliferous clays and marls or limestones of the Kincaid. In Hunt and Hopkins counties the contact is between dark, siltless clays above and grayish to yellowish silty clay below. The contact in Brazos River valley is at the base of a glauconitic layer and at the top of the Tehuacana limestone lentil. In Colorado River valley the contact is between the glauconitic layer carrying *Venericardia bulla* Dall in large numbers and dark clay below carrying lower Midway or Kincaid fossils.

The upper contact of the Wills Point clay with the Seguin formation of the Wilcox group is not sharp in most places. It is taken as the plane that separates upper coarse, evenly laminated, gray sands or sandy clays from lower fine, unevenly bedded, black, silty clay. In many places the Wills Point clays grade into the overlying sands, and no sharp line can be drawn. In most places the Wills Point clays below the Wilcox contact are unfossiliferous, except for a few arenaceous foraminifera. They are darker colored and finer textured than the basal beds of the Wilcox group. The beds above the contact contain more sand and much larger, rougher-surfaced concretions. In a few localities the large concretions and rarely the fine sands contain fossils, which are distinguished easily from Midway forms. The plane of demarcation between the Midway and Wilcox is thought to be conformable.

The Wills Point formation in northeast Texas has been subdivided into the following members:

County, 10 miles; in Rains County, 8 miles; in Franklin and Hopkins counties it is nearly 11 miles wide. In Bowie County in the extreme northeastern corner of the state, it narrows to an average width of 8 miles. The formation occurs also on the north side of Keechi Creek salt dome in Anderson County and near the center of Butler dome in Freestone County far south of its regular outcrop.

The Wills Point formation is not well represented in southwestern Texas south of Bexar County. It is overlapped, at least in most of this southwestern area, by the overlying Wilcox or Carrizo. A small exposure of the basal sands of the formation occurs at a locality 1 mile southwest of Noonan in Medina County, another on Frio River below Myrick's apiary in Uvalde County, and typical strata are encountered in wells drilled south of the outcrop. About 300 feet of upper Midway fossiliferous beds were penetrated in the Pratt well[34] 5 miles southwest of Encinal in Webb County, and 290 feet in the Oppenheimer well[35] in Frio County. It is well developed also in northeastern Mexico, and probably underlies most of the Gulf Coastal Plain. The total extent of the outcrop in Texas is estimated to be 2700 square miles.

The thickness of the Wills Point formation varies markedly. It is estimated to have a thickness of about 250 feet along the outcrop from Bexar County northward through Falls County. In Freestone and Limestone counties the thickness increases to about 350 feet. In Navarro, Kaufman, Hunt, and Hopkins counties the thickness is estimated to be 500 to 650 feet. In southwestern Arkansas the thickness is not over 200 feet. In northeastern Mexico, however, the formation thickens enormously, to 3100 feet or more, and younger marine strata come in toward the top of the section. The combined thickness of the Wills Point and marine Wilcox is reported by R. A. Jones (886b, p. 129, 1925) to be several thousand feet. The Wills Point formation also thickens in passing southeastward beneath younger strata. The thicknesses in various areas are shown in the following table:

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[34]Jones, R. A., 892, p. 136, 1929.

[35]MacNaughton, L. W., personal communication, 1932.

The contact of the Wills Point and Kincaid formations of northeast Texas is drawn at the top of the Pisgah clay member and base of the upper glauconite bed of the Midway group of strata. In Limestone County the division lies between the Tehuacana limestone and glauconite above. In central Texas it is drawn at the base of the *Venericardia bulla* zone. In south Texas it is at the top of the Elstone limestone lentil. The amended definition of the Wills Point has been accepted by the Bureau of Economic Geology and by most of the geologists working in Cenozoic formations.

The type locality for the Wills Point formation consists of the exposures near the town of Wills Point, Van Zandt County. The clay pit at the brick plant in Mexia, however, is a good place to study the basal beds of the formation; exposures along the road from Mexia to Teague show excellently the middle and upper beds; the banks of Willow Creek,[33] a small northward-flowing branch of Tehuacana Creek in eastern Limestone County, 4 miles east of Mexia, reveal a complete section of the uppermost strata and show the contact with the Wilcox group. The Mexia-New Hope area furnishes the most accessible complete section of the Wills Point formation.

Regional geology.—The outcrop of the Wills Point formation is topographically featureless, and everywhere, except in those areas where it is crossed by streams, it is a broad, flat, gently rolling, southward-inclined plain. The monotony of the outcrop suggested the name "Flatwood" to early geologists working in Mississippi, and the term is appropriate for the outcrop across northeast and central Texas. The lack of escarpments and the prevalence of thick soils render exposures scarce. Until extensive core drilling was undertaken to locate structures favorable for oil accumulation, the thickness and details of character of the individual beds of the Wills Point formation were little known.

The featureless outcrop of the Wills Point formation extends in a narrow, continuous belt about 2½ to 3 miles wide from central Bexar County on the south, northeastward to northern Falls County, where it widens to 5 miles or more. The width of the surface exposure in Limestone and Freestone counties is about 6 miles; in Navarro County it has an average width of 11 miles; in Van Zandt

[33]Plummer, Helen Jeanne, 1235, pp. 53, 54, fig. 11, Sta. 37, 1927; 1238b, Sta. 81–T–2, 1932.

WILLS POINT FORMATION[32]

Definition.—The name Wills Point was applied by Penrose (**1189**, p. 19, 1890) to clays of lower Tertiary age in the vicinity of Wills Point, Van Zandt County. Under the heading "Basal or Wills Point Clays" he writes:

> At the base of the Tertiary and immediately overlying the eroded surface of the uppermost Cretaceous in East Texas is a great bed of stratified clay, which, on account of its position as the lowermost bed of the Eocene in this region, had been provisionally called the Basal Clays.

After giving a clear description of the clays, he continues:

> Such deposits are found well developed at Wills Point in Van Zandt County. Going east from this place, they are traceable for two and a half miles, when they finally dip under the overlying sandy strata. West of Wills Point similar strata are seen until we reach Rocky Cedar Creek, a distance of five miles. Here is seen a deposit of shell limestone, composed almost entirely of shells of Lower Eocene fossils. . . The shell limestone bed is probably of limited extent, occupying no very important stratigraphical position, and appearing at the base of, and as a component part of, the Basal Clays.

It is clear that Penrose intended his Wills Point formation to include all beds from the top of the Cretaceous to the base of the Wilcox. As a result of the detailed work by Harris (**660**, pp. 22–36, 1894; **662**, pp. 115–270, 1896), who showed that the lower Tertiary beds of Texas and Arkansas are equivalent to beds named Midway by Smith and Johnson in 1887, most geologists dropped the name Wills Point in favor of the older name Midway. In 1927 the work of Mrs. Plummer (**1235**, pp. 1–206, 1927) on the foraminifera and that of Miss Gardner (**571**, p. 277, 1928) on the large fossils demonstrated that the Midway is composed of two easily mappable units containing distinctly different faunas. The United States Geological Survey on the preliminary edition of the geologic map of Texas published in 1932 proposes to restrict Penrose's name and to apply it to the upper division of the Midway only. Wills Point, as now defined, includes all the strata below the Wilcox group and above the Tehuacana limestone lentil or its equivalent horizon.

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[32]LITERATURE—Penrose, R. A. F., **1189**, pp. 19–21, 1890. Kennedy, W., **911**, pp. 144–160, 1895. Harris, G. D., **662**, pp. 127–130, 1896. Deussen, A., **415**, pp. 330–335, 1914; **421**, pp. 40–47, 1924. Plummer, Helen Jeanne, **1235**, pp. 14–31, 1927; **1238b**, 1932.

up of the following minerals[38] arranged in order of their abundance: albite-orthoclase feldspar, microcline feldspar, muscovite, biotite, and gypsum. The biotite shows fresh flakes, green alteration products, and brown crinkly alterations.

The upper silty beds contain large, rough-surfaced, boulder-like calcareous concretions 3 or 4 feet in diameter. They are larger than those in the basal Wills Point beds but not so large as those in the Seguin formation of the Wilcox group above. They are round, some are fossiliferous, and in the basal Wills Point strata are impregnated with veins. They are so fragile that when struck with a hammer, they shatter easily into angular fragments. The concretions are made up of the same material that is found in the surrounding sediments, and are consequently syngenetic in origin. They represent simply local spots of cementation.[39]

Chemical analyses of the Wills Point clay show a higher percentage of silica and alumina, and less lime, manganese oxide, and carbonate than the clays of the underlying Kincaid formation. The following analysis made by Ries (**1320**, p. 171, 1908) of a typical sample of the lower Wills Point clay from the clay pit of the Bem Brick Company southwest of San Antonio in Bexar County shows the proportions of each constituent.

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[38]Barnes, Virgil E., personal communication.

[39]The origin of concretions has been discussed by many geologists (Todd, J. E., Concretions and their geological effects: Bull. Geol. Soc. Am., vol. 14, pp. 354–368, 1903. Gardner, J. H., Physical origin of certain concretions: Jour. Geol., vol. 16, p. 452, 1908. Daly, R. A., Calcareous concretions of Kettle Point, Lambton County, Ontario: Jour. Geol., vol. 8, p. 135, 1900. Bradford, S. C., The Liesegang phenomenon and concretionary structure in rocks: Nature, vol. 97, pp. 80–81, 1916. Sheldon, J. M. A., Concretions from Champlain clays of the Connecticut Valley, Boston, 1900. Tarr, W. A., Syngenetic origin of concretions in shale: Bull. Geol. Soc. Am., vol. 32, pp. 373–384, 1921. Burt, F. A., Formative processes in concretions formed about fossils as nuclei: Jour. Sedimentary Petrology, pp. 38–45, 1932.). A workable hypothesis explains their origin as due to electrolysis in underground water. In the silty, water-saturated layers local differences in potential develop slight differences in concentration of mineral matter, in which anode and cathode areas are set up. These anode and cathode spots are connected by salt water solutions that serve as conductors. In the anode areas soluble negative ions,— Cl_2, SO_4, HS, HCO_3, etc. accumulate, and H, Na, Ca, K, Fe, etc. ions go into solution. In the cathode areas the positive ions, Na, K, Ca, etc. concentrate. Of these Ca is least soluble and slowly precipitates in the form of calcium carbonate firmly cementing the sand and silt grains within the cathode area. The action is the same as in an electrolytic cell in which, for example, iron dissolves in sulphuric acid to form an iron sulphate solution made up of Fe and SO_4 ions. The Fe ions will then travel to and deposit on a metallic cathode to form iron. The iron will, of course, react immediately with oxygen in a water solution to form hydroxide that may be further changed by natural processes to an oxide and eventually become limonite, hematite, or other more complex mineral. Whatever the origin of these interesting forms, a knowledge of their shape, composition, and characteristics is important in the identification of Cenozoic formations, and some concretions mark definite zones in the geologic section.

	Per cent
SiO_2	59.47
Al_2O_3	18.24
Iron oxide	4.77
CaO	4.30
Na_2O	.24
CO_2	3.25
H_2O	5.70
Organic matter	.55

Distinctive characteristics.—The Wills Point formation can be distinguished in the field by the following criteria:

1. Concretions. Small, egg-shaped, ferruginous concretions 1 to 6 inches in length occur in greater abundance in the Wills Point than in the Wilcox or Kincaid beds. The calcareous concretions are flatter, less rounded, and have rougher surfaces. The surfaces of many of these are fretted with an intricate network of calcite veins. Most of the Navarro and Kincaid concretions are smooth and more or less rotund.
2. Stratification. The strata of the Wills Point formation in most places are distinctly laminated. The laminations, especially in the middle portion of the section, are wavy and uneven. They consist of paper-thin layers of silt sparkling with selenite crystals. The clay layers in the Kincaid formation are well bedded also, but the bands are more uniform and the lines less wavy.
3. Soils. The soils of the Wills Point formation are lighter in color, more silty, much less calcareous, and less colloidal than those of the Kincaid or Navarro outcrops. They are much less sandy than the Wilcox.
4. Mineral content. Silica and selenite are present in larger proportions and glauconite and gypsum in smaller quantities. Carbonaceous matter, pyrite, limonite, a little muscovite, and considerable altered biotite are present but are very minor constituents and are much less prevalent than they are in the overlying Wilcox.
5 Fossils. The Wills Point formation is easily distinguished from the Kincaid formation below and Wilcox strata above by its delicate, fragile fossils. Both the large shells and the foraminifera are distinctive. A list of the more important fossils is included in the paragraph on paleontology.

Paleontology.—The fauna of the Wills Point formation in Texas has not been described. Miss Julia Gardner has in preparation a monograph on the paleontology of the Midway. Until her publication appears, it is necessary to refer to descriptions of fossils of similar age from other states published by Conrad,[40] Whitfield,[41] Heilprin,[42] Meyer,[43] Aldrich,[44, 45] Dall,[46] Harris,[47] Clark,[48] and others from 30 to 100 years ago. The fauna, as represented by the collections in the Bureau of Economic Geology, is made up of a rich assemblage of delicate, thin-shelled fossils exemplifying forms adapted to waters having a noncalcareous, muddy-bottom environment. The muds were richer in organic matter and lower in calcium carbonate than those of the Kincaid or Navarro seas. Most of the animals were small and their shells were thin, and the surfaces of most of the gastropods were ornamented. Gastropods were the most numerous; next, small clams of the *Leda* and *Nucula* type; then small, simple corals, most of which belong to the genus *Flabellum.* Next in numbers were the tiny scaphopods, *Dentalium* and *Cadulus,* and finally nautiloids belonging to the genus *Hercoglossa* were fairly common. Species of *Ostrea, Cucullaea, Protocardia, Callocardia, Corbula, Crassatellites,* and the large thick-shelled gastropods were, if present, much rarer in the Wills Point formation than in the Kincaid. Altogether the list of large fossils from the Wills Point clay identified at the Bureau of Economic Geology comprises 25 genera and 40 species.

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[40]Conrad, T. A., Fossil shells of the Tertiary formations of North America: pp. 1–56, Philadelphia, 1832–1835, reprinted by G. D. Harris, 1893. Description of new species of Eocene and Cretaceous fossils of Mississippi and Alabama: Jour. Acad. Nat. Sci. Phil., vol. 4, 2d. ser., pp. 275–298, 1860. These two papers contain descriptions of eight or ten upper Midway fossils.

[41]Whitfield, R. P., Descriptions of new species of Eocene fossils: Am. Jour. Conchology, vol. 1, pp. 259–268, 1865. Includes descriptions of six upper Midway fossils.

[42]Heilprin, A., On some new species of Eocene Mollusca from the southern United States: U. S. Nat. Mus. Proc., vol. 3, pp. 149–152, 1886. Includes descriptions of two or three Midway fossils.

[43]Meyer, Otto, Contributions to the Eocene Paleontology of Alabama and Mississippi: Geol. Survey Alabama Bull. No. 1, pp. 63–85, 1886. Describes at least one species from upper Midway.

[44]Aldrich, T. H., Tertiary fossils of Alabama and Mississippi: Geol. Survey Alabama Bull. No. 1, pp. 18–41, 1886. Includes descriptions of nine or ten new upper Midway fossils.

[45]Aldrich, T. H., New or little known Tertiary Mollusca from Alabama and Texas: Bull. Am. Pal., vol. 1, No. 2, pp. 53–82, 1895. Includes descriptions of at least six upper Midway fossils.

[46]Dall, W. H., Tertiary fauna of Florida: Wagner Free Inst. of Sci. Trans. vol. 3, pt. 2, pp. 201–446, 1892. Includes descriptions of several upper Midway species.

[47]Harris, G. D., 662, pp. 115–270, 1896; 663, pp. 45–88, 1896. This first paper is the only comprehensive account of the paleontology of the Midway so far published. Harris figures about 145 species. About 20 of these are from the upper Midway, and the rest are from the lower Midway. Five new species from Texas are described.

[48]Clark, B. C., and Martin, G. C., The Eocene deposits of Maryland: Maryland Geol. Survey, pp. 1–259, 1901. Includes descriptions of six species which are referred to forms in Midway of the Gulf Coast.

The commonest and most characteristic large fossils in the Wills Point formation are as follows:

Modiola saffordi Gabb (8)
Crassatellites harrisi Gardner (1)
Arca sp. (2)
Natica reversa Whitfield (3)
Natica perspecta Whitfield (4)
Amauropsis cf. perorata Conrad (2)
"Pleurotoma" whitfieldi (Aldrich) (2)
"Pleurotoma" adeona Whitfield (2)
"Pleurotoma" longipersa Harris (2)
"Pleurotoma" mediavia Harris (2)
Levifusus pagoda (Heilprin) (1)
Levifusus suteri Aldrich ? (1)
Fusus ostrarupis Harris (5, 2)
Volutocorbis texana Gardner n. sp. (MS.) (2)
Fusus harrisi Aldrich (2)
Olivella mediavia Harris (2)
Ringicula alabamensis Aldrich (5)
Pseudoliva ostrarupsis Harris (1)
Venericardia bulla Dall (8)
Venericardia wilcoxensis Dall (6)
Flabellum concoideum var. matthewense Vaughan (7)
Balanophyllia desmophyllum Milne-Edwards & Haime (7)
Trochocyathus hyatti Vaughan (7)
Dentalium mediaviense Harris (7)

Localities recorded after specific names above—

1. One-half mile west of New Hope, Freestone County (Sta. 37, Univ. Texas Bull. 2644).
2. Rocky Ford, Trinity River, Navarro County (Sta. 21, Univ. Texas Bull. 2644).
3. Burton's Bluff, Trinity River, Henderson County (Sta. 16, Univ. Texas Bull. 2644).
4. Three miles southeast of Kerens, Navarro County (Sta. 174-T-6, Univ. Texas Bull. 3201, p. 62).
5. On Brazos River, 5½ miles below Eloise, Milam County.
6. Five miles north of Kemp, Kaufman County.
7. Creek bank 3½ miles north of Mexia, Limestone County.
8. Five miles southwest of Elgin along southwestward-flowing branch of Wilbarger Creek just west of the Knox No. 1 dry hole, Bastrop County.

The commonest and most widespread of the diagnostic foraminifera of the Wills Point are *Hemicristellaria subaculeata* var. *tuberculata* (H. J. Plummer), *H. longiforma* (H. J. Plummer), and *Vaginulina robusta* H. J. Plummer. Other species[49] found commonly in the Wills Point formation are as follows:

Haplophragmoides aff. canariensis (d'Orbigny)
Ammobaculites expansus Plummer
Ammobaculites midwayensis Plummer
Spiroplectammina expansa (Plummer)
Textularia agglutinans d'Orbigny
Textularia eocaena (Gümbel)
Clavulina aff. angularis d'Orbigny
Dentalina pauperata d'Orbigny
Dentalina spinulosa (Montagu)
Nodosaria affinis d'Orbigny
Nodosaria longiscata d'Orbigny
Vaginulina legumen var. elegans d'Orbigny
Vaginulina plumoides Plummer
Vaginulina robusta Plummer
Flabellina budensis Hantken

[49]List prepared by Helen Jeanne Plummer.

Flabellina projecta var. delicatissima (Plummer)
Frondicularia goldfussi Reuss
Frondicularia aff. gracilis Franke
Polymorphina cushmani Plummer
Loxostoma applinae (Plummer)
Bifarina eleganta (Plummer)
Lamarckina rugulosa Plummer
Eponides tener (H. B. Brady)
Lenticulina degolyeri (Plummer)
Lenticulina midwayensis (Plummer)
Lenticulina pseudo-mamilligera (Plummer)
Lenticulina turbinata (Plummer)
Hemicristellaria longiforma (Plummer)
Hemicristellaria subaculeata var. tuberculata (Plummer)
Marginulina costata (Batsch)
Eponides exiguus (H. B. Brady)
Gyroidina aequilateralis (Plummer)
Gyroidina soldanii var. subangulata (Plummer)
Siphonina prima Plummer
"Truncatulina" culter (Parker and Jones)
Ceratobulimina perplexa (Plummer)
Globigerina compressa Plummer
Globigerina pseudo-bulloides Plummer
Globigerina triloculinoides Plummer
Anomalina ammonoides var. acuta Plummer
Anomalina midwayensis (Plummer)
Anomalina vulgaris (Plummer)
Anomalina welleri (Plummer)
Cibicides alleni (Plummer)

The distribution of the most significant foraminifera in the Midway strata penetrated by the Wise No. 1 core test, Reiter and Foster, near Cameron, Milam County, are shown in figure 35.

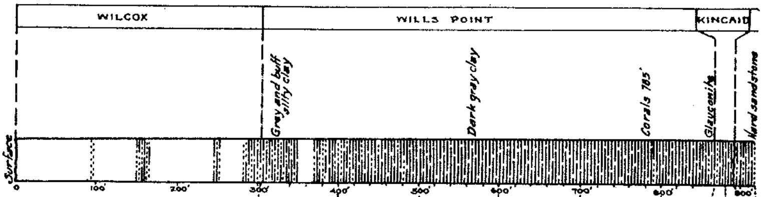
The fossils of the Wills Point formation have not been studied in sufficient detail to establish definite stratigraphic zones. Three paleontologic zones can be recognized, as follows:

3. *Ammobaculites midwayensis* zone
2. *Flabellum conoideum* zone
1. *Venericardia bulla* zone

The *Venericardia bulla* bed is characterized by an abundance of this rotund pelecypod. It is confined to a glauconitic sand or glauconitic clay layer that occurs only at the base of the Wills Point formation. It is exposed typically on Colorado River northeast of the Caldwell ranch house in Bastrop County.[50] The zone is developed only in central Texas, where it can be traced from Brazos River across Bastrop and Caldwell counties to Guadalupe River.

The *Flabellum conoideum* zone occupies the lower 25 to 35 feet of the Mexia clay member just above the *Venericardia bulla* zone. These small turbinolid corals range probably through the Wills Point, but nowhere are they common except in the lower beds, and in places they are the most plentiful fossil. This zone is typically exposed along a northward-flowing branch of Tehuacana Creek three and one-half miles north of Mexia. It is a persistent zone,

[50]Deussen. Alexander, 421, pp. 43, 44, fig. 11, Sta. 214, 1924.



WILLS POINT	Ammobaculites midwayensis Plummer, n. sp.	R	C	F	F	C	F	F	C	C	C	R			R		R															
	Ammobaculites expansus Plummer n. sp.		F		F	F	R	F	C	C	C	C	F	R		R	F	R	R	R	R			R	R		R	R	R			
	Lenticulina midwayensis (Plummer)							R	R	F	C	F	C	F	C	C	R	F	F	F	F	F	F	R		C	F	F	F	C	C	
	Hemicristellaria longiforma (Plummer)									R	F	F	F	F	R	R																
	Globigerina pseudobulloides Plummer										F	F	R	F	R	C	F	A	A	A	A	A	C	A	A	A	A	C	C		A	
	Globigerina triloculinoides Plummer											R			R	R		F	R	C	C	C	C	C	C	C	C	C	C			
	Ceratobulimina perplexa (Plummer)											C			F	A	F	C	F	F	F		F	F	R	R	F	R	R		F	
	Lenticulina turbinata (Plummer)											R			R	F	R	F	R	R	R		R	R		F	F	R	R		R	
	Textularia eocaena (Gümbel)											R	R		R	C	C	C	R	F	R	F	F	R	F		R					
	Textularia agglutinans d'Orbigny											R				F	F	R	R	R	R	R				F	F	F	R			
	Spiroplectammina aff. carinata (d'Orbigny)											R	R		F	F	C	F	C	C	C	R	R	R		R	F	R	R			
	Anomalina welleri Plummer												R		R	F	R	R	R	F	R		R	R	R	R	R	R	F		F	
	Siphonina prima Plummer												R	R	R	F	R	F	R	C	C	C	R	R	R	R	F	R	R		F	
	Eponides exigua (H. B. Brady)												C		R	R		R	F	R	F	F		F	R	C	F	C	R			
	Anomalina vulgaris (Plummer)												R	R	F	R	R				R	C	R	F		C	C	R		C	F	
	Lenticulina degolyeri (Plummer)												R		F		R		R		R	R	R	R		R	F				R	
	"Truncatulina" culter (Parker & Jones)													R				R	C	F		C	F	C	C	C	C	C			F	
	Bifarina elegantа (Plummer)													R	F	F	R	R	R	R	F	R	R	R	R			R				
	Gyroidina subangulata (Plummer)													R	C	A	F	F	C	C	C	C	F	C	R	C	C	C	F			
	Hemicristellaria subaculeata tuberculata (Plum.)														F	C	R	F	F		F		R	R		F	R					
	Anomalina midwayensis (Plummer)														C		R	F	C	C	F	A	C	A	C	A	C	C	A	C	C	
	Cibicides alleni (Plummer)														R	C	F	C	C	F	C	F	R	R	R	C	F		R			
	Vaginulina plumoides Plummer														R	R	R		R		R	R		R							F	
	Anomalina acuta Plummer														R	F	R	R	R	R	R	C	R	F	R	C	C	C	C	C	C	
	Flabellina budensis Hantken															R		R		R		F		R								
	Loxostoma applinae (Plummer)															R	F	F	C	F	F	F	R	F	F	F	F	R			R	
	Globigerina compressa Plummer															R	R	F	F	C	R	F	F	F	R		F	R	R			
	Vaginulina robusta Plummer																R		F	F	R	R	R			C	F	R	F			
	Bathysiphon sp.																R	R	F	F				R				C	F			
	Frondicularia striatula Reuss																	R								R	R			R		
	Frondicularia goldfussi Reuss																	R	R		R	R				R	R	R				
	Clavulina aff. angularis d'Orbigny																	R			R	C	F	F	R	A	C	C	F			
	Gyroidina aequilateralis (Plummer)																	R			R	C		R	R	R	F	R	R	C		
	Lamarckina rugulosa Plummer																		R			R				R		R	R		R	
	Lenticulina pseudomamilligera (Plummer)																			R	R	R				F	R	R	R			
	Epistomina aff. elegans (d'Orbigny)																				R	R			R	C	F	C	C		F	
	Valvulina aff. trochoides (Reuss)																					R	R	R	R							
	Eponides tenera (H. B. Brady)																						R	R	F	F	F	F				
	Flabellina projecta (Carsey) var.																									R	F	R	R	R		
	Polymorphina cushmani Plummer																									R						
	Gümbelina sp.																										F	R	R		C	
KINCAID	Vaginulina gracilis Plummer																													C	F	
	Lituola cf. taylorensis Cushman & Waters																													C	F	
	Eponides exigua limbata (Plummer)																													F	C	
	Frankeina aff. taylorensis Cushman & Waters																														C	
	Lenticulina pseudocostata (Plummer)																														F	
	Flabellina rugosa d'Orbigny																														F	
	Flabellina oldhami (Plummer)																														R	
NAVARRO	Dorothia bulletta (Carsey)																															F
	Lenticulina navarroensis (Plummer)																															F
	Astacolus dissonus Plummer																															R
	Hemicristellaria ensis (Reuss)																															R
	Vaginulina gracilis cretacea Plummer																															F
	Vaginulina webbervillensis Carsey																															R
	Gümbelina spp.																															A
	Pseudotextularia sp.																															R
	Loxostoma plaitum (Carsey)																															C
	Gyroidina depressa (Alth)																															F
	Globigerina rugosa Plummer																															A
	Globotruncana arca (Cushman)																															F

Fig. 35. Significant foraminifera and their occurrence in the Kincaid and Wills Point formations in the Wise No. 1 core test, 6 miles northeast of Cameron, Milam County. (Prepared by Helen Jeanne Plummer.)

which is encountered in core drilling throughout central and eastern Texas.

The *Ammobaculites midwayensis* zone occupies about the uppermost 50 feet of the Wills Point formation. It is characterized by the foraminifer *Ammobaculites midwayensis* H. J. Plummer, which in many places is the only fossil. The zone contains more sand and silt than the zones below. Evidently the end of the Midway epoch was not favorable for abundant marine life, for fossils are much rarer than in the lower zones east of Kerens. These upper strata of the Wills Point are typically exposed near the Humble pumping plant on Trinity River 1 mile north of the St. Louis and Southwestern Railroad in Navarro County where the following fossils have been collected by Miss Gene Ross:

Yoldia eborea (Conrad)
"Pleurotoma" cf. longipersa Harris
"Pleurotoma" cf. langdoni Aldrich
"Pleurotoma" mediavia Harris
Levifusus (?) dalei Harris
Levifusus cf. trabeatus Conrad
Volutocorbis texana Gardner n. sp. (MS.)
Ranularia n. sp.
Olivella mediavia Harris
Ringicula alabamensis Aldrich
Ammobaculites midwayensis H. J. Plummer

Correlation.—The Wills Point fauna is much more restricted than the fauna of the Kincaid formation, and less well known, so that correlations made at this time must be tentative. The *Flabellum conoideum* zone, which occurs near the base of the Mexia clay member, is present in the Naheola formation at Naheola Landing on Tombigbee River, Oak Hill, and Matthews Landing on Alabama River in Alabama. Foraminifera belonging to the Mexia clay zone have been identified by Helen Jeanne Plummer[51] from Porter's Creek clay in Oktibbeha County, Mississippi. A fauna of upper Midway age has been reported by Julia Gardner[51] from northeastern Mexico.

The following table shows a tentative correlation of the Wills Point strata in the Gulf Coast province.

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[51]Personal communication.

GEORGIA	ALABAMA	MISSISSIPPI	ARKANSAS	NORTHEAST TEXAS	NORTHEAST MEXICO
Upper Midway ?	Naheola and Sucarnooche	Porter's Creek	Upper Midway	Wills Point	Upper Midway

Economic resources.—The economic resources of the Wills Point formation are its siliceous clays, used in the manufacture of brick and tile, and its rich, silty soils, suited to raising cotton, corn, and grains. Brick plants deriving their clay from the lower strata of the Mexia member of the Wills Point formation are located at Mexia, Groesbeck, and San Antonio. According to Ries (**1320**, pp. 170–171, 1908), the clays at San Antonio burn red and form a very dense body at comparatively low temperature. The material runs quite high in soluble salts, has a little grit, but is very plastic and highly colloidal, so that it has to be worked by the dry-press process and dried very slowly to prevent air cracking. When handled properly, it makes a good common red brick.

The soils of the Wills Point formation consist chiefly of two types: Wilson clay loam and Crockett fine sandy loam.

The Wilson clay loam, derived from the Mexia clay member, is dark grayish brown, from 4 to 10 inches thick, and is underlain by dark, grayish-black, tough clay. Neither the surface nor the subsurface layers react to hydrochloric acid. The surface is a natural prairie but may have a scattered growth of mesquite. About 90 per cent of the area is cultivated to cotton, the rest to corn and oats. About one-fourth of a bale of cotton is produced per acre. Under most favorable conditions and intensive cultivation two and one-half bales have been obtained. Corn yields from 15 to 25 bushels and oats from 40 to 75 bushels per acre.

The Crockett fine sandy loam, derived from the Kerens member, consists of dark-gray or grayish-brown, noncalcareous, sandy loam from 6 to 10 inches thick. The surface is underlain by gray, heavy, noncalcareous, brittle clay, in places black or reddish brown. It is a semiprairie soil which occurs in the marginal areas between prairie lands and timbered country. Cotton is the principal crop, but small patches of corn, grain, sorghum, and sudan grass are grown. In good locations cotton yields from one-third to one bale to the acre and corn from 15 to 30 bushels.

WILCOX GROUP[52]

DEFINITION

The Wilcox group[53] received its name from Crider[54] in 1906, although the division had been known for a long time and had been described under other names by several geologists. The first geologic sections of the lower Cenozoic formations in the Gulf Coast district were published by Hale[55] in 1848. Another was described by Tuomey[56] in 1850. The first comprehensive descrip-

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[52]SELECTED LITERATURE—Hilgard, E. W., Report on the geology and agriculture of the state of Mississippi, pp. 110–123, 1860. Conrad, T. A., Observations on the Eocene lignite formation of the United States: Proc. Acad. Nat. Sci. Philadelphia, vol. 17, 1865. Heilprin, A., Notes on the Tertiary geology of the southern United States: Proc. Acad. Nat. Sci. Philadelphia, vol. 33, p. 159, 1881. Smith, E. A., and Johnson, L. C., Tertiary and Cretaceous strata of the Tuscaloosa, Tombigbee, and Alabama rivers: U. S. Geol. Survey Bull. 43, pp. 38–57, 1887. Penrose, R. A. F., Jr., **1189**, pp. 22–47, 1889; Dumble, E. T., **470**, pp. 130–139, 1892. Smith, E. A., Johnson, L. C., and Langdon, D. W., Jr., Report on the geology of the Coastal Plain of Alabama: Bull. Geol. Survey Alabama, pt. 1, pp. 154–167, 1894. Harris, G. D., **660**, pp. 55–86, 1894; **664**, pp. 193–294, 1897; **664a**, pp. 1–128, 1899; **665a**, pp. 11–17, 1902. Kennedy, William, **911**, pp. 134–144, 1896. Vaughan, T. W., The stratigraphy of northwestern Louisiana: Am. Geol., vol. 15, p. 209, 1895. Dall, W. H., A table of North American Tertiary horizons correlated with one another and with those of western Europe with annotations: U. S. Geol. Survey 18th Ann. Rpt., pt. 2, pp. 334, 344–345, 1898. Harris, G. D., and Veatch, A. C., **664c**, pp. 64–73, 1899. Crider, A. F., Geology and mineral resources of Mississippi: U. S. Geol. Survey Bull. 283, pp. 25–28, 1906. Veatch, A. C., **1691**, pp. 34–36, 1906. Ries, H., **1320**, pp. 73–74, 86–102, 1908. Willis, Bailey, **1761d**, pp. 725–726, 1912. Deussen, A., **415**, pp. 37–51, 1914. Berry, E. W., Erosion intervals in the Eocene of the Mississippi embayment: U. S. Geol. Survey Prof. Paper 95-F, pp. 73–80, 1915. Berry, E. W., Geologic history indicated by the fossiliferous deposits of the Wilcox group at Meridian, Mississippi: U. S. Geol. Survey Prof. Paper 108, pp. 61–66, 1917. Liddle, R. A., **992**, pp. 82–86, 1918. Dumble, E. T., **506**, pp. 37–55, 1918. Deussen, A., **421**, pp. 48–62, 1924; reprinted, 1930. Cooke, C. Wythe, Correlation of the Eocene formations in Mississippi and Alabama: U. S. Geol. Survey Prof. Paper 140, pp. 133–136, 1925; and The Cenozoic formations of Alabama: Geol. Survey Alabama Spec. Rpt. 14, pp. 257–268, 1926. Semmes, Douglas, Oil and gas in Alabama: Geol. Survey Alabama Spec. Rept. 15, pp. 239–259, 1929. Barksdale, Jelks, Lignite in Alabama: Geol. Survey Alabama Bull. 33, pp. 10–69, 1929.

[53]In weighing the validity of names with a view to selecting the most appropriate term with which to designate a formation or group which already has more than one name, priority and usage by good authorities are the main factors considered. Priority is important, but where a name for some reason has fallen into desuetude and another has taken its place and come into general acceptance, it is useless to try to revert to the older name. Thus, the name Lagrange was used by Safford in 1864 and Chickasaw by Hilgard in 1871 for the next to lowest division of Eocene long before the word Wilcox was proposed by Crider in 1906. Yet nearly every geologist now prefers Wilcox. On the other hand, Wilcox and Indio are both in good usage for the strata between the Midway and Claiborne groups. Now, however, since the Carrizo sand has been removed to the Claiborne group, Indio becomes a synonym for Wilcox. The latter name is preferred by most people because it has been used longest.

[54]Crider, A. F., Geology and mineral resources of Mississippi: U. S. Geol. Survey Bull. 283, pp. 25–28, 1906.

[55]Hale, C. S., Geology of south Alabama: Am. Jour. Sci., 2nd ser., vol. 6, pp. 354–363, 1848.

[56]Tuomey, Michael, First Biennial Rpt. on the geology of Alabama, 1850.

tions of the strata as a whole, however, were given by Hilgard[57] in 1860. Under the name Northern Lignitic Group he included all the lower Cenozoic strata from the base of the Midway to the base of the Claiborne. In 1864 Hilgard's group of strata was named Lagrange group by Safford.[58] In 1869 Hilgard (**721a**, p. 340, 1869) subdivided his Lignitic group into Flatwoods beds (present Midway) and Mansfield group (Wilcox and younger). In 1871 he suggested (**721b**, pp. 394–396, 1871) a third name, Chickasaw, for the Lignitic group. Hilgard's work remained the leading authority on the early Cenozoic strata for years. It was not until the late eighties that important new observations were published. In 1887 Smith and Johnson[59] published a bulletin on the Tertiary of Alabama, in which they used Hilgard's nomenclature. The next year Hill (**753**, pp. 49–53, 1888) named the Tertiary beds of Arkansas the Camden series and included therein all the southern Arkansas beds from the uppermost Cretaceous up to and including the fossiliferous Jackson. In 1890 Penrose (**1189**, pp. 22–47, 1890) described about the same strata in Texas under the name Timber Belt or Sabine River beds. A little later the nonmarine beds, which make up the present Wilcox group, were separated by Kennedy (**905**, pp. 50–52, 1892) and designated Lignitic. In 1894 the same beds in Arkansas were classified as Lignitic stage by Harris (**660**, pp. 55–86, 1894), and the term was used in Alabama by Smith and others,[60] and in Louisiana by Vaughan (**1683a**, p. 209, 1895) for equivalent strata. The same group of beds was termed Chickasaw again by Dall[61] in 1898, Sabine by Veatch (**1691**, pp. 34–36, 1906) in 1906, and Wilcox by Crider[62] the same year. Crider's name Wilcox was adopted by the United States Geological Survey (**1761d**, p. 725, 1912), used by Deussen (**415**, pp. 37–51, 1914) in

[57]Hilgard, E. W., Report on the geology and agriculture of the state of Mississippi, pp. 110–123, 1860.

[58]Safford. On the Cretaceous and Superior formations of west Tennessee: Am. Jour. Sci., 2nd ser., vol. 37, pp. 369–370, 1864.

[59]Smith, E. A., and Johnson, L. C., Tertiary and Cretaceous strata of the Tuscaloosa, Tombigbee, and Alabama rivers: U. S. Geol. Survey Bull. 43, pp. 38–57, 1887.

[60]Smith, E. A., Johnson, L. C., and Langdon, D. W., Jr., Report on the geology of the Coastal Plain of Alabama: Geol. Survey Alabama, pt. 1, p. 27, 1894.

[61]Dall, W. H., A table of North American Tertiary horizons correlated with one another and with those of western Europe with annotations: U. S. Geol. Survey 18th Ann. Rpt., pt. 2, pp. 344–345, 1898.

[62]Crider, A. F., Geology and mineral resources of Mississippi: U. S. Geol. Survey Bull. 283, pp. 25–28, 1906.

describing the strata overlying the Midway and underlying the marine beds of the Claiborne group in east Texas, and is now well established in geologic literature.

Smith and others[63] as early as 1887 separated the Wilcox of Alabama into four formations. Lowe[64] in 1913 divided the same beds in Mississippi into three formations, and two years later he[65] added a fourth. Trowbridge (**1610**, pp. 89–92, 1923) divided the Wilcox in southwestern Texas into two formations and mapped and described each division. The Wilcox, therefore, properly becomes a group term, and its subdivisions are raised to the rank of formations. The strata referred to the Wilcox group include all the deposits between the marine silty clays of the Midway group below and the marine, glauconitic, fossiliferous sands of the Claiborne group above. The basal beds of the Wilcox mark a transition from the marine muds and silts of the underlying Wills Point formation to the coarser, littoral, deltaic, and nonmarine deposits of the Wilcox.

The strata of the Wilcox group comprise a heterogeneous series, several hundred feet thick, of sandy, lignitiferous littoral clays, cross-bedded river sands, compact, noncalcareous lacustrine or lagoonal clays, lignite lentils, and stratified deltaic silts. The upper layers have a larger proportion of sand, and some massive beds from 50 to 100 feet thick are made up entirely of medium-grained sand, largely of continental origin, but possibly reworked to some extent by the transgressing shoreline waters that inaugurated the Claiborne epoch.

In east Texas sedimentation was continuous from the Midway into the Wilcox. No evidence indicates extensive erosion and removal of Midway beds before the Wilcox was deposited. Several good exposures of the contact show that the laminated basal sands and sandy clays of the Wilcox were deposited evenly over the Midway clays in such a way as to indicate a gradual transition of one series into the other. The appearance of the two formations, nevertheless, is different, and in most places it is easy to distinguish the carbonaceous sands of the Wilcox group from the silty clays of the

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[63]*Op. cit.*, pp. 38-57, 1887.

[64]Lowe, E. N., Preliminary report on the iron ores of Mississippi: Miss. Geol. Survey Bull. 10. pp. 23-25, 1913.

[65]Lowe, E. N., Miss. Geol. Survey Bull. 12, p. 71, 1915.

Midway by their respective lithologic characters and by their fossils.

In Bexar County the basal Wilcox strata rest on middle Wills Point beds. The upper Kerens silty clays are missing from the outcropping section.

In Maverick and Uvalde counties the Carrizo sand has overlapped the Wilcox strata and rests disconformably upon the Kincaid formation so that in most places all of the Wilcox strata are covered.

The contact of the Wilcox strata with the Carrizo formation above is sharp and represents an unconformity, in which the Carrizo sand of the Claiborne group was deposited upon the somewhat uneven surface of the Wilcox beds. The contact is marked everywhere by an abrupt change from thinly laminated sandy clays and fine sands to coarse gray or massive reddish cross-bedded sand.

SUBDIVISIONS

The Wilcox group has been divided into the following formations:

3. Sabinetown
2. Rockdale
1. Seguin

SEGUIN FORMATION[66]

Definition.—The name Seguin is here proposed to designate all the marine strata between the compact silty clays of the Midway group and the base of the nonmarine Rockdale formation above. In most places the base is marked by the contact of thinly laminated carbonaceous and fossiliferous sands with silty clays. The top is limited by a thin concretionary layer made up largely of shells of *Ostrea multilirata* Conrad. The type locality is the section exposed along the banks of Moss Branch 10 miles northwest of Bastrop in northwestern Bastrop County about 1 mile north of old Caldwell village. Another equally good locality is the exposure along Solomon's Creek 6 miles south and 1 mile west of Elgin in the same county. The formation at Seguin is obscured largely by alluvium along Guadalupe River. It can be observed in Geronimo Creek 1½ miles east of town, and along the highway 2 miles south-southwest of town south of Guadalupe River.

Regional geology.—The Seguin formation can be recognized and mapped most of the distance from Trinity River to the Rio Grande.

[66]LITERATURE.—Gardner, J. A., 566, pp. 141–145, 1924.

Typical strata do not occur in all areas. In eastern Navarro County and in central Bexar County, due to a local change in the facies of sediments or to concealment of the outcrop by Pleistocene deposits, the oyster bed and fossiliferous strata appear to be absent. The Seguin formation occupies a narrow belt of sparsely forested land about one mile wide forming the western border of the Wilcox outcrop (fig. 36). It is best exposed in branch streams flowing across the Midway-Wilcox contact in the vicinity of the larger rivers. Fossils from its strata have been recognized by J. A. Waters[67]

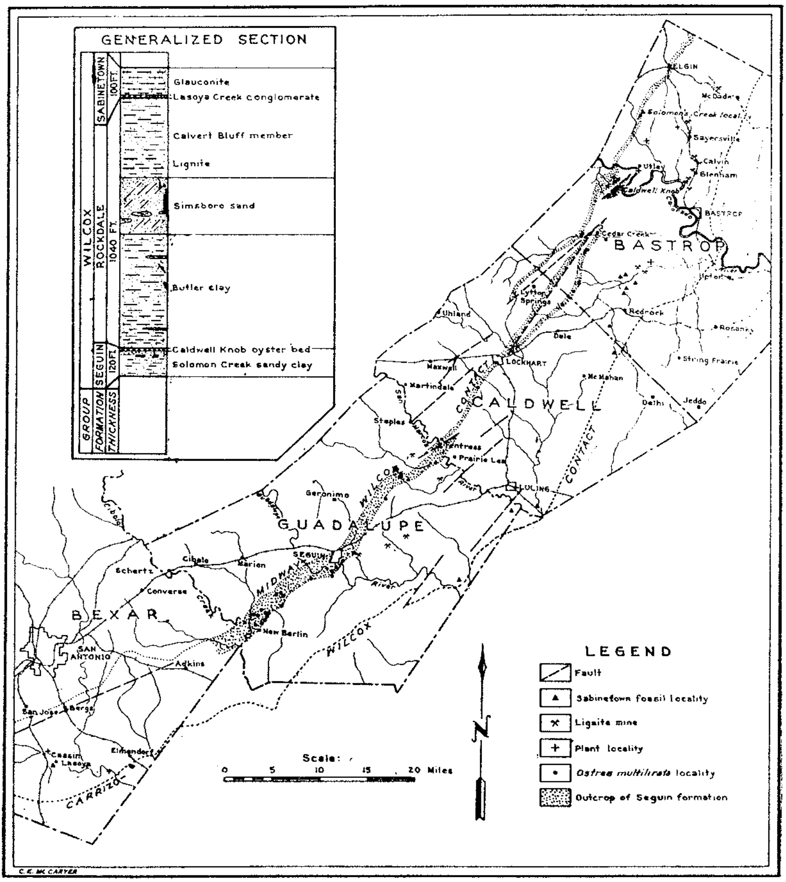

Fig. 36. Outcrop of the Seguin formation in Bastrop, Caldwell, Guadalupe, and Bexar counties.

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[67]Personal communication.

in a number of deep wells south of its outcrop and also in wells in Upshur County in northeast Texas east of its surface exposure. It undoubtedly extends over a wide area.

The thickness of the Seguin formation on the outcrop is about 65 feet. Throughout central Texas it varies from 50 to 75 feet. In Rio Grande Valley, it may be greater, as Jewell[68] has measured a section that appears to show 190 feet of basal marine strata. In wells drilled south of its outcrop the Seguin formation has a thickness ranging from 100 to 160 feet. The measurements of a few typical sections are shown in the following table:

LOCATION	COUNTY	THICKNESS *Feet*	AUTHORITY
Solomon's Creek, 6 miles S. of Elgin	Bastrop	65+	F. B. Plummer
Red Bank Oil Co. core test No. 2, James McLaughlin Survey, 2 mi. W. of Brazos River	Milam	53	Do
York Creek, 2½ mi. S. of Fentress	Caldwell	60	Do
Cranfill and Germany, Norman No. 1 core test, ½ mi. NW. of Fentress	Caldwell	50+	H. J. Plummer
Rio Grande, Indio ranch	Maverick	190	W. R. Jewell
Oppenheimer No. 1, Amerada Oil Co.	Frio	152	MacNaughton

Stratigraphy.—The Seguin formation rests conformably upon the upper Wills Point strata (Kerens member) in northeast Texas, disconformably upon the middle Wills Point in some places in south-central Texas, and disconformably upon the Kincaid formation in southwest Texas. It is overlain by the Rockdale formation. It is thought that the contact of the Seguin and Rockdale is conformable, but it is possible that the upper Seguin strata have been removed in places, since in some areas the basal strata of the Wilcox group resemble the Rockdale, and no lower fossiliferous strata are present. No unconformable contacts have as yet been observed.

The Seguin formation can be divided into two members:

2. Caldwell Knob oyster bed
1. Solomon Creek clays and sands

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[68]Jewell, W. R., personal communication, 1924. See also Gardner, J. A., 566, pp. 141–145, 1924.

The Solomon Creek member is composed of gray, laminated, silty clay, fine, uniformly grained, gray sand containing large, flat, rough-surfaced, calcareous concretions from one to twelve feet in length and from a few inches to several feet thick, and layers of silty, carbonaceous clay containing plant remains, sulphur and gypsum crystals. This member carries no lignite beds. The strata are typically exposed in Solomon's Creek, 6 miles south 25 degrees west of Elgin, Bastrop County.

The Caldwell Knob member consists of a layer of oyster shells varying from a few inches to several feet in thickness, the average thickness being about one foot. The oysters, in most places *Ostrea multilirata* Conrad, lie in a matrix of calcareous silt which in most places is cemented into a hard sandy limestone. The bed has been traced by Miss Gardner (566, p. 143, 1924) from a point near Brazos River in Milam County to the Rio Grande Valley and has been identified on the Guerrero structure near Guerrero in Mexico. It is not continuous along the outcrops. In many places it is covered by loose sand from adjacent beds or by gravel from Pleistocene deposits. In other places it may have been removed by pre-Rockdale erosion, or it may never have been deposited. Its outcrop in central Texas is shown in figure 36. The type locality of this member is Caldwell Knob located 10 miles north of Bastrop and about 2 miles south of Colorado River in Bastrop County, where the oyster *Ostrea multilirata* Conrad var. *duvali* Gardner is abundant.

The characteristics of the Seguin formation in the various areas are best shown by the following sections:

Core test No. 2, Red Bank Oil Company, on James McLaughlin Survey about 2 miles west of Brazos River, eastern Milam County.

(Core samples furnished by B. F. Robinson)

	Thickness *Feet*
Shell bed, gray, hard, made up of large numbers of fragments of oyster shells set in a matrix of silt firmly cemented by calcite	1
Silt, gray, very uniformly fine grained, thinly bedded, with wavy bedding lines and an impression of a complete leaf	6
Clay, gray, interbedded with thin layers of gray silt	10
Sand, light gray, uniformly fine grained, containing thin layers of tough, compact clay	10

Silt, gray, uniformly fine grained, containing small fragments of plant remains and very thin layers of silt clay	21
Sand, light gray, very fine grained, thinly bedded. The bedding lines are wavy in places and show cross bedding with very fine partings of silt, in which the sand and silt laminae alternate. About 40 laminae comprise one inch of section	10
Total thickness	53

Section along Solomon's Creek from a point near its junction with Wilbarger Creek northeastward up the creek to a point about .1 of a mile southwest of Lawrence Solomon's farmhouse, on the Elgin-Utley road, 5.8 miles by road south-southwest of the railroad crossing about 1 mile south of Elgin, Bastrop County.

	Thickness *Feet*
Seguin formation—	
7. Sand, buff gray, in layers 1″ to 2′ thick, interbedded with thin beds (¼″ to ¾″) of dark gray clay. Sand is strongly cross-bedded	16
6. Sand, light gray, very fine, in layers from 3″ to 8″ thick, and lentils interbedded with fine silty shale; concretions less numerous than lower in section	10
5. Silty clay, gray, soft, thinly laminated, contains large, rough-surfaced concretions and reddish-gray ferruginous concretions. One concretion is full of a species of *Turritella* about 1 inch long	12
4. Sandy clay, thin bedded, contains log-shaped colony of calcareous tubes resembling fucoids having white, shell-like surfaces, black, carbonaceous matrix. Contains also more or less rounded boulderlike concretions in large numbers	15
3. Sand, buff gray, fine grained, thin bedded, with thin lentils of unlaminated sand 3″ to 6″ thick. Contains large, hard, buff-colored, flat, irregularly shaped, smooth-surfaced concretions from 1′ to 7′ or more long and from 6″ to 4′ thick. Concretions are plentiful and cover creek bottom. Some have very rough, irregular, and wavy surfaces and occur in a concretionary ledge about 4′ thick	4
2. Sandy clay or silt, gray, stained with rusty streaks, thin bedded, carbonaceous, having yellow film of sulphur on some bedding planes, limonite on others	5
Wills Point formation—	
1. Clay, dark bluish gray, brittle, weathering light gray, fossiliferous: *Natica reversa* Whitfield, *Dentalium*, "*Pleurotoma*" sp., *Ringicula alabamensis* Aldrich, frequent ostracods, foraminifera. This is the type locality for *Ammobaculites midwayensis* H. J. Plummer and *A. expansus* H. J. Plummer	5
Total thickness measured	67

Section of Seguin formation in Norman No. 1 (shallow core test), one-half mile northeast of Fentress, Caldwell County (drilled by Cranfill and Germany).

	Thickness Feet
Seguin formation—	
Clay, yellow, brown, loose, sandy. Washed sample contains lumps of selenite, angular and subangular etched quartz grains, few magnetite grains, and traces of glauconite	30
Clay, yellow, brown, loose, sandy. Washed sample is made up of finely divided siliceous and argillaceous grains bound together by crystals of selenite and limonitic matter, little mica	15
Clay, brownish gray, compact, silty. Washed sample is composed of fine, brown, micaceous silt, lumps of selenite, little limonite and magnetite, and rounded to angular quartz grains	5
Wills Point formation—	
Clay, dark, tough, heavy bedded. Washed sample very small and composed of fine micaceous silt, little glauconite, little pyrite, few grains of selenite, and a generous scattering of tests of *Ammobaculites midwayensis* H. J. Plummer and *A. expansus* H. J. Plummer	5
Total thickness measured	55

Sedimentology.—The Seguin formation is composed of shallow-water marine sediments deposited in the littoral zone and along the beach of a flat, featureless marshy coast. The materials of these beds are much coarser than those of the underlying Midway, and they are interbedded with thin layers of subaqueous plant detritus such as accumulates in a tidal marsh. The laminations in the sand and silt are fairly evenly spaced, from ten to twenty to the inch, and indicate moderately rapid deposition. The oyster bed indicates perhaps a beach deposit in which the shells accumulated as beach shingle. In many places they appear to be wave worn and piled up by wave action. The sands and silts were probably derived from the adjacent coastal plain and perhaps from Upper Cretaceous strata.

Lithology.—The strata of the Seguin consist of about 50 per cent fine sand, 30 per cent silt, 19 per cent clay, and 1 per cent carbonaceous matter. The mineral grains consist of angular and subangular quartz, few selenite crystals, limonite, considerable altered mica, traces of magnetite, and a little glauconite.

All the beds are unconsolidated except the concretions, which are large, rough surfaced, oblate, and firmly cemented with calcite.

A chemical analysis of typical clays from the Seguin formation is as follows:

Analysis[69] *of clay from Elgin, Bastrop County*

	Per cent
Silica	71.3
Alumina	19.7
Ferric oxide	1.0
Lime	2.1
Magnesia	Trace
Soda	0.08
Potash	Trace
Titanic acid	Trace
Water	5.8
Total	99.98

Distinguishing characteristics.—The Seguin formation can be distinguished by the following criteria:

1. Characteristic oyster bed at top of section.
2. Uniformly finely textured and finely laminated sands containing black flakes of leaf fragments, interbedded with thin layers of black carbonaceous matter. The uniformly darker, silty clays of the underlying Wills Point have very little or no carbonaceous matter.
3. Large, rough-surfaced, calcareous concretions containing white-shelled fragments, oysters, and ornamented gastropods of the genus *Cerithium*. These concretions are larger, more evenly laminated, and more numerous than those in the Rockdale. They do not contain plant leaves. The concretions in the Rockdale formation are less distinctly laminated, and have no shell fragments.
4. The sands and clays in most places are more thinly laminated and have less lignitic matter than the overlying Rockdale formation.

Paleontology.—The fauna of the Seguin formation has not yet been described.[70] It was first reported by oil geologists working in Bastrop County about 1922 and first mentioned in literature by Trowbridge (**1610**, p. 90, 1923) and Gardner (**565**, p. 109, 1923).

[69]Ries, Heinrich, **1320**, p. 77, 1908.

[70]Mr. C. B. Claypool, aided by a fellowship granted by the National Research Council (1932), is engaged in a study of the faunas of the Wilcox group at the University of Illinois.

The fossils, with the exception of the common oyster, *Ostrea multilirata* Conrad, which is found in great numbers as var. *duvali* Gardner in the Caldwell Knob member, occur in large calcareous concretions. Collections from the Solomon Creek beds and in the Bureau of Economic Geology contain the following forms:

Gastropoda—
- Natica (Lunatia) cf. N. eminula Conrad
- Turritella n. sp.
- Cerithium mediaviae Harris
- Cerithium n. sp., A
- Cerithium n. sp., B
- Cerithium n. sp., C
- Cerithium n. sp., D
- Pseudoliva cf. P. unicarinata Aldrich
- Pseudoliva ostrarupis var. pauper Harris
- Levifusus aff. L. supraplanus Harris
- Levifusus pagoda (Heilprin) cf. var. Harris
- Levifusus n. sp.
- Fusus ostrarupis Harris
- Volutocorbis limposis (Conrad) var.
- Fusoficula cf. F. juvensis (Whitfield)
- Olivella sp.
- "Pleurotoma" ostrarupis Harris
- "Pleurotoma" aff. P. nodoideus Aldrich
- "Pleurotoma" aff. P. moorei Gabb

Pelecypoda—
- Ostrea multilirata Conrad
- Ostrea multilirata Conrad var. duvali Gardner
- Nucula sp.
- Tellina sp. cf. T. trumani Harris
- Yoldia sp.
- Leda milamensis Harris
- Leda sp. cf. L. corpulentoides Aldrich
- Venericardia sp.
- Cardium sp.
- Protocardia sp.
- Callocardia sp. cf. C. nuttalliopsis var. greggi (Harris)

Cephalopoda—
- Hercoglossa sp. cf. H. vaughani Gardner

Most of these fossils appear to be identical with, or related to, early Wilcox forms in Alabama and Mississippi. They are more closely related to the Wilcox faunal groups at Alabama Landing and Greggs Landing in Alabama than they are to any Midway assemblages. In fact, only 6 out of 40 species identified from Solomon's Creek can be referred to Wills Point species. The fossils are more thick shelled and consist largely of oysters, large forms of *Venericardia*, *Cerithium*, and *Levifusus*. There are fewer of the delicately ornamented, small gastropods and none of the small, delicate corals frequent in the Wills Point strata. It is a near-shore, shallow-water assemblage.

Another marine fauna occurs in the Rio Grande Valley about 190 feet above the base of the Wilcox group, as mapped by W. R. Jewell. It belongs possibly to the Rockdale formation, but more likely it represents the upper portion of the Seguin, which may have thickened southwestward. The fossils were collected by Jewell 3 miles northwest of Jacal ranch house and about 18 miles southeast of Eagle Pass in Maverick County, and identifications were made by Miss Gardner (566, p. 144, 1924) as follows:

Cornulina armigera (Conrad)
Pseudoliva vetusta (Conrad)
Pseudoliva sp. cf. P. vetusta (Conrad)
Pseudoliva sp.?
Levifusus ? sp.
Cerithium sp.
Cerithopsis ? sp.
Cerithiopsis ? n. sp.
Turritella mortoni Conrad
Turritella humerosa Conrad
Turritella sp.
Calyptraea aperta (Solander)
Architectonica ? sp.
Natica sp.
Limopsis ? sp.
Ostrea sp. cf. O. thirsae (Gabb)
Modiolus sp.
Venericardia planicosta Lamarck
Venericardia sp.
Cardium cf. C. tuomeyi Aldrich
Cardium hatchetigbeense Aldrich
Cardium n. sp.?
Cardium sp.
Callocardia sp. cf. C. nuttalliopsis (Heilprin) var. greggi (Harris)
Pteropsis n. sp.

Few, if any, of these species are similar to the forms just described from the lower Seguin. Many of these forms occur in the Wilcox strata of Alabama, and such species as *Turritella mortoni* Conrad, *T. humerosa* Conrad, *Ostrea thirsae* (Gabb) and *Callocardia nuttalliopsis* var. *greggi* (Harris) are found in the Nanafalia, or oldest division of the Wilcox group in that state. It is remarkable that *Ostrea thirsae* (Gabb), so very persistent in the lower Wilcox strata in Alabama, should not occur in Mississippi or anywhere in Texas except in the Rio Grande Valley. It has been reported from the Wilcox in northern Mexico and may yet be discovered in central Texas.

Two distinct fossil zones occur in the Seguin formation in central Texas. The diagnostic forms of each are of great aid in correlating the lower Wilcox strata.

2. *Ostrea multilirata* zone at the top of the Seguin formation and comprising the Caldwell Knob member. This zone is marked by a great abundance of *O. multilirata* Conrad, *Cerithium penrosei* Harris and *C. texana* Heilprin.

1. *Turritella turneri* n. sp. (MS.) zone near the base of the Seguin formation. Remains of this small turreted and lirated gastropod occur with "*Pleurotoma*" *sylvaerupis* Harris and other gastropods in concretions. It is easily recognized and serves to distinguish the strata at once from the underlying Midway.

Correlation.—The fauna of the Seguin formation has not been studied sufficiently to warrant definite correlations with other groups. The fossils are related unquestionably to the faunas of the lower members of the Wilcox group of Alabama. They seem to have close affinities with the fossils of the Ackerman formation of Mississippi and the Nanafalia formation of western Alabama. Their relationships with faunas of the Atlantic coast, of California, and of Mexico are not known.

Economic resources.—The Seguin formation has no noteworthy economic resources other than agricultural products and forests. The soils and agricultural products are similar to those of the middle Wilcox beds and are discussed fully in the paragraphs on economic resources of the Rockdale formation.

The large, hard, boulderlike concretions are sufficiently numerous in some places to furnish a supply of rock for crushing for road ballast or concrete mixtures where terrace gravels are not available. At present they are not being utilized except at one locality in Navarro County.

ROCKDALE FORMATION[71]

Definition.—The name Rockdale is proposed to designate all the nonmarine strata of the Wilcox group from the top of the Caldwell Knob oyster bed or its equivalent beds to the base of the marine strata of the Sabinetown formation, the upper division of the Wilcox group. In areas where the Sabinetown formation is absent the Rockdale formation is limited at the top by the Carrizo sand of the Claiborne group.

The type locality of the Rockdale formation comprises exposures in central Milam County in the vicinity of Rockdale, where the lignitic members of the formation are mined.

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[71]LITERATURE—Dumble, E. T., **470**, pp. 130—139, 1892; **506**, pp. 37–55, 1918. Liddle, R. A., **992**, pp. 82–86, 1918. Sellards, E. H., **1402**, pp. 57–63, 1919. Trowbridge, A. C., **1610**, pp. 90–101, 1923. Deussen, A., **421**, pp. 48–63, 1924. Brucks, A. W., **164**, p. 831, 1927. Getzendaner, F. M., **578**, p. 1434, 1930.

Regional geology.—The surface of the Rockdale formation is everywhere steeply rolling and undulating, drainage lines are frequent, large branch streams occupy rather wide and shallow valleys separated by smooth ridges and rounded hills, which are trenched in places by gullies and ravines. The drainage is in most places excellent, the soil is thick and sandy. Escarpments are not common.

Most good exposures of the strata occur along the banks of the larger streams and in road and railroad cuts. The surface of the formation in the central area, except where cleared and cultivated, is covered by a rather heavy growth of post oak and some blackjack oak. In the northeastern area the surface is timbered with pine, oak, and other hardwood trees. In the southern area the outcrop is occupied by mesquite and thorny brush. The tree-covered aspect of the belt of Wilcox outcrop suggested to Penrose the name "Timber Belt" as an appropriate name for this brand of outcropping strata. The wooded character is in so strong a contrast to the open, flat, mesquite-sprinkled prairies of the Midway that the Wilcox-Wills Point boundary in many areas shows very clearly from an airplane and on aerial maps.

The outcrop of the Rockdale formation occupies the west flank of the Sabine uplift and outcrops over a broad belt of territory thirty miles or more wide along the west flank of the east Texas monocline from central Hopkins County northward through Wood, Van Zandt, Henderson, Freestone, eastern Limestone, and western Robertson counties. Around the south side of the Llano uplift the width of the outcrop decreases to ten miles or less through Milam, Lee, Bastrop, Caldwell, and Bexar counties to central Medina County. Southwest of Medina County the Rockdale in some places is overlapped completely by the Carrizo sand.

The Rockdale formation is known to extend down dip for long distances. It has been found as far south as wells have been drilled deep enough to reach it.

The thickness of the Rockdale formation can be determined approximately by substracting 200 feet from the total thickness of the Wilcox. Thicknesses of the Wilcox group at various localities are shown in the following table:

LOCALITY	THICKNESS *Feet*	AUTHORITY
Surface sections—		
Sabine River Valley	800–900	Veatch, 1691, p. 36, 1906
Mineola, Wood County	500	Deussen, 415, p. 44, 1914
Sulphur Springs, Hopkins County	684	Dumble, 506, p. 48, 1918
Brazos River Valley	840	Deussen, 421, p. 47, 1924
Sutherland Springs, Bexar County	657	Deussen, 421, p. 47, 1924
Colorado River Valley	900	Plummer
Bexar County	500	Sellards, 1402, p. 57, 1919
Medina County	600	Liddle, 992, p. 82, 1918
Uvalde County	350–600	Getzendaner, 578, p. 1434, 1923
Dimmit County	648	Trowbridge, 1610, p. 90, 1923
Well sections—		
J. J. Ott No. 1, ¼ mi. SW. of String Prairie, Bastrop County	1065	Sellards, 1422, p. 33, 1929
Core No. 1, Eiser et al, Guadalupe County	1152	Ellisor, personal communication

The thickness of the Rockdale as determined by core tests put down in eastern Milam County and western Robertson County is shown in the following section:

	Thickness *Feet*
3. Sabinetown formation	40
2. Rockdale formation—	
c. Calvert Bluff clay	1000
b. Simsboro sand	240
a. Butler clay	400
1. Seguin formation	160
	1840

The thickness of the Rockdale, as determined by core tests drilled by Humble Oil and Refining Company near the outcrop in Guadalupe County, is shown in the following section:

	Thickness *Feet*
3. Sabinetown formation	100
2. Rockdale formation	1000
1. Seguin formation	52
	1152

Stratigraphy.—The Rockdale formation occupies approximately the middle four-fifths of the Wilcox section and comprises all its nonmarine strata. The basal beds lie conformably upon the Seguin formation. The contact of the Rockdale with the overlying Sabinetown formation or with the Carrizo is apparently unconformable.

In south Texas the Carrizo overlaps the Wilcox strata so that it rests on the Sabinetown in Bexar County, on the Rockdale in Medina and eastern Uvalde counties, on the Seguin and older beds in southwestern Uvalde and Zavala counties, and on middle strata of the Rockdale in southwestern Dimmit County. In Bexar County an unconformity marked by a basal conglomerate separates the Rockdale and Sabinetown formations.

Many attempts have been made by geologists to divide the Rockdale strata into mappable subdivisions. Most of the strata, however, are so lenticular and surface exposures are so obscured in most places by soil and surface sand, that such attempts have not proved successful. In east Texas lentils of sand can be traced and mapped for several miles, and some of the lignite beds can be followed by core drilling for fifteen miles or more, so that locally the strata can be divided into members separated by lignite beds. Since such divisions are not continuous they do not constitute satisfactory units. In central and south Texas, especially in the area between the Brazos and Frio rivers, it is possible to divide the Rockdale formation into three members, as follows:

3. Calvert Bluff clay beds. These strata are typically exposed at Calvert Bluff on Brazos River and comprise (a) gray sand weathering red and buff, varying in texture from coarse quartzitic sand to very fine silty argillaceous material that stands up like loess in steep banks; (b) dense, black, lignitic beds, from 1 to 9 feet thick; (c) dark gray, compact, carbonaceous clay in thick beds or in lentils interbedded with silt.
2. Simsboro sand. This member was named by W. A. Reiter during his detailed work on the Wilcox in the Mexia district. The name was taken from the town of Simsboro in Freestone County, where the sand is typically exposed. The member has been mapped by Reiter[72] from near Rockdale in Milam County to Trinity River. Others have traced the outcrop southward from Rockdale through Sayersville in Bastrop County, Kingsbury in Guadalupe County, and Adkins in Bexar County to Uvalde County. The strata consist of gray, soft sand containing fossil wood, lumps of water-rolled clay, seams and lentils of blue-gray clay that in some places are chocolate-brown, and a little lignite. In most places the clay constitutes a minor

[72]Reiter, W. A., letter of Oct. 27, 1932.

part of this member. The average thickness in Limestone and Freestone counties is 250 to 300 feet and the width of the outcrop is about 3 miles (fig. 37).

1. Butler clay. This member is typically exposed at the town of Butler, where the clay is used extensively for making brick. These beds comprise: (a) gray and buff, lenticular, fine-grained, thin-bedded sand, which contain indurated and laminated, rough-surfaced concretions; (b) micaceous clays that in most

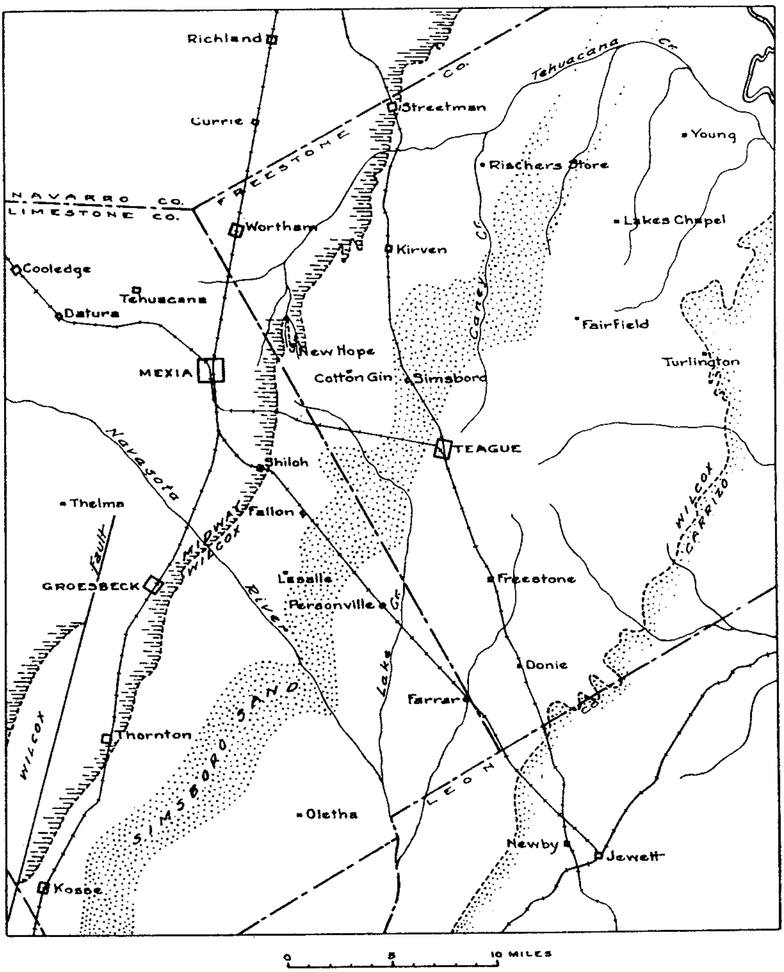

Fig. 37. Outcrop of the Simsboro sand in Limestone and Freestone counties. (adapted from a map furnished by W. A. Reiter).

places are rather free of sand, tough and massive, in other places silty and laminated and characterized by limonitic partings; (c) seams and lentils of lignite.

The characteristics of the Rockdale formation in the various parts of the state are best presented by described and measured sections.

Section[73] *at Calvert Bluff on Brazos River, Jesse Webb League, Robertson County.*

Rockdale formation, Calvert Bluff member—	Thickness *Feet*
16. Sand, gray	3
15. Lignite	12
14. Clay, dark blue	3
13. Lignite	3
12. Clay, dark blue	6
11. Lignite	3
10. Sand, dark grayish blue	15
9. Sandstone, calcareous	½
8. Sand, dark gray	2
7. Lignite, poor quality	½
6. Sand, dark gray	8
5. Sandstone, gray, calcareous	1
4. Sand, dark bluish gray, contains pyrite	8
3. Sandstone, gray, calcareous, contains boulders of clay ironstone and nodules of iron ore, and thin seams of ferruginous sandstone with fossil leaves	2
2. Sandstone, gray	1½
1. Sand, bluish gray, at water's edge	2
Total thickness measured	70½

Section of middle sandy portion of Calvert Bluff member of Rockdale formation measured along Texas and Brazos Valley Railroad two miles northwest of Freestone, Freestone County.

	Thickness *Feet*
3. Sand, gray, massive, containing several large sandstone concretions; largest concretion measured 15 feet in diameter. Toward the south end of the exposure the massive sand changes to cross-bedded, laminated sand interstratified with silt and appearing to be a fluviatile deposit	15

[73]Measured by A. Deussen, 415, p. 43, 1914.

	Thickness *Feet*
Unconformity	
2. Clay, gray, sandy, containing lumps and stream-rolled clay nodules set in a clay matrix and mixed with small iron oxide concretions 1 to 5 inches in diameter. Some of the smaller concretions are made up of layers of limonite precipitated around a central core of light gray clay	20
1. Sand, white or reddish gray, or mottled red and white, massive, in places poorly bedded, uniformly medium grained and in other places interstratified with thin layers of sandy micaceous clay. The sand is composed of ashy or tuffaceous particles which when rubbed between the fingers are easily pulverized. These beds are exposed in stream gullies below the railroad	15
Total thickness measured	45

Section[74] *of a portion of the Rockdale formation of the Wilcox group in shaft of Rockdale Mining Company at Vogal, near Rockdale, Milam County.*

	Thickness *Ft.*	*in.*
15. Sand, brownish gray	1	6
14. Clay, red	4	
13. Clay, black, waxy	4	
12. Sand and clay, laminated dark gray sand and clay laminae from one-eighth to one inch in thickness, the clay being generally thicker than the sand	15	
11. Clay, gray	12	
10. Sand, gray	1	6
9. Clay, gray	8	
8. Lignite	5	
7. Clay, gray	8	
6. Sand and gray clay	6	
5. Clay, gray	8	
4. Sand, gray	1	6
3. Lignite	9	10
2. Sand	30	
1. Lignite	4	
Total thickness measured	119	4

[74]Measured by A. Deussen, 415, p. 49, 1914.

Core test No. 1, B. F. Robinson, in James McLaughlin Survey, 1 mile west of Brazos River, Milam County.

	Thickness
Surface material	?
Rockdale formation—	
Clay, dark gray, almost black, conchoidal, noncalcareous, containing small flakes of mica	56
Silt, dark gray, very fine grained, laminated, laminae about 2 mm. apart, micaceous	29
Sand, gray, poorly laminated to thinly laminated, carbonaceous, with lignitic flakes impregnating the sand and in thin laminae	80
Sand, brown, very fine, pulverizes to silt, noncalcareous	20
Silt, gray to buff-gray, noncalcareous, uniformly grained	32
Sand, light gray, uniformly fine grained, noncalcareous, unconsolidated	8
Sand, black, medium to coarse grained, heavily impregnated with carbonaceous matter	10
Clay, dark gray, silty in upper part, streaked with blotches of amorphous calcite in lower part, laminated	30
Silt, or silty clay, dark gray, thinly and evenly laminated with one or two laminae to the millimeter, micaceous, noncalcareous	63
Silt or silty clay, light to dark gray, laminated, noncalcareous, carbonaceous	17
Clay, dark gray, carbonaceous, noncalcareous, poorly laminated	11
Sand, light gray, very fine silty, noncalcareous	9
Lignite, black, sandy, impure, friable, sandy	20
Sand, dark gray, medium to fine grained, micaceous, carbonaceous	21
Clay, gray, very sandy, slightly carbonaceous, laminated, noncalcareous	10
Sand, light gray, very fine grained, laminated	19
Clay, dark to light gray, noncalcareous, compact in upper part, silty in lower part	30
Silt, dark gray, interbedded with conchoidal clay and containing fragments of plant remains, poorly bedded	9
Clay, black, carbonaceous, grading into black lignite and containing fragments of calcite and iron sulphate. Lignite is fragmentary but apparently pure and free from sand	8
Clay, light gray, compact, massive, containing few impressions of plant stems and poorly preserved plant fragments	10
Clay, dark gray, carbonaceous, containing veins of lignite, one bed being 10 feet thick, streaks of light-gray, conchoidal clay, noncalcareous, siltless	42
Lignite, black, soft, fairly pure, interbedded with gray, carbonaceous, silty sand	10
Clay, light gray, silty, noncalcareous, unlaminated	3

	Thickness Feet
Sand, light gray, very fine grained, carbonaceous, micaceous, thinly laminated	49
Lignite, black, fairly pure, soft, breaks into fine fragments, interbedded with light gray and compact, very silty clays	10
Sand, light gray, very friable, micaceous, interbedded with very carbonaceous silt	110
Clay, gray, silty and hard above, compact and colloidal and very hard below	30
Sand, gray to white, medium grained	20
Clay, light gray, compact, poorly bedded, noncalcareous	10
Sand, dark gray, interbedded with some light gray layers and with thin beds of lignite	23
Silt, gray, very thinly and evenly laminated containing large concretions	427
Sand, light gray, medium grained, silty, of uniform texture	41
Sand, gray, coarse grained, unconsolidated, rounded grains resembling beach deposit, contains ½-inch layer made up of fairly well-preserved plant leaves	14
Silt, gray, lignitic, noncalcareous	62
Silt and sand, gray, very hard, cemented by calcite	38
Silt, light gray, thinly laminated with gray siliceous clay containing minute fragments of plant leaves	65
Seguin formation—	
Siltstone, gray, hard, very fossiliferous, contains oysters and small *Tellina*	10
Sand, light gray, medium grained, soft and evenly bedded, typical marine sand	6

Sedimentology.—The strata of the Rockdale formation exhibit everywhere a continental facies, largely fluviatile in origin, but partly palustrine and deltaic. No other group of strata in east Texas, except the Woodbine sands of the Cretaceous, and the Catahoula beds of the upper Tertiary, show such remarkable conditions of deposition as is exhibited by the Rockdale sediments.

At the end of the Seguin stage the sea withdrew, and a belt of the Gulf Coast at least one hundred miles wide from north to south along the whole length of the strand line became a low and gently inclined coast. The Rockdale sediments record clearly an epoch of heavy rainfall. Abundant river water heavily laden with sand and silt meandered across the flat coastal plain and spread far and wide its deposits. The rivers built up natural levees of cross-bedded sand, overflowed their levees into the lower lands between the river courses and produced lakes and land-locked lagoons, and laid down fine silts and sandy clays of the deltaic and lake-bed type. Later shifting currents of these rivers undercut clay banks, rolled along chunks and balls of clay, buried them in sand banks, and spread the sand over the lake beds. A humid climate[75] induced a very thick growth of vegetation. Plant detritus was washed downward with the silt and deposited with the clays. Trunks of trees, logs, and large branches were carried downward by the currents and buried in the sand. The lakes filled up, marshes and swamps prolific in vegetation succeeded, peat beds accumulated and replaced upward the lacustrine deposits, to be covered in turn later by a great river flood brought about by further shifting of a river channel. The heterogeneous mixtures of sands, clays, and lignites, the remarkable exhibits of current bedding, the stream ripple marks, and the lenticular shape of the sand and lignite layers can be explained only by a constant shifting of river beds over a flat, swampy coastal plain. None of the east Texas lignite beds can be traced laterally for more than 10 or 15 miles, consequently the main stream lines were not more than 25 or 30 miles apart. Their levees were probably 5 to 10 miles apart and the intervening marshes not over 10 or 15 miles across. The Rockdale was an epoch of nearly continuous river and marsh sedimentation brought to a close only when the waters of the Gulf again transgressed and brought with them the marine sands, marine bedding, and marine fossils of the Sabinetown formation toward the close of the Wilcox period.

Lithology.—The strata of the Rockdale formation consist on the average[76] of 65 per cent sandy clay, 20 per cent sand, 10 per cent siliceous clay, 3 per cent lignite, and 2 per cent large concretions. The most characteristic features of the lithology are:

1. Massive, cross-bedded sand.
2. Large broken chunks of petrified wood.
3. Lentils of black lignite.
4. Large rough-surfaced boulderlike concretions.

The sand of the Rockdale is fine grained. Most of the grains are subangular. According to Lonsdale (**1013c**, pp. 73–81, 1931) no

[75]Climatic conditions of the Wilcox epoch are discussed fully by E. W. Berry (**112**, pp. 33–40, 1930).

[76]Estimated from the study of the proportions of rock materials in well samples from holes drilled through the Rockdale.

grains are larger than .295 mm., and 50 per cent are between .074 and .175 mm. About 95 per cent of the grains are quartz, 4 per cent are minerals of the feldspar group, and less than 1 per cent are heavy minerals. Leucoxene and ilmenite are the commonest heavy minerals. One characteristic of the Rockdale sand is its extreme friability. A chunk observed in a hand specimen looks coarse grained, because it is composed of small clusters of minute grains of ash and silt clinging together. If this is rubbed, the grains disintegrate at once, and the whole mass will rub down to fine powder.

The silicified wood is white or reddish buff, and many pieces show quartz crystals on some of the surfaces. Pieces and blocks from one to three feet long and from three to twelve inches in diameter are common. The petrifactions take a beautiful polish, and are collected frequently for ornamental purposes.

The soft, black lentils of lignite are made up of a mass of plant detritus pressed together into a compact mass, which when fresh breaks off in large chunks. The layers, however, are much altered, and the woody material in most places is poorly preserved. When exposed to the air it crumbles, slacks, and decomposes. Outcrops are poor except along fresh road or stream cuts. The percentage composition of typical samples of the lignite are shown in the following table:[77]

	MINE MOISTURE	VOLATILE MATTER	FIXED CARBON	ASH	B.T.U.
King shaft, Sulphur Springs, Hopkins County	22.92	50.28	21.66	5.14	?
Dallas mine, Henderson Co.	25.00	34.47	33.25	7.28	?
Bray shaft, Donie, Freestone Co.	31.00	32.09	30.29	6.62	7500
Rockdale mine, Milam Co.	24.20	36.28	30.62	8.90	7659
Sayer mine, McDade, Bastrop Co.	32.50	28.96	32.18	6.36	7325

The concretions in the Rockdale are of two types:

1. Small, dark red or buff, potato-shaped, ferruginous nodules from one to twelve inches in diameter. Some of these concretions have hollow centers, others contain a ball of clay surrounded by shells of limonite and siderite.
2. Large, elongate, massive boulders of sandstone, brownish gray or buff, from one to three feet thick and several feet long, made up of the same material as the enclosing soft sediments, but solidly cemented by calcium carbonate.

[77]Schoch, 1378, pp. 75–88, 189–195, 1918.

The clays of the Rockdale are of two types: (1) Stratified sandy clays interbedded with thin layers of sand and thin bands of carbonaceous matter of fluviatile and deltaic origin; and (2) compact, colloidal, siliceous clays of lacustrine or lagoonal origin. The latter type constitutes good brick and tile clays. Chemical analyses of typical samples of the lacustrine clays are included below:

Chemical analyses[78] *of Wilcox clays.*

LOCALITY	H_2O	SiO_2	Al_2O_3	Iron oxide	CaO	MgO	K_2O	Na_2O	TiO_2
				Bastrop County					
North of McDade	?	74.30	16.00	1.40	Tr.	0.00	0.50	0.60	0.50
Near Elgin	5.07	71.30	19.70	1.00	Tr.	Tr.	Tr.	0.08	Tr.
Near Elgin	5.80	68.45	21.10	1.10	1.40	Tr.	Tr.	1.25	0.05
Near Elgin	6.75	72.70	9.50	4.10	4.10	0.80	2.40	Tr.	0.60
				Milam County					
Near Rockdale	5.46	69.23	19.38	1.07	0.87	0.86	Tr.	0.12	1.40
Near Rockdale	4.20	72.90	14.70	4.50	0.60	0.30	1.50	0.70	1.00

Distinctive characteristics.—The strata of the Rockdale formation can be distinguished from those above and below by the following criteria:

1. Vegetation. The outcrop underlain by Rockdale strata is more forested than that of the Midway and has a more varied flora than that of the Carrizo. The forest of the Carrizo consists almost exclusively of black oak, black hickory, ivy, wild grape, and sand-loving weeds. The forests of the Rockdale comprise a mixture of blackjack oak, post oak, elm, and hackberry mixed with patches of mesquite. The Midway is more thinly forested, the oaks are less numerous, and the mesquite and lime-loving plants are more plentiful.
2. Lignite. The lignite of the Rockdale formation is black, compact, and when fresh breaks into large chunks. The lignites of the strata above, with the exception of the lower Claiborne lignite of Webb County, are brown, thinner, less compact, break into thinner plates, and have a higher percentage of ash.
3. Concretions. The ferruginous concretions of the Rockdale are commonly hollow or the centers may be clay filled. They are larger, flatter, and more irregular in shape than the small, hard, oval "ironstones" of the Midway. The large calcareous sandstone concretions are larger, rougher surfaced, coarser

[78]Schoch, 1378, pp. 171 and 173, 1918.

grained, and flatter than the Midway or the Navarro concretions. They are not impregnated with veins of calcite or aragonite, like most Navarro concretions, nor with the fine veinlets found in the Wills Point boulders.

4. Sand. The sand of the Rockdale is somewhat coarser, more distinctly cross-bedded, thicker bedded, and occurs in proportionately larger quantities than the sand of the Seguin formation. This formation has a larger proportion of silt and clay layers between the sand strata. The bedding planes of the Rockdale sand are marked in many places by carbonaceous matter stained with iron oxide. Such seams are more common in the Rockdale than in the overlying Carrizo. The Carrizo is coarser.

Paleontology.—The Rockdale formation contains no marine fossils, but its flora is notable for its numbers and very large variety of leaves of plants, shrubs, and trees. Berry (**112**, p. 19, 1930) has identified 205 species from a single locality near Puryear, Henry County, Tennessee, and altogether 543 different species have been described from the Wilcox group and Carrizo formation. Ball (**58**, p. 109, 1931) has identified and named more than 117 species from the Rockdale formation in Texas.

The most notable localities for collections of plant remains in Texas are:

1. Port Caddo Landing, Harrison County.
2. Little Sandy Creek, on P. F. Wade Survey, Bastrop County.
3. Barton's Ranch on Wilbarger Creek, 2 miles north of Utley, Bastrop County.
4. Railroad cut north of Sayersville station, Bastrop County.
5. Gully 11 miles south of San Antonio just east of Earle (now renamed Cassin), Bexar County.
6. Clay pit near Elmendorf, Bexar County.
7. Banks of Calaveras Creek, near the bridge on the Saspamco-Calaveras road, about ¾ of a mile northwest of Calaveras, Wilson County.

The large variety of species is due partly to the presence of plants from two types of environments, an upland flora, represented by Barton's ranch, Sayersville, and Earle (now Cassin) localities, and a palustral or lagoonal flora, represented by the collections from Port Caddo Landing and the Little Sandy. The upland flora contains hickories, walnuts, sycamore, poplars, laurels, and pawpaws, one maple, and oaklike leaves *(Dryophyllum)*, but, strange to say, no true oaks. The palustral flora contains leaves of the breadfruit tree, fan-palms, feather-palms, numerous ferns, several species of figs, *Euonymus*, and others.

Distribution of a few of the common typical plants in the Rockdale formation. (Modified from Ball, 58, p. 18, 1931).

SPECIES	LOCALITIES[a]					
	1	2	3	4	5	6
Asimina eocenica Lesquereux	----	----	x	----	----	----
Euonymus splendens Berry	x	x	----	x	----	----
Ficus berryi Ball	----	x	----	----	----	x
Ficus vaughani Berry	----	x	----	----	?	----
Laurus wardiana Knowlton	----	----	x	----	----	x
Oreodaphne obtusifolium Berry	----	x	----	----	----	----
Pourouma texana Berry	----	----	x	----	----	x
Sapindus linearifolium Berry	----	----	----	----	x	----
Terminalia hilgardiana (Lesquereux)	----	----	x	----	----	x
Terminalia lesleyana (Lesquereux)	----	----	x	----	x	----
Sabalites grayanus Lesquereux	x	----	----	----	----	----

[a]Localities:

1. Bank on Little Sandy Creek about 2 miles NW. of Sayersville, Bastrop County, NW. cor. P. F. Wade original survey.
2. Barton's Ranch, 4½ miles W. of Sayersville, Bastrop County, in banks of Spring Creek near its confluence with Wilbarger Creek, ¼ mile NW. of Bench mark 391, Bastrop quadrangle.
3. Railroad cut just north of the station at Sayersville, Bastrop County.
4. Pope's Bend, Colorado River, Bastrop County.
5. Calaveras Creek, southeastern Bexar County.
6. Creek bank just east of Cassin (formerly Earle), Bexar County.

The only animal remains so far discovered in the continental deposits of the Rockdale are a group of Unios discovered by B. F. Cummins on Mustang Creek 1 mile south of Denny, Falls County, and the bone of a crocodile, *Crocodylus gryphus* Cope, collected at Rockdale by Alexander Deussen.

Correlation.—The exact correlation of the Rockdale formation with other lower Eocene formations is at present difficult because the plant fossils on which the age depends are of very restricted geographic range. Few of the species have been found anywhere except in the strata of the Gulf Coast section. Out of more than five hundred species that Berry has described, fewer than seventy-five are known in areas other than those in which they were discovered.

According to Berry (**109**, p. 89, 1924), the plants of the Rockdale formation, with the exception of the species from Cassin (formerly Earle) in Bexar County and those from Sayersville in Bastrop County, are younger than the lower Wilcox floras found in the Ackerman formation and represent either the Holly Springs or Grenada epoch. Berry has correlated tentatively the two florules obtained from Cassin and Sayersville as probable late Midway. Both these outcrops, however, are fully 200 feet above the marine fossiliferous zone of the upper Seguin formation, which is certainly younger than Midway and is closely related to, if not identical with, the lower fossiliferous strata of the lower Wilcox in Alabama. It appears therefore that all the strata of the Rockdale formation in central Texas are Wilcox in age.

Correlations of the Texas Wilcox formations with those of the eastern Gulf Coast states are presented below:

ALABAMA	MISSISSIPPI	TEXAS
Hatchetigbee	Grenada[79]	----------
Bashi	----------	Sabinetown
Tuscahoma	Holly Springs	Rockdale
Nanafalia	Ackerman	Seguin

Outside the Gulf Coast province, according to Berry (**112**, p. 29, 1930), the Wilcox finds its closest correlative in the Ypresian floras of southern England and the Paris Basin and in a general way with the Fort Union of the Rocky Mountain province. Other correlations have not been attempted.

Economic resources.—The natural resources of the Rockdale are its soils, lignite, and the clays used in the manufacture of brick, tile, and pottery. The soils of the Rockdale consist of fine sands and sandy loams. The sand is gray, or yellowish gray, loose, fine, 6 inches or more deep, and underlain in most places by yellowish-gray and orange sandy clay. It is naturally a wooded soil where uncultivated. The growth consists of post oak, blackjack, hickory, shrubs, and weeds. The soil is utilized chiefly for grazing cattle and cultivating small truck farms. Near towns and in more populated areas some of the soil is cultivated for cotton. Carter (**199a**, p. 35, 1931) has estimated that between 16 and 40 per cent of the soils are being tilled and the remainder used for pasture and timber. The farms are small, and the chief crop is cotton, although watermelons, sweet potatoes, and tomatoes are important minor products. Cattle and hogs are raised on most farms and range through the forest-covered sand hills. The price of the land on the average ranges from $10 to $15 per acre.

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[79]Field work in Mississippi has recently demonstrated that the Grenada is in part Tallahatta in age.

Lignite[80] is more widespread, occurs in thicker seams and at more stratigraphic positions in the Rockdale than in any other geologic formation in Texas. The deposits were mentioned in notes of early Spanish explorers and were known to the earliest settlers in Texas. According to Dumble (**470**, p. 18, 1892), the first published description of Texas lignite was by Riddell (**1316**, pp. 216-217, 1839), who explored the lignite outcrops along Trinity River. In 1892 Dumble[81] listed seven principal operating mines located on the Wilcox strata and commented on the lack of success in mining operations. In 1902 Phillips and Brooks (**1200**, pp. 1–2, 53, 1902) reported fourteen lignite mines in operation in the Wilcox area. In 1927 there were twenty-three operating mines producing 1,205,235 tons valued at $1,534,798, or $1.27 per ton.

The following lignite mines were in operation in Texas during 1931:

COMPANY	MINE	LOCATION
Anderson County		
Palestine Salt & Coal Co.	Palestine No. 2	Palestine salt dome
Atascosa County		
Lytle Coal Co.	Lytle mine	Lytle
Bastrop County		
Bastrop Lignite Coal Co.	Titanic No. 2	McDade
Chalmers Lignite Co.	Rosedale	Bastrop
Denison Coal Co.	Erhart No. 1	McDade
R. L. Denison	Sayers No. 1	McDade
Waugh Coal Co.	Calvin No. 3	Calvin
Bexar County		
John Belto	Bartette	S. of San Antonio
Henderson County		
Tredlow Lignite Co.	No. 5	Near Athens
Malakoff Fuel Co.	Nos. 1, 2, 3	Malakoff
Milam County		
Buniva Coal Co.	Consolidated	Rockdale
Sundow Lignite Co.	Strip Nos. 1, 2	Rockdale

[80]REFERENCES—Ashburner, C. A., **35**, pp. 495–506, 1881. Weitzel, R. S., **1722**, pp. 98-103, 1890. Lerch, Otto, **983**, pp. 38–63, 1891. Dumble, E. T., **470**, pp. 1–243, 1892. Phillips, W. B., Brooks, R. C., Hill, B. F., and Harper, H. W., **1200**, pp. 1–37, 1902. Phillips, W. B., Worrell, S. H., Phillips, D. M., **1215**, pp. 1-134, 1911. Phillips, W. B., and Worrell, S. H., **1218**, pp. 1–287, 1913. Barksdale, J., Lignite in Alabama: Geol. Survey Alabama Bull. 33, pp. 1–64, 1929.

[81]Dumble, E. T., **470**, pp. 1-243, 1892.

COMPANY	MINE	LOCATION
Rains County		
Morton Salt Co.	No. 1	SW. of Alba near Sabine R.
Titus County		
East Texas Lignite Co.	Titus No. 1	Winfield
Greenville Lignite Co.	No. 2	Winfield
Titus County Lignite Co.	Titus Nos. 1, 2	Winfield
Wood County		
Consumers Lignite Co.	Hoyt No. 16	Alba

The total production of lignite[82] in Texas during 1926 amounted to 920,664 tons valued at $1,146,000.00 or $1.24 per ton. The production in 1931 was 655,613 tons valued at $879,655, or $1.34 per ton.

The mines are of small capacity and are operated on a comparatively small scale. When the large number and wide extent of the known lignite occurrences in Texas are considered, present operations seem insignificant. The reason for the lack of large-scale operations is the present small demand for lignite, which is unable to compete with the more cheaply produced petroleum.

The lignite occurs in layers and lentils from a few inches to 9 feet thick. The thickness and extent of the beds vary in different areas. They may thin rapidly to a few inches or play out entirely. The lignite when first mined is dull black and poorly laminated and breaks into fairly large chunks or blocks. Exposed to sun or heat, it gives up its water, crumbles, slacks, and pulverizes. Upon heating in a furnace, it disintegrates even more easily and will pass through the grate unburned or only partly burned, unless special grates and efficient draft are provided. It is much more satisfactory as a fuel if pressed into briquettes.[83] The briquettes give a more concentrated heat and are more conveniently and easily handled. According to Barksdale[84] the lignites are adapted especially well to the

[82]U. S. Dept. of Commerce, Mineral Resources for 1926, 1931.

[83]The briquettes are made by drying the lignite, then heating it in a retort at a low temperature to drive off volatile gases and tar. The residue is then mixed with a little coal tar pitch and pressed into briquettes. The gaseous by-products from the retort can be recovered and utilized for heating purposes. (Barksdale, J., Lignite in Alabama, Geol. Survey of Alabama Bull. 33, p. 55, 1929. The process was first advocated in Texas by E. T. Dumble as early as 1881, 470, pp. 22–23, 1892).

[84]Barksdale, J., Lignites in Alabama: Alabama Geol. Survey Bull. 33, p. 57, 1929.

manufacture of producer gas. One ton of lignite used in a gas-producer plant will yield as much power as the best Pennsylvanian coals. The high power production developed by Texas lignite in gas engines capable of operating dynamos for generation of cheap electricity gives promise of future developments of large lignite-powered electric plants for the east and south-central Texas regions. Of even greater prospective value, however, is the utilization of the lignite for the manufacture of hydrocarbons such as benzol, gasolene, and light oils by the hydrogenation process. The process consists of heating lignite in a retort under several hundred pounds pressure in contact with hydrogen gas, then fractionating the distilled products by means of pressure stills. Hydrocarbon products of almost any desired gravity can be produced by the proper control and correct manipulation of the pressure and temperature. When the oil fields are exhausted, the lignite beds will take their place as the future fuel, lubricant, and power-producing resource of the state.

The lagoonal and lacustrine clays of the Rockdale constitute good brick and stoneware clays.[85] The deposits consist of grayish, colloidal, highly plastic, refractory or semi-refractory clays that occur in lentils at various stratigraphic positions in the Rockdale formation, but most commonly in the lower, or Butler, member associated with the lignite beds. Chemical and ceramic tests made on these clays are given in the accompanying tables.

Chemical composition of typical Rockdale clays[86]

Locality	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	K_2O	Na_2O	H_2O
Elgin	65.60	22.5	1.20	0.7	Tr.	Tr.	1.70	7.7
Athens	74.04	15.1	0.50	0.5	0.27	0.42	1.12	6.0
Malakoff	62.10	25.1	0.30	?	0.21	Tr.	0.10	10.0
Sulphur Springs	74.03	17.1	0.57	0.10	0.22	0.30	0.60	6.1

Ceramic tests of clays from the Rockdale formation[87]

LOCALITY	PLASTICITY	LINEAR SHRINKAGE	BURNING BEHAVIOR	BURNED COLOR	HARDNESS	QUALITY
Rockdale	Good	9	Good	Light buff	Hard	Good
Luling	Good	16	Bad	Red	Medium	Good

[85]REFERENCES—Ries, H., 1319, pp. 767-805, 1906; 1320, pp. 1-316, 1908. Schoch, E. P., 1378, pp. 189-195, 1918. Potter, A. D., and McKnight, D., 1245, pp. 1-228, 1931.

[86]Ries, H., 1320, pp. 88, 94, 97, 99, 1908.

[87]Potter, A. D., and McKnight, D., 1245, Table 5, 1931.

The brick clays are characterized by low lime, potash, and soda content, by high plasticity, medium shrinkage, good burning behavior, and they yield buff, light buff, and in some places red bricks. The best clays are adapted to the manufacture of common brick, face brick, and some stoneware.

Brick plants operating in the Rockdale formation during 1932

COMPANY	LOCATION
Elgin Standard Brick Mfg. Co.	Butler, Bastrop County
Elgin Butler Brick Co.	Butler, Bastrop County
Star Brick and Tile Co.	Elmendorf, Bexar County
Athens Pottery Co.	Athens, Henderson County
Athens Brick and Tile Co.	Athens, Henderson County
Texas Clay Products Co.	Malakoff, Henderson County
Thermo Fire Brick Co.	Sulphur Springs, Hopkins County

SABINETOWN FORMATION[88]

Definition.—The name Sabinetown is used to designate the marine strata of Wilcox age between the Rockdale formation below and the Carrizo sand above. Marine fossils in these strata were discovered on Sabine River near Sabinetown before 1870 and reported by Hilgard,[89] who mistook them for shells of Vicksburg age. Harris (**664**, p. 201, 1897) studied a collection of fossils from this locality and at once identified them as upper Wilcox and correlated them correctly with the Woods Bluff fauna of Alabama. Deussen (**415**, p. 50, 1914) described the section on Sabine River but did not give any name to the beds. Dumble (**506**, p. 40, 1918) designated the marine strata in the Sabine River valley as the Sabine phase of the Wilcox and announced the discovery of marine Wilcox fossils southwest of San Antonio by C. L. Baker. Sellards (**1402**, p. 60, 1919) quotes Baker's description of the marine strata and correctly places them in the top of the Wilcox section. Miss Gardner (**566**, p. 141, 1924) confirmed the upper Wilcox age of this assemblage of forms and published a preliminary list of the fossils collected in Bexar

[88]LITERATURE—Hilgard, E. W., Supplementary and final report of a general reconnaissance of the state of Louisiana: Rpt. Louisiana Geol. Survey, pp. 19–21, 1873. Harris, G. D., **664**, pp. 201-202, 1897; **664b**, pp. 299–309, 1899. Deussen, A., **415**, p. 50, 1914. Dumble, E. T., **506**, pp. 40–45, 1918. Sellards, **1402**, p. 60, 1919. Gardner, Julia A., **566**, pp. 141–145, 1924.

[89]Hilgard, E. W., Supplementary and final report of a geological reconnaissance of the state of Louisiana, p. 19, 1873.

and Wilson counties. D. J. Crawford and W. A. Reiter[90] discovered fossiliferous greensand beneath the Carrizo in Limestone and Freestone counties in 1927 and 1928. The fauna from this stratigraphic position was designated as the Sabinetown fauna by Berry (**112**, p. 9, 1930), and the type locality for the formation of this same name is Sabinetown Bluff on Sabine River.

Regional geology.—The Sabinetown formation is a thin though distinctive unit of the Wilcox group. It is well developed in Alabama and in Mississippi but outcrops in Texas only as remnants that escaped erosion or complete overlap by the Carrizo.

Strata of Sabinetown age occur at Pendleton Bluff and at Sabinetown on Sabine River, Sabine County, in eastern Limestone County, in southern Bastrop County, and in creek banks exposing uppermost Wilcox strata in southeastern Bexar County. South of the outcrop these beds have been recognized in a few well sections. The lithology, however, so closely resembles that of the underlying Rockdale and Seguin formations that, unless the section is cored or the well samples are very carefully taken, this formation can not be distinguished from the Rockdale.

The thickness of the Sabinetown formation ranges from 60 to 100 feet.

Stratigraphy.—The contact of the Sabinetown formation with the Rockdale is not exposed in the Sabine River bluffs. On Losoya Creek, at the bridge on the South Flores road south of San Antonio, Bexar County, the marine strata lie unconformably upon the eroded surface of massive Rockdale sandstone. This contact is marked by a one-foot bed of wave-worn beach pebbles and marine shells. The upper contact of the Sabinetown formation with the Carrizo sand is thought also to be unconformable.

The absence of the Sabinetown beds in many places may be due to removal of these strata by erosion before deposition of the Carrizo sand. Details in the stratigraphy of the Sabinetown formation are best shown by described and measured sections.

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[90]Reiter, W. A., personal communication, Oct. 27, 1932.

Section[91] at Pendleton Bluff on Sabine River, Pendleton Gaines Survey, 7.1 miles by road east of Milam and about ⅛ of a mile north of the ferry where the old Spanish ford was located, Sabine County.

	Thickness *Feet*
Sabinetown formation—	
4. Clay, chocolate-brown, colloidal, laminated and interbedded with brown micaceous sand containing plant fragments	15
3. Sand, dark blue, weathering brown, glauconitic, the glauconite occurring in more or less continuous layers	4
2. Sand, dark gray, weathering greenish brown, medium grained, soft, glauconitic, containing small particles of clay, very thin lentils of lignite, and numerous small round iron oxide concretions; fossils numerous	6½
1. Sand, dark greenish gray, weathers brown, medium gray, well stratified, contains minute crystals of pyrite and small iron concretions. The sand is interbedded with layers of carbonaceous clay less than one-quarter inch in thickness having wavy bedding lines and containing a few fossils	9
Total thickness measured	34½

Section[92] on Sabine River at Sabinetown, Sabine County.

	Thickness *Feet*
Sabinetown formation—	
6. Clay, lignitic	15
5. Sand, medium grained, yellow	25
4. Clay, light brown, interbedded with yellowish lignitic sand	40
3. Sand, greenish, somewhat clayey, capped by a hard layer containing fossils, most of which are in concretions	15
2. Sand, bluish green, fossiliferous, contains iron oxide concretions	15
1. Clay, drab, thinly bedded	2
Total thickness measured	112

Section on Losoya Creek, one-half mile south of the bridge over Medina River, south of San Antonio, on the South Flores road, Bexar County.

	Thickness *Ft.*	*In.*
Sabinetown formation—		
4. Clay, gray streaked with rusty brown tints and black lamination lines, sandy, interbedded with layers of fine-grained sand that vary from ¼ inch to 8 inches in		

[91]Modified from a description by C. L. Baker in 506, p. 42, 1918.
[92]Modified from a description by C. L. Baker in 506, p. 43, 1918.

	Thickness Ft.	In.
thickness. These beds contain particles of carbonaceous matter and numerous small ferruginous concretions from 3 to 8 inches in diameter	15	6
3. Clay, brown, carbonaceous, thinly laminated	4	
2. Conglomerate, reddish buff, made up of wave-worn eliptical pebbles from 1 to 3 inches in diameter in a matrix of brown sand containing a mass of very poorly preserved marine shells and shell impressions, shark's teeth, and pieces of petrified wood. The pebbles of this conglomerate were apparently derived from the underlying strata, rest on the uneven river ripple-marked surface of the concretionary sandstone and denote clearly an unconformity at the top of the Rockdale member		6–8
Rockdale formation—		
1. Sandstone, brownish buff, medium grained, everywhere ripple marked with fluviatile ripples. The sandstone is cross-bedded and unevenly cemented to form large concretionary masses 3 to 10 feet and more in diameter	10	
Total thickness measured	30+	

Sedimentology.—The sediments of the Sabinetown formation are of a near-shore and shallow-water facies. The basal beds were deposited on the beach, and the pebbles and fossils were worn and rounded by wave action. The upper sediments contain sand and glauconite evenly bedded and were doubtless deposited near shore in fairly quiet waters. The conditions of sedimentation were quite similar to those of the Seguin epoch, except that the Seguin strata record a retreating sea ending in beach and continental deposits. The Sabinetown beds were deposited in a transgressing sea that began with beach deposits and ended with deeper water deposition. The sediments, in part at least, were derived from the adjacent Wilcox land.

Lithology.—The Sabinetown formation consists of thinly laminated, light gray sand, lentils and thin beds of blue sandy clay containing thin partings of impure sand and numerous large, somewhat flat and smooth-surfaced, ferruginous concretions. In some places the base is marked by a layer of conglomerate, and in other places by a layer of glauconitic sand. The loose sand, the concretions, and the conglomerate are in some places fossiliferous.

Distinguishing characteristics.—The Sabinetown formation is distinguished from the overlying Carrizo by its finer sand grains, its smooth, ferruginous, and in places fossiliferous concretions, and by its fossils. The shells are larger, more robust, and thicker shelled than those from the Solomon Creek member of the Seguin formation. The strata contain less lignite and carbonaceous matter than the Rockdale or Seguin formations.

Paleontology.—The Sabinetown fauna, as identified by Harris[93] from the type locality for the formation and by Miss Gardner (566, p. 142, 1924) from material collected in Bexar County is as follows:

Sabine River bluffs

Venericardia horatiana Gardner
Modiola alabamensis Aldrich
Barbatia cuculloides (Conrad)
Pholas alatoideus Aldrich
Leda aldrichiana (Harris)
Leda corpulentoides (Aldrich)
Cardium tuomeyi Aldrich
Kellia prima Aldrich
Mactra bistriata Harris
Corbula alabamiensis Lea
Lucinia ozarkana Harris
"Pleurotoma" silicata Aldrich
"Pleurotoma" huppertzi Harris var. penrosei Harris
"Pleurotoma" veatchi Harris
Buccinanops ellipticum (Whitfield)
Cancellaria quercollis (Harris) var. greggi Harris
Pseudoliva vetusta (Conrad)
Pseudoliva petrosa (Conrad)
Levifusus indentus Harris
Levifusus supraplanus Harris
Levifusus pagoda (Heilprin)
Levifusus trabeatus (Conrad)
Levifusus sp. aff. L. trabeatus (Conrad)
Mazzalina plena (Aldrich)
Tritonidea pachecoi Harris
Alectrion exilis (Conrad)
Calyptraphorus trinodiferus Conrad
Cassidaria brevidentata Aldrich
Fusoficula juvenis (Whitfield)
Turritella mortoni Conrad
Turritella praecincta Conrad
Natica eminula Conrad
Natica aperta Whitfield
Natica alabamiensis Whitfield
Solarium bellense Harris

Southeastern Bexar County

Venericardia planicosta Lamarck
Leda aldrichiana (Harris)
Leda sp. aff. L. corpulentoides (Aldrich)
Corbula aldrichi Meyer?
Callocardia sp. cf. C. nuttalliopsis (Heilprin) var. greggi (Harris)
Cardium hatchetigbeense Aldrich?
Turris sp. cf. T. silicata (Aldrich)
Alectrion sp. cf. A. exilis (Conrad)

All the species in the above list occur in the Wilcox in Alabama, and most of them are found only in the Bashi or middle division of the group.

Correlation.—The Sabinetown formation is correlated by Harris with the Woods Bluff of Alabama, which belongs to the Bashi formation of middle Wilcox age. The Bashi is placed by Clark and

[93]Harris, G. D., The geology of Louisiana: Rpt. Geol. Survey Louisiana, pp. 299–310, pls. 53–55, 1899.

Martin[94] in the upper Chickasawan substage and is correlated with the Nanjemoy stage in Maryland, as shown by the following table:

TEXAS	MISSISSIPPI	ALABAMA	ATLANTIC EAST COAST
Sabinetown	(Hiatus)	Bashi	Nanjemoy

CLAIBORNE GROUP[95]

DEFINITION

The name Claiborne was first used by Tuomey[96] to designate the fossiliferous Eocene beds of Alabama exposed in Claiborne Bluff on Alabama River. The nonfossiliferous strata between the "Lignitic Group" (now Wilcox) and the Claiborne fossiliferous strata were named Buhrstone. Hilgard[97] in 1860 placed the two divisions together under the name Claiborne group and published sections and full descriptions of the two divisions. Hilgard's section[98] shows clearly that he included in his assemblage all the strata from the "Lignitic Group" below to the fossiliferous Jackson formation above.

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[94]Clark, W. B., and Martin, G. C., The Eocene deposits of Maryland: Maryland Geol. Survey, Eocene, p. 84, 1901.

[95]LITERATURE—

Stratigraphy—Hilgard, E. W., Geology and agriculture of the state of Mississippi, pp. 123–128, 1860. Smith, E. A., and Johnson, L. C., Tertiary and Cretaceous strata of the Tuscaloosa, Tombigbee, and Alabama rivers: U. S. Geol. Survey Bull. 43, p. 2, 1887. Penrose, **1189**, pp. 22–47, 1889. Dumble, E. T., **460**, pp. 7–31, 1891; **509**, pp. 97–101, 1918. Kennedy, Wm., **905**, pp. 52–54, 1892; **906**, pp. 15–22, 1893; **911**, pp. 89–160, 1895. Crider, A. C., Geology and mineral resources of Mississippi: U. S. Geol. Survey Bull. 283, pp. 28–33, 1906. Deussen, **415**, pp. 55–61, 1914; **421**, pp. 62–84, 1924. Trowbridge, A. C., **1610**, pp. 93–97, 1923. Cooke, Wythe, The Cenozoic formation: Geol. Survey Alabama, Spec. Rpt. 14, pp. 268–274, 1926. Ellisor, A. **523**, pp. 1335–1346, 1929. Wendlandt, E. A., and Knebel, G. M., **1728**, pp. 1347–1375, 1929. Renick, B. C., and Stenzel, H. B., **1299**, pp. 81–108, 1931. Trowbridge, A. C., **1613a**, pp. 81–140, 1932.

Paleontology—Conrad, T. A., Fossil shells of the Tertiary formations of North America: pp. 1–56, 20 pls., 1832–1835. Lea, Isaac, Contributions to geology, pp. 1–227, pls. 1–6, Philadelphia, 1833. Aldrich, T. H., Preliminary report on the Tertiary fossils of Alabama and Mississippi: Geol. Survey Alabama Bull. 1, pp. 1–63, pls. 1–6, 1886. Meyer, Otto, Contributions to the Eocene paleontology of Alabama and Mississippi: Geol. Survey Alabama Bull. 1, pp. 63–85, pls. 1–3, 1886; Beitrag zur Kenntnis der Fauna des Alttertiärs von Mississippi und Alabama: Ber. Senckenberg. naturf. Gesell., pp. 1–20 (separate), pls. 1, 2, 1897. Meyer, Otto, and Aldrich, T. H., The Tertiary fauna of Newton and Wautubbee, Mississippi: Jour. Cincinnati Soc. Nat. Hist., vol. 9, pp. 40–50, pl. 2, 1886. Gregorio, A de, Faune éocénique de l'Alabama, pp. 1–316, pls. 1–46, 1890. Harris, G. D., **660**, pp. 85–183, 1894; **663**, pp. 45–88, 1896. Aldrich, T. H., **24**, pp. 53–82, 1895. Vaughan, T. W., A brief contribution to the geology and paleontology of northwestern Louisiana: U. S. Geol. Survey Bull. 142, pp. 1–52, pls. 1–4, 1896; **1687a**, pp. 15–205, pls. 1–24, 1900. Gardner, Julia, **565**, pp. 109–115, pls. 1–5, 1923; **570**, pp. 362–383, figs. 1–44, 1927; **569**, pp. 245–251, 1927. Price, W. A., and Palmer, K. van W., **1275**, pp. 20–31, pls. 6, 7, 1928.

[96]Tuomey, M., First Biennial Report on the geology of Alabama, p. 150, 1850.

[97]Hilgard, E. W., Geology and agriculture of the state of Mississippi, pp. 123–128, 1860.

[98]*Idem*, p. 108.

These strata are characterized lithologically by an abundance of glauconite and paleontologically by a related series of faunas containing notably *Ostrea sellaeformis* Conrad, the range of which is limited to this group. No locality in the Tertiary formations of America is more famous than Claiborne Bluff, and no series of strata in the Eocene is more clearly defined or more appropriately named than the Claiborne. Unfortunately much diversity in the definition of the group and some confusion in the usage of the name, especially in Texas, has been introduced by geologic publications since the work of Hilgard.

Smith and Johnson[99] in 1887 limited the Claiborne to the strata between the top of the Buhrstone and the base of the Jackson. Penrose (**1189**, p. 22, 1889) grouped the Wilcox and Claiborne together under the name Timber belt or Sabine River beds. Kennedy (**905**, p. 52, 1892) separated the Claiborne, exclusive of the Carrizo, into a group that he named Marine beds. Lerch[100] used the name Marine Claiborne to designate the beds between the Lower Lignitic (now Wilcox) and Upper Lignitic (now Yegua). Harris (**660**, p. 87, 1894) used Claiborne for all the strata above the Lignitic (now Wilcox) and below the Jackson. Vaughan[101] designated the strata between the Lignitic and the Cockfield Ferry (now Yegua) Lower Claiborne, and stated that the Cockfield Ferry beds were equivalent to the upper Claiborne of Alabama. Veatch (**1691**, p. 36, 1906), Crider,[102] and Deussen (**415**, p. 51, 1914) followed the classification of Harris. Udden, Baker, and Böse (**1652**, p. 83, 1916) included in the Claiborne all the strata from the base of the Carrizo to the top of the Frio, thus placing all the Jackson in the Claiborne group. Dumble (**506**, p. 56, 1918) included in the Claiborne all the strata from the base of the Carrizo to the top of the Fayette, a formation now regarded as equivalent to a portion of the Jackson. He did not, however, include the typical Jackson beds in his definition. Trowbridge (**1610**, p. 93, 1923) limited the Claiborne to the strata from the top of the Bigford (a formation above the Carrizo) to the top

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[99]Smith, E. A., and Johnson, L. C., Tertiary and Cretaceous strata of the Tuscaloosa, Tombigbee, and Alabama rivers: U. S. Geol. Survey Bull. 43, p. 25, 1887.

[100]Lerch, Otto, Preliminary report on the hills of Louisiana: Bull. Louisiana State Exper. Sta., Geology and Agriculture, pt. 2, p. 78, 1893.

[101]Vaughan, T. W., A brief contribution to the geology and paleontology of northwestern Louisiana: U. S. Geol. Survey Bull. 142, p. 15, 1896.

[102]Crider, A. C., Geology and mineral resources of Mississippi: U. S. Geol. Survey Bull. 283, p. 28, 1906.

of the Yegua. Deussen (**421**, p. 62, 1924) drew the Claiborne contacts at the top of the Carrizo and the top of the Yegua. Miss Ellisor (**523**, p. 1339, 1929) and Wendlandt and Knebel (**1728**, p. 1351, 1929) included in the Claiborne group all strata from the base of the Carrizo to the top of the Cockfield (now Yegua). Renick and Stenzel (**1299**, pp. 81, 90, 1931) placed the formations from the base of the Carrizo to the base of the Yegua in the lower Claiborne group, and the Yegua alone in the upper Claiborne group. It now appears probable that the Carrizo is equivalent[103] to the Tallahatta (Buhrstone) of Mississippi. Recent writers that have placed the Carrizo sand in the Claiborne group are therefore not only following the original usage by Hilgard, as published seventy-two years ago, but are also placing the base of the group at the most appropriate stratigraphic position, a major unconformity that separates two distinct faunal and lithologic groups of strata. The Claiborne group in Texas, as now defined, includes the beds between the base of the Carrizo sand and the top of the Yegua. The type section is at Claiborne Bluff on Alabama River, near Claiborne, Alabama.

SUBDIVISIONS

Soon after Kennedy gave the name Marine to the Claiborne strata in Texas, he attempted a twofold division (**905**, p. 52, 1892). He writes:

> They (*i.e.*, Marine beds) are known to overlie the red and white sands of the Queen City beds in Harrison County, three miles north of Marshall. . . To the west of Marshall they are again seen overlying the Queen City beds. . . .
>
> The Marine beds may be divided into two groups—the Basal, from its greatest development in Cherokee County, may be called tentatively the "Mount Selman" series, while the uppermost, from its typical development in Houston County, may be denominated the "Cook's Mountain" series.
>
> The beds of the Mount Selman series . . . consist of a series of brown sands, blue clays, greensands, altered greensands, glauconitic sandstone and laminated iron ore, and are more or less fossiliferous throughout.

[103]Plant leaves in the Carrizo correlate closely with leaves in the Grenada formation of Mississippi. Recent field work has shown that the Grenada is, in part at least, Tallahatta (Guide Book, Ninth Annual Field Trip, Shreveport Geol. Soc., June, 1932).

The type locality of his Basal or Mount Selman series is regarded as the exposed section at Mount Selman, Cherokee County, although Kennedy described the section from Jacksonville to Bullard in defining the formation. It seems clear, however, that Kennedy intended his name for the formation now called Weches, which includes the strata between the top of the Queen City and the base of what is now Sparta sand.

Kennedy described the Cook's Mountain as

> an extensive series of greensands, greensand marls, altered greensands containing thin strata of carbonate of iron, indurated altered fossiliferous greensand, green fossiliferous clays, glauconitic sandstones and clays, stratified black and gray sandy clays, brown fossiliferous sands, and black or yellow clays with limy concretions. . . . The prevailing deposits, however, are the greensands.

He described the section from Independence Post Office, in Cherokee County, to Alto as representing the beds of this division. It is now known that this section includes typical Weches strata, which belong to his Mount Selman, or lower, division. His description also, as quoted above, fits much better the Mount Selman division than it does the upper, or Cook's Mountain, division. It is certain that Kennedy's two divisions, as defined by him, overlap, and this lack of clarity has led to much confusion.

Dumble named the beds above the marine division Yegua. He believed that Kennedy's Cook's Mountain beds included only the richly glauconitic strata that are now referred to the Weches formation, and therefore he included in his Yegua division not only nonmarine clays, but also most of the marine clays down to the glauconites, and thus overlapped much, if not all, of that part of Kennedy's upper division that was not included in what is now Weches.

Deussen restricted the name Yegua to the nonmarine strata for the most part and divided the marine beds below into the two divisions Mount Selman and Cook Mountain (spelling discussed by Wendlandt and Knebel, **1728**, p. 1359, footnote). He expanded the Mount Selman to include the Queen City sands and the underlying marine beds now called Reklaw, and he placed the highly fossiliferous strata at Smithville, Bastrop County, and several other outcrops in the upper or Cook Mountain division. The Smithville locality is now known to belong in the lower division.

The geologists of the United States Geological Survey in preparing the new geologic map of Texas have employed the names Mount Selman and Cook Mountain. They have also followed Deussen in making the Mount Selman division include all Claiborne strata above the top of the Carrizo sand and have drawn the upper boundary at the top of the Weches. They have limited the Cook Mountain division to the strata from the top of the Weches to the base of the nonmarine Yegua. This twofold division of the marine series of Claiborne strata is easy to map in east Texas but difficult to follow in south Texas, because the basal sand member of the upper division is absent, and the two divisions grade into one another. This confusion in the definitions of the formations in east Texas and the difficulty in mapping the divisions in south Texas has led field geologists to employ a new classification for the Claiborne group in east Texas and to leave the group in south Texas undifferentiated until more detailed field mapping can be done.

The strata of the Claiborne group in east Texas consist of a rhythmic series in which marine and continental alternate, as follows:

Continental sandy clays, lignites
Marine glauconitic clays and sands
Continental and coastal sands
Marine glauconitic clays and sands
Continental and beach sand
Marine glauconitic sandy clay
Continental cross-bedded sand

Each change from massive sand to fossiliferous glauconitic clay indicates a change in the strand line. The sands mark the land epochs; the fossiliferous clays, the marine epochs; and the brown lignites, the palustrine epochs. The assemblage of beds deposited during a single epoch of deposition and belonging to a definite facies constitutes a natural division. Seven natural divisions have been recognized by Miss Ellisor (**523**, pp. 1335–1346, 1929) and by Wendlandt and Knebel (**1728**, pp. 1347–1375, 1929) and are made the basis of a new classification of Claiborne strata in east Texas, where a marine fossiliferous formation alternates regularly with a sandy and nonmarine formation, as follows:

Formation	Facies
7. Yegua	Continental and palustrine
6. Crockett	Marine and littoral
5. Sparta	Continental and littoral
4. Weches	Marine and littoral
3. Queen City	Continental and littoral
2. Reklaw	Littoral and palustrine
1. Carrizo	Continental

Miss Ellisor recognizes (**523**, pp. 1339–1340, 1929) also two additional formations named by her the Saline Bayou and the Milams, which intervene between the Crockett and the Cockfield (now Yegua) formations along the outcrop in east Texas east of Angelina County and in Louisiana on the Sabine uplift (fig. 44). These formations are found below the Yegua in the sections penetrated by wells throughout the Gulf Coast province. They have characteristic faunas, by which they can be identified, and Miss Ellisor believes that they are overlapped along the outcropping Claiborne section except in the vicinity of the Sabine uplift. Since these beds occupy so small a part of the Claiborne exposure, however, and since this paper deals mainly with surface outcrops, they are not treated as separate formational units in the above classification.

The classification as outlined above furnishes divisions that are easy to distinguish and to map in east Texas, and they have been accepted by most geologists working in that area. Some geologists, however, prefer a fourfold grouping of the strata. The U. S. Geological Survey has adopted therefore the following arrangement:

Yegua (restricted)	
Cook Mountain	Crockett Sparta
Mount Selman	Weches Queen City Reklaw
Carrizo	

The classification of Claiborne strata most commonly used by Texas geologists is shown by the columnar sections, figure 38.

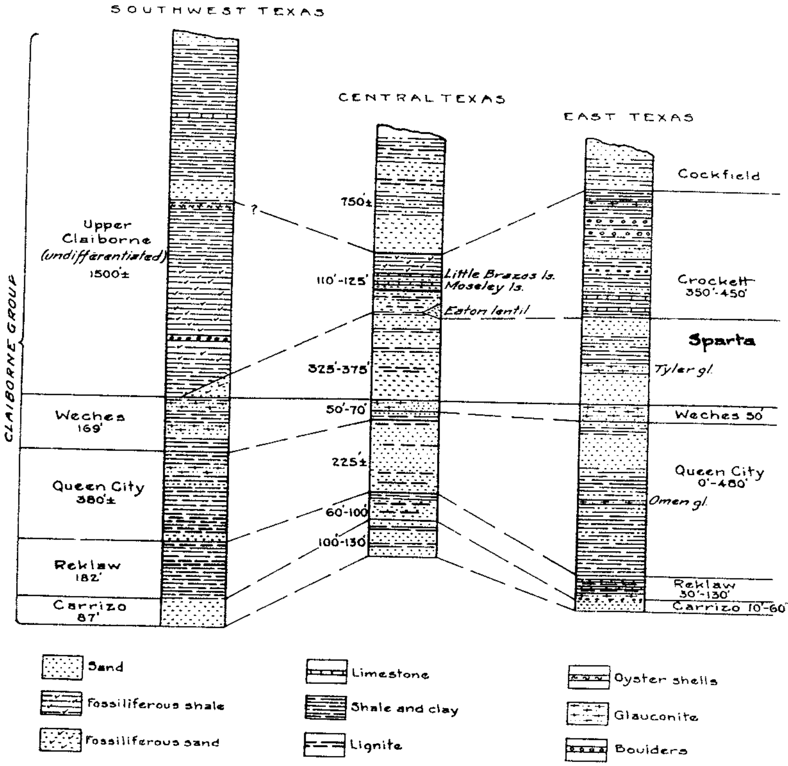

Fig. 38. Columnar sections showing Claiborne formations across Texas.

CARRIZO FORMATION[104]

Definition.—The Carrizo formation was named by Owen (454, p. 70, 1889), who separated an upper, massive, sandy layer from the underlying clays of the lower Lignitic beds and named it the Carrizo sandstone, because it furnished well water to the town of Carrizo Springs. Dumble (494, pp. 929, 930, 1903), after studying Kennedy's report on the unconformable relationships of the underlying clays with the Carrizo sands, believed that this sand should be separated from the Wilcox group and be correlated with

[104]LITERATURE—Owen, J., **454**, pp. 70–74, 1889. Vaughan, T. W., **1687**, p. 45, 1900. Dumble, E. T., **494**, pp. 929, 930, 1903; **498**, pp. 52, 53, 1911; **506**, pp. 37–55, 1918. Liddle, R. A., **992**, pp. 87–93, 1918. Sellards, E. H., **1402**, pp. 63, 64, 1919. Trowbridge, A. C., **1610**, pp. 91–93, 1923; **1613a**, pp. 52–64, 1932. Deussen, A., **421**, pp. 58–62, 1924. Brucks, A. W., **164**, p. 831, 1927. Getzendaner, F. M. **578**, p. 1434, 1930.

the Queen City sand of east Texas and with the Tallahatta formation of Alabama. Udden, Baker, and Böse, (**1652**, pp. 83–84, 1916) and Liddle (**912**, pp. 87–93, 1918) treated the Carrizo as a separate formation and placed it in the Claiborne group. Sellards (**1402**, pp. 63–65, 1919) also separated it from the Wilcox and made it a formation of equal rank, but did not group it with the Claiborne. Berry (**105a**, p. 4, 1922) obtained plant fossils from the Carrizo sand and concluded that the plants were more closely related to the Wilcox flora than to the plants in the overlying strata. Trowbridge (**1610**, p. 89, 1923), influenced by Berry's determinations, placed the Carrizo in the Wilcox group and named the strata below the Carrizo the Indio formation.[105] Wendlandt and Knebel (**1728**, pp. 1350–1352, 1929) mapped the Carrizo around the flanks of the Sabine uplift and across northeast Texas from Leon County to Sulphur River. These authors and Miss Ellisor (**523**, p. 1343, 1929) have shown that the Carrizo does not correlate with the Queen City, as Dumble thought, but with a sand below the Reklaw at the base of the Claiborne section. Renick and Stenzel (**1299**, p. 81, 1931) mapped and described the Carrizo sand in Brazos River valley. Miss Gardner, in assisting in the preparation of the new geologic map of Texas, has traced the outcrop of the Carrizo from the Rio Grande to Sabine River and has shown its true relationships across the state.

The exact age of the Carrizo is still somewhat problematical. The reasons for including it in the Claiborne are (1) the Carrizo sand is separated from the underlying Wilcox by a definite unconformity; (2) it merges into the Reklaw sediments above by a gradual transition; and (3) its color, lithology, and physical characteristics are more like those of the Claiborne than the Wilcox. The Carrizo sand so closely resembles the Queen City sand, that for a long time the two were believed to be equivalent (Dumble **506**, p. 61, 1918). (4) The evidence offered by the plant remains in the Carrizo, criteria that influenced Trowbridge and Deussen to place the Carrizo in the Wilcox, is now regarded as inconclusive, since the Grenada sand with similar plant remains is now known to correlate

[105]Trowbridge originally described three formations within the Wilcox group. It was discovered later, however, that his upper division, the Bigford, correlated with the lower strata of the Claiborne group in east Texas, and accordingly it was removed from the Wilcox.

with the Tallahatta of Alabama and not with the Wilcox in that area.

Owen in naming the formation did not designate a type locality. Berry (**105a**, p. 4, 1922) states that the type locality is the outcrop in the quarries one-half mile west of Carrizo Springs. These quarries are now thought to lie in the base of the Reklaw and not in the original series of underlying sands defined as Carrizo. Geologists working in the district agree that if a type locality is to be designated, it should be the exposure known as Brand Rock on Peña Creek west of Carrizo Springs.

Regional Geology.—The surface expression of the Carrizo formation is a ridge of moderate relief covered by loose buff or gray sand and forested by a more or less thick growth of blackjack oak, sandy-land hickory, poison ivy, and cucumber-leafed sunflower.

The formation outcrops in a belt about three miles wide along the southeast edge of the Wilcox group of formations from the Rio Grande on the southwest to Sulphur River on the northeast. In the extreme northeast part of the state the outcrops are obscured by alluvium and terrace deposits of the Sabine and Sulphur rivers and their many tributaries, but the formation is thought to extend into Louisiana. On the west side of the Sabine uplift the Carrizo occurs also in a belt from a fraction of a mile to three miles wide west of the Wilcox outcrop. Southeast of the outcrop of the Carrizo along the central Texas monocline and west of its outcrop on the flanks of the Sabine uplift it is penetrated in all the wells that have been drilled sufficiently deep.

The thickness of the Carrizo varies from a few feet on the west side of the Sabine uplift to nearly 300 feet in Nueces River valley in south Texas. Measurements in several areas in Texas are shown in the following table:

LOCALITY	COUNTY	THICKNESS *Feet*	AUTHORITY
Christian No. 1, Amerada Pet. Co., Felix Flores Survey	Smith	43	Denison
Core test, near Rusk	Cherokee	50	Wright
Wade No. 1, J. H. Fields Survey	Upshur	80	Do
Outcrop section	Camp & Morris	40–50	Do
Outcrop section, E. of Lavernia	Wilson	87	Deussen
Outcrop section	Medina	75–100	Liddle
Outcrop section	Uvalde	100	Getzendaner

LOCALITY	COUNTY	THICKNESS *Feet*	AUTHORITY
T. R. Price No. 1, W. E. Erskine Survey, sec. 34	Zavala	255	Do
Weathersby No. 1, A. B. & M. Survey, Bk. A, sec. 44	Zavala	231	Do
Huffman No. 3, 3 mi. N. of Indio	Zavala	137	Do
Holmsombuck water well, Crystal City	Zavala	300	Do
Outcrop section, Rio Grande Valley, SW. of Carrizo Springs	Dimmit	118	Trowbridge
Oppenheimer No. 1, Amerada Pet. Co.	Frio	295	MacNaughton

Stratigraphy.—The Carrizo sands are disconformable with the beds of the underlying Wilcox group. In Sabine River valley, in the San Antonio area, and in Rio Grande valley the sand rests upon the Sabinetown formation. In most other districts the Sabinetown has been eroded, is overlapped by the Carrizo, or is present in an unrecognizable nonmarine facies. Whatever the relationship, in some places the Carrizo sand rests upon cross-bedded and nonmarine sandy clays, in other places upon unevenly bedded, glauconitic, sandy, marine strata, and in still other places on cross-bedded deltaic beds. These relationships leave no doubt of an abrupt change in sedimentation between the Wilcox and Carrizo epochs. The upper contact of the Carrizo with the Reklaw is conformable,[106] and in some places it is difficult to draw the line of demarcation.

The Carrizo formation has not been subdivided into members, and divisions are not feasible in so uniform a sand. The character of the strata in the various districts is best shown by sections.

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[106]Deussen, A., 421, p. 60, 1924. In this treatise localities are described to illustrate the unconformable relationships between the Carrizo and Mt. Selman formations. The author's excellent work was done before the Carrizo had been mapped or the present subdivisions of the Claiborne differentiated, so that the localities mentioned by him are not at the top of the Carrizo, as now designated, but at or near the base of the sand. For comparison, see the outcrop of the Carrizo in Bastrop County, as mapped by Miss Julia Gardner (396c, 1932).

Section[107] *of Carrizo sandstone 1½ miles north and west of Chupadera ranch, near the southwest corner of Dimmit County.*

	Thickness *Feet*
7. Gray, concretionary sandstone	10
6. Interbedded brown and gray sandstone	10
5. Gray shale with a few slabs of gray to brown sandstone	8
4. Smooth gray sandstone, brown on surface	⅓
3. Gray shale	1
2. Gray, shaly sandstone, cross-bedded	2–4
1. Gray sandstone in thin slabs	10
Total thickness measured, about	44

Section[108] *of Carrizo sand on Sutherland Springs road 3 miles east of Lavernia, Wilson County.*

	Thickness *Feet*
Sandstone, red, ferruginous, soft	20
Shale, red, ferruginous, with argillaceous sand	2
Sand, red	4
Shale, white, sandy	1
Sand, red	2
Unexposed	8
Sand, red, ferruginous	10
Unexposed	15
Sand, gray, laminated, argillaceous	3
Sand, red, ferruginous	2
Sand, reddish gray, laminated	20
Total section measured	87

Sedimentology.—The Carrizo sand, for the most part, is a continental deposit laid down by streams that dropped their loads on a flat coastal plain and built up a broad alluvial apron all along the coast. Several factors operated to bring about deposition of a sand sheet so widespread. The Sabinetown sea of the late Wilcox epoch withdrew, and increased rainfall furnished floods of water to the valleys. The continental base-level was brought down to the position of the Paluxy and Trinity sands. The capping limestones had been cut by erosion, and large quantities of unconsolidated sand were transported seaward by the floods and spread broadcast

[107]Trowbridge, 1613a, p. 61, 1932.

[108]Measured by A. Deussen, 421, p. 60, 1924.

by the streams along the present coastal plain. The epoch ended by a slow return of the sea, a decrease in the gradient of the streams, and a slow replacement of the continental deposits by shallow-water, marine sediments of the Reklaw formation.

Lithology.—The Carrizo formation consists of about nine-tenths medium-grained sand and one-tenth sandy clay. No lignite has been definitely reported from this formation in northeast Texas, but the sand contains carbonaceous material and plant leaves in many places. The sand in some places contains considerable ferruginous material, which lends a brilliant color to the outcrop and life to the soils.

The basal strata of the Carrizo are composed chiefly of rounded and subangular quartz grains that average about one millimeter in diameter. In places these grains are cemented by ferruginous matter to form concretions. The upper strata are slightly finer grained, less ferruginous, and more uniformly textured. In some places they contain lentils of yellow, ferruginous clay.

Lonsdale and his assistants (**1013c**, pp. 77–81, 1931) have investigated the microscopic characters and mineral composition of the Carrizo sands. They find about four-fifths of the grains are subangular and the minerals comprise the following in order of abundance:

Low-gravity minerals	High-gravity minerals
Quartz	Leucoxene
Microcline	Ilmenite
Plagioclase	Magnetite
Glauconite	Tourmaline
	Zircon
	Staurolite
	Rutile
	Muscovite

Distinguishing characteristics.—The distinguishing characteristics of the Carrizo strata are:

1. Texture. The sand is slightly coarser than that of the Wilcox strata. The size of the grains ranges up to 2 mm. in diameter, whereas the Wilcox grains are rarely larger than .3 mm.
2. Stratification lines. The Carrizo strata are thicker, more massively bedded, more conspicuously cross-bedded, and they contain a larger proportion of sand beds in the outcropping section than do the average Wilcox strata below or the Reklaw above.

3. Color. The Carrizo shows more mottling of red and buff shades in its exposures than does the underlying Wilcox. It is less intense a red and has fewer limonitic stains and less ferruginous matter than the overlying Reklaw.

Paleontology.—No vertebrate fossils have been reported from the Carrizo formation. Plant leaves and stems are found in a few places, but most of these are very poorly preserved. The plants listed by Berry (**105a**, pp. 3, 4, 1922) from the Carrizo in south Texas are thought to belong in overlying strata.

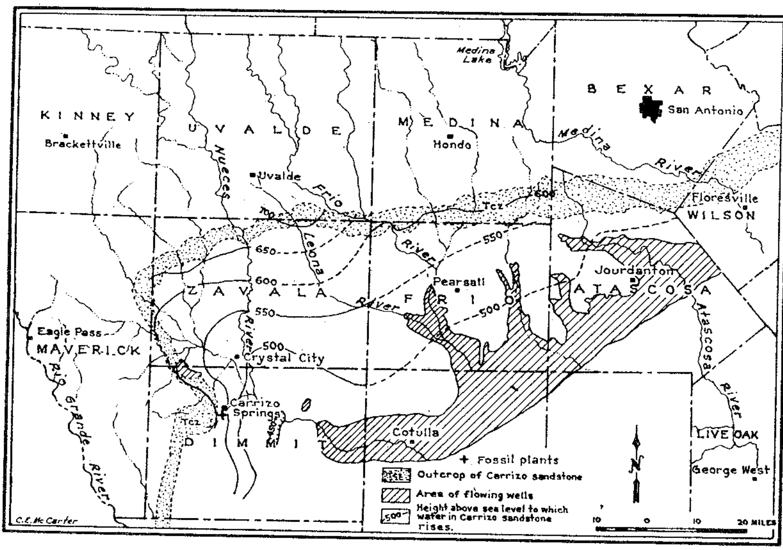

Fig. 39. Outcrop of the Carrizo sand in southwest Texas and area to which it furnishes abundant artesian water (after Lonsdale, Robinson, Turner, and Sayre, 1013b, map 3, 1931).

Correlation.—The correlation table of Claiborne formations in the Gulf Coast area (fig. 40) and the section along the Gulf Coast (fig. 41) show the Carrizo sand as the equivalent of the lower part of the Tallahatta formation of Mississippi and Alabama.

Economic resources.—The chief economic resources of the Carrizo are its underground-water supply and its glass sand.

Water occurs in the formation throughout its extent, and most farms located south of its outcrop derive their water supply from its beds. In the southwestern Texas area, according to Lonsdale and associates (**1013b**, p. 3, 1931) waters from the Carrizo are used extensively for irrigation. More than five hundred pumping plants and artesian wells, most of which obtain their supply from the Carrizo, are in operation and altogether 29,000 acres of land are irrigated in this way. The water-bearing stratum has an average thickness of 200 feet. The belt in which the sandstone can be reached within a depth of a thousand feet has an average width of fifteen miles (fig. 39). The average permeability is about 200 gallons a day through a cross section a foot high and a mile wide with a gradient of one foor per mile, or 24,000,000 gallons per day for the pumped districts of Zavala and Dimmit counties. When the value of all this water to the crops and cattle in a region of low summer rainfall is considered, it will be found that this resource in the long run ranks as high in value as the lignite in the Wilcox or the oil in the Jackson.

The Carrizo sand occurs in sufficient purity in some places to make glass. The quartz fuses to produce clear, green glass suitable for the manufacture of bottles, vases, and other articles. A factory established at Three Rivers, Live Oak County, procures its sand from Haiduk Switch on the San Antonio, Uvalde and Gulf Railroad in the north edge of Atascosa County. It is manufacturing glass successfully on a large scale.

REKLAW FORMATION[109]

Definition.—The Reklaw formation was named by E. A. Wendlandt and G. M. Knebel (**1728**, p. 1352, 1929) to designate the strata in east Texas below the Queen City and above the Carrizo sand. Trowbridge (**1610**, p. 92, 1923) had given the name Bigford to certain clay strata south of Carrizo Springs which he supposed to be a portion of the Wilcox group. Miss Gardner (**396c**, 1932) regards the Bigford as contemporaneous with, but not exactly equivalent to, the Reklaw and has preferred to retain Trowbridge's name in place of Reklaw for strata immediately above the Carrizo southwest of Atascosa County. Trowbridge (**1610**, p. 92, 1923) defined Bigford as follows:

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[109]LITERATURE—Trowbridge, A. C., 1610, p. 92, 1923. Ellisor, A. C., 523, p. 1342, 1929. Wendlandt, E. A., and Knebel, G. M., 1728, p. 1352, 1929. Renick, B. C., and Stenzel, H. B., 1299, pp. 83–84, 1931. Trowbridge, A. C., 1613a, pp. 65–80, 1923.

> South of Carrizo Springs the sand and sandstone of the Carrizo give place along the strike to clay, thin-bedded sandstone, and lignite. To these beds, which consist so largely of clay that they are not to be called Carrizo sandstone, the name Bigford is here given.

The description as well as the map accompanying Trowbridge's report indicates clearly that Trowbridge intended Bigford to be a facies of the Carrizo—simply a change from sand to clay along the strike. On the map by Trowbridge (**1610**, pl. 28, 1923) the Carrizo merges abruptly into Bigford 8 miles due south of Carrizo Springs. The line drawn between the Bigford and Carrizo by Miss Gardner is only 1 mile southeast of Carrizo Springs. Accordingly, Miss Gardner has amended and expanded the Bigford formation of Trowbridge, in order to make it a valid formation and has separated it from the Carrizo. The Nueces Valley embayment was shallower than the east Texas embayment, received some sediments from a north Mexico land mass as well as from the northern sources, was so elevated at certain times that the sea withdrew, and continental sand and palustral coal beds were interbedded with marine strata. Such local conditions produced deposits in south Texas somewhat different from those in east Texas. It seems, however, unnecessary to use two names for contemporaneous strata, even though they are lithologically somewhat different. Since the name Reklaw has priority over the amendation of Miss Gardner, and since it is in established usage by geologists[110] of the state, it is preferable to adopt it exclusively, if possible.

The type locality of the Reklaw formation is the section along the Texas and New Orleans Railroad 1 mile east of Reklaw in Cherokee County.

Regional geology.—The surface exposure of the Reklaw formation is typically a gentle, rolling, mature topography characterized by red soil. The outcrop is less rugged and less forested than the Carrizo or Queen City and may be described as a red prairie belt between two broad, oak-forested ridges. The Reklaw formation has two belts of outcrop in Texas. One extends around the west flank of the Sabine uplift from the northwest corner of Marion County southwest to western Rusk County, thence southeast to the Louisiana line in east-central Sabine County (**1728**, p. 1349, 1929). The

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[110]Renick, B. Coleman, and Stenzel, H. B., **1299**, p. 83, 1931. Levorsen, A. F., **987a**, p. 263, 1931. Warner, C. A., **1709a**, p. 48, 1932.

other extends from Sulphur River on the Arkansas line southwestward to the southeast corner of Van Zandt County, thence southward to Navasota River in western Leon County and across central Bastrop and northwestern Wilson counties to Atascosa County. Southwestward from Atascosa River to the Rio Grande the strata belonging to this formation are more sandy, less lignitic, and, although contemporaneous, are thought by Miss Gardner[111] to differ sufficiently lithologically to make the exact relationships of her Bigford strata with the Reklaw of east Texas uncertain. As now represented on the geologic map of Texas (**396c**, 1932) the belt of outcrop of the Bigford is much wider than that of the Reklaw in east Texas and extends across northern Frio, western Zavala, and western Dimmit counties to northwestern Webb County. The average width of the outcrop in northeast Texas is 1½ miles, but in the Rio Grande district the outcrop widens, if correctly mapped, to 12 miles or more. Throughout its extent from Louisiana to Atascosa River the Reklaw is a distinctive and easily distinguishable formation, which deserves more recognition and more detailed study than it has received in the past.

The subsurface contacts of the Reklaw in well logs and sets of well samples are not determined so easily as the boundaries of the surface outcrop. In the area immediately south of its outcrop the formation can be recognized as clay strata between two prominent sandstone zones. Farther south at a distance of 50 or 75 miles from the outcrop the sands above and below merge into marine sandy clays, change in character, and lose their identity so that the Reklaw beds can be distinguished only by their microfossils, which are so similar to the fauna of the Weches formation that the limits of the formation cannot be marked accurately in most wells.

The thickness of the Reklaw varies from 80 feet in central Texas to 700 feet or more in the Rio Grande district. The few records where authentic measurements of the thickness have been obtained are shown in the following table:

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[111]Miser, H. D., Personal communication to E. H. Sellards, August 4, 1932.

LOCALITY	COUNTY	THICKNESS Feet	AUTHORITY
Thompson No. 1, Humphreys Corp.	Cherokee	142	Wendlandt and Knebel
Brazos River Valley	Robertson	60–100	B. C. Renick
Core test near Troup	Smith	75	A. C. Wright
Core test	Cherokee	80	Do
Bonner No. 1-A, core test, Wm. Elliott Surv.	Angelina	125	Wendlandt and Knebel
So. Pine No. 4-A, core test, Humble O. & R. Co.	Houston	180	Alva Ellisor
So. Pine No. 1-A, core test, Humble O. & R. Co.	Trinity	150	Do
Renfro No. 1, Simms Oil Co.	Angelina	95	Do
Generalized section	Zavala	700–800	F. M. Getzendaner
Oppenheimer No. 1, Amerada Pet. Co.	Frio	650	MacNaughton
J. H. Strickling core test, D-395	Leon	53	Wm. Penn

Stratigraphy.—The Reklaw formation rests conformably upon the underlying Carrizo sand and is overlain conformably by the Queen City sand.

In Cherokee County and in some other places in east Texas the lower contact is marked by a thin, dark-green glauconite bed in the base of the Reklaw, and in many places this bed contains large numbers of *Venericardia planicosta* Lamarck. Where this bed is not present the contact is marked by an abrupt downward change from the glauconitic Reklaw sand to laminated yellowish clay typical of the Carrizo. The upper contact is marked by an abrupt change from yellow, ferruginous clay to medium-grained sand.

In southwest Texas the Reklaw-Carrizo contact is less sharp. In the Rio Grande area the contact is drawn where the strata change upward from predominately sandy to predominately clayey. The contact of the Reklaw with the Queen City formation is likewise indefinite, because the typical sandy layers that mark the overlying beds in east Texas are not so characteristically developed in southwest Texas, and exposures are fewer. Where contacts can be observed the division is made where the clays give place upward to glauconitic, cross-bedded, sandy layers.

The Reklaw formation has not been subdivided into small units, nor have its individual layers been studied or carefully traced in the field. In east Texas it appears to consist of a single unit of clay containing thin glauconite beds, and some lignite. The character of the strata of the Reklaw formation is shown in the following sections:

Section[112] of Reklaw formation in the Thompson No. 1 core test drilled by Humphreys Corporation in the northeast corner of William F. Williams Survey, Cherokee County, Texas.

	Thickness *Feet*
Shale, gray with laminae of sand and a few thin layers of glauconite	5
Shale, brown with laminae of sand and stringers of glauconite containing fossil casts	20
Shale, brown with laminae of sand, clay, ironstone concretions, and casts of fossils	1
Glauconite, impure, sandy, containing a few fossils	4
Shale, brown, containing some sand and a few fossils	8
Shale, brown, sandy, fossiliferous, containing thin stringers of glauconite	10
Shale, brown, sandy with lenses of glauconite containing echinoid spines and other fossils	15½
Shale, gray, containing small fossils	32½
Glauconite, containing Bryozoa and many other fossils	13
Shale, brown, fossiliferous, having laminae of gray sand	5
Shale, brown, containing lenses of glauconite	10
Shale, brown, sandy, fossiliferous	6
Shale, brown, sandy, containing stringers of glauconite	19
Total thickness measured	149

Section of the Reklaw formation (499 to 552 feet) in core test D-395 on the J. H. Strickling farm, S. J. West Survey, by Shell Oil Company and Penn Oil Company, Leon County.

	Thickness *Feet*
Clay, chocolate-colored, containing some greensand	7
Clay, chocolate-colored, sandy, containing some greensand, concretions, and fossils near the top and bottom	15
Greensand, clayey, containing concretions at bottom	13
Greensand, clayey	2
Clay, chocolate-colored, with greensand, few fossils and concretions	14
Greensand, clayey	2
Total thickness	53

[112]Described by Wendlandt and Knebel, 1728, p. 1354, 1929.

Sedimentology.—The sediments of the Reklaw formation were deposited in shallow water along a flat-lying or gently inclined coastal plain. In the east Texas embayment and in central Texas most of the sediments accumulated slowly in marine water not over 15 fathoms deep. In the south Texas area the waters were shallower, and during some of the time at least palustrine conditions existed and peat accumulated in swamps and lagoons that later became interbedded in the clay and silts, some of which are nonmarine. The chief distinction in sedimentation between the Reklaw and Carrizo and Queen City appears to be less clastic deposition due to less rainfall or lower stream gradients. During the Reklaw epoch much less sand was washed into the sea, the land was probably somewhat lower, and marine waters advanced farther landward in the embayments, working over and burying the Carrizo sands with finer sediments. The strand line appears to have oscillated somewhat, because in several areas, especially in the Rio Grande district, lignite beds occur within marine sediments.

Lithology.—The Reklaw formation in east Texas consists of about 90 per cent glauconitic clay, 8 per cent glauconitic sand, and 2 per cent impure lignite. The section consists essentially of stratified clay made up of thin beds of glauconitic, black, sandy clay, green glauconitic clay, and gray and yellow gypsiferous clay. The formation is marine in the embayment areas and partly nonmarine in the intervening areas.

In south Texas the formation consists of about 70 per cent gray, brown, yellow, and red clay interbedded with 25 per cent of gray, green, and brown laminated, fine-grained sandstone and 3 to 5 per cent brown lignite. Samples of the sand examined under the microscope do not have grains larger than .589 mm. They are subangular and contain a larger percentage of glauconite than either the Queen City or Carrizo sand.

Distinguishing characteristics.—The Reklaw formation can be distinguished from the adjacent formations by the following criteria:

1. Deep red color of its soils.
2. Larger percentage of clay in its section.
3. Finer-grained, more glauconitic sand, the grains never over 0.6 of a mm. Grains from Carrizo in many places up to 2 mm. in size.

4. Fossils. In most places fossils are less numerous and smaller than those in the Weches and Crockett.
5. Interbedded lignites are less pure and browner than the lignites in the Rockdale formation.
6. Glauconitic layers are thinner and less prevalent than are those in the Weches or Crockett formation.

Paleontology.—The first fossils from the Reklaw were named by Heilprin (701, pp. 393–406, 1891) from a collection of fossils sent him by R. A. F. Penrose, Jr., collected from Devil's Eye, a shoal in Colorado River about 8 miles southeast of Bastrop in Bastrop County. Since the time of Penrose very little work has been done on the paleontology of this formation.

The beds are not very fossiliferous. Most of the fossils are in the form of casts or molds, which are poorly preserved and difficult to identify. The fauna, as it is known from the collections obtained in the Colorado River valley, is characterized by small size of the fossils, predominance of gastropods, absence or scarcity of oysters, and small number of species of pelecypods. The most common forms are:

Venericardia planicosta Lamarck
Volutocorbis petrosa (Conrad)
Cornulina armigera (Conrad)
Surcula gabbi Conrad
Corbula sp. cf. C. smithvillensis Harris

The complete fauna has not been studied or collected at all systematically. The specimens from authentic localities in the Reklaw which have been identified[113] and deposited in the Bureau of Economic Geology are as follows:

Dump at side of old "copper" prospect. Alsobrook land, Pullen Survey, 4½ miles northeast of Harwood, Caldwell County.

Ancilla staminea (Conrad)
Cancellaria sp.
Latirus aff. L. moorei (Gabb)
Murex sp.
Natica sp.
Pleurotoma cf. P. texanopsis Harris
Pleurotoma carlottae Harris
Sigaretus sp.
Turritella n. sp.
Turris cf. T. moorei (Gabb)
Glycimeris sp.
Venericardia cf. V. densata Conrad
Corals, 3 spp.

[113]Identified by F. E. Turner, Museum of Paleontology, University of California.

*Chrysodomus sp.
*Fusus venustus Lea var.
*Fusus aff. F. altonis Lea var.
*Pleurotoma sp.
*Pleurotoma penrosei Harris var.
*Ancilla staminea (Conrad)
*Turris cf. T. moorei (Gabb)
*Plejona haleana (Whitfield) var.
*Solarium elaboratum Conrad var.

*Occur also at Burleson Bluff on Brazos River.

Marine fossils are rare in the Reklaw strata in south Texas. Sandstones containing plant leaves and lentils of coal carrying a swamp flora are found. Berry collected plant fossils from a deep arroyo 1½ miles south of the La Pryor crossing of Nueces River in Dimmit County and from a sandstone quarry one-half mile west of Carrizo Springs in the same county. These two localities, originally described as Carrizo, are now regarded by geologists working in southwest Texas as Reklaw. The following species have been listed by Ball (58, p. 21, 1931):

Banksia puryearensis Berry
Eugenia grenadensis Berry
Gleditsiophyllum eocenicum Berry
Mespilodaphne coushatta Berry
Myrcia vera Berry
Persea lonngipetiolata (Hollick)
Sabalites grayanus Lesquereux
Anona ampla Berry
Anona wilcoxiana Berry
Canavalia eocenica Berry
Cassia tennesseensis Berry
Cinnamomum vera Berry
Dryophyllum tennesseense Berry
Ficus mississippiensis (Lesquereux)
Nectandra pseudocoriacea Berry
Oreodaphne obtusifolium Berry
Oreodaphne puryearensis Berry
Palmocarpen butlerensis Berry
Pterobalanus texanus Berry
Sophora wilcoxiana Berry
Sterculia wilcoxensis Berry

Correlation.—As shown by figure 40), the Reklaw is correlated with the lower portion of the Cane River sand of Louisiana and with the middle portion of the Tallahatta of Mississippi and Alabama.

<table>
<tr><th>EAST TEXAS</th><th>LOUISIANA</th><th>MISSISSIPPI</th><th>ALABAMA</th></tr>
<tr><td colspan="3">Cockfield</td><td>Gosport</td></tr>
<tr><td>Crockett</td><td>Cook Mt</td><td>Wautubbee</td><td rowspan="3">Lisbon</td></tr>
<tr><td colspan="2">Sparta</td><td>Kosciusko</td></tr>
<tr><td>Weches</td><td rowspan="4">Cane River</td><td>Winona</td></tr>
<tr><td>Queen City</td><td colspan="2" rowspan="3">Tallahatta</td></tr>
<tr><td>Reklaw</td></tr>
<tr><td>Carrizo</td></tr>
</table>

Fig. 40. Correlation table of the Claiborne formations in the Gulf Coast area.

Economic resources.—The only natural resources in the Reklaw are its rich acid soils and its lentils of lignite and coal. The Reklaw lignite and coal occur in south Texas only. Getzendaner (578a,

p. 117, 1931) records a thin bed of lignite along Nueces River southeast of La Pryor in the upper part of the Reklaw and states that samples from many widely distributed wells show that the lignite occurs rather generally throughout Zavala County.

The excellent deposits of cannel coal described by Dumble (**470**, pp. 188–190, 1892), Vaughan (**1687**, pp. 1–88, 1900), and Ashley (**36**, pp. 251–270, 1918) in Webb County occur in the upper part of the Reklaw formation in Nueces Valley. This is the best deposit of cannel coal in Texas and has been known and mined intermittently since 1830. The first mines were located northwest of Espandilla Creek near Santo Tomas in Webb County. The mines near Minera were opened up in 1881, and those near Darwin in 1895. At present one mine is operating.

The cannel coal occurs in two seams about 90 feet apart stratigraphically. The upper, or Santo Tomas bed, is from 24 to 36 inches thick; the lower, or San Pedro bed, averages 24 inches. The coal outcrops along the small creeks that flow into the Rio Grande and has been penetrated by drill holes over an area ten miles long and about one and one-half miles wide extending along the Rio Grande from Parafox to Dolores. The coal is bright, glossy black, breaks with conchoidal fracture, has a brilliant luster, is as hard on the average as bituminous coal, and does not deteriorate and dehydrate like the lignites. The average of ten analyses of this coal is as follows:

	Per cent
Moisture	4.4
Volatile matter	40.6
Fixed carbon	34.1
Ash	19.5
Sulphur	2.6

According to tests made by the U. S. Bureau of Mines (**36**, p. 260, 1918), a ton of Santo Tomas coal yields upon low-temperature distillation 52 gallons of oil of .938 specific gravity, and 5.672 cubic feet of gas at 760 mm. pressure. The loss in weight during distillation amounts to 44.3 per cent. This yield is better than the yield of the cannel coal at Cannelton, Pennsylvanian, which has been used successfully in the production of oil. The coal is especially well adapted for this purpose, both because of its quality and its proximity to gas fields for fuel to use in heating the retorts. If the oil produced is subjected also to the hydrogenation process, gasolene, toluol, and other valuable products can readily be made. When the production of petroleum declines, this will doubtless be one of the first fuel reserves in south Texas to be utilized.

QUEEN CITY FORMATION[114]

Definition.—The name Queen City was given by Kennedy (**905**, p. 50, 1892) to a "series of laminated or thinly stratified, white and red sands and sandy clays" at the top of the Lignitic beds, which outcrop typically in the neighborhood of Queen City, Cass County. Dumble (**506**, p. 61, 1918) regarded the sand as the equivalent of the Carrizo sand of south Texas and placed it at the base of the Claiborne group and designated it as a separate formation under the name Carrizo. Deussen (**415**, p. 44, 1914) retained the name Queen City and provisionally placed it as a member of the Wilcox formation. He noted the occurrence of the sand at a number of localities in east Texas, but did not attempt to map the outcrop. Wendlandt and Knebel (**1728**, p. 1355, 1929) were the first geologists to map the outcrop across east Texas and adequately describe the strata. They treated it as a member of the Mount Selman formation of the Claiborne group. Miss Ellisor (**523**, p. 1342, 1929) correlated the Queen City with strata in Louisiana and described them as divisions of the Claiborne group, thus giving the sands the rank of a separate formation. Renick and Stenzel (**1299**, p. 84, 1931) followed Miss Ellisor's usage. Miss Gardner (**396c**, 1932) traced the outcrop of the Queen City formation from the Rio Grande to the Texas-Louisiana boundary and proved that the Queen City sands are younger than, and stratigraphically above, the Carrizo formation.

The type locality for the Queen City formation is the series of exposures in the vicinity of Queen City, Cass County. Other good outcrops are along the bluffs of Brazos River from Burleson Bluff in northeastern Burleson County upstream for several miles.

Regional geology.—The outcrop of the Queen City formation produces a gently rolling, mature type of topography of slightly more relief than that of the underlying Reklaw and is occupied

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[114]LITERATURE—Kennedy, William, **905**, p. 50, 1892. Dumble, E. T., **506**, pp. 61–64, 1918. Deussen, A., **415**, p. 44, 1914. Ellisor, A. C., **523**, p. 1342, 1929. Wendlandt, E. A., and Knebel, G. M., **1728**, p. 1335, 1929. Renick, B. C., and Stenzel, H. B., **1299**, p. 84, 1931

largely by pine and oak forests. The sandy and light grayish-brown soils of the Queen City resemble those of the middle sand member of the Rockdale and the fine-grained soil of the Carrizo. The surface exposure occupies the trough of the east Texas geosyncline except in the structurally lowest areas where it is overlain by younger Claiborne strata. The Queen City has the largest areal extent of any formation except the Rockdale. It extends southward from Cass County over most of southern Morris, southern Camp, and most of Upshur and Gregg counties and outcrops in eastern Smith and northern Cherokee counties. Its outcrop stretches southward in a belt 15 to 20 miles wide from northeastern Wood County to central Leon County. In southern Leon County the outcrop narrows to five miles and continues southwestward through eastern Bastrop County to the western corner of Wilson County. Southwestward from here its facies changes; it loses its identity and merges with the sandy section of the lower Claiborne. This series of strata continues southward through Frio and LaSalle counties to the Rio Grande west of Laredo in Webb County. South of its outcrop it dips beneath the surface and can be traced in well sections for 50 to 75 miles, though its contacts in subsurface section are difficult to recognize in south Texas.

The thickness of the Queen City ranges from 80 to 400 feet and varies considerably in short distances due either to actual thickening or to a merging with sandy beds in overlying formations. In general, its thickness is greatest in the east Texas basin and in the Nueces basin and is least on the flanks of the bordering monoclines. It thins in central Texas south of the Llano uplift. Typical measurements of its thickness are shown in the following table:

LOCALITY	COUNTY	THICKNESS *Feet*	AUTHORITY
Outcrop section, vicinity of Queen City	Cass	65	William Kennedy
So. Pine No. 4, Humble O. & R. Co.	Houston	125	Alva Ellisor
Thompson No. 1, Humphreys Corp.	Angelina	331	Wendlandt and Knebel
Bonner No. 1-A, Humble O. & R. Co.	Cherokee	122	Do
Christian No. 1, Amerada Pet. Corp.	Smith	262	R. A. Denison

LOCALITY	COUNTY	THICKNESS *Feet*	AUTHORITY
Core test, 4 mi. E. of Rusk	Cherokee	350	A. C. Wright
Core test near Buffalo	Leon	370	Do
Outcrop section, Brazos River Valley	Robertson	225	Renick and Stenzel
J. H. Strickling core test	Leon	453	Wm. Penn

Stratigraphy.—The Queen City formation overlies conformably the Reklaw clays and is overlain probably disconformably by the Weches glauconite. The contact with the underlying Reklaw is taken as the plane where the predominatingly sand strata are replaced by clay beds containing glauconite and traces of fossils. In well sections most geologists[115] place the top of the Reklaw where the first marine fossils occur below the thick sand section of the Queen City. The upper contact of the Queen City with the Weches is the plane where the nonmarine, cross-bedded sands change abruptly upward to thick, nearly pure glauconite beds.

The Queen City formation in the geosynclinal area of east Texas consists of three members as follows:

3. Upper member. Thin-bedded, cross-bedded sand containing in its upper 100 feet two layers of bentonite, and two layers of brown lignite in its lower 100 feet. The total thickness is 200 to 230 feet.
2. Omen greensand member. Named for the town of Omen in Smith County by MacNaughton.[116] It extends from Harrison, through Gregg, northwestern Rusk, eastern Smith, and eastern Cherokee counties. It is a dark-green and black, partly cross-bedded, friable, sandy, unfossiliferous glauconite 10 to 15 feet thick.
1. Lower member. Gray and brown sand and gray sandy shale with irregularly shaped lentils of sand. This member is from 140 to 150 feet thick.

The Queen City formation in central Texas, where the sandy beds are thinner, has not been subdivided into members. The unit, however, is well developed and can be traced and mapped easily as far south as Atascosa River. From Atascosa County southwestward in southwest Texas the Queen City sands merge into a sandy facies of

[115]Thomas, N. L., Personal communication.

[116]Private report written for Humble Oil and Refining Co., Feb. 10, 1929. The name was published by Wendlandt and Knebel (1728, pp. 1348, 1355, 1929).

the lower Claiborne, exposures are poor, and that part of the Claiborne section occupied by the Queen City has not been differentiated sufficiently to permit definite correlation of the strata with the east Texas section. The stratigraphy of the formation, where it has been studied in detail, is shown in the following sections:

Section of Queen City formation measured along the Texas and Pacific Railroad, one-quarter of a mile east of Mineola, Wood County.

	Thickness *Feet*
7. Clay, sandy, yellow and mottled	1½
6. Sand, yellow and red mottled	4
5. Sand, gray, well stratified	2
4. Unexposed	?
3. Sand, brown, cross-bedded, medium grained	4
2. Sand, gray, interstratified with purplish-colored lentils of clay	20
1. Sand, blue and gray, well stratified	2
Total section measured	33½

Section of the Queen City sand (46 to 499 feet) in the core test D-395 on the J. H. Strickling farm, S. J. West Survey, by Shell Oil Company and Penn Oil Company, Leon County.

	Thickness *Feet*
Clay, brown, sandy at top	7
Clay, brown	4
Sand, loose (core lost)	6
Clay, brown, sandy	20
Clay, brown, sandy, some brown sand, trace of greensand	10
Sand, loose (core lost)	10
Sand, light (lost 8-foot core)	10
Sand, light (lost 8-foot core)	10
Sand, loose	277
Clay, gray, sand partings at top, slightly lignitic (portions of core lost)	35
Clay, dark gray, with some light sand, slightly lignitic, few fossils	6
Clay, sandy, chocolate-colored, few fossils, trace of greensand (lost 2-foot core)	9
Clay, sandy, chocolate-covered, trace of greensand	4
Clay, gray, little sandy claystone at base	8
Clay, gray, somewhat sandy	3
Clay, gray and chocolate-colored (lost 2-foot core)	15
Clay, gray and chocolate-colored	5

	Thickness *Feet*
Clay, chocolate-colored (lost 2-foot core)	8
Clay, dark gray	6
Clay, sandy, gray	2
Total thickness	453

Section[117] of Queen City sand from the log of the Humphreys Corp. Thompson No. 1 core test, northeast corner of W. F. Williams Survey, Cherokee County.

	Thickness *Feet*
Sand and silt, brown	20
Sand, loose (no core obtained)	10
Glauconite in thin layers	4
Shale, brown, containing cross-bedded laminae of gray sand and stringers of glauconite	19
Sand, clay, and shale, containing plant remains	4
Sand, gray, micaceous, containing much silt and a few thin layers of shale	18
Sand and shale, brownish gray, laminated	20
Sand, gray	40
Sand and shale, containing plant remains	10
Sand, gray, silty	10
Sand, loose (no core obtained)	95
Clay, gray, with irregular lenses of gray sand containing plant remains	3
Shale, brown, containing irregular lenses of sand and thin stringers of impure glauconite	10
Shale, brownish gray, containing laminae of sand	10
Clay, gray, containing a few layers of brown clay and gray sand	13
Shale, gray, containing laminae of sand	10
Shale, brown, containing laminae of sand	16
Sand, loose (no core obtained)	4
Total thickness	316

Section of Queen City formation from the log[118] of Humble Oil and Refining Company's J. L. Bonner No. 1-A, northwest corner of Wm. Elliott Survey, Angelina County.

	Thickness *Feet*
Sand	71
Shale, sandy	8
Shale, gray, sticky, with streaks of sandy shale	9

[117]Wendlandt, E. A., and Knebel, G. M., 1728, p. 1354, 1929.
[118]Wendlandt, E. A., and Knebel, G. M., 1728, p. 1357, 1929.

	Thickness *Feet*
Shale, gray, sticky	31
Sand	3
Total thickness	122

Sedimentology.—The Queen City formation is largely a continental fluviatile deposit laid down by meandering and shifting rivers on a flat coastal plain. The strata merge gulfward with shallow-water beds that were in a part laid down in marshes and bays, in which plant detritus was abundant, and in part were delta deposits in shallow waters. The glauconitic lentils may have been washed in from eroded Midway and Reklaw strata or may have originated in shallow marine waters. The glauconite, however, does not contain diagnostic foraminifera and larger fossils to support or deny either hypothesis. According to Wendlandt and Knebel the formation is thickest in the middle of the east Texas trough and thins toward its edges. It may be regarded as having been deposited, in part at least, as the result of renewed deposition resulting from rejuvenation of streams following the elevation of the land area at the end of the Reklaw epoch. It is not, however, entirely confined to the trough, but stretches southwestward across south-central into southwest Texas.

Lithology.—The Queen City formation consists of about 70 per cent sand, 22 per cent sandy silty clay of shale, 1 per cent lignite, 1 per cent bentonite, and 5 per cent glauconite. The sand is light gray, cross-bedded, and composed of medium to very fine-grained quartz with a small proportion of other minerals. It resembles some of the Wilcox sands, except that mineral analysis reveals more glauconite. It is slightly finer grained than the Carrizo sand. The clay and sandy shale beds are lenticular, brown, impregnated with some organic matter, and in many places contain some sand and silt as thin laminae or as layers and thin lentils. The lignite consists of a layer of brown, impure, lignite or very carbonaceous brown silt from 8 to 12 inches thick, occurring about 160 feet below the top of the formation. It is geographically restricted and has not been observed in wells outside the east Texas trough. The bentonite consists of thin layers of impure volcanic ash, which occurs about 100 feet below the top of the formation. Most of the glauconite is confined to the lower third of the formation. One layer, named the Omen member, lies about 200 feet below the top of the formation. In the middle of the trough it has a thickness of 10 feet and consists of impure, cross-bedded, fine-grained, black and green glauconite grains mixed with sand.

Distinguishing characteristics.—The Queen City sand is distinguished by its position above the red sandy clays of the Reklaw and below the red ferruginous glauconitic beds of the Weches. Its surface outcrop of thick, gray sand resembles the sand layers in

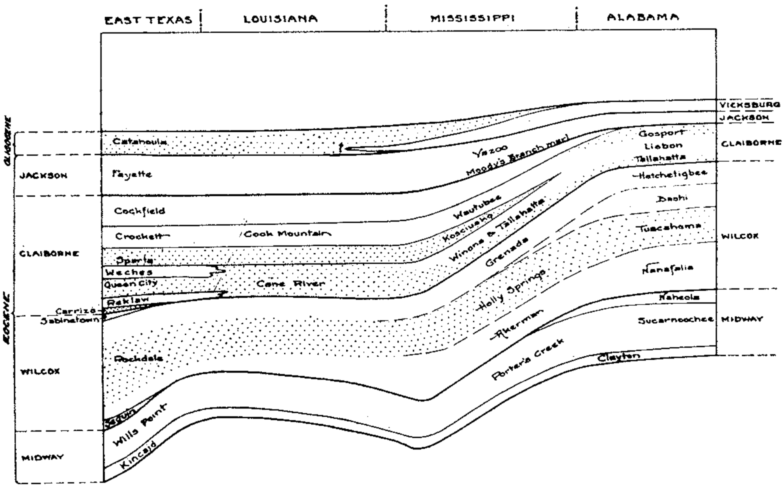

Fig. 41. Section along the Gulf Coast showing relationships of Eocene formations (adapted from Moody, 1125, p. 542, 1931).

the Wilcox below and the Sparta above. In some parts of its section it has more glauconite than either the Wilcox or the Sparta sands. It is thicker than the Sparta and somewhat more cross-bedded. In most places it contains less lignite, less carbonaceous clay, and fewer concretions than the typical Wilcox beds. It is somewhat finer textured than the Carrizo sand.

Paleontology.—No invertebrate fossils have been reported from the Queen City formation. The carbonaceous clays in places contain a large assemblage of plant leaves, which in some places are well preserved. These have not been collected systematically or identified, so far as known.

Correlation.—The stratigraphic position of the Queen City above the Reklaw and below the Weches suggests a correlation of this sand with part of the Cane River of Louisiana, the lower part of the Winona of Mississippi, and the lower Lisbon of Alabama (fig. 41).

Economic resources.—The only economic resource of importance in the Queen City formation is underground water. The sand throughout east Texas and south-central Texas carries an abundance of pure water that furnishes good supplies to farms and small towns located south of its outcrop.

WECHES FORMATION[119]

Definition.—The name Weches was proposed by Wendlandt and Knebel (**1728**, p. 1356, 1929) to designate the prominent middle glauconite bed between the Queen City and Sparta sands of the Claiborne group, and it has been adopted by the U. S. Geological Survey for these beds, as shown on the new geologic map of Texas. Veatch (**1688a**, p. 127, 1902) referred to strata carrying a similar fauna, regarded as belonging to this formation, as Low Creek beds named for Low Creek south of Sabinetown, Sabine County. Deussen (**415**, p. 56, 1914; **421**, p. 66, 1924) and Dumble (**506**, p. 66, 1918) described this glauconite bed in a number of localities as a member of the Cook's or Cook Mountain[120] formation. Renick (**1298**, p. 531, 1928) referred to this bed as the San Augustine member of the Cook Mountain formation. Dumble (**510**, p. 428, 1924), however, had already used San Angustine as a group name to replace Kennedy's old term "Marine" to include all strata from the top of the Wilcox group to the base of the Yegua (Cockfield) and therefore Renick's name cannot be adopted. Miss Ellisor (**523**, p. 1341, 1929) used Wendlandt and Knebel's name in a paper on the correlation of the Claiborne group in Texas and Louisiana. Moody (**1125**, p. 536, 1931) designated these same strata Mount Selman, thus restricting the old definition and using it to include only strata between the

[119]LITERATURE—Dumble, E. T., **461**, pp. 303–326, 1891; **506**, pp. 67–70 (Sabine River section), pp. 75–80 (San Augustine section), pp. 88, 89 (Alto section), p. 90 (Hall's Bluff section), pp. 97–101 (Brazos River section), 1918. Burchard, E. F., **180**, pp. 69–109, 1915. Price, W. A., and Palmer, K. van W., **1275**, pp. 20–30, 1928. Ellisor, A. C., **523**, pp. 1341–1343, 1929. Wendlandt, E. A., and Knebel, G. M., **1728**, pp. 1356–1359, 1929. Cushman, J. A., and Thomas, N. L., **374**, pp. 176–184, 1929; **379**, pp. 33–41, 1930. Renick, B. C., and Stenzel, H. B., **1299**, pp. 84–91, 1931.

[120]For a discussion of the spelling of this name, see Wendlandt and Knebel, **1728**, footnote, p. 1359, 1929.

Queen City and Sparta sands. Renick and Stenzel (**1299**, p. 84, 1931) described the Weches in a paper on the lower Claiborne of Brazos River valley. The fossiliferous greensand comprising the Weches formation is now recognized generally as one of the most significant units of the Claiborne group. It is a persistent and easily recognized key bed for stratigraphic and structural mapping. Its glauconite and iron ores give it much economic importance.

The type locality of the Weches has not been definitely designated. Wendlandt and Knebel state, in their description of the formation, that iron ores of the upper beds of its section are well exposed in the Southern Pine Lumber Company's 75-acre tract in the W. F. Richardson Survey, 10 miles southeast of Palestine, Anderson County, and hence this might be regarded as the type locality. It is best known to geologists, however, at Alto, 10 miles northwest of Weches in Cherokee County, where it was described by Kennedy (**905**, pp. 105–108, 1892), and at its well-known outcrop at Smithville on Colorado River. Its lower beds are best exposed along Burleson Bluff of Brazos River near Collard's or Collier Ferry in the J. C. Robinson Survey in northeastern Burleson County, where it has been visited by geologists since the days of Penrose.

Regional geology.—The Weches formation is essentially a section of glauconite and glauconitic clay, characterized by beds of black and brown iron ore. The soluble ingredients of the glauconite leach out, and the iron becomes concentrated in the form of hematite, siderite, and limonite in the upper layers. The resistant ferruginous beds cap hills and escarpments throughout most of the area of its outcrop in east Texas and produce a picturesque, rugged topography of steep, high, flat-topped hills dissected by deep V-shaped valleys. In central and south Texas, in places where the iron ore has not been concentrated, the unconsolidated beds weather to form rolling, open prairies with fields of rich, red soil in striking contrast to the oak-covered sand that characterizes the outcrops of the Queen City and Sparta sands. The Weches outcrops as isolated hills or along slopes and ridges covered by the overlying Sparta on the stream divides along the middle of the east Texas geosyncline (fig. 42). The formation has been mapped also in a rather tortuous belt from Sabine River, south of Sabinetown, westward through San Augustine, Nacogdoches, Weches, Palestine, and Centerville to Burleson Bluff in the northeast corner of Burleson County, thence southwest to

Smithville on the Colorado, thence through Oak Forest in Gonzales County, south of Floresville in Wilson County, through Pleasanton in Atascosa County, to Derby in Frio County. In Frio County and southward through the Nueces and Rio Grande valleys the Claiborne strata above the Queen City have not been differentiated, and the exact course of the outcrop in southwest Texas is not known.

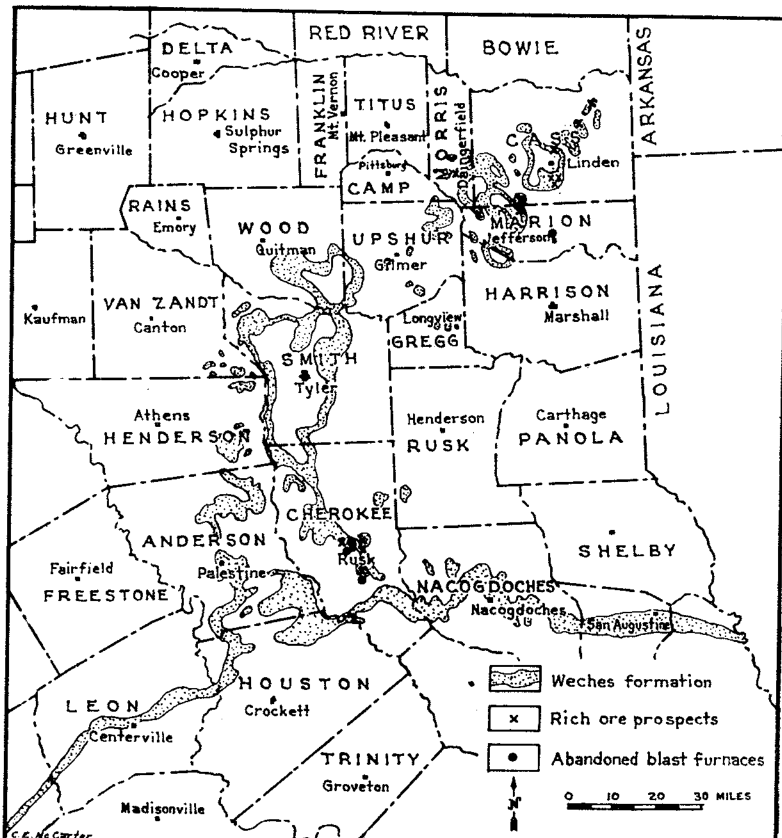

Fig. 42. Distribution of the Weches formation in east Texas (after Wendlandt and Knebel, 1728, fig. 1, 1929).

The average width of the outcrop from Sabine River to Trinity River is 5 miles, from the Trinity to the Brazos 2 miles, from the Brazos to the Colorado 1½ miles, and from the Colorado to San Antonio River 1 mile. The average thickness of the outcrop of the

Weches in east Texas is 50 feet; the thickness in central Texas is about 30 feet. In well sections south of its outcrop the thickness ranges from 50 to 150 feet. The measurements of thickness in various localities are shown in the following table:

LOCALITY	COUNTY	THICKNESS *Feet*	AUTHORITY
J. L. Bonner No. 1-A, Humble O. & R. Co., Wm. Elliott Survey	Angelina	70	Wendlandt and Knebel
Thompson No. 1, Humphreys Corp., W. F. Williams Survey	Cherokee	53	Do
South of Palestine	Anderson	73	MacNaughton
S. Pine No. 3-D, Humble O. & R. Co.	Houston	145	A. C. Ellisor
So. Pine No. 1-A, Humble O. & R. Co.	Trinity	150	Do
Brazos River section	Robertson	50–70	Renick and Stenzel
Rainey No. 1	Cherokee	55	N. L. Thomas
Outcrop, hill 15 mi. SE. of Buffalo	Leon	50	A. C. Wright
Outcrop, northeastern corner of county	Smith	50	Do

Stratigraphy.—The Weches formation is described as the marine, fossiliferous, glauconitic beds between the Queen City and Sparta sands. The base is taken as the contact of the fossiliferous glauconitic layer with the underlying gray, unfossiliferous sand. The basal contact in the east Texas basin and in the central Texas area is more or less conformable. In a few places, especially in Anderson County, a thin bed of glauconitic iron ore occurs at the base of the Weches at its contact with the Queen City and suggests an old weathered zone between the two formations, and Stenzel reports a slight unconformity in Burleson and Leon counties. The contact on the flanks of the Sabine uplift, especially in exposures along Sabine River valley, is unconformable. The greensand rests upon the Reklaw, and eastward it overlaps the Reklaw and lies upon the Carrizo. The upper contact of the formation is marked everywhere on the outcrop by layers of limonite and black, porous iron ore in contact with gray and buff sand belonging to the Sparta formation. In most places the contact appears to be conformable. Stenzel has observed a slight discordance at the top of the formation in Leon County.

The Weches formation in east Texas is made up of two divisions; (a) an upper division consisting of concretionary, ferruginous strata in which the glauconite has weathered and altered to iron ore, and (b) a lower bed containing more or less pure or clayey, fossiliferous glauconite free of quartz sand but interstratified with clay or marl. The same strata in central Texas between the Brazos and Colorado river valleys consist also of two divisions; (a) an upper division made up of impure glauconite containing some iron ore overlying a very pure, very richly fossiliferous glauconite containing large numbers of gastropods and having at its base a lentil of limestone, and (b) a lower division consisting of a layer of dark-gray or black glauconitic clay and a lower fossiliferous green sand containing large numbers of pelecypods and other fossils. The stratigraphy of the Weches in the different districts is best shown by the following described sections:

Section[121] of Weches formation on Sabine River about one mile above mouth of Low Creek a short distance south of Sabinetown, Sabine County.

	Thickness Ft.	in.
4. Limestone, dark green, filled with large grains of greensand and containing large numbers of *Pecten cornuus*[122] and crustacean remains	5	
3. Greensand, fossiliferous, oolitic, containing spots of green clay, which weathers red	7	
2. Limestone, green, containing small, rounded, greensand grains, weathers red		4
1. Clay, green, fossiliferous, containing much greensand	10	
Total section measured	22	4

Section[123] of Weches formation at Alto in southern Cherokee County.

	Thickness Feet
6. Iron ore, laminated, and brown sand	10–15
5. Sand, brown, yellowish brown, altered, glauconitic, containing streaks and nodules of calcareous material and a rich fauna of well-preserved fossils	6

[121]Measured by Veatch, **1688a**, pp. 127, 128, 1902.
[122]Now known as *Pecten scintillatus* Conrad var. *corneoides* Harris (**668a**, p. 28, 1919).
[123]Measured by A. Deussen, **415**, p. 63, 1914; see also descriptions by Kennedy, **905**, pp. 105–109, 1892.

	Thickness *Feet*
4. Glauconite, yellowish brown, grayish brown, and grayish green, indurated, containing rich fauna	20
3. Glauconite, green, containing casts of fossils	6
2. Sandstone, brown, altered, glauconitic, containing casts of fossils	30
1. Glauconite, green, containing fish teeth and a fairly well-preserved fauna	8
Total thickness	80–85

Section[124] *of Weches formation 800 to 1000 feet west of highway bridge across Colorado River at Smithville, Bastrop County, one of the most famous and most frequently visited Cenozoic fossil localities in Texas.*

	Thickness *Feet*
12. Marl, green, glauconitic, fossiliferous	2
11. Greensand, indurated, fossiliferous	1
10. Marl, brownish black, fossiliferous, glauconitic	1½
9. Limonite, or indurated, weathered glauconite	¼
8. Marl, brown, laminated, fossiliferous	4
7. Limonite, very hard, fossiliferous	2
6. Marl, green, glauconitic, fossiliferous	5
5. Limonite, or indurated, weathered glauconite	1
4. Marl, green, laminated, fossiliferous	1
3. Unexposed	10
	27¾

About 20 feet beneath the bottom of this section at the mouth of Gazley Creek about 1600 feet west of the bridge and separated from the above section by a small fault and unconformity, a soft, white shell marl outcrops at low water, if not covered by river mud. The section may be continued as follows:

2. Marl, green, highly glauconitic, mostly unexposed	20±
1. Sand, white, medium grained. Beach sand containing a bed made up of a shell bank of white pelecypods belonging to the genus *Pitaria* and containing about 12 species of fossils, which have been described by Katherine Palmer (1275, pp. 20–30, 1928). Some of the shells are eroded by waves (?)	3
Total thickness of Weches formation at Smithville	57±

[124]Measured by Deussen, 421, p. 70, 1924.

Section[125] *of Weches formation along road 2 miles south of courthouse at Floresville, Wilson County, Texas.*

	Thickness *Feet*
10. Clay, red, forming the subsoil and containing yellow limestone concretions averaging 1 foot in diameter	2
9. Limonite, red, siliceous	½
8. Clay, red, sandy, weathered	1
7. Limonite, red, siliceous	½
6. Clay, red, sandy	1
5. Sandstone, red, ferruginous, consisting of altered greensand	1
4. Clay, red, ferruginous, containing limestone concretions 1 to 2 feet in diameter having septarian structure	3
3. Unexposed	8
2. Shale, brown, containing limestone concretions 1 to 2 feet in diameter	15
1. Clay, reddish, sandy, exposed in creek bed	3
Total section measured	35

Sedimentology.—The sediments of the Weches formation were deposited in moderately shallow, clear, marine waters, which deepened as the epoch advanced. The rolled and wave-worn shells at the base of the formation indicate a shallow littoral or beach facies. The thick beds of glauconite rich in fragile, perfectly preserved gastropod shells of the upper strata indicate an off-shore facies in which the water was 200 to 600 fathoms deep, where animal life was very abundant and where little coarse sediment of any kind was deposited. The material that accumulated was fine, calcareous ooze and colloidal silicate in the form of iron potassium silicate ($K, Fe, Si_2O_6H_2O$) which in the presence of sea water precipitates in the form of glauconite grains. The exact process of formation has been much discussed by geochemists and geologists.[126]

[125]Measured by Deussen, 421, p. 62, 1924.

[126]SIGNIFICANT LITERATURE ON GLAUCONITE—Murray, J., Deep sea deposits: *Challenger* Exped., p. 383, 1891. Bailey, J. W., On the origin of greensand and its formation in the oceans of the present epoch: New Jersey Geol. Survey Ann. Rept., p. 219, 1892. Clark, W. B., A preliminary report on Cretaceous and Tertiary formations of New Jersey with special reference to Monmouth and Middlesex counties: New Jersey Geol. Survey Ann. Rept., pp. 167–245, 1892; Origin and classification of the greensands of New Jersey: Jour. Geol., vol. 12, pp. 167–177, 1894. Clark, F. W., The composition of glauconite and greenalite: U. S. Geol. Survey Mon. 43, pp. 243–247, 1903. Prather, J. K., Glauconite: Jour. Geol., vol. 13, pp. 509–513, 1905. Collet, L. W., and Lee, G. W., Researches on glauconite: Proc. Roy. Soc. Edinburg, vol. 26, pp. 238–278, 1906. Caspari, W. A., Contributions to the chemistry of submarine glauconite: Proc. Roy. Soc. Edinburgh, vol. 30, pp. 364–373, 1910. Palmer, Chase, Genesis of glauconite: Geol. Soc. Am. Bull, vol. 25, p. 91, 1914. Goldman, M. I., The petrography and genesis of the sediments of the Upper Cretaceous of Maryland: Maryland Geol. Survey Rept., pp. 111–182, 1916. Audley, J. A., Silica

Latest ideas are that the glauconite grains precipitate out of sea water around a minute nucleus according to the method of formation of minute concretions or oolites. The chemical reactions appear to be a replacement of Al ions from aluminum silicate by Fe and K ions. The K ions are probably present in the sea water as soluble potassium salts; the Fe ions are thought to be produced by reduction of insoluble iron mineral matter by organic compounds produced by decomposition of animal or plant matter. At an anode (nucleus) set up by the reduction of ferric to ferrous ions, SiO_2 molecules are precipitated forming a colloidal iron silicate. This colloid absorbs potassium and traces of other positive ions to form a double silicate. Clark thinks that after the reduction of the iron, colloidal ferrous hydroxide forms first, and that this colloid absorbs and reacts with K and SiO_2 ions to produce the double salt, potassium iron silicate. In either case the final product is a colloidal silicate, which takes on a more or less spherical shape. The precipitation may take place inside the shell of a minute fossil in such way that the glauconite filling is a perfect cast of the interior of the shell. Murray found that glauconite is forming today abundantly in water below the mud line at depths of 100 to 900 fathoms where deposition is slow and where there is little land-derived sediment.

Lithology.—The Weches formation along the outcrop consists of about 55 per cent glauconite, 30 per cent glauconitic clay, 10 per cent glauconitic sand, 4 per cent clay, and 1 per cent iron ore, mostly in the form of limonite. The glauconite consists of dark-green or greenish-black spherical, oval, and elongate grains that average 1 mm. in size. Some have the shape of minute fossils and are the casts of the interior of fossil shells, but by far the greater portion resemble rounded sand grains, some of which are nearly perfect spheres and have the appearance of oolite. The chemical analysis (Schoch, **1378**, p. 170, 1918) of typical samples of the glauconite is given in the following table.

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and the silicates, pp. 6, 27, 29, 30, 101–102, and 172, London, 1921. Hummel, K., Glauconite, a recent example of iron enrichment through chemical precipitation from sea water: Geol. Rundschau, vol. 13, pp. 41–81, 97–136, 1922. Berz, C., Researches on glauconite: Neues Jahrbuch Min. etc., pt. 2, p. 207, 1923. Clark, F. W., Data of geochemistry: U. S. Geol. Survey Bull. 770, pp. 519–522, 1924. Twenhofel, W. H., Treatise on sedimentation, pp. 336–341, Baltimore, 1926. Gill, J. E., Origin of the Gunflint iron-bearing formation: Econ. Geol., vol. 22, pp. 719–722, 1927. Schneider, Hyram, A study of glauconite: Jour. Geol., vol. 35, pp. 289–301, 1927.

Locality	Percentage Composition								
	P_2O_5	SiO_2	Al_2O_3	Fe_2O_3	FeO	MgO	CaO	Na_2O	K_2O	H_2O
Mount Selman, Cherokee Co.	0.00	20.95	16.28	47.62		1.46	1.81	3.94	0.93	3.65
1 mi. S. of Palestine, Anderson Co.	4.21	9.20	7.48	15.31		......	29.51	......	......	3.1
Near Dialville, Cherokee, Co.	0.54	14.40	2.07	56.23		5.00	3.05	Tr.	4.61	14.0
¼ mi. S.E. of Nacogdoches, Nacogdoches Co.	0.41	30.5	24.47	4.93	14.49	3.66	2.31	Tr.	2.05	17.00
1 mi. S.W. of Chireno, Nacogdoches Co.	Tr.	34.10	14.58	2.06	14.94	3.68	8.28	2.03	0.68	19.0
Near San Augustine, San Augustine Co.	0.12	37.50	8.89	32.33		0.80	2.39	0.65	0.99	13.02

The high percentages of Al_2O_3, MgO, and CaO show that all the glauconite is impure. The samples from the Weches, with the exception of the one from Dialville, are all low in potash and high in aluminum oxide.

The glauconite, where it exists in beds, is for the most part free of sand but contains some fine, argillaceous clay or marl and an abundance of fossil shells. It weathers to a brownish-buff and dull brick-red color and forms dark-red soils. In some places in central Texas the Weches formation contains a thin layer of impure fossiliferous glauconitic limestone. The clay in most places is light gray, thin-bedded, and fine-grained and contains small flakes of mica, fossil shells, and spherical grains of glauconite. The iron ore is altered glauconite in which the iron has been concentrated either by leaching out of the potash and silicates, a process that leaves the iron oxide in the form of a black, honey-combed, porous layer 1 to 3 feet thick, or the iron has dissolved and precipitated as a limonite seam along porous layers. It occurs also less commonly in the form of carbonate as round, biscuit-shaped concretions in impervious beds. The iron ore occurs in the upper few feet of the outcrop following the contour of the surface of the ground without regard to the bedding planes of the strata. The ore is found capping the hills and mesas at or a few feet beneath a sand-covered surface. In central Texas and in well sections south of the outcrop, the Weches beds contain a smaller proportion of glauconite, much less iron ore, and more marl and thicker beds of fossiliferous, glauconitic clay. In central and south Texas the clay in places contains smooth, hard, nodular, ferruginous concretions 6 inches to 1 foot in diameter which have peculiar botryoidal shapes.

Samples of the Weches formation examined under the microscope are found to contain a larger proportion of spherical glauconite, less plagioclase feldspar, fewer heavy minerals, except leucoxene and ilmenite which are common, less pyrite, and fewer carbonate minerals than samples from most other marine formations in the Claiborne.

Distinguishing characteristics.—The Weches formation is distinguished easily by the following criteria:

1. Iron ore. The bands of black, porous, and honey-combed layers of iron ore capping thick beds of glauconite and glauconitic clay are characteristic of the Weches formation.
2. Red soil. The deep brick-red soil which colors the fields, the roads, and landscapes of east Texas help to distinguish this formation from the gray, sandy, and brownish soil of the Queen City below and Sparta above.
3. Glauconite. The glauconite beds are thicker, purer, more persistent, and more fossiliferous in the Weches than in other Claiborne formations.
4. Fossils. Certain index fossils, especially *Vertagus wechesensis* Stenzel, *Turritella femina* Stenzel, *Rimella texana* Harris, *Latirus singleyi* Harris, and *Scutella mississippiensis* Twitchell,[127] are index fossils of the Weches.

Paleontology.—The Weches formation is one of the most richly fossiliferous Cenozoic formations of the Gulf Coastal Plain. In number of species it is surpassed only by the Crockett. Many of its fossils are hard and well-preserved original shells, which occur in large numbers. The outcrops of the Weches along the Texas rivers have delighted fossil hunters since the days of Roemer. The most famous localities are as follows:

LOCALITY	COUNTY	ZONE
Low Creek south of Sabinetown	Sabine	Upper
Roadside exposures east of San Augustine	San Augustine	Middle
Vicinity of Alto	Cherokee	Upper
Hall's Bluff on Trinity River	Houston	Lower
Robbins-Centerville road, 0.6 of a mile east of Robbins	Leon	Complete section
Bluff at old iron bridge on Navasota River	Leon	Upper
Burleson Bluff on Brazos River	Burleson	Lower
Bluff on Colorado River, Smithville	Bastrop	Middle and upper
Gazley Creek, Smithville	Bastrop	Lower

[127]Commonly referred to in literature as *Scutella caput-sinensis* Heilprin (see Stenzel, 1525d, p. 318, 1932).

The following list of fossils from Smithville is representative of fossils that occur[128] in the middle and upper beds of the Weches formation:

Foraminifera[129]—
- Spiroplectammina zapotensis (Cole)
- Textularia aff. tumidula Cushman
- Quinqueloculina yeguaensis Weinzierl and Applin
- Triloculina trigonula (Lamarck)
- Lenticulina alato-limbata (Gümbel)
- Guttulina problema d'Orbigny
- Globulina inaequalis Reuss
- Sigmoidella plummerae Cushman and Ozawa
- Nonionella sp.
- Bolivina cf. B. gracilis Cushman and Applin
- Discorbis yeguaensis Wienzierl and Applin
- Eponides guayabalensis Cole
- Eponides exiguus (H. B. Brady)
- Siphonina claibornensis Cushman
- Lamarckina yeguaensis Cushman
- Gyroidina soldanii var. octocamerata Cushman and G. D. Hanna
- Asterigerina aff. A. bracteata Cushman
- Amphistegina cf. A. californica Cushman and G. D. Hanna
- Ceratobulimina eximia (Rzehak) var.
- Globigerina sp.
- Globorotalia cf. G. crassata (Cushman)
- Anomalina sp.
- Anomalina costiana Wienzierl and Applin
- Cibicides pseudowuellerstorfi Cole

Anthozoa[130]—
- Platytrochus stokesi (Lea), C
- Discotrochus orbignianus Milne-Edwards and Haime, C
- Turbinolia pharetra Lea, C
- Paracyathus alternatus Vaughan
- Oculina singleyi Vaughan
- Madracis johnsoni Vaughan
- Balanophyllia irrorata var. mortoni (Gabb and Horn)

Gastropoda[130]—
- Cylichna kelloggi (Gabb), C
- Terebra houstonia Harris, C
- Conus smithvillensis Harris, C
- "Turris" nodocarinata Gabb, C
- "Turris" moorei (Gabb)
- "Pleurotoma" huppertzi Harris
- "Pleurotoma" huppertzi var. penrosei Harris
- "Pleurotoma" insignifica Heilprin
- "Pleurotoma" finexa Harris
- "Pleurotoma" rebeccae Harris
- "Pleurotoma" vaughani Harris
- "Pleurotoma" enstricrina Harris
- Drillia prosseri Harris
- Drillia texanopsis Harris, C
- Microdrillia infans (Meyer), C
- Ancistrosyrinx bella (Conrad)
- "Eucheilodon" reticulatoides Harris
- Cancellaria bastropensis Harris, C
- Cancellaria penrosei Harris
- Trigonostoma panones (Harris)
- Trigonostoma panones var. smithvillensis (Harris)
- Trigonostoma panones var. junipera (Harris)
- Volutocorbis petrosa (Conrad), C, R
- Volutocorbis dalli (Harris)
- Lapparia dumosa Conrad
- Conomitra polita (Gabb), C
- Pyramitra costata (Lea), C
- Pseudoliva vetusta (Conrad), C
- Levifusus trabeatoides Harris, C
- Fusinus bastropensis (Harris)
- Euthriofusus mortoniopsis (Gabb), C
- Latirus moorei (Gabb), C
- Alectrion scalatus (Heilprin)
- Astyris bastropensis Harris, C
- Murex vanuxemi Conrad
- Ficopsis penita (Conrad)

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128 Capital letters after fossil names indicate occurrence also in the Crockett (C) formation and Reklaw (R) formation.

129 List made by Helen Jeanne Plummer. Material collected from dark glauconitic and fossiliferous clay near the top of the section exposed upstream from the bridge at Smithville.

130 The names of the Anthozoa and Gastropoda have been furnished by H. B. Stenzel.

Turritella nasuta Gabb, C
Tuba antiquata (Conrad), C
Architectonica alveata (Conrad)
Liotia tricostata Conrad, C
Vertagus wechesensis Stenzel
Clavilithes kennedyanus Harris
Pyramidella bastropensis Harris
Natica semilunata, Lea, C
Neverita arata (Gabb), C
Sinum arctatum (Conrad)
Sinum bilix (Conrad), C

Scaphopoda—
Dentalium minutistriatum Gabb
Cadulus abruptus Meyer and Aldrich

Pelecypoda—
Ostrea alabamiensis Lea
Ostrea sellaeformis Conrad var. smithvillensis Harris
Pecten burlesonensis Harris
Trinacria pulchra (Gabb), C
Trinacria decisa (Conrad)
Arca ludoviciana Harris
Arca reticulata Gmelin
Nucula magnifica Conrad
Venericardia rotunda Lea, C
Venericardia rotunda Lea var. flabellum Harris
Venericardia rotunda Lea var. coloradonis Harris
Lirodiscus smithvillensis (Harris), C
Crassatellites antestriatus (Gabb), C
Crassatellites trapaquarus Harris
Sphaerella anteproducta Harris
Callocardia texacola (Harris)
Tellina tallicheti Harris
Corbula deusseni Gardner
Corbula smithvillensis Harris, C, R

The following list from Burleson Bluff on Brazos River is representative of the fauna of the lower Weches[131] (identified by H. B. Stenzel, 1299, pp. 106–108, 1931):

Gastropoda—
"Pleurotoma" huppertzi Harris var. penrosei Harris
Surcula n. sp., cf. S. gabbi (Conrad), UW
Oliva bombylis Conrad
Mitra cf. M. dubia (H. Lea)
Volutocorbis petrosa (Conrad), UW
Fusus interstriatus Heilprin?
Clavilithes chamberlaini Grabau and Johnson
Clavilithes papillatus (Conrad)
Clavilithes kennedyanus Harris?
Metula brazoensis Johnson
Pyrula penita Conrad, UW
Cassidaria brevidentata Aldrich
Rostellaria (Calyptraphorus) velata (Conrad)
Rimella texana Harris
Rimella texana Harris var. plana Harris
Xenophora conchyliophora (Born)
Natica limula Conrad
Natica mamma Lea
Neverita arata (Gabb)
Tuba antiquata (Conrad)
Sinum (Sigaretus) bilix Conrad
Calyptraea aperta (Solander)

Pelecypoda—
Corbula engonatoides Gardner
Tellina tallicheti Harris var.
Meretrix texacola Harris
Cardium claibornense Aldrich
Venericardia planicosta Lamarck, UW
Venericardia trapaquara Harris var. texalana Gardner
Pecten burlesonensis Harris
Ostrea sellaeformis Conrad, UW
Ostrea alabamiensis Harris (non Lea)
Arca deusseni Gardner

[131]The symbol, UW, after some of the fossil names indicates occurrence also in the upper Weches.

Scaphopoda—
- Dentalium minutistriatum Gabb, UW

Anthozoa—
- Turbinolia pharetra Lea, UW
- Platytrochus stokesi (Lea), UW
- Paracyathus alternatus Vaughan, UW
- Balanophyllia irrorata (Conrad), UW
- Balanophyllia irrorata var. mortoni (Gabb and Horn), UW

The fauna of the upper Weches, exemplified by collections from Smithville at the Bureau of Economic Geology, contains 8 corals, 47 gastropods, 2 scaphopods, and 19 pelecypods. Of these, 37 species or about half occur also in the Crockett, whereas only about 3 per cent are found in the Reklaw. The fauna of the lower Weches represented by the species from Burleson Bluff contains 4 corals, 22 gastropods, 10 pelecypods, and 1 scaphopod. Only 10 species, or about 25 per cent of the total number of species, occur in the upper Weches. The similarity of the upper Weches and lower Crockett is due probably to similarity of facies and environmental conditions. The upper Weches and lower Crockett faunas in central Texas are moderately deep-water, off-shore assemblages. The lower Weches is a near-shore, littoral fauna.

Three fossil zones have been recognized in the Weches formation:

3. Upper zone characterized by *Calyptraphorus velatus* Conrad, *Turritella femina* Stenzel, *Vertagus wechesensis Stenzel,* and by the abundance and excellent preservation of its gastropods.
2. Middle limestone lentil, which occurs in San Augustine County and can be traced eastward to Sabine River; especially characterized by *Scutella mississippiensis* Twitchell (see footnote 126).
1. Lower zone characterized by large numbers of *Anomia ephippoides* Gabb, numerous shells of *Pecten burlesonensis* Harris, and a small variety of *Ostrea sellaeformis* Conrad described by Stenzel (**1299**, p. 87, 1931).

Correlation.—The Weches formation is absent on top of the Sabine uplift in Louisiana, but according to Miss Ellisor (**523**, p. 1344, 1929) it occurs north of the uplift in Arkansas. Also the fauna of the beds in the vicinity of Minden and Mount Lebanon on the east side of the uplift appears to be related to the Weches.

The Weches formation is apparently equivalent to the Mount Selman as restricted by Moody (**1125**, p. 538, 1931), the upper Winona of Mississippi, and the middle Lisbon of Alabama (fig. 41).

Economic resources.—The economic resources of the Weches formation are iron ore, glauconite, and petroleum. The iron deposits[132] are estimated to amount to more than a billion tons. These deposits were well known and worked on a small scale before and during the Civil War. During the reconstruction period that followed the Civil War, the mines fell into disuse and were not operated again till the 70's. In 1870 the Loo Ellen (or Kelly) furnace, located 5 miles north of Jefferson in Marion County was put into blast and operated for a decade. In 1891 another charcoal blast furnace having an annual capacity of 13,500 tons was installed on the north edge of the town of Jefferson and was operated until about 1900. In 1884 a blast furnace was opened on Texas state land about three-quarters of a mile northeast of Rusk in Cherokee County. It was designed for an output of 25 tons a day and was operated by convict labor until 1909. The Tassie Belle furnace was built southeast of Rusk in 1890 and the Star and Crescent three-quarters of a mile east of Rusk in 1891. This furnace had a capacity of 18,000 tons of iron annually and was operated until 1907. Pig iron of good grade was turned out and used at Marshall for manufacture of car wheels. Since that date mining and smelting operations have been allowed to lapse, and the great reserves of low-grade iron ore remain for future industrialists of the state to develop.

The distribution of the iron-bearing formation is shown in figure 42. The richest beds are found in the upper member of the Weches formation around the rim of ridges and mesas capped by ledges of ferruginous sandstone. All the outcrops are located in the trough of the east Texas geosyncline. The ore occurs in three forms:

1. Soft, brown, laminated limonite in beds from 1 inch to 4 feet thick.
2. Curly, honey-combed, hard, black, residual limonite in sheets and layers.
3. Concretionary nodular ore of limonite or carbonate in the form of botryoidal, bulblike concretions in the glauconitic beds.

[132]LITERATURE ON IRON ORE DEPOSITS—Johnson, L. C., 880, pp. 1–54, map, 1888. Penrose, R. A. F., 1189, pp. 65–89, 1890; 1191, pp. 44—50, 1892. Birkinbine, John, 116, pp. 33–37, 1891. Walker, W. B., 1705, pp. 225–300, 1891. Dumble, E. T., Kennedy, Wm., et al, 461, pp. 7–326, map, 1891. Kennedy, Wm., 910, pp. 258–288, 862, 863, 1895. Eckel, E. C., 514, pp. 348–354, 1905. Phillips, W. B., The iron ore resources of Texas: Eng. Soc. West Penn. Proc., pp. 64–79, March, 1902; The iron situation in east Texas: Min. World, p. 994, Nov. 26, 1910. Linton, Robert, 1000, pp. 1153–1156, 1913. Burchard, E. F., 180, pp. 69–109, map, 1915.

The ore consists chiefly of brown hydrated sesquioxide of iron ($2Fe_2O_3$-$3H_2O$) with a minor amount of nodular carbonate ore ($FeCO_3$) in the lower layers below the oxidized zone (fig. 43). Both the oxide ore and carbonate ore contain more or less silica and alumina and other impurities, as shown by the following analysis:

Average composition[133]

	Per cent
Metallic iron	54.91
Silica	5.18
Alumina	4.30
Phosphorus	.073
Sulphur	.067

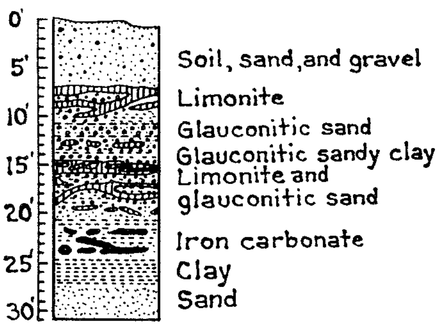

Fig. 43. Columnar section showing occurrence of iron ore on Surratt tract, Cass County (after Burchard, 180, p. 79, 1915).

The ore occurs in a more or less continuous laminated bed that varies from 1½ to 4 feet thick near the top of hills and in upper portions of small branch gullies cutting back into the flat-topped divides. It is in the form of lenses and ledges, sheets and layers, and in the lower beds in nodules, everywhere associated or interbedded with oxidized glauconitic sand. The ratio of ore to barren material in average exposures is about 25 to 30 per cent of ore by volume or about 40 to 50 per cent by weight. No cheap method for removing barren rock has been developed. Hand picking renders

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133Phillips, W. B., Iron and steel making in Texas: Iron age, Jan. 11, 1912. Average composition from 65 samples from Marion County.

the process too expensive to meet competition of other mining districts under present conditions. The ore has been mined by stripping off the surface sand from 1 to 6 feet deep with wheel scrapers, blasting the consolidated layers by light charges of dynamite, separating the best ore from the glauconite by hand, loading and transporting it by trucks or trams to the furnace. If a cheap method can be developed to concentrate the ore-bearing material, handpicking can be abolished, and the whole operation of handling the ore can be reduced to the work of machinery, and the iron-ore deposits can be developed. Perhaps when sufficient demand for these ores arises, methods will be devised for handling economically this vast store of potential iron.

The glauconite of the Weches formation is one of the largest deposits in the United States. It is low in potash and phosphoric acid. Most samples have less than 2 per cent K_2O compared with 4 per cent in the Midway glauconite, and 5 per cent in much of the glauconite in New Jersey. Consequently this deposit is not suitable for fertilizer or for the manufacture of potash. The purer deposits can be utilized as water softeners that employ the zeolite process.[134] Zeolite softening has displaced practically all other methods of water softening in industrial plants and for domestic use. Processed greensand is the best possible zeolite. It softens water as fast as it can be forced through it, will operate with waters containing CO_2, and is not injured by turbid, iron-bearing waters. The process of preparing the material is simple, and glauconite should find a market with concerns manufacturing zeolite for softeners.

Oil occurs in the Weches formation in the shallow Chireno field southeast of Nacogdoches, where it has been developed on a small scale since 1877. The occurrence, however, is more of historic than of economic interest, since all the wells are shallow and small

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[134]LITERATURE ON ZEOLITE WATER SOFTENERS—Barthel, E. L., Preparation of zeolite water-softening material: Iowa Acad. Sci. Proc., vol. 31, pp. 275–276, 1926. Behrman, A. S., Recent developments in zeolite softening: Jour. Ind. Eng. Chem., vol. 19, pp. 445–447, 1927. Kneeland, H. C., Water softening on a large scale by the zeolite process: West Virginia Coll. Eng., Tech. Bull. 1, pp. 66–74, 1927. White, A. H., Walker, J. H., Partridge, E. P., and Collins, L. F., Zeolite water treatment in a large central heating plant; Jour. Am. Water Works Assoc., vol. 18, pp. 219–249, 1927. Campbell, J. T., and Davis, D. E., Softening municipal water supplies by zeolite: Jour. Am. Water Works Assoc., vol. 21, pp. 1035–1053, 1929. Shreve, R. N., Greensand as a water softener: U. S. Bur. Mines Bull. 328, pp. 30–43, 1930.

producers. In the deep wells on the coastal and near-coastal salt domes, the Weches is thought to be a clay or marl, and the oil, if present in the Claiborne, is found in the adjacent Sparta and Queen City sands (see sections by Heath, Waters, and Ferguson, **696**, pp. 52–53, 1931).

SPARTA FORMATION[135]

Definition.—The Sparta sand was first defined by Vaughan[136] as deep quartz sand extending across Louisiana and well developed near Sparta in Bienville Parish. Vaughan confused some of the Pleistocene sands, so plentiful in eastern Louisiana, with the Sparta, for he states "These sands overlap both the lower Claiborne and the Grand Gulf extending entirely across the Jackson and Vicksburg." Since he gave the type locality as Sparta, Spooner[137] amended the original definition to include only the Claiborne sands that occur at the same stratigraphic position as those near Sparta. This section includes about one hundred feet of strata above the fossiliferous red clays. Miss Ellisor (**523**, p. 1345, 1929) has correlated these sands with those overlying the Weches formation in Texas and has retained the Louisiana name for the beds of the same age in Texas. This name Sparta was used at the same time by Wendlandt and Knebel (**1728**, p. 1359, 1929), who made these sands the lower member of the Cook Mountain formation. Renick (**1298**, p. 531, 1928) preferred the name Nacogdoches, which had been given by Dumble (**506**, p. 67, 1918) to the transition beds between the Cook Mountain greensand and the gypsiferous clays of the Yegua. Dumble at this time regarded the beds lying above the Sparta and known now as Crockett as the marine Yegua. Dumble's name Nacogdoches therefore appears to be a synonym for Vaughan's older name Sparta as restricted by Spooner. Since some doubt exists as to just what Dumble intended to include in his "transition" beds, and since the name Sparta was in good usage in

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[135]LITERATURE—Vaughan, T. W., A brief contribution to the geology and paleontology of northwestern Louisiana: U. S. Geol. Survey, Bull. 142, pp. 25, 26, 1896. Spooner, W. C., Interior salt domes of Louisiana: Bull. Amer. Assoc. Pet. Geol., vol. 10, p. 235, 1926. Ellisor, Alva, **523**, pp. 1338 and 1341, 1929. Wendlandt, E. A., and Knebel, M. G., **1728**, pp. 1359–1360, 1929. Renick, C. B., and Stenzel, H. B., **1299**, p. 90, 1931.

[136]Vaughan, T. W., A brief contribution to the geology and paleontology of northwestern Louisiana: U. S. Geol. Survey, Bull. 142, pp. 25, 26, 1896.

[137]Spooner, W. C., Interior salt domes of Louisiana: Amer. Assoc. Pet. Geol. Bull., vol. 10, p. 235, 1926.

Louisiana, Miss Ellisor and Wendlandt and Knebel have been justified in dropping the name Nacogdoches. Sparta has since been recognized by Renick and Stenzel (1299, p. 90, 1931) and by the U. S. Geological Survey on the new geologic map of this state.

Regional geology.—The Sparta formation in east Texas occurs on the high ridges above the greensand beds and caps most of the ferruginous hills along stream divides in the east Texas syncline. In central Texas it forms a belt of moderate relief characterized by sandy soils and post oak timber. The formation has been mapped in a continuous belt from Columbus, Louisiana, south of Sabinetown to the center of the west line of Lee County. The average width of the outcrop in east Texas is two and one-half miles, except in the east Texas basin, where it widens to ten miles or more in Houston and Anderson counties. Southwest of Lee County it narrows to one mile and continues southwestward in a belt from one to one and one-half miles wide to the valley of Lucas Creek in northeastern Atascosa County. South of the outcrop it has been recognized in well sections as far south as Clay Hill salt dome and doubtless constitutes one of the deep oil sands on some of the coastal domes. In southwest Texas it occurs in well sections in LaSalle and McMullen counties.

The Sparta formation in east Texas varies in thickness from 230 to 300 feet, as shown in the following table:

LOCALITY	COUNTY	THICKNESS *Feet*	AUTHORITY
J. L. Bonner, No. 1-A, Humble O. & R. Co.	Angelina	242	Wendlandt and Knebel
So. Pine No. 4-A, Humble O. & R. Co.	Houston	250	Alva Ellisor
So. Pine No. 2-A, Humble O. & R. Co.	Trinity	275	Do
Outcrop section, Brazos River Valley	Robertson	300–350	Renick and Stenzel
Schirmer No. 1, Sun Oil Co., Clay Creek	Washington	150	J. A. Waters

Stratigraphy.—The Sparta sand in Texas lies apparently conformably upon the Weches formation and is overlain disconformably by the Crockett. In Louisiana, according to Spooner's section, it separates the Cane River and St. Maurice formations. In most places where penetrated by the drill or studied at good exposures on the outcrop the formation appears to be a stratigraphic unit made up largely of sand and sandy clay. The top of the formation is placed at the contact of chocolate-colored, glauconitic, ferruginous, fossiliferous sand of the Crockett formation with the coarser-grained, more carbonaceous, nonfossiliferous beds of the Sparta. The fossiliferous glauconitic sand named "Eaton lentil" by Renick and Stenzel is regarded as the lower part of the overlying Crockett. The base of the Sparta formation is placed at the contact of gray sand with green or reddish-yellow, glauconitic and iron-bearing beds. In the southern part of Smith County and in the vicinity of Tyler a glauconite layer about 120 feet above the base of the Sparta can be traced for some distance. This stratum is thought by Wendlandt and Knebel (1728, p. 1359, 1929) to be a lentil in the Sparta but by other geologists to represent the lower layer of the overlying Crockett. The fact that it occurs only in the basin where the Sparta would normally be thickest and has only about 120 feet of sand below it in any area where the normal section of the Sparta is fully 250 feet thick is evidence in favor of a Sparta age for the lentil. The member has been named Tyler greensand by Wendlandt and Knebel.

The stratigraphy of the Sparta formation is best described by the following sections:

Section of Sparta sand in Humble Oil and Refining Company's No. 1-A, William Elliott Survey, Angelina County.

	Thickness *Feet*
Sand, partly consolidated	11
Shale, sandy	20
Sand, brown	31
Rock	2
Shale, sandy	6
Shale, sticky	15
Sand, gray and brown, containing streaks of lignite	19
Shale, hard	2
Sand, brown, containing streaks of lignite	53
Shale, hard, sticky	15
Sand	41
Shale, sticky	20
Sand, brown	7
Total thickness measured	242

Sedimentology.—The sediments of the Sparta sand are thought to be mostly continental in origin. The basal sands were laid down on a beach and coastal plain in conjunction with the withdrawal of the Weches sea. The middle sands are mainly fluviatile deposits spread broadly over a flat terrain. The upper sediments were deposited along a transgressing shoreline laid down in advance of the Crockett sea and were worked over by later marine waters. Strata of such an origin[138] wedge out seaward and expand landward. The basal and upper layers show shore conditions with beach sands, dune deposits, and interfingering shallow deltaic strata. Cross-bedding formed by streams and river-made ripple marks are noteworthy in the middle beds. Thin laminae made up of the remains of land and marsh plants also occur there, but there are no layers of lignite of any thickness.

Lithology.—The Sparta formation consists of about 70 per cent sand, 25 per cent sandy shale or clay, 3 per cent glauconitic sand, 1 per cent limonite, and 1 per cent lignite. The sand is gray or buff, and in places where it contains some glauconite it weathers to reddish hues. It is nearly everywhere laminated and in some places decidedly cross-bedded. It consists of round and subangular quartz grains about 0.5 mm. in diameter mixed with a small percentage of exceedingly fine grains. In most places the sand is unconsolidated and erodes easily to form rounded uneven slopes. In a few places where it contains ferruginous material it is consolidated into thin ledges impregnated with limonite. The clays are most prevalent in the upper part of the formation. They are gray or chocolate-colored and contain considerable carbonaceous matter.

Distinguishing characteristics.—The following criteria are useful in identifying the Sparta formation:

1. Lack of compactness. The Sparta sand is distinguished by its loose, unconsolidated makeup. It does not form cliffs or steep banks, and in drilling will not hold together in a core barrel.
2. Brown carbonaceous matter. The carbonaceous clays are chocolate-colored and the plant remains are brown, not black like those of the Carrizo.
3. Paucity of limonite and greensand. The small amount of limonite and glauconite as compared with the iron ore and glauconitic

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[138]Grabau, A. W., Principles of stratigraphy, pp. 734–738, A. G. Seiler and Co., New York, 1913.

beds of the Weches and Crockett distinguish the Sparta sand from the formations above and below.

4. Absence of fossils. There are very few marine fossils and no richly fossiliferous beds in the Sparta sand like those so common in the Weches and Crockett formations.

Correlation.—The Sparta formation is correlated with the Sparta sands of Louisiana, with strata in the Kosciusko formation in Mississippi, and with strata in the upper Lisbon formation in Alabama (fig. 41).

Economic resources.—The chief resources found in the Sparta sand are water near its outcrop and oil in deep wells located on or near salt domes. According to Heath, Waters, and Ferguson (**696**, p. 53, 1931) the upper producing sand on the Clay Creek dome in Washington County is in the Sparta formation. Doubtless it yields oil in other wells of the northern coastal domes. The sand along its outcrop and for a distance of 25 miles south contains a good supply of potable water and supplies farms and small towns in central San Augustine, southern Nacogdoches, central Houston, south-central Leon, and south-central Robertson counties. The soils derived from the Sparta sand are rather poor for agriculture but produce some timber in east Texas and furnish pasturage and oak wood for fuel in central Texas.

CROCKETT FORMATION[139]

Definition.—The upper marine strata above the Sparta sands were classified as a part of the Cook's Mountain of the Marine beds by Kennedy (**905**, p. 54, 1892), as a part of the Cook Mountain formation by Deussen (**415**, p. 56, 1914), and lower or marine part of the Yegua by Dumble (**506**, pp. 102–108, 1918). The locality along Elm Creek in Lee County, selected by Dumble as the type locality for his Yegua, is typical of strata now assigned to the Crockett. Renick (**1298**, pp. 531–534, 1928) designated the same beds Lufkin member of the Cook Mountain, stating that this term

[139]LITERATURE—Deussen, A., **415**, pp. 58–59 (Moseley's Ferry section), p. 61 (Alabama Bluff section), 1914; **421**, p. 69 (Moseley's Ferry section), p. 71 (section northeast of Caldwell), p. 73 (Colorado River section 4½ miles east of Smithville), pp. 75, 76 (Nueces section at Cotulla), 1924. Dumble, E. T., **506**, pp. 67, 79–86, 91–97, 99–101, 1918. Gardner, J., **569**, pp. 245–251, 1927. Stadnichencko, Maria M., **1517**, pp. 221–243, 1927. Renick, B. C., **1298**, p. 531, 1928; and Stenzel, H. B., **1299**, pp. 91–96, 1931. Ellisor, A., **523**, p. 1340, 1929. Wendlandt, E. A., and Knebel, G. M., **1728**, p. 1360, 1929. Weinzierl, L. L., and Applin, E. R., **1721**, pp. 384–410, 1929. Heath, F. E., Waters, J. A., and Ferguson, W. B., **696**, p. 46, 1931.

had been introduced by Knebel and Miss Ellisor. Wendlandt and Knebel (**1728**, p. 1360, 1929), however, in their later publication named these strata Crockett member of the Cook Mountain for the town of that name in Houston County. The name was used by Miss Ellisor (**523**, pp. 1339–1340, 1929) to designate that portion of the Cook Mountain formation that lies between the Sparta sand and the Milams member of the Cook Mountain on the Sabine uplift and between the Sparta sand and the Cockfield formation in the type area for the Crockett in Houston County.

Miss Ellisor recognizes a change in the facies and in the faunas of the upper part of the Cook Mountain division in the region of the Sabine uplift and divides the strata on a basis of microfaunas and lithology into three divisions: Crockett at the base, Milams

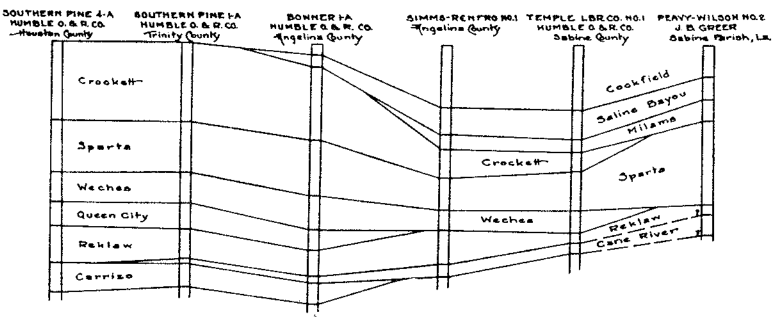

Fig. 44. Cross-section showing stratigraphic relationships of the Claiborne divisions in east Texas and Louisiana (after Ellisor, **523**, fig. 2, 1929).

and Saline Bayou at the top. She believes the Cockfield overlaps the Milams and Saline Bayou strata west of Angelina County. The relationships, as she has worked them out, are shown in figure 44. The United States Geological Survey has not accepted all these small divisions of the upper Claiborne section but has classified all the strata above the Weches as Cook Mountain. Renick and Stenzel (**1299**, p. 91, 1931) have used Crockett as the upper member of the Cook Mountain in describing the section in Brazos River Valley, and Heath, Waters, and Ferguson (**696**, p. 46, 1931) have followed the same usage in their discussion of the stratigraphy of the Clay Creek salt dome in Washington County. The name Crockett is now fairly well established by usage.

The type locality of the Crockett formation comprises the outcrops in the vicinity of Crockett, Houston County. There are good exposures of certain strata of the formation along the San Pedro Creek near the road southeast of Augusta in Houston County, at Alabama Bluff on Trinity River, at Shipp's Ford on Colorado River just north of the Bastrop-Fayette county line, and along Pinoak Creek east of Smithville, Bastrop County.

Regional geology.—The Crockett formation is made up of soft clays and unconsolidated, fine-grained sands which weather to produce a red soil and a more or less featureless, slightly rolling topography except in areas close to rivers where it may be trenched deeply enough to produce good exposures. The formation outcrops south of the east Texas geosyncline and therefore has a fairly straight and moderately narrow outcrop that extends from Sabine River opposite Columbus, Louisiana, westward to Crockett in Houston County, thence southwestward to Stone City on Brazos River in Brazos County, thence to Colorado River above West Point, crosses San Marcos River west of Gonzales, and reaches the Atascosa River below Coughran. From Atascosa County southward the formation has not been mapped. The character of the formation changes somewhat so that it is more difficult to distinguish it from the adjacent formations. It is possible, however, to trace equivalent beds from a locality east of Cotulla in LaSalle County southward to Laredo in Webb County. At Laredo the strike of the beds swings southeastward, so that the outcrop of the upper marine beds border the valley of the Rio Grande as far southeast as Lopeño in Zapata County. The width of the outcrop in northeast Texas is about four miles except across the Trinity River valley, where it widens to seven miles or more. The average width is three miles between the Colorado and Atascosa rivers. South of Atascosa County its width has not been determined.

The Crockett formation dips southeastward beneath the surface, except in the Nueces River valley, where it has been bent into a southeastward-plunging trough. It has been recognized in sections of deep wells as far south as the northernmost salt domes. In the Clay Creek salt dome, for example, according to Heath, Waters, and Ferguson (696, p. 53, 1931), it was encountered between depths 600 and 1200 feet.

The thickness on the outcrop varies from 125 to 450 feet. The measurements of thicknesses in the different districts where information is available are shown in the following table:

LOCALITY	COUNTY	THICKNESS Feet	AUTHORITY
J. L. Bonner No. 1-A, Humble Oil & Rfg. Co.	Angelina	455	Wendlandt and Knebel
Southern Pine No. 1-A, Humble Oil & Rfg. Co.	Trinity	400	Alva Ellisor
Brazos River Valley[a]	Robertson	125	Renick and Stenzel
Well sections, Clay Creek salt dome	Washington	225	J. A. Waters

[a]Renick and Stenzel placed in the Sparta formation 25 to 50 feet of strata regarded by some others as lower Crockett. Including the questionable beds, the thickness is 150 to 175 feet.

Stratigraphy.—The Crockett formation lies upon the Sparta sand and is overlain by nonmarine beds of the Yegua formation. The basal contact in most places is sharp and is marked by the contact of laminated, fossiliferous clay interbedded with lentils of beach sand of the Crockett formation with coarser, more massive sands of the Sparta below. The top of the formation is regarded as the contact of the fossiliferous marine strata with the overlying nonmarine beds of the Yegua formation, into which it grades somewhat. The Crockett formation contains several limestone lentils. One of these outcrops in the vicinity of Crockett in Houston County. Two have been described by Renick and Stenzel (1299, pp. 91, 92, 1931) in the Brazos River valley. The lower limestone, which occurs about 50 to 80 feet above the base of the fossiliferous beds, is named Moseley limestone. Another, which occurs 65 to 75 feet below the top, is called the Little Brazos limestone lentil.

The stratigraphy of the Crockett formation in the different districts of Texas is best illustrated by the following described sections:

Section[140] of a portion of the Crockett formation at the type locality along the Crockett-Palestine highway from a point 1.8 miles north of Crockett to the courthouse and thence along the Crockett-Midway road to a point 2.6 miles southwest of the courthouse, Houston County.

	Thickness *Feet*
8. Clay, brownish gray, fossiliferous, containing a zone of small, ferruginous concretions	15
7. Sand, brown, medium to fine grained	2
6. Clay, grayish brown, having sand partings and containing a few ferruginous concretions	14
5. Clay, brown, much weathered	30
4. Sandstone, ferruginous, containing glauconite	10
3. Clay, chocolate-brown, calcareous, fossiliferous, carbonaceous, containing streaks of light-gray sand	25
2. Sand, ferruginous, cross-bedded, containing lumps of clay	5
1. Clay, grayish brown, containing selenite crystals	30
Total thickness measured	131

Crockett formation[141] in Humble Oil & Refining Company's J. L. Bonner No. 1-A, northwest corner William Elliott Survey, Angelina County.

	Thickness *Feet*
Shale, grayish brown, containing fragments of fossils	33
Rock, brown, ferruginous, having texture of clay	1
Shale, gray, sandy, containing streaks of gray sand	62
Clay, brown, cemented with ferruginous cement	1
Shale, sandy	16
Clay, brown, cemented with ferruginous cement	1
Shale, sandy, containing streaks of gray sand	22
Shale, hard	5
Shale, greenish gray, glauconitic, fossiliferous	16
Shale, hard	19
Shale, brown, containing a few streaks of sand	18
Rock	13
Shale, hard	13
Shale, greenish gray, glauconitic and fossiliferous	2
Shale, dark, slightly greenish gray, sandy	11
Shale, hard	16
Shale, gray, sticky	37
Rock	1

[140]Measured by Alva Ellisor, 523, pp. 1340–1341, 1929.

[141]Described by Wendlandt, E. A., and Knebel, G. M., 1728, p. 1357, 1929.

	Thickness Feet
Shale, gray, sticky	54
Shale, gray, sticky, containing fossils	47
Shale, gray brown, sticky, containing streaks of glauconite and fossils and one layer of rock 4 inches thick	47
Shale, sandy, containing streaks of sand	21
Total thickness of section	456

Sedimentology.—The sediments of the Crockett formation show much variation both in kinds of sediments and types of life which they contain. In the early part of the epoch, waters were shallow, and the fossils and aspect of the sediments indicate a shifting shore line in which continental, beach, and littoral conditions alternated. Toward the middle of the epoch, waters were deeper, more glauconite was formed, thin layers of calcium carbonate mixed with sand and silt accrued, and conditions were favorable for a varied animal life. Later waters shallowed, and zones containing crabs, clams, and other forms that enjoyed a littoral environment replaced the gastropod faunas. At the end of the epoch the sediments show a gradual transition from marine to palustrine and continental deposits. In the Sabine uplift area and in the Nueces valley embayment in south Texas, the clear-water facies of the middle Crockett appears to be absent, and the fauna so well known from Alabama Bluff and Moseley's Ferry is absent. Shallow, muddy waters were the rule, although at certain intervals brackish water and even land conditions may have interrupted marine sedimentation.

Lithology.—The Crockett formation in east Texas consists of about 90 per cent fine sediments, clay, shale, and sandy shale, 9 per cent medium-grained sediments, sand and glauconite, and 1 per cent rock, limestone, and ferruginous concretions. In south Texas it contains a larger proportion of sands and sandy clays. The glauconite is distributed uniformly through the sands and sandy clays and does not occur in thick, pure beds as in the Weches. Some of the glauconite grains may have been transported from older formations and redeposited in the Crockett. The clays are bluish gray and black, weathering to buff and yellow colors. They are colloidal, and some layers are distinctly calcareous, whereas others do not react to acid. Most of the concretions are ferruginous. One interesting type, described by Burt (185d, pp. 33–45, 1932), is rich in alumina, contains fossils, and appears to have formed around the fossils as nuclei. The concretions are dark gray, spherical to spheroidal, average 55 mm. in diameter, and have a core varying from dark reddish brown to bluish black. The core is in direct contact with, or has replaced, the shell and body of an enclosed fossil crab. They have the following mineral (Burt, **185d**, p. 40, 1932) and chemical (Zeller, **185d**, p. 40, 1932) percentage composition:

	SiO_2	CaO	MgO	Fe_2O_3	CuO	MnO	Al_2O_3	H_2O_2	P_2O_5
Core	4.94	12.80	5.15	2.49	0.20	0.065	57.50	3.21	5.32
Case	36.6	13.07	1.37	7.23	0.00	0.000	23.30	5.56	5.79

Alumina	58.1
Calcite and dolomite	15.3
Collophanite	12.2
Quartz	5.2
Iron oxide minerals	2.5
Aluminum hydroxide minerals	2.3
Magnesium sulphate	1.9
Glauconite, etc.	2.5

These concretions occur in middle strata of the Crockett along Little Brazos River in Brazos County. Similar concretions, but not containing crabs, have been found in the Crockett on the bluffs of Sabine River west of Columbus, Louisiana.

Distinguishing characteristics.—The Crockett formation is distinguished from other Claiborne formations by the following criteria:

1. Predominence of clay. The Crockett strata in east Texas and especially where penetrated by wells south of the outcrop are characterized by much clay. Sand in the section occurs only in thin layers and mixed with clay. Thick lentils of sand are rare.
2. Glauconite. The beds of glauconite are thinner than the beds of the Weches, and the glauconite contains more sand, silt and other impurities. Much of the glauconite in the Crockett does not occur in beds but is scattered throughout sandy clays and limestone lentils.
3. Concretions. The concretions in the clay are more nearly spherical, smaller on the average, and a larger proportion of them are more ferruginous than the concretions described in other formations. The concretions in the sandy layers in south Texas

are large, boulderlike, and made up of crystalline calcium carbonate. A few contain fossils.

4. Fossils. The middle strata of the Crockett are the most richly fossiliferous strata in Texas. More than 250 different species of large fossils have been identified. The variety and excellent preservation of the fossils at once distinguish these clays from any other Claiborne formation except the Weches.

Paleontology.—The glauconitic marls of the Crockett formation contain a rich and varied assemblage of beautifully preserved fossils. The richness of the faunas have attracted many paleontologists to the Crockett localities, and a number of short papers have been published,[142] but no comprehensive treatment of the fauna as a whole has been undertaken. Until such a monograph can be written, any summary of the characteristics or conclusions regarding the relationships of the different faunules will be premature. A study of the collections at Texas Agricultural and Mechanical College and The University of Texas shows that the Crockett fauna has the

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[142]Roemer (1328, p. 23, 1848) discovered the first fossils at Moseley's Ferry on the Brazos. Gabb (555a, p. 375–389, 1860) described the fauna on Cedar Creek near Wheelock in Robertson County. Penrose (1189, pp. 27, 1889), collected fossils from Moseley's Ferry on the Brazos, which Heilprin (701, pp. 393–406, 1891) identified and published. Penrose, Kennedy, and Harris visited the locality together in 1891 or 1892, and Kennedy (911, pp. 126–127, 1896) published a list of the fossils which Harris identified. Harris prepared a monograph on the Eocene fossils of the state containing more than 200 pages of manuscript and 40 plates. Unfortunately, the printing of the monograph had to be abandoned when the Texas Geological Survey was discontinued in 1893. Harris (663, pp. 45–88, 1896), however, described most of his new species, and later he (668a, pp. 1–268, 1919) illustrated and described many of the bivalves of the Claiborne in a monograph on the St. Maurice fauna. Veatch (1608a, pp. 129–130, 1902) published a list of fossils from the outcrops along Sabine River in the vicinity of Columbus, Louisiana. Kennedy (911, pp. 116–119, 121–129, 1896) published lists of fossils from the upper Cook Mountain, now called Crockett, from outcrops in the vicinity of Crockett, Alabama Bluff on the Trinity, an outcrop in the northwest corner of Madison County, Cedar Creek near Wheelock, and Moseley's Ferry on the Brazos. Deussen (415, pp. 56–65, 1914) described again most of the localities mentioned by Kennedy, and in a later report he (421, pp. 64, 65, 1924) published lists of fossils from the Crockett from the following localities: mouth of Little Brazos River, Brazos County; Davidson's Creek near Caldwell, Burleson County; Pinoak Creek near southeast line of Bastrop County; Nueces River at Cotulla, La Salle County; and a well section at Fowlerton, La Salle County. Julia Gardner, in connection with a report published by Trowbridge (1610, pp. 95–96, 1923), has presented lists of fossils from the Cook Mountain formation of south Texas. The upper members of the Cook Mountain in the Rio Grande valley are thought to be Crockett in age, although having a somewhat different assemblage of fossils. Maria Stadnichenko (1517, pp. 221–243, 1927) described the ostracods and foraminifera from Elm Creek north of Giddings in Lee County. Weinzierl and Applin (1721, pp. 394–410, 1929) studied the foraminifera of the Crockett from eight localities along the outcrop and from a number of well sections south of the outcrop, and listed and described the foraminifera. Cushman and Thomas (374, pp. 176–184, 1929; 379, pp. 33–41, 1930) described foraminifera from several localities in east Texas. Renick and Stenzel (1299, pp. 99–105, 1931) published the most complete list of fossils from Moseley's Ferry and also lists of fossils collected from three localities in Robertson County and presented a brief discussion of the Crockett fauna as a whole.

largest number of species of any Cenozoic formation in Texas. The large assemblage can be naturally grouped into at least two faunules as follows:

2. Cost, or upper Crockett, zone
1. Alabama Bluff, or lower Crockett, zone

The Alabama Bluff, or lower Crockett, zone is represented by the fossils below the Moseley limestone on the Brazos, in Alabama Bluff on the Trinity, the vicinity of Macune in San Augustine County, on Cedar Creek north of Wheelock in Robertson County, and exposures at Evergreen and Orell's crossings on Elm Creek in Lee County. Gastropods predominate in this fauna. Stenzel (**1299**, p. 93, 1931) has pointed out that *Conus sauridens* Conrad, *Surcula gabbi* Conrad, *Borsonia plenta* Harris, *Latirus moorei* (Gabb), *Distorsiò septemdentata* Gabb, and *Neverita arata* (Gabb) are most conspicuous.

The following lists of gastropods, scaphopods, and pelecypods are the species collected and identified by H. B. Stenzel at Moseley's Ferry on Brazos River (Renick and Stenzel, **1299**, pp. 99–105, 1931). These are typical of the Crockett assemblage:

Gastropoda—
Cylichna kelloggi (Gabb)
Volvula conradiana Gabb
Volvula minutissima Gabb
Ringicula trapaquara Harris
Acteon pomilius Conrad
Conus sauridens Conrad
"Pleurotoma" enstricrina Harris
"Pleurotoma" texana Gabb
Turris cristata Gabb
Surcula gabbi Conrad
Surcula moorei Gabb
"Turris" nodocarinata Gabb
Drillia texacona Harris
Glyphstoma harrisi Aldrich
Eucheilodon reticulata Gabb
Scobinella conradiana Aldrich
Borsonia plenta Harris
Terebra houstonia Harris
Terebra texagyra Harris
Cancellaria penrosei Harris
Olivula punctulifera Gabb
Marginella semenoides (Gabb)
Conomitra polita (Gabb)
Volutocorbis petrosa (Conrad)
Caricella subangulata Conrad var. cherokeensis Harris
Fusus mortonii Lea var. mortoniopsis Gabb
Latirus moorei (Gabb)
Terebrifusus cf. amoenus Conrad
Pseudoliva carinata Gabb var.
Pseudoliva fusiformis Lea
Pseudoliva linosa Gabb
Phos texanus (Gabb)
Cornulina armigera Conrad
Neptunea enterogramma Gabb
Levifusus pagoda Heilprin
Levifusus trabeatoides Harris
Distortio septemdentata Gabb
Pyrula penita Conrad
Calyptraphorus trinodiferus Conrad
Rimella stephensoni Stenzel
Turritella nasuta Gabb
Turritella dumblei Harris
Mesalia claibornensis Conrad
Natica semilunata Lea
Natica sp. aff. mamma Lea
Neverita arata (Gabb)
Sinum bilix (Conrad)
Sinum declive (Conrad)
Calyptraea aperta (Solander)
Solarium bastropensis Harris
Solarium elaboratum Conrad
Solarium scrobiculatum Conrad
Solarium texanum Gabb
Scalaria carinata Lea

Tenuiscala trapaquara Harris
Pyramidella bastropensis Harris
Tuba antiquata Conrad
Eulima exilis Gabb
Eulima texana Gabb
Teinostoma sp.
Adeorbis exacua Conrad
Delphinula depressa Lea

Scaphopoda—
Dentalium minutistriatum Gabb
Cadulus juvenis Meyer

Pelecypoda—
Corbula alabamiensis Lea
Corbula smithvillensis Harris
Corbula texana Gabb
Tellina papyria Conrad var. mooreana Gabb
Callocardia texacola (Harris)
Callocardia trigoniata (Lea) var. bastropensis (Harris)
Protocardia gambrina Gabb
Venericardia planicosta Lamarck
Crassatellites antestriatus Gabb
Pholadomya harrisi Gardner
Modiolus houstonius Harris
Anomia ephippioides Gabb
Pecten scintillatus Conrad var. corneoides Harris
Ostrea sellaeformis Conrad var.
Ostrea sp. cf. alabamiensis Lea
Arca cuculloides (Conrad) var. ludoviciana Harris
Trinacria declivis (Conrad)
Trinacria pulchra (Gabb)
Leda bastropensis Harris
Leda opulenta Conrad var. compsa Gabb
Nucula magnifica Conrad var. mauricensis Harris

Foraminifera[143]—
Haplophragmoides excavata Cushman and Waters var.
Ammobaculites sp.
Spiroplectammina zapotensis (Cole)
Textularia cf. T. articulata d'Orbigny
Verneuilina cushmani Wienzierl and Applin
Quinqueloculina yeguaensis Wienzierl and Applin
Quinqueloculina vulgaris d'Orbigny
Quinqueloculina longirostra d'Orbigny
Quinqueloculina cf. Q. juleana d'Orbigny
Quinqueloculina aff. Q. agglutinans d'Orbigny
Triloculina trigonula (Lamarck)
Cornuspira involvens (Reuss)
Lenticulina alato-limbata (Gümbel)
Lenticulina aff. papillosa (Fichtel and Moll)
Astacolus jugosus (Cushman and Thomas
Pseudoglandulina sp.
Lagena vulgaris d'Orbigny
Guttulina problema d'Orbigny
Globulina inaequalis Reuss
Sigmomorphina pseudoregularis (Cushman and Thomas)
Nonion planatus Cushman and Thomas
Nonionella floriensis (Cole)
Nonionella mexicana (Cole)
Robertina arctica d'Orbigny
Virgulina zetina Cole
Bolivina sp.
Bolivina sp.
Discorbis sp.
Siphonina claibornensis Cushman
Gyroidina soldanii var. octocamerata Cushman and G. D. Hanna
Eponides guayabalensis Cole
Asterigerina texana (Stadnichenko)
Asterigerina aff. A. bracteata Cushman
Asterigerina n. sp.
Ceratobulimina eximia (Rzehak) var.
Globigerina triloculinoides Plummer
Globigerina inflata d'Orbigny
Globorotalia spinulosa Cushman
Globorotalia incrassata (Cushman)
Cibicides pseudowuellerstorfi Cole

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[143]Collected and identified by Helen Jeanne Plummer from three exposures along Pinoak Creek east of Smithville, Bastrop County, at Evergreen Crossing on Elm Creek, Lee County, and at Alabama Crossing on Trinity River, Houston County.

The Cost, or upper Crockett, zone is represented by the southernmost outcrops of the Crockett on Sabine River, a locality on Mill Creek 2½ miles north-northeast of Davisville in Angelina County, the upper beds at Caro Bluff on the Trinity, the localities on Cedar Creek southeast of Wheelock in northeastern Brazos County, the strata on Davidson Creek at Caldwell in Burleson County, the strata on Pinoak Creek near its confluence with Colorado River in Fayette County, and a roadside exposure just north of Cost in Gonzales County. The type locality for this zone was described first by Wienzierl and Applin (**1721**, pp. 384–410, 1929).

The fauna of this zone has fewer gastropods than the lower Crockett zone. Pelecypods predominate as a striking contrast to the abundant gastropod fauna of the lower zone. The following list of large fossils collected at Cost, Gonzales County, and identified by H. B. Stenzel are typical of the assemblage of this zone:

Ostrea sellaeformis Conrad (small variety cf. var. 1, Stenzel)
Venericardia planicosta Lamarck var.
Crassatellites sp. cf. C. clarkensis Dall
Callocardia sp. cf. C. texacola (Harris)
Nucula sp. cf. N. magnifica Conrad
Lucina sp.
Lirodiscus sp. cf. L. smithvillensis (Harris)
Loripes sp. cf. L. subvexa Conrad
Phos texanus (Gabb) var. cf. form 3, Stenzel
Fusus sp. cf. F. mortonii Lea
Flabellum cuneiforme Lonsdale cf. var. wailesi Conrad
Dendrophyllia sp. cf. D. striata Vaughan

The following foraminifera from the exposure north of Cost have been identified by Mrs. Plummer:

Spiroplectammina zapotensis (Cole)
Textularia dibollensis Cushman and Applin
Textularia claibornensis Wienzierl and Applin
Quinqueloculina yeguaensis Wienzierl and Applin
Triloculina trigonula Lamarck
Cornuspira involvens Reuss
Lenticulina rotulata Lamarck
Astacolus jugosus (Cushman and Thomas)
Globulina gibba d'Orbigny
Guttulina problema d'Orbigny
Sigmomorpha pseudoregularis Cushman and Thomas
Nonion planatus Cushman and Thomas
Uvigerina sp.
Gyroidina soldanii var. octocamerata Cushman and Hanna
Eponides guayabalensis var. yeguaensis Wienzierl and Applin
Siphonina claibornensis Cushman
Globigerina inflata d'Orbigny
Globorotalia crassata (Cushman)
Anomalina costiana Wienzierl and Applin
Virgulina dibollensis Cushman and Applin
Bolivina, 2 spp.
Nonionella sp.
Ceratobulimina eximia (Rzehak)

Correlation.—The fauna of the Crockett has many fossils similar to, and identical with, fossils from the Wautubbee marl of Mississippi and from the Lisbon formation at Claiborne, Alabama, and at Indian Mound, three miles east of Newton, Mississippi. A small number are identical with species found in the Gosport sand of Alabama. It is thought by most paleontologists that the Crockett correlates with the upper Lisbon formation, although others believe that the upper zones of the Crockett are Yegua in age and belong with the Gosport. The correlation table, figure 41, shows the relationships in the Gulf Coast area.

YEGUA FORMATION[144]

Definition.—The beds that occur in the geologic section above the Crockett were originally named Fayette by Penrose (**1189**, p. 47, 1890), who made this division include all the strata that lie between the "uppermost fossiliferous strata of the marine Tertiary below and the Post-Tertiary clays, limestones, and pebble beds above." Penrose described the formation excellently and correlated it with the Grand Gulf of Mississippi. The Fayette thus included all the Eocene strata that comprise the Yegua formation and the overlying Jackson group. No marine fossils had been discovered in beds above the marine Claiborne at the time Penrose wrote.

Kennedy (**905**, pp. 58–60, 1892) named the beds above the marine Claiborne the Lufkin or Angelina County deposits. Dumble (**470**, pp. 148–153, 1892) during the same year named the same strata Yegua division, which he defined as the lower part of the deposits originally classed as Fayette beds by Penrose. If Dumble had been satisfied with his first definition, he would have saved much confusion. Two years later, however, he (**478**, p. 552, 1894) stated that the fauna of the Yegua "connects it directly with marine beds" showing that he included in his division some of the fossiliferous marine strata, and he stated: "Typical exposures of the beds may be seen near Alto and Lufkin, on the Yeguas in Lee County, and between Pleasanton and Campbellton." Alto and Pleasanton are on the Weches formation, the Yegua Creek exposures are mostly Yegua,

[144]LITERATURE—Penrose, R. A. F., **1189**, pp. 47–58, 1890. Kennedy, Wm., **905**, pp. 58–60, 1892; **911**, pp. 99–108, 1896. Dumble, E. T., **470**, pp. 148–153, 1892; **478**, pp. 549–567, 1894; **506**, pp. 108–122, 125–130, 1918; **510**, pp. 429–431, 1924. Udden, J. A., Baker, C. L., and Böse, Emil, **1652**, pp. 85–86, 1916. Deussen, A., **415**, pp. 65–67, 1914. Reed, L. C., and Longnecker, O. M., **1288**, pp. 163–174, 1929. Trowbridge, A. C., **1613a**, pp. 129–140, 1932.

and Lufkin and Campbellton are on the nonmarine strata above the Yegua. It is clear, therefore, that Dumble included in his Yegua some strata that are now named Crockett, although the overlying nomarine beds made up the bulk of the division.

Kennedy (**911**, pp. 99–108, 1896) included in the Yegua clays nearly 1000 feet of strata between the Marine Beds and the Fayette sands. Kennedy's description of his boundaries of the Yegua shows that he included in his formation not only the nonmarine beds below the Jackson, but also some strata now named Crockett in east Texas, and also some strata that are now designated Sparta.

The same year Vaughan[145] named strata in Louisiana approximately equivalent to Dumble's nonmarine Yegua Cocksfield Ferry beds and made the division include strata between the St. Maurice and marine Jackson. Deussen (**415**, pp. 65–67, 1914) restricted the Yegua to Dumble's original 1892 definition and included only the nonmarine strata between the marine Claiborne beds below and the Jackson above and stated that this formation was equivalent to the Cockfield Ferry beds of Vaughan. This definition was approved by the United States Geological Survey and became generally accepted by geologists working in the Southwest.

Dumble (**506**, pp. 102–103, 1918), however, described sections on Elm Creek and Yegua Creek in Lee County and published lists of marine fossils from the outcrop along Elm Creek north of Giddings, which he gave as the type locality for the Yegua formation. Miss Gardner (**569**, pp. 245–251, 1927) reviewed the complicated nomenclature of the Yegua and concluded that the fauna of the Yegua at its type locality is referrable to the lower Claiborne section, although modified by special conditions attending the close of that epoch. She stated, however, "It should be remembered that Dumble included in the Yegua a considerable thickness of beds overlying the type section and covering a broad area to the northeast of them." She, therefore, rejected Deussen's restricted definition of the Yegua and returned to Dumble's grouping of the marine and nonmarine strata in her interpretation of the Yegua formation. Miss Stadnichenko (**1517**, pp. 221–243, 1927) followed Miss Gardner's usage.

Mrs. Wienzierl and Mrs. Applin (**1721**, pp. 384–410, 1929), although both did work under Dumble's direction, described the

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[145]Vaughan, T. W., The stratigraphy of northwestern Louisiana: Amer. Geol., vol. 15, pp. 205–229, 1895.

beds at Elm Creek and the foraminifera from the type locality for the Yegua and also from supposedly similar stratigraphic zones at a number of other localities under the name "Claiborne formation." In their paper, however, they use the word "Yegua," as for example, "Yegua samples," "Yegua deposits," "Yegua times," and "Yegua period," and state that on the coastal domes the Claiborne formation is "Yegua (upper Claiborne) in age." It is inferred that they intended "Yegua" as a group name and "Claiborne formation" for the marine beds (Dumble's marine Yegua) only.

Wendlandt and Knebel (**1728**, p. 1351, 1929) used the term Yegua in the restricted usage of Deussen to designate the section between the Crockett and Jackson strata. Miss Ellisor (**523**, p. 1339, 1929) used Cockfield for the same division. Renick and Stenzel (**1299**, p. 78, 1931) preferred Yegua in its restricted usage. Heath, Waters, and Ferguson (**696**, p. 46, 1931) also selected Yegua (restricted). Moody (**1125**, p. 536, 1931) uses Cockfield. The United States Geological Survey (**396c**, 1932) have adopted Cockfield, and Trowbridge (**1613a**, p. 129, 1932) in his recent bulletin on the geology of the Rio Grande area has used the name Cockfield. The author and most of his colleagues in Texas prefer the name Yegua (restricted) with which so many geologists are familiar and which has been used so much in most local geologic reports. Finally, as this manuscript goes to press, word is received from Mendenhall[146] that the United States Geological Survey has decided to use the name in its restricted sense in the future.

Regional geology.—The Yegua formation occupies a forested, gently rolling, more or less sandy belt in east and central Texas. In south Texas the outcrop has about the same aspect, but the trees give way to thorny brush, mesquite, and prickly pear.

The outcrop, as delineated on the new geologic map of Texas prepared by the United States Geological Survey, extends in a band averaging 12 miles wide from Sabine River in the vicinity of Bayou and Yellow Pine in south-central Sabine County westward and southwestward across central Angelina, northern Trinity, southern Houston, southern Madison, northern Grimes, northern Brazos, and central Burleson counties to First Yegua Creek southwest of Deanville. From First Yegua Creek the outcrop narrows and traverses a

[146]Mendenhall, W. C., letter to E. H. Sellards, December, 1932.

belt about 5 miles wide through Lee, Fayette, Gonzales, and southern Wilson counties to Atascosa River in Atascosa County. From central Atascosa County the outcrop widens to 12 to 15 miles and trends across northern McMullen, La Salle, Webb, and Zapata counties to the Rio Grande. The Yegua formation dips to the southeast except where affected by abnormal structure and passes beneath younger strata. It is penetrated in oil wells as far south as the coast.

The thickness of the Yegua formation varies in the different districts between 600 and 1000 feet and averages 750 feet. Measurements in various places where a complete section has been penetrated in wells or measured on the outcrop is shown in the following table:

LOCALITY	COUNTY	THICKNESS *Feet*	AUTHORITY
Outcrop along Nueces River	La Salle	1049	Deussen
Outcrop and well sections near Bryan	Brazos	755	
Oil-well sections	Webb	1533	Trowbridge

Stratigraphy.—The Yegua formation lies unconformably upon the Crockett formation and is overlain by strata of the Jackson group. Its basal contact is where its nonmarine, sandy clays and sands lie upon the laminated marine strata of the underlying formation. The Crockett marine strata are more thinly and evenly laminated, their sediments are better assorted, and in most places the beds contain fragments of shells, casts of fossils, or foraminifera. The Yegua strata contain more sand, more carbonaceous matter, more gypsum, and in some places plant remains and fossilized wood, and the clays are darker colored and in many places are distinctly chocolate-colored. The sands are much more cross-bedded. There are thin beds of bentonite and some volcanic ash in the Yegua; none in the Crockett. In most places the contact is easily recognized.

The strata of the Yegua have not been separated into individual units. In general the formation is a heterogeneous complex of layers of sand, clay, lignite, sandy clay, and carbonaceous clay lentils. None of the layers can be traced far or correlated from one core test to another, unless the tests are very close together. Although the section as a whole in one place looks about like a section in another place, yet the individual layers that make up the section are variable.

The succession of strata in the different districts is shown in the following described sections:

Section[147] of the lower half of the Yegua formation described from a core test 2½ miles south and 1 mile west of Bryan, Brazos County.

	Thickness *Feet*
8. Surface soil and sand	25
7. Sand and clay containing thin seams of bentonite	35
6. Lignite, brown	1
5. Clay, gray, sandy, unstratified	44
4. Sand, gray, medium grained, containing water	55
3. Lignite, brown, occurring in two thin beds separated by gray, sandy clay	10
2. Clays and sands, gray, partially stratified	90
1. Sand, medium grained, containing water	125
Total section measured	385

Section[148] of middle portion of Yegua formation of Westmoreland Bluff, Trinity River, 4 miles west of Weldon, Houston County.

	Thickness *Feet*
12. Shale, black, carbonaceous, finely laminated, containing petrified logs	3
11. Shale, black, carbonaceous, containing small selenite crystals and grading toward the east end of the bluff into sandy clay interbedded with carbonaceous shale and containing a lentil of brown iron-stained sand containing petrified logs	25
10. Clay, yellowish brown	3
9. Sand, grayish brown, containing 1 foot of bluish-black, carbonaceous, sandy clay	7
8. Sand, black and brown, carbonaceous, containing small, black leaf fragments	¾
7. Sand, laminated, dark brown	1
6. Clay, greenish drab, compact, sticky	½
5. Shale, chocolate-brown, carbonaceous, thinly laminated	1
4. Lignite, compact, hard, good quality	5
3. Clay, dark drab, fine, fracturing into small fragments	2

[147]Measured by L. C. Reed and O. M. Longnecker, 1288, p. 172, 1929.

[148]Condensed from description by C. L. Baker and J. R. Suman (506, p. 127, 1918).

	Thickness *Feet*
2. Sand, brown, compact, laminated, containing small crystals of selenite. The lamination planes are stained a rusty color with limonite and in places colored yellowish with sulphur	5
1. Sand, gray, micaceous, fine grained, unconsolidated	4½
Total thickness measured	57¾

Sedimentology.—The Yegua epoch was a repetition of the events and physical conditions of the Rockdale epoch. The Claiborne sea withdrew, and a thick series of fluviatile sands, palustrine peats, and lacustrine clays were deposited over the marine, glauconitic clays and beach deposits of the Crockett epoch. The strand line was more even in the Yegua than in the Rockdale. There were fewer embayments, fewer lagoons, fewer widespread lignite beds, and less massive sand deposits—more of a coalescing of a very great number of smaller sedimentary lentils. In the resulting assemblage of lentils no one layer can be traced far. It is essentially a piedmont, coastal, alluvial fan built up by the coalescing of stream levees and deltas. Apparently there were two major river systems with intervening minor ones. One that may have been an ancestral Trinity before its headwaters were captured by the west branches of the Mississippi flowed through the east Texas basin area, where it built up a broad piedmont apron from Sabine to Burleson County. Another large stream, an ancestral Rio Grande, flowed down the Nueces synclinal area and built up a thick apron from Atascosa County to southern Webb County. The area along the old coast line between Burleson and Atascosa counties was fed only by smaller streams unable to build up so thick an alluvial deposit as the two major streams on the northeast and southwest. The climate was perhaps warmer than that of the Rockdale. Palms, palmetto, and figs flourished in great luxuriance, and the whole coastal plain teemed with plant life. Large petrified stumps of the palm *Palmoxylon*[149] are common in sandy silts of the upper Yegua beds in Lee, Fayette, and Gonzales counties.

Lithology.—The Yegua formation consists of about 50 per cent sand, 26 per cent sandy clay, 22 per cent compact clay, and 1 per

[140]Identified by G. R. Wieland.

cent lignite, and 1 per cent bentonite. The sands are massive, laminated, cross-bedded, and made up of medium to fine grains averaging 0.2 mm. in diameter. The grains, however, show considerable range in size. According to Lonsdale and his associates (**1013c**, p. 76, 1931) from 60 to 81 per cent of the grains are between 0.295 mm. and 0.147 mm. in diameter, from 19 to 32 per cent are between 0.147 mm. and 0.074 mm., and from 4 to 8 per cent are smaller than 0.074 mm. Burt (**184**, pp. 665–666, 1927) studied some quicksand grains washed from the Yegua formation in Turkey Creek, Brazos County, and found the following range in texture:

1%	larger than	0.84 mm.	(20-mesh screen)
1%	Do	0.42 mm.	(40-mesh screen)
10%	Do	0.25 mm.	(60-mesh screen)
27%	Do	0.18 mm.	(80-mesh screen)
18%	Do	0.10 mm.	(100-mesh screen)
43%	smaller than	0.10 mm.	(100-mesh screen)

The grains are subrounded to subangular in shape. Burt found the coefficient of roundness to be 44.00. Lonsdale calculated that from 5 to 10 per cent are subround, from 64 to 84 per cent are subangular, and from 10 to 20 per cent are angular. The grains are predominantly quartz (99.4 per cent) with muscovite, traces of leucoxene, ilmenite, tourmaline, zircon, cyanite, staurolite, rutile, and limonite. Some of the quartz grains are rough and pitted, but the largest percentage consists of clear or smoky quartz with a minor amount of gray and greenish-gray chert grains. The chert grains resemble material found only in Pennsylvanian formations and suggest that the source of some of the Yegua sediments was in the Strawn outcrops in central Texas.

The clays in the Yegua formation vary from dark chocolate-brown to gray and greenish-gray. According to Dumble (**510**, p. 429, 1924) the dark-colored clays are more common in the lower part of the formation, and the light gray and green and white clays are in the upper part. The clays are highly colloidal, jointed, and most of them are well laminated. They are noncalcareous and rich in silica and alumina, as shown in the following analysis of a clay from an outcrop near Lufkin, Angelina County:

	Per cent		Per cent
SiO_2	67.3	CaO	1.97
Al_2O_3	14.58	MgO	1.46
Fe_2O_3	5.73	SO_2	4.52
Na_2O and K_2O	1.47	H_2O	4.06

The clays contain gypsum in the form of minute crystals along the bedding planes, in the form of thin seams and, in a few places especially in the southern district, as beds of impure calcium sulphate a foot or more in thickness. Thin beds of volcanic ash occur also in the Yegua formation in the south Texas area. Lentils of brown lignite are found in the Yegua throughout the Gulf Coast, and small fragments of carbonaceous matter are common in the clays.

Two types of concretions occur: (1) flat ironstone concretions from a few inches to a foot or more in diameter; (2) large, dark-colored, calcareous concretions a foot or more in diameter, many of which are cracked and contain veins and pockets filled with quartz crystals.

Distinguishing characteristics.—The Yegua along its outcrop is essentially a continental deposit. It has the heterogeneous lithology of stream, swamp, and lake beds in striking contrast to the uniform and evenly bedded strata of the underlying marine beds of the Crockett formation. The following criteria distinguish it from other Claiborne formations:

1. Chocolate-brown color. The clays are in most places impregnated with enough organic matter to give them a reddish-brown color.
2. Brown lignite. More lignite and lignitiferous material occur in this formation than in other formations of the Claiborne group. The lignites are brown and chocolate-brown in contrast to the dull black lignites of the Rockdale formation.
3. Gypsum. More gypsum and gypsiferous material occur in the Yegua than in the other Claiborne formations.
4. Concretions. The clays of the Yegua contain ironstone concretions in the form of flattened masses of ferruginous clay in which the original carbonate has been altered to limonite. Some of the flat concretions are more than a foot in diameter. The concretions in the underlying Crockett are more nearly spherical.

5. Silicified wood. Fragments of dark-colored, petrified wood and petrified logs are common throughout the strata of the Yegua formation. They are most common in the sands and sandy clays associated with the beds of lignite.

Paleontology.—Fossils are rare in the outcropping section of the Yegua formation. The invertebrate fossils mentioned and listed by Dumble and Kennedy in descriptions of the Yegua were collected from the Crockett formation and not from the Yegua as now defined. Marine fossils have been discovered in a few places on the outcrop of the Yegua and in thin zones in wells drilled south of the outcrop.

The large oyster *Ostrea georgiana* Conrad occurs in a number of zones in the Yegua in southwest Texas. The length of the shell is six to eight inches and more, and the species occurs in layers a few inches thick, which can be traced for several miles. In most places the oyster is the only species present. Poorly preserved shells of *Venericardia* occur in a few places.

The faunas in the Yegua in general seem to be more closely related to the Claiborne faunas than to the Jackson or Vicksburg collections.

Dumble (**506**, p. 123, 1918) made a collection of plant leaves from the Yegua formation near the station of Cut on the International and Great Northern Railroad between Crockett and Lovelady in Houston County. The list as identified by E. W. Berry is as follows:

Phoenicites occidentalis Berry
Dryophyllum n. sp.
Myristica catahoulensis Berry
Cedrela n. sp.
Mespilodaphne n. sp.
Nectandra n. sp.
Nectandra n. var.
Nyssa n. sp.
Carpolithus n. sp.

A piece of petrified wood collected near Wooters station in Houston County was identified by Berry as *Cupressionoxylon dawsoni* Penh. Two specimens from this list are known to occur in the Claiborne strata in other states, and three have been collected from localities in the Jackson. Other plant localities from which lists of supposedly Yegua fossils have been published by Dumble (**506**,

p. 125, 1918) and by Deussen (**421**, p. 77, 1924) are now known to be in the Jackson formation.

Correlation.—The strata described under the name Yegua in Texas are correlated with the Cockfield of Louisiana and the upper beds of the Gosport sand of Alabama. The correlation is shown in figure 41.

Economic resources.—The economic resources of the Yegua are petroleum, lignite, and clays for manufacture of brick and tile, and fertile soils. The soils of the Yegua outcrop consist principally of sandy loams with minor amounts of clay loams and a little clay. The most typical soil is the fine, sandy Lufkin loam, which occupies fully half the area of the outcrop. According to Veatch and Waldrop[150] the soil consists of 10 to 12 inches of grayish-brown, rather compact, fine, sandy loam underlain by drab or yellow clay. In places on the higher ridges the fine sandy upper layer is only about 6 inches deep. In the lowlands, however, it is much thicker. The total average thickness of the soil layer in central Texas is from 3 to 5 feet. Practically the whole of the land occupied by this soil is capable of cultivation, although only about one-half is now improved. The unimproved land in east Texas supports a growth of pine in places. Elsewhere and throughout central Texas the soil is rather thinly forested with post oak, a little blackjack oak, and near streams, some hickory and elm. The principal crops are cotton and corn. The average yield of cotton is about one-third of a bale to the acre. Some oats and sorghum are grown. Fruit trees are generally short lived. In general the land is not so valuable for agriculture as the soils of most of the other Claiborne formations.

Lignite has been mined by the Houston County Coal Company near Wooters station on the International and Great Northern Railroad 3 miles north of Lovelady. According to Dumble (**506**, p. 285, 1918) the lignite averages 5 feet 10 inches in thickness over 5500 acres and is everywhere overlain by a 3-foot layer of stiff clay, which forms an excellent roof. The lignite is reached by a two-compartment shaft 58 feet deep and is mined by the room-and-pillar method. In 1918 the average output amounted to 300 cars

[150]Veatch, J. O., and Waldrop, C. S., Soil survey of Brazos County, Texas: U. S. Dept. Agric., Bur. Soils, pp. 22–25, 1916.

of 60,000 pounds each per month during the summer, and 350 cars per month during the winter. The lignite is dark brown, breaks in large cuboidal blocks, and disintegrates when exposed to air for some time or to heat for a short time. An analysis of the coal by William B. Phillips of the Bureau of Economic Geology is as follows:

Volatile and combustible matter	52.90%
Fixed carbon	33.00%
Ash	13.11%
Sulphur	0.80%
Heating value	10.120 B.T.U.

Other occurrences of lignite in the Yegua formation which have been reported in the literature or are on record in the files of the Bureau of Economic Geology are as follows:

Angelina County—

Huntington; at 25 feet below the surface is a 12-foot lignite bed that outcrops along Gilland Creek east of the town.

Burke; lignite from 4 to 7 feet thick occurs 15 feet below the surface.

Angelina River bank south of Ewing; outcrop of a 4-foot bed of black lignite having a lamellar structure and pitchy lustre.

Houston County—

Hyde's Bluff on Trinity River west-northwest of Weldon; from 2 to 4 feet of black lignite is exposed and is overlain by 10 feet of blue sand and gray clay for a distance of nearly one-half mile along the river bank. Five miles east of Hyde's Bluff 2 feet of lignite was penetrated in water wells.

Flat Creek in southeastern part of the county; a 4-foot bed of lignite outcrops along the stream bank. It is bright glossy black and weathers to dull brown.

Madison County—

Shepherd's Creek; from 2½ to 4 feet of lignite exposed. The lignite is black and light in weight and is intermediate in grade. The outcrop caught fire in 1915 and burned a long time.

Cottonwood Prairie on Amy Boatwright Survey; about 10 feet of lignite were penetrated at a depth of 20 feet in a water well. It is said to be of good grade.

Larrison Creek on William Curry Survey; outcrop of 2 to 3 feet of a fair grade of lignite.

McMullen County—

San Miguel Creek, 8 miles east-northeast of Tilden; about 10 feet of lignite exposed in a shaft. The bed contains thin layers of bituminous shale in its upper portion. The lower 3½ feet is of fairly good quality. The same bed is encountered between 500 and 550 feet in wells near Tilden, so it is known to have considerable horizontal extent.

The clays of the Yegua formation in most places are too sandy to constitute good brick clays. Many lentils of compact noncalcareous clays occur, however, which could be utilized for brick and tile manufacture.

Rich oil sands occur in the upper strata of the Yegua. The most notable oil pools in this zone are the Pettus oil sand, which lies from 20 to 50 feet below the top of the formation in Refugio County, and the Conroe oil sand, which lies from 220 to 260 feet below the top of the formation in Montgomery County.

JACKSON GROUP[151]

DEFINITION

The name Jackson has been used continuously since the time of Conrad[152] to designate upper Eocene strata in Louisiana, Mississippi, and Alabama. It is now one of the best-known geologic names in the Eocene section. The Jackson group in Texas includes all Eocene strata above the Claiborne group. It lies conformably

[151]LITERATURE—Conrad, T. A., [Jackson group] Acad. Nat. Sci. Philadelphia Proc., vol. 7, p. 257, 1856. Hilgard, E. W., [Jackson group] Report on the geology and agriculture of the state of Mississippi, pp. 128–138, 1860. Hopkins, F. V., [Jackson group] Geol. Survey Louisiana 2nd Ann. Rept., pp. 7–15, 1871. Lerch, Otto, [Jackson group] A preliminary report on the hills of Louisiana south of the Vicksburg, Shreveport and Pacific Railway: Louisiana State Exper. Sta., Geol. and Agric., pt. 2, pp. 88–91, 1893. Dall, W. H., [Jackson stage] U. S. Geol. Survey, 18th Ann. Rept., pt. 2, p. 343, 1898. Harris, G. D., and Veatch, A. C., [Jackson stage] Geol. Survey Louisiana, Rpt. for 1899, pp. 89–93, 1900; Geol. Survey Louisiana, Rpt. for 1902, pp. 22, 23, 131, 132, 164–167, 1902. Veatch, A. C. [Jackson formation] Geology and underground water resources of northern Louisiana and southern Arkansas: U. S. Geol. Survey Prof. Paper 46, pp. 39–40, 1906. Lowe, E. N., [Jackson group] Mississippi, its geology, geography, and soils: Miss. State Geol. Survey Bull. 14, pp. 80–85, 1919. Cooke, C. W., Correlation of the deposits of Jackson and Vicksburg ages in Mississippi and Alabama: Washington Acad. Sci. Jour., vol. 8, pp. 186–198, 1918; [Deposits of Jackson age] Geology of Alabama: Geol. Survey Alabama Spec. Rpt. 14, pp. 274–278, 1926. Stephenson, L. W., Logan, W. N., and Waring, G. A., [Jackson formation] The underground-water resources of Mississippi: U. S. Geol. Survey Water-Supply Paper 576, p. 53, 1928. Semmes, Douglas, [Formations of Jackson age] Oil and gas in Alabama: Geol. Survey Alabama Spec. Rpt. 15, pp. 271–275, 1929.

[152]Conrad, T. A., Observations on the Eocene deposits of Jackson, Mississippi, with descriptions of four new species of shells and corals: Acad. Nat. Sci. Philadelphia Proc., vol. 7, p. 257, 1856.

upon the Yegua and is overlain unconformably by the Catahoula and Frio formations. It consists of shallow-water, marine, and beach deposits, composed of medium- and fine-grained, thin-bedded sand, argillaceous and tuffaceous clays and tuffs, and lentils of coarse, rounded, and polished sand grains. In many places the beds are somewhat fossiliferous. They represent the lower, or Eocene, portion of the pyroclastic epoch, during which violently active volcanoes began to play an important part in supplying material to the sediments.

SUBDIVISIONS

The Jackson group of strata has not been subdivided into formational units in Texas. All the strata are referred by the United States Geological Survey to one formation, which they (**396c**, 1932) have designated Fayette formation. Some geologists[153] regard the Frio formation as upper Eocene or Oligocene; if it is Eocene, it belongs to the Jackson group. The correlation of subsurface data seems to indicate, however, that the outcropping Frio grades down dip above strata that carry a microscopic fauna related to marine lower Oligocene faunas of the Gulf Coast region. The Frio formation has therefore been removed from the Jackson group in recent publications[154] and is classified with Oligocene formations. The Jackson group in Alabama and Mississippi is divided by Cooke[155] into the Jackson formation proper and the Ocala limestone. The Ocala limestone does not occur in Texas.

FAYETTE FORMATION[156]

Definition.—The upper Eocene, Miocene, and Pliocene strata from the top of what is now known as the Crockett formation to the top of the Lagarto clays were grouped together by Penrose

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[153]Deussen, A., **421**, p. 92, 1924. Dumble, E. T., **510**, p. 435, 1924. Trowbridge, A. C., **1610**, pp. 97, 98, 1923. Bailey, T. L., **40**, pp. 50, 51, 1926.

[154]Geologists of the Humble Oil and Refining Company, The geology of the Gulf Coast area of Texas and Louisiana: Natl. Oil Scouts Assoc. Yearbook, p. 54, 1931.

[155]Cooke, Wythe, The Cenozoic formations: Geol. Survey Alabama Special Rpt. 14, p. 274, 1926.

[156]LITERATURE—Penrose, R. A. F., **1189**, pp. 47–58, 1890. Dumble, E. T., **470**, pp. 154–157, 1892; **494**, pp. 913–987, 1903; **506**, pp. 134–144, 1918; **510**, pp. 426–427, 431–435, 1924. Kennedy, Wm., **905**, pp. 60–62, 113–116, 1892; **906**, pp. 45–46, 1893; **911**, pp. 95–99, 1896. Hayes, C. W., and Kennedy, Wm., **692**, pp. 21–23, 32–61, 1903. Deussen, A., **415**, pp. 68–72, 1914; **421**, pp. 80–91, 1924. Cooke, C. W., Correlation of the deposits of Jackson and Vicksburg ages in Mississippi and Alabama: Washington Acad. Sci. Jour., vol. 8, pp. 186–198, 1918. Trowbridge,

(1189, p. 47, 1890) under the name Fayette. Dumble (**470**, pp. 148–157, 1892) split this original group of Penrose into two divisions, Yegua at the base and Fayette (restricted) at the top. Later Dumble (**478**, pp. 556–559, 1894) revised the classification in south Texas and added two more divisions, the Frio and Oakville. Since the publication of these early reports by Penrose and Dumble the name Fayette has been used variously by geologists. Kennedy (**905**, pp. 60–62, 1892) included the Catahoula sandstone in his Fayette sands, making the division include strata from the Lufkin formation (now Yegua) up to the Fleming. Veatch (**1691**, p. 43, 1906) and Deussen (**415**, p. 68, 1914) included the Fayette in their Catahoula formation. Udden, Baker, and Böse (**1652**, p. 86, 1916) included in the Fayette from 400 to 600 feet of strata between the Yegua and Frio southwest of Brazos River and from 400 to 500 feet of beds between the Yegua and Catahoula sand northeast of the Brazos. Dumble (**506**, p. 134, 1918) still further restricted his definition of the Fayette to include certain strata in east Texas between his Yegua and fossiliferous beds that he found to be of Eocene age. He apparently intended to restrict the name to a single bed of fossiliferous sand below the base of the Jackson in east Texas and below the Frio in south Texas. On his map of a portion of east Texas (**506**, pl. 1, 1918) he shows the Fayette only in patches, possibly outliers, upon the Yegua outcrop, and he designated (**506**, p. 134, 1918) as the type locality for his restricted Fayette the section of strata on Colorado River east of West Point in the extreme western corner of Fayette County. He states that the first high bluff down the river from the railroad bridge two miles north of West Point, called by Penrose "Chalk Bluff," has "Yegua at its base, but higher up a different formation comes in characterized by light colored sands and joint clays which belong to the Fayette . . . Criswell Creek just east of West Point gives excellent exposures of the Yegua-Fayette contact." These localities are within the outcrop of the Yegua, as shown on the new geologic map of Texas (**396c**,

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A. C., **1610**, p. 97, 1923. Applin, Esther, Ellisor, Alva, and Kniker, Hedwig, **32**, pp. 111-122, 1925. Bailey, T. L., **40**, pp. 37–44, 1926. Cushman, J. A., and Applin, Esther, **352**, pp. 154–189, 1926. Moree, R. W., **1139**, p. 227, 1930. Cushman, J. A., and Ellisor, Alva, **382b**, pp. 51–58, 1931; **382h**, pp. 40–43, 1932. Ellisor, Alva, Jackson formation in Texas: Ms, of paper presented at meeting of Society of Economic Paleontologists and Mineralogists, March 1931. Howe, H. V., and Wallace, W. E., Foraminifera of the Jackson Eocene at Danville Landing on the Ouachita: Louisiana Dept. Conservation Geol. Bull. 2, pp. 1–118, 1932. Trowbridge, A. C., **1613a**, pp. 141–155, 1932.

1932). Dumble (**506**, p. 134, 1918) placed his Fayette beds in the Claiborne group and believed they were distinct from the Jackson.

Dumble's type locality for his restricted Fayette formation was selected unwisely, and his definitions are not clear, so that unfortunately interpretations of the name Fayette are varied. Trowbridge, for example, (**1610**, p. 97, 1923) designated the strata between the Frio and Yegua as Fayette. Deussen (**421**, p. 80, 1924) influenced by the United States Geological Survey followed the same usage in his report on the geology of the Coastal Plain west of the Brazos. Deussen, however, states definitely that the beds are not of "Claiborne age but of Jackson age," yet he did not regard them as equivalent to the Jackson, because he remarks (**421**, p. 80, 1924) that "west of the Brazos the Fayette sandstone lies above the Yegua, but in eastern Texas and western Louisiana it lies above the Jackson." Dumble (**510**, p. 431, 1924) finally emended his former definitions and described the Fayette as a series of beds that is exposed in a northward-facing escarpment in Lipan Hills east of Campbellton and extends in a broken line for some 20 miles or more northeast and southwest. In this same paper Dumble (**510**, pp. 433–434, 1924) divided his Fayette into two members, Whitsett beds above and Lipan beds below. He stated that he felt fully warranted in referring the upper member to the Jackson but still held that the lower or Lipan member was Claiborne.

Miss Ellisor[157] uses Jackson as a formation name to designate the strata between the Yegua and Catahoula and divides these beds into three divisions: Caddell, McElroy, and Whitsett. The United States Geological Survey (**396c**, 1932) has assigned the name Fayette to all the strata between the Yegua and the Catahoula in northeast Texas and between the Yegua and the Frio in south Texas. Trowbridge (**1613a**, pp. 141–155, 1932) used Fayette again for the strata in south Texas between the Frio and Yegua. Shearer,[158] Moody (**1125**, p. 536, pl. 1, 1931), and Heath, Waters, and Ferguson (**696**, p. 46, 1931), on the other hand, have preferred to use the older term Jackson as a formation name instead of Fayette.

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[157]Ellisor, Alva, Jackson formation in Texas: Paper presented at San Antonio meeting of the Society of Economic Paleontologists and Mineralogists, March, 1931. She originally used the word Fayette to designate the upper member, but changed it in 1932 to Whitsett.

[158]Sherer, H. K., Geology of Catahoula Parish, Louisiana: Bull. Am. Assoc. Pet. Geol., vol. 14, p. 434, 1930.

The diagram, figure 45, summarizes this complicated nomenclature.

The name Jackson now seems to be preferable for a group name to designate all the uppermost Eocene strata above the top of the Claiborne. Fayette is employed as a formation name for Texas strata between the Yegua below and the Catahoula or Frio above. The section exposed at Lipan Hills, as described by Dumble in his final description of the Fayette, is now regarded as the type section of the Fayette formation.

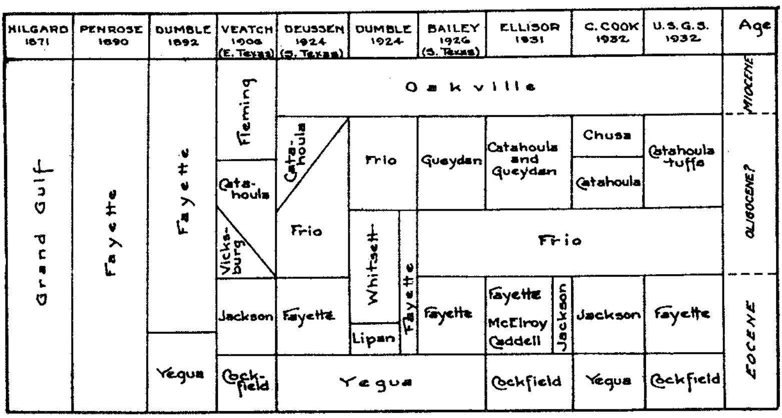

Fig. 45. Development of the nomenclature of the middle Cenozoic formations from 1871 to 1932 (adapted from Carroll Cook, Univ. Texas thesis, 1932).

Regional geology.—The outcrop of the Fayette formation is characterized by undulating topography in which moderate slopes, wide valleys, and ranges of low hills are the rule. More than half the surface is unforested.

The Fayette strata consist of marine, brackish-water, near-shore, and continental deposits of light-colored sand, sandy clay, and green tuffaceous clay. The beds outcrop in a belt that averages five miles in width, which extends from Sabine River south of Robinson's Ferry westward and southwestward across Trinity River at the north line of Walker County, and across Brazos River at the southeast corner of Burleson County. The belt can be traced from the Brazos to the Colorado in central Fayette County, thence to Frio River in eastern McMullen County, and to the Nueces in the southeastern corner of La Salle County. From the Nueces the

Fayette swings southward to the Rio Grande and crosses the river just above Rio Grande City. The outcrop in central and south Texas is shown on the map, figure 46.

The beds dip southeastward except in Rio Grande Valley and extend beneath the surface at least as far as the Gulf Coast area, where the formation is penetrated in many wells.

The thickness of the Fayette formation varies from 400 to 1650 feet. It is thickest in south Texas and thinnest on the Sabine uplift. Measurements of its thickness in various sections are shown in the following table:

LOCALITY	COUNTY	THICKNESS *Feet*	AUTHORITY
Well sections, Aviator field	Webb	1400	Alva Ellisor
Wormser No. 1, Houston Oil Co.	Brooks	1650	Do
McKinney No. 1, Houston Oil Co. and Humble Oil Co., Pettus field	Bee	1040	Do
Dubois No. 2, Green et al	Gonzales	900	Do
Danforth No. 1, Goliad Oil Co.	Goliad	1650	Do
E. B. Wilson No. 1, Humble Oil Co., Raccoon Bend oil field	Washington	1240	Do
Warren No. 7, Humble Oil Co.	Harris	1600	Do
Becker No. 7, Sinclair, Damon Mound	Brazoria	410	G. M. Bevier
West Columbia oil field	Brazoria	633	D. P. Carlton
Flourney No. 1, Helmerick & Payne	Jasper	1000	Alva Ellisor
Oil wells	Webb and Zapata	1275	A. C. Trowbridge
Palmatier No. 1, Sunshine Oil Co.	Polk	1065[a]	H. C. Ferguson

[a] Still in lower Fayette at bottom of hole.

Stratigraphy.—The Fayette formation lies conformably upon the Yegua and is overlain disconformably in southwest Texas by the Frio clay and unconformably in central and northeast Texas by the Catahoula formation. It is difficult in many areas to recognize the contact of the littoral deposits of the Fayette with the nonmarine deposits of the Yegua on the outcrop; it is still more difficult in well sections where the Yegua strata also may have a marine facies.

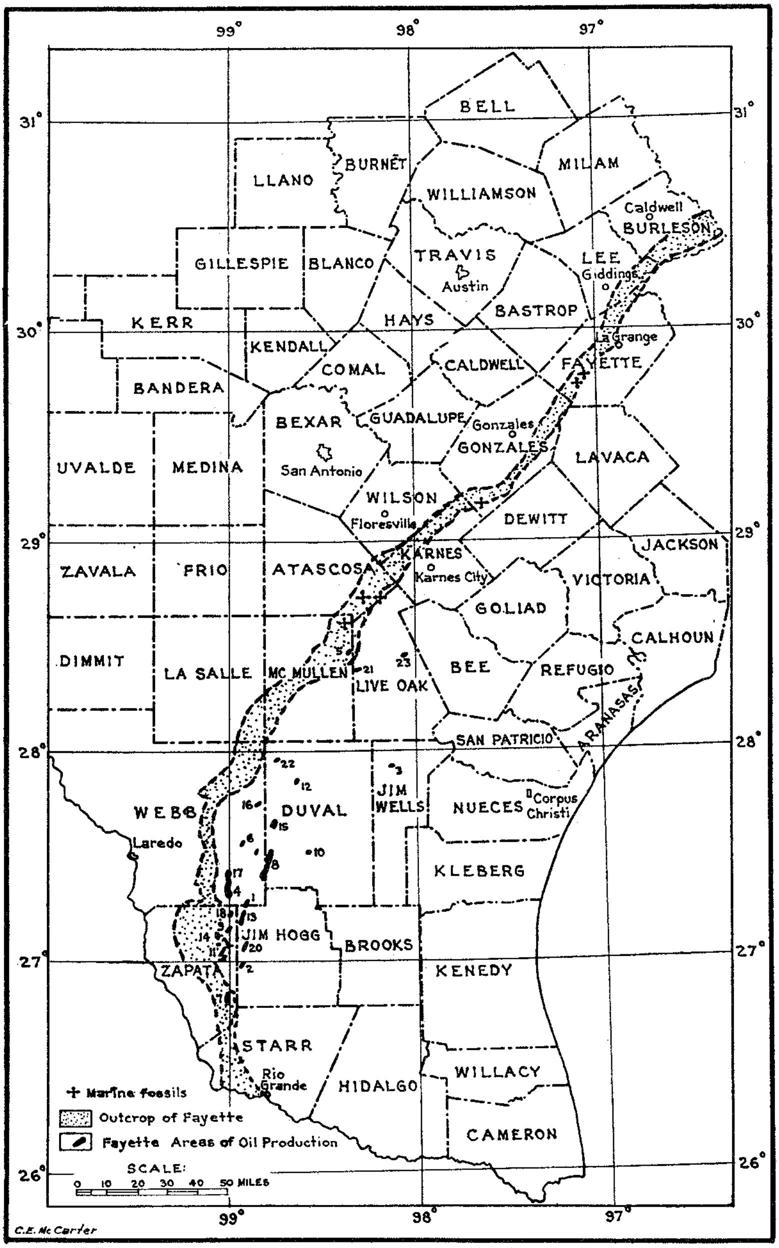

Fig. 46. Outcrop of the Fayette formation in southwest Texas showing fields that derive their oil from this formation (copied from map by C. A. Warner, Oil & Gas Journal, p. 53, June 16, 1932).

1. Albercas
2. Alworth
3. Amargosa
4. Aviator
5. Callihan
6. Carolina-Texas
7. Charco-Redondo
8. Cole
9. Cuellar
10. Driscoll
11. Escobas
12. Government Wells
13. Henne-Winch-Farris
14. Jennings
15. Kohler
16. Leaseholders
17. Mirando City
18. Mirando Valley
19. Pettus area
20. Randado
21. Simmons
22. S. R. C.
23. Three Rivers
24. West Cole

The contact is now drawn definitely, both on the outcrop and in well sections, between beds having a Claiborne fauna and beds having a Fayette fauna (see faunal lists in the section on paleontology). Unfortunately the Yegua strata on the outcrop contain almost no fossils, and fossils are rare and in most places poorly preserved in the Fayette. Accordingly one has to rely largely upon lithologic characteristics in mapping the contact between the two formations. In the upper Yegua the clays are sandy, characteristically chocolate-colored, and the sands are in most places cross-bedded and unconsolidated. The basal Fayette clays in many outcrops are somewhat greenish and contain volcanic ash and grains of glauconite, which weather to form a reddish-brown soil. Some of the beds carry traces of fossils and brown, evenly laminated, fossiliferous boulders. The Fayette sands are more consolidated, lighter colored, and more evenly bedded, and in many places they contain impressions of marine shells. In northeast Texas where the basal consolidated sands of the Fayette are present above the lower Fayette clays, the basal Fayette strata are marked by a persistent ridge or cuesta, which can easily be mapped.

The upper contact of the Jackson with younger overlapping strata is difficult to distinguish in some places. In well sections the line is drawn at the top of a persistent sand that overlies the upper Fayette microfauna known as the "*Textularia hockleyensis* zone." The beds above the Fayette sand have much more volcanic glass and fewer foraminifera. In most sections the beds immediately above the Fayette are unfossiliferous. On the outcrop in central and southwest Texas the line is drawn at the top of a persistent siliceous fossiliferous tuff or tuffaceous clay containing upper Eocene fossils. In east Texas the line is drawn at the base of a persistent sandstone or conglomeratic bed of the Catahoula, referred to as "rice sands," and above a tuffaceous clay bed. The Fayette strata carry less volcanic matter, more marine fossils, and fewer plant remains than the Catahoula. The plant fossils of the Fayette are in most places remains of deciduous trees. The Frio and Catahoula strata contain more petrified fragments of the stems and leaves of palm trees, and large stems and stumps of palm trees are common locally.

The Fayette formation has been divided into the following units:

EAST TEXAS[159]	CENTRAL AND SOUTH TEXAS[160]
3. Whitsett	2. Whitsett
2. McElroy	1. Lipan
1. Caddell	

The Caddell member was named by Dumble (**506**, p. 177, 1918) for the small town of Caddell in southwestern San Augustine County near Angelina River. These beds comprise from 30 to 45 feet of basal strata of the Fayette in northeast Texas. They consist of chocolate-colored and greenish clays, which weather to brownish and purplish hues and which contain dark-brown, calcareous, fossiliferous sandstone concretions, large amounts of selenite crystals, and minor amounts of glauconite. Some of the clay near the top contains layers of fine sand one inch or less in thickness. The member is bounded at the base by the Yegua formation and at the top by a persistent bed of sandstone, named Wellborn sandstone by Kennedy (**906**, p. 45, 1893). The type locality comprises exposures in the vicinity of Caddell in San Augustine County. Miss Ellisor (MS.) during recent detailed subsurface studies has been able to recognize this member in well sections throughout the Gulf Coast district. The lower part of the Caddell member of Dumble is especially characterized by the abundance of *Textularia dibollensis* Cushman and Applin. A list of the common foraminifera in this zone is given in the section on paleontology. In subsurface sections the Caddell member is about 120 feet thick.

The McElroy member was named by Miss Ellisor[161] for McElroy, a small town in Sabine County. Previously the basal sandstone beds of this division had been named Wellborn by Kennedy (**906**, p. 45, 1893) and the clays above the Manning beds by Dumble (**506**, p. 176, 1918). Dumble did not define his division clearly nor designate a type section, and consequently geologists have had difficulty in distinquishing the limits of the Manning beds. Cushman and Applin (**352**, pp. 158–159, 1926) referred to the middle division of the Fayette as "*Textularia hockleyensis* zone." Most other geologists[162] have preferred the new name McElroy. The member consists of

[159]Ellisor, Alva, personal communication, 1932.

[160]Dumble, E. T., 510, pp. 433–434, 1924.

[161]Ellisor, Alva, Jackson formation in Texas with notes on the Frio formation (MS.): paper read at meeting of Society of Economic Paleontologists and Mineralogists, San Antonio, March, 1931.

[162]The geology of the Gulf Coast area of Texas and Louisiana: Natl. Oil Scouts Assoc. Yearbook, pp. 39, 42, 1930.

brownish-gray, gypsiferous, plastic clays containing fossiliferous, limonitic concretions and layers of thin-bedded, fossiliferous sand or sandstone. Casts of pelecypods and gastropods occur in the clays and sands. The outcrop is not especially fossiliferous, but the subsurface equivalent strata carry a rich microfauna, which is characterized by an abundance of *Textularia hockleyensis* Cushman and Applin. The member is limited at the top by a more or less persistent sandstone,[163] which passes through the town of Groveton in Trinity County and caps the Lipan Hills near Campbellton in Atascosa County. The member is limited at the base by the Caddell clays. The dividing line between the McElroy and Caddell is drawn at the base of the Wellborn sandstone. The type locality for the McElroy member is the railroad cut just north of the station of McElroy, a small town north of Brookeland on the Santa Fe Railroad in Sabine County. The thickness of the McElroy averages 200 feet along the outcrop.

The Lipan beds were named by Dumble (**510**, p. 433, 1924) for the exposures in Lipan Hills (Dumble, **494**, p. 946, 1903) southeast of Campbellton in Atascosa County. This section is essentially equivalent to the McElroy and Caddell members as now defined in east Texas. The Lipan member forms a northward-facing escarpment capped by a persistent sandstone, which can be traced along the strike for more than twenty miles. The strata consist of a series of lignitic clays, volcanic ash, carbonaceous clays, and impure lignitic layers interbedded with thin sandstone beds capped by a thick, rough-surfaced sandstone. The member is limited at the top by the sandstone that caps Lipan Hills and at the base by the Yegua formation.

The upper or Whitsett member of the Fayette formation in south Texas was named by Dumble (**510**, p. 433, 1924) for the town of Whitsett in Live Oak County. The same member in east Texas was named Fayette by Miss Ellisor[164] in 1930. Later geologists of the Humble Oil Company were able to trace beds from east Texas to

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[163]Ellisor, Alva, Personal communication 1932.

[164]Ellisor, Alva, Jackson formation in Texas with notes on the Frio: manuscript read at meeting of Society of Economic Paleontologists and Mineralogists, San Antonio, 1931. See also the Geology of the Gulf Coast area of Texas and Louisiana, Texas Gulf Coast Oil Scouts Assoc., Bull. No. 1, pp. 42 and 89, 1930.

Atascosa County and prove the east Texas member essentially equivalent to the Whitsett beds, so that they[165] dropped Fayette as a member name. The Whitsett beds consist of greenish-gray and yellow clay, dark-colored, waxey, carbonaceous clays, and sandy clays interbedded with gray, yellow, and white sand. The sands are lighter colored, thinner, finer textured, and less consolidated than those in the lower members. They contain impressions and casts of marine fossils in some places. Some of the clays contain pieces of opalized wood, chalcedony, and spherical septarian concretions containing veins of quartz. The member is definitely limited at the base by the top of the McElroy or Lipan member. The contact of the McElroy and Whitsett is at the base of the persistent sandstone locally known as Groveton or "quarry" sandstone which caps the top of Lipan Hills. The top of the Whitsett is its contact with the overlying Frio or Catahoula formations. White, tuffaceous clays at the top of the member carry in many places characteristic Jackson fossils. The common fossils are listed in the section on paleontology. The thickness is estimated by Dumble to be about 500 feet. The type locality comprises the exposures in the vicinity of Whitsett.

The following sections show details of the stratigraphy of the Fayette formation in various places:

Section[166] of McElroy member of Fayette formation measured along Rocky Creek on northwest corner of J. M. Deane League, 11 miles east of Groveton, Trinity County.

	Thickness *Feet*
5. Clay, chocolate-colored, laminated	2
4. Sandstone, gray to yellowish brown, soft, thin-bedded, containing casts of lamellibranch and gastropod fossils	1
3. Sand, gray to white, standing in perpendicular walls and containing abundant, poorly preserved lamellibranch shells limited for the most part to 3 species	8
2. Sand, dark gray and bluish gray, coarse, angular, containing a few grains resembling glauconite, lignitized wood, and shells of oysters. In places the oyster shells are abundant enough to form almost a shell bed	3
1. Clay, blue, grading into chocolate-color, thin and massively bedded, containing many fairly well preserved lamellibranch remains	3½
Total thickness of section measured	17½

[165] Ellisor, Alva, Personal communication, 1933.
[166] Measured by C. L. Baker, 506, p. 175, 1918.

Section[167] *of Lipan member of Fayette formation measured at the point of the ridge on the east side of Lipan Creek, 2 miles southeast of Campbellton, Atascosa County.*

	Thickness *Feet*
11. Sandstone, gray, containing black specks and fragments of opalized wood; most of ledge has been removed by erosion	8
10. Sandstone, red and white, very compact, massively bedded. The white portions are in lines and seams enclosing the red. The red portion is softer and weathers away, leaving the white portions protruding from ½ to 6 inches beyond the surfaces of the red portions	8
9. Sandstone, light brown, unevenly bedded, rusted and streaked with ferruginous stains	2
8. Quartzite	2
7. Sandstone, gray, with white and yellow bands, laminated, breaking along bedding planes into thin slabs. These beds contain fossiliferous layers	30
6. Sandstone, white, shaly	6
5. Sandstone, brown	2
4. Sand, white, containing opalized wood	6
3. Coal, brown	1
2. Sand, laminated, containing opalized wood	10
1. Clay and sand, lignitic, containing particles of sulphur	5
Total thickness measured	80

Section[168] *of the Whitsett member of the Fayette formation measured at Whitsett Bluff on Atascosa River near Whitsett, Atascosa County.*

	Thickness *Feet*
8. Sandstone, gray, weathering yellow	2
7. Sandstone, gray, lying in beds from 2 to 6 inches thick and interbedded with layers of unconsolidated sand from 2 to 10 inches thick	10
6. Sand, brown, cross-bedded, laminated in places, and fossiliferous	3
5. Sandstone, light colored, interbedded with thin layers of clay	15
4. Sandstone, light brown, containing concretions showing cone-in-cone structure	6
3. Sand, fossiliferous, containing crystals of gypsum	3
2. Sand	11
1. Clay and sand, containing crystals of sulphur	6
Total thickness of section measured	56

[167]Measured by E. T. Dumble, 494, p. 946, 1903.

[168]Measured by E. T. Dumble, 494, p 947, 1903.

Section[169] *of the Fayette formation one-half mile west of Roma barracks on bluffs of the Rio Grande, Starr County.*

	Thickness Ft.	in.
Sandstone, brownish gray, calcareous	21	
Rock, gray, soft, bearing casts of small pelecypods	1	
Sandstone, heavy beds with gray clay partings	11	
Sandstone and clay in alternating beds, containing fossils	15	9
Clay, gray, weathering yellow	21	
Oyster bed	1	
Clay, partly concealed	12	
Concealed by river silt	5	
Oyster bed, large shells	1	
Clay, gray	3	6
Sandstone, calcareous, containing oyster shells	1	
Clay	2	
Oyster bed		9
Clay, gray	4	
Oyster bed, large shells		9
Clay, gray	3	
Concealed by river silt	10	6
Sandstone, gray, concretionary, irregularly bedded, containing oyster shells	13	
Oyster bed, large shells	1	
Total thickness measured	128	3

Sedimentology.—The sediments of the Fayette formation are for the most part littoral, shallow-water, near-shore deposits interstratified in the middle and upper portions with continental and beach deposits. The Jackson epoch records the advance of the sea over the Yegua deposits, one or more recessions of the sea during the middle of the epoch, and the withdrawal of the sea toward the end. Much sand was spread over the sea bottom by shifting shore currents and waves, and mud and peat deposits were laid down with, and on top of, the sand.

Volcanic ash was an important ingredient in the sediments at various times during the epoch. Igneous activity in northwestern Mexico, west Texas, and New Mexico, which seems to have started in Cockfield times, became pronounced during the middle and latter part of the Fayette. Volcanoes poured out dust, which drifted northeastward and found its way into the drainage lines of the central

[169]Measured by A. C. Trowbridge, 1613a, p. 152, 1932.

and east Texas rivers. It was picked up by these streams and redeposited along with the muds to form the light-colored "kaolinite" beds, which were sorted from the other sediments in such a way as to produce the chalky-looking fuller's earth deposits. Some of the ash beds have dune bedding and are thought by some geologists to be of eolian origin. It is possible that the ash was first brought down by streams and after deposition on the alluvial terraces and ancient flood plains it was worked over by winds and piled up into the lenticular deposits in which it is found today. The distribution of the ash throughout the extent of the Fayette, however, is rather uniform. Since its source was southwest of the present deposits, it would be expected that more ash would occur in southwest Texas than in northeast Texas and Louisiana. This is true for the Catahoula strata, but appears not to hold for the Fayette. The Fayette strata in Trinity River valley carry as much ash as they do in Atascosa River valley. Perhaps the early eruptions in the Davis Mountains area of west Texas were explosions that threw ash high into the air, so that it drifted great distances and was deposited on land and sea alike. The land deposits were eroded by streams and redeposited in lentils and blown into dunes by the winds. Logs and pieces of wood in some places were buried with the ash. Water charged with dissolved silica from the ash precipitated its burden in the woody cells and the original plant structure became opalized. Altogether the sediments of the Fayette constitute a varied and unusual section of much interest to students of sedimentology.

Lithology.—The strata of the Fayette consist of about 40 per cent sand, 40 per cent sandy, or ashy clay, 10 per cent clay, 5 per cent bentonite or fuller's earth, 4 per cent quartzite, and 1 per cent lignite. The color of the sand ranges from light cream-color to bluish gray and dark brownish gray. In most places it is well stratified in thin regular beds changing in places to irregular layers deposited at various angles. The grains are of fine and medium sizes, subrounded and angular, and made up laregly of quartz with a noticeable amount of plagioclase feldspar. Wendler[170] found the average of twelve samples of Fayette sand from central Texas to have the following texture:

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[170] Wendler, A. P., Heavy minerals of the Catahoula of Fayette County: Univ. Texas Thesis, pl. 6, 1932.

MESH	DIAMETER	PER CENT
	mm.	
40–60	.420–.250	31.7
60–80	.250–.177	24.93
80–180	.177–.084	33.66
Smaller than 180	.084	11.83

From 55 to 70 per cent of the grains were subround; from 30 to 45 per cent were subangular; and from 1 to 3 per cent were angular. The samples studied contained the following minerals:

Light minerals—
- Quartz (42.58%), average of 12 samples
- Feldspar (8.5%)
- Alteration products (49.25%)

Heavy minerals—

Magnetite (A)[a]	Rutile (R)
Zircon (A)	Monzanite (R)
Limonite (C)	Biotite (C)
Pyrite (C)	Muscovite (R)
Ilmenite (C)	Spinel (R)
Leucoxene (C)	Garnet (R)
Kyanite (R)	Anatase (R)
Tourmaline (R)[b]	

[a](A) abundant; (C) common; (R) rare.

[b]Tourmaline was found in very small quantity but was present in every sample examined.

The sandy clay is light brown, drab, and gray, slightly calcareous, and thinly and irregularly laminated. It contains leaf impressions in many places and rarely the small pelecypod, *Tellina eburniopsis* Conrad. The clay varies from yellow and buff to dark chocolate-brown. It is poorly laminated, highly colloidal, and contains dark-brown ferruginous concretions in many places, and very few fossils. The volcanic ash is greenish gray, dirty gray, or creamy white. It is gritty and in places is cross-bedded. The beds vary from a few inches to eight or ten feet in thickness. Some of the ash beds contain plant remains and even stumps of trees that have been completely opalized. Other beds have thin seams of limonite. A few ash beds are fairly pure, very fine grained, and are termed locally "kaolin" because of their resemblance to true kaolinite, but they are really a form of bentonite known as fuller's earth. Such beds vary in color from chocolate-brown to light greenish-yellow and light greenish-blue, and they weather to pure white. They are hard and break with conchoidal fracture, cut like talc, and can be scratched with the finger nail. Ash beds grade laterally into beds of sand and fine-grained clay. A sample from a typical exposure southeast of Lena, Fayette County, gave the following analysis reported by Reis (**1320**, p. 276, 1908):

	Per cent
Silica (SiO_2)	73.0
Alumina (Al_2O_3)	15.79
Ferric oxide (Fe_2O_3)	.63
Lime (CaO)	1.29
Magnesia (MgO)	1.53
Soda (Na_2O)	.16
Potash (K_2O)	.10
Titanic acid (TiO_2)	1.43
Water (H_2O)	5.76

The lignite in the Fayette formation is brown, impure, and in places less than a foot in thickness and of small economic value.

Distinguishing characteristics.—The Fayette formation can be distinguished in outcrop by the following criteria:

1. Bedding and texture. The sandstone ledges are thinner, more uniformly bedded, and more indurated than the sands of the Yegua. They are finer and more uniformly grained, thinner bedded, and contain less opaline cement than the Catahoula formation.
2. Color. The sandstones are white and weather to brownish drab, and the soils take on the same shades. The fossil impressions and casts have also the characteristic brownish tones. The Catahoula outcrops have light shades but have more ash and more opaline cement, and the Yegua sands are gray, buff, and in places reddish.
3. Fossil remains. Many thin ledges of Fayette sandstone contain impressions of marine fossils. Marine forms are extremely rare in the Yegua and Catahoula formations.
4. Feldspar content. The sandstones of the Fayette formation in south Texas contain a larger percentage of plagioclase feldspar than the strata in the Claiborne. Bailey (**40**, p. 41, 1926) found that a washed sample from northern Live Oak County contained 35 per cent plagioclase feldspar, 4 per cent orthoclase, and only 35 per cent quartz and chert grains. Wendler[171]

[171]Wendler, A. P., Heavy minerals of the Catahoula of Fayette County: Univ. Texas thesis, pl. 8, 1932.

found from 5 to 15 per cent feldspar in samples from Fayette County.

5. Concretions. The lower member of the Fayette contains yellow and brown fossiliferous concretions, which are not found in the underlying Yegua.

Paleontology.—The study of the larger fossils of the Fayette deposits in Texas has been neglected. No comprehensive treatment of the fauna has been published, no adequate lists are available, and no attempts have been made to work out fossil zones. Most of the fossils are near-shore and sandy-bottom species. Pelecypods predominate; most of the gastropods are of the thick-shelled, wave-resisting type exemplified by *Haminea grandis* Aldrich, *Callocardia, Tellina, Corbula,* and several species of *Turritella.* The following species collected from the vicinity of Caddell and published by Dumble (506, p. 171, 1918) are typical of the fauna of the lower beds of the Caddell member:

Ostrea cf. O. contracta Conrad
Arca sp.
Venericardia planicosta Lamarck
Pectunculus idoneus Conrad
Pectunculus sp.
Crassatella texana Heilprin
Crassatella flexura Conrad
Corbula alabamiensis Lea
Corbula oniscus? Conrad
Cytherea tornadonis Harris
Tellina mooreana Gabb
Tellina sp.
Turricula sp.
Cylichna kelloggi (Gabb)?
Turritella nasuta Gabb?
Turritella houstonia Harris?
Solarium alveatum Conrad
Solarium huppertzi Harris
Volutocorbis petrosus (Conrad)
Cassidaria sp.
Calyptrea sp.
Dentalium dumblei Harris
Flabellum wailesii Conrad

Another well-known locality in the upper beds of the Caddell occurs about three-fourths of a mile south of Robinson's Ferry on Sabine River, Sabine County. The following forms have been identified:

Ostrea trigonalis Conrad
Arca (Scapharca) rhomboidella Lea
Crassatellites flexurus (Conrad)
Protocardia nicolletti Conrad
Corbula wailesiana Harris
Dione securiformis Conrad
Mitra millingtoni Conrad
Hipponyx americanus Conrad
Calyptrea trochiformis Lamarck

The McElroy member of the Fayette formation carries an assemblage of fossils composed largely of pelecypods, of which the following are the most common:

Tellina eburniopsis Conrad
Callocardia discoidalis (Conrad)
Corbula alabamiensis Lea

The Whitsett member contains a somewhat similar fauna. A partial list of fossils from the lower beds of the Whitsett member are as follows:

Nucula sp.
Callocardia sp.
Corbula alabamiensis Lea
Tellina sp.
Tellina eburniopsis Conrad
Crassatellites sp.
Cerithium sp.
Volutocorbis sp.
Murex sp.
Turritella sp.
Ostrea georgiana Conrad
Leda sp.

Fossils have recently been discovered in white ashy clays near the top of the Whitsett member of the Fayette formation at a number of localities. All the fossils appear to belong to the same fauna. They are of much aid in helping to establish the Eocene age of the upper Whitsett beds and enable geologists to draw the boundary line between the Fayette and overlying Catahoula and Frio formations more definitely. The fossils are poorly preserved and specific identification of many of them is impossible. The following is a partial list:

Mazzalina oweni Dall (2, 3, 5)
Spisula sp. (2, 5)
Venericardia sp. (2, 5)
Callocardia cf. C. discoidalis (Conrad) (2, 3, 5)
Leda cf. L. mather Meyer (2, 3, 5)
Ostrea sp. (5)

Localities recorded in above list—

1. Quarry at Benford, 3 mi. E. of Corrigan, Polk County.
2. About one hundred yards west of the Flatonia-La Grange road, 4½ mi. in a direct line NE. of Flatonia, Fayette County (discovered by Leslie Bowling).
3. Near railroad, east edge of town of Flatonia, Fayette County (discovered by Leslie Bowling).
4. About 7 mi. NE. of Whitsett on Whitsett-Fashing road, W. Jacobs Survey, Live Oak County near Atascosa County line (discovered by L. W. MacNaughton).
5. Three miles west-northwest of Fashing, Atascosa County (reported by Willis Clark).

The fossils collected near Flatonia (fig. 48) were identified by Miss Gardner for Bowling.[172] According to Miss Gardner, *Mazzalina oweni* Dall is identical with forms that have been described from the

[172]Bowling, Leslie. Manuscript read at Houston meeting of Texas Academy of Science, November, 1932.

Jackson formation at White Bluff on Arkansas River, northwestern corner of Jefferson County, Arkansas. The presence of *Mazzalina, Venericardia,* and *Callocardia* give a strong Eocene aspect to the fauna. Miss Gardner correlated the strata near Flatonia, Texas, with those at White Bluff, Arkansas.

These fossil lists are all incomplete and unsatisfactory, partly because the specimens are poor, but mostly because the faunas have not been sufficiently studied. Incomplete as the data is, however, the collections from the Fayette of Texas give some clue to the correlation of the upper Eocene faunas. The fossils from the Caddell member are related to forms from the lower Jackson of Montgomery, Louisiana, and from Moody's Branch, Jackson, Mississippi. The fossils from the Whitsett, according to Miss Gardner, are related to those of White Bluff, Arkansas.

The foraminifera of the Fayette formation in Texas have been described by Cushman and Applin (**352**, pp. 154–189, 1926) and by Cushman and Ellisor (**382b**, pp. 51–58, 1931; **382h**, pp. 40–43, 1932), and have been discussed by Miss Ellisor in a manuscript now ready for publication. The foraminifera of the Jackson at Danville Landing have been studied recently by Howe and Wallace.[173]

The following list of species of foraminifera in material collected from the Caddell member three-quarters of a mile south of Robinson's Ferry on Sabine River has been furnished by Mrs. Plummer:

Spiroplectammina mississippiensis (Cushman)
Textularia dibollensis Cushman and Applin
Textularia dibollensis var. humblei Cushman and Applin
Gaudryina sp.
Quinqueloculina spp.
Biloculina sp.
Lenticulina articulata var. texana (Cushman and Applin)
Lenticulina alato-limbata (Gümbel)
Astacolus propinqua (Hantken)
Astacolus fragaria var. texasensis (Cushman and Applin)
Nodosaria jacksonensis Cushman and Applin
Guttulina spp.
Nonion umbilicatulus (Montagu)
Nonion advena (Cushman)
Nonionella hantkeni var. spissa Cushman
Operculinella sp.
Uvigerina alata Cushman and Applin
Uvigerina topilensis Cushman
Uvigerina gardnerae Cushman and Applin
Virgulina dibollensis Cushman and Applin
Bolivina jacksonensis var. striatella Cushman and Applin
Bolivina jacksonensis Cushman and Applin

[173]Howe, H. V., and Wallace, W. E., Foraminifera of the Jackson Eocene at Danville Landing on the Ouachita: Louisiana Dept. of Conservation, Geol. Bull. 2, pp. 1–118, 1932.

Bolivina gracilis Cushman and Applin
Tubulogenerina? eocenica Cushman and Ellisor
Discorbis hemisphaerica Cushman
Gyroidina soldanii var. octocamerata Cushman and G. D. Hanna
Siphonina jacksonensis Cushman and Applin
Siphonina advena var. eocenica Cushman and Applin
Cibicides jacksonensis var. texanus (Cushman and Applin)
Cibicides jacksonensis var. dibollensis (Cushman and Applin)
Cibicides antigua (Cushman and Applin)
Cibicides yazooensis Cushman
Eponides jacksonensis (Cushman and Applin)
Amphistegina sp.
Globigerina inflata d'Orbigny
Globigerina sp.
Anomalina affinis (Hantken)

The most significant species of foraminifera in the McElroy member is *Textularia hockleyensis* Cushman and Applin, and these strata are often referred to as the "*Textularia hockleyensis* zone." The following species have been chosen by Miss Ellisor as diagnostic of the McElroy member:

Haplophragmoides dibollensis Cushman
Ammobaculites hockleyensis Cushman and Applin
Textularia hockleyensis Cushman and Applin
Massalina decorata Cushman
Massalina humblei Cushman and Ellisor
Robulus alato-limbatus (Gümbel)
Robulus articulatus (Reuss) var. texanus (Cushman and Applin)
Robulus limbosus (Reuss) var. hockleyensis (Cushman and Applin)
Marginulina jacksonensis (Cushman and Applin)
Marginulina pediformis Bornemann
Guttulina spicaeformis (Roemer)
Pseudopolymorphina dumblei (Cushman and Applin)
Sigmomorphina jacksonensis (Cushman)
Nonion chapapotensis Cole
Buliminella subfusiformis Cushman
Discorbis farishi Cushman and Ellisor
Cibicides yazooensis Cushman

The following list of significant Whitsett foraminifera has been furnished by Miss Ellisor:

Textularia adalta Cushman
Textularia mayeriana d'Orbigny
Spiroplectammina carinata (d'Orbigny)
Massalina pratti Cushman and Ellisor
Trochammina teasi Cushman and Ellisor
Robulus limbosus (Reuss)
Robulus propinquus (Hantken)
Planularia truncana (Gümbel)
Nonion hantkeni (Cushman and Applin) var. fayettei Cushman and Ellisor
Nonion laevis (d'Orbigny) var. marginatus Cushman and Ellisor
Nonion scapha (Fichtel and Moll) var. inflatus Cushman and Ellisor
Elphidium eocenicum Cushman and Ellisor
Elphidium whitsettense (Cushman and Applin)
Plectofrondicularia mexicana (Cushman)
Tubulogenerina? eocenica Cushman and Ellisor
Eponides pygmaeus (Hantken)
Valvulineria texana Cushman and Ellisor
Siphonina carltoni Cushman and Ellisor
Globorotalia cocoaensis Cushman
Anomalina barrowi Cushman and Ellisor

The Fayette formation contains in several places a large number of plant fossils. The best-known localities are:

1. Nevil's Prairie, about 6 miles southwest of Lovelady, Houston County.
2. Bluff on Colorado River, one-half mile below Rabb's Creek, Fayette County.
3. Creek on Hamilton League, Fayette County.
4. Railroad cut at Striker, northern Polk County, near the Fayette-Catahoula contact.
5. Ash beds 2½ miles north of Miraflores ranch, near Jennings gas field, Zapata County.
6. Ash beds 4½ miles north of Miraflores ranch, Zapata County.

The following plants have been identified by Berry from four of the localities listed above. The numbers following the plant names refer to these localities:

Anemia eocenica Berry (2)
Apocynophyllum, 2 n. spp. (1, 5–6)
Arundo pseudogoepperti Berry (1, 2)
Bombacites, n. sp. (5–6)
Cinnamomum sp. (5–6)
Citrophyllum eocenicum Berry (2)
Citrophyllum sp. (1)
Coccolobis clairbornensis Berry (2)
Coccolobis columbianus Berry (2)
Conocarpus eocenicus Berry (5–6)
Diospyros, n. sp. (5–6)
Ficus sp. (1, 2)
Inga, n. sp. (5–6)
Lygodium kaulfussi Heer (1)
Mespilodaphne, n. sp. (1, 5–6)
Mimosites georgianus Berry (1)
Momisia americana Berry (1)
Myristica catahoulensis Berry? (5–6)
Nectandra, n. sp. (1, 5–6)
Oreodaphne obtusifolium Berry (5–6)
Oreodaphne sp. (1)
Papilionites, n. sp. (5–6)
Persea sp. (1)
Pisonia, n. sp. (5–6)
Sabalites vicksburgensis Berry (5–6)
Sapindus dentoni Lesquereux (5–6)
Sapindus formosus Berry (1)
Sapindus georgianus Berry (1)
Sapotacites, n. sp. (5–6)
Sophora claibornensis Berry? (5–6)
Sophora wilcoxiana Berry (1)
Sterculia sp. (1)
Terminalia phaeocarpoides Berry (5–6)
Ternstoemites, n. sp. (5–6)
Thrinax eocenica Berry? (2)

Economic resources.—The economic resources of the Fayette formation consist of soils, lignite, fuller's earth and petroleum deposits. The soils of the Fayette outcrop in northeast Texas are for the most part sandy loams and sands. In some places the outcrop is forested by a rather sparse growth of post oak and hickory. In other places the tree growth is scattering, due perhaps to unequal drainage or to the lenticular character of the deposits from which the soils are derived. About half the land is cultivated. Under favorable conditions cotton, corn, sweet potatoes, and ribbon cane can be raised profitably. Land throughout the unimproved areas can be purchased at prices varying from $5 to $12 per acre.[174]

The lignites of the Fayette are thin, impure, and of poor quality. A few deposits of some economic value occur, and the following have been reported by Deussen (421, p. 85, 1924):

LOCALITY	COUNTY	THICKNESS *Feet*
Richard Harvey Survey, NW. of Ledbetter	Washington	9½
Near the town of Ledbetter	Washington	8
Owl Creek, 2 mi. SW. of Nechanitz	Fayette	?
Colorado River, 2½ mi. NW. of La Grange	Fayette	2–15
W. F. Hamilton League, 3 mi. S. of West Point	Fayette	?

The following lignite deposits have been reported by Dumble (506, pp. 289–291, 1918):

LOCALITY	COUNTY	THICKNESS *Feet*
1½ mi. N. of M.K.&T. R.R. on White Rock Creek	Trinity	6–8
Western portion of Jacobs League, ¼ mi. N. of Potomac	Polk	3½
Near Groveton	Trinity	9
Bed of Angelina River on Aaron Ashley Survey, 15 mi. E. of Zavala	Angelina	5
Bed of Kelso Creek near middle of S. Young Survey on Walker-Grimes county line	Grimes	8
Bank of Tanyard Creek on Boatwright Headright near Piedmont Springs	Grimes	7
Richard Hardy Survey, northeast of Ledbetter	Washington	9½

None of the localities listed above have been developed except the one near Ledbetter in Washington County, where a small mine has operated in the past but is now abandoned.

Deposits of volcanic ash in the form of fuller's earth[175] occur at several places along the Fayette outcrop. The principal use of

[174]Bennett, H. H., and Shaw, C. F., Soil survey of Robertson County, Texas: U. S. Dept. Agric., Bur. Soils, p. 37, 1909.

[175]LITERATURE—Parsons, C. L., Fuller's earth: U. S. Bur. Mines Bull. 71, 1913. Dumble, E. T., 506, pp. 360–365, 1918. Ladoo, R. B., Non-metallic minerals, their occurrence, preparation, and utilization: McGraw-Hill Book Co., New York, pp. 91–97, 1925. Ross, C. S., and Shannon, E. V., Minerals of bentonite and related clays, and their physical properties: Jour. Amer. Cer. Soc., vol. 9, pp. 82–83, 1926. Davis, C. W., and Vacher, H. C., Bentonite, its properties, mining, preparation, and utilization: U. S. Bur. Mines, Tech. Paper, 438, 1928. Baker, C. L., Volcanic ash in Texas: Bur. Econ. Geol. Univ. Texas Min. Res. Circ. No. 2, pp. 1–4, 1932; Circ. No. 3, pp. 1–7, 1932. Broughton, M. N., Texas fuller's earths: Jour. Sedimentary Petrology, vol. 2, pp. 125–139, 1932.

fuller's earth is for filtering and clarifying mineral and vegetable oils. Deposits in the Fayette formation are located as follows:

LOCALITY	COUNTY	THICKNESS *Feet*
Sulphur Spring, 5 mi. N. of Chester	Tyler	6
Chalk Bluff, northwest part of county	Polk	8
Near Potomac	Polk	5
Near Groveton	Trinity	?
Wm. Fitzgibben Survey, near Piedmont Springs	Grimes	2
2 mi. E. of Union Hill	Grimes	4
SW. cor. James Tuttle Survey	Grimes	4–5
W. P. Zuber Survey	Grimes	4–5
W. F. Hamilton Survey, 3 mi. SW. of West Point	Fayette	10
6½ mi. S. of Gonzales	Gonzales	3
Conquiesta Crossing, 4 mi. W. of Falls City	Karnes	10

Mines from which fuller's earth is being produced at present are as follows:

LOCALITY	COUNTY	COMPANY
Near West Point	Fayette	Texas Co.
6½ mi. S. of Gonzales	Gonzales	Coon Co., Inc.
	Fayette	Crown Central Pet. Co.
	Grimes	Standard Fullers Earth

The fuller's earth is mined by stripping the overburden with a steam shovel. The material is then excavated and dried thoroughly. After grinding to a very fine powder, some grades are treated with acid to remove any carbonate content, then washed and placed in filters.

A large supply of fuller's earth in Texas is available from both the Fayette and Catahoula formations. The product is used mainly by oil companies in their refineries. A much larger demand for the product could undoubtedly be developed by introducing it on a larger scale into other uses, such as abrasive soaps, polishes, insulating compounds, and as a filler in paints.

Oil is produced from sands in the Jackson formation on many of the Gulf Coast salt domes and from about fifteen fields in south Texas. The oil sands are fine grained, unconsolidated, from 10 to 100 feet thick, and yield from 5000 to 30,000 barrels per acre in the more productive fields. The locations of the fields yielding oil from the Fayette from south Texas are shown in figure 46.

Oligocene System

GUEYDAN GROUP

DEFINITION

No group name has been published for Oligocene strata between the top of the Fayette formation and the base of the Miocene. All the fossiliferous Oligocene strata in Texas are overlapped on the outcrop by nonmarine beds, and the faunas and classification of the subsurface strata have not been comprehensively treated. The marine Oligocene beds in Alabama and Mississippi are included in the Vicksburg group by C. Wythe Cooke.[176] The name Vicksburg group was also used by Carroll Cook[177] to include all Oligocene strata in Texas. Miss Ellisor[178] has identified about eighty typical Vicksburg species of foraminifera from the lower Oligocene subsurface strata of Texas. The Oligocene beds above this Vicksburg zone carry faunas of younger age and constitute a major part of the Oligocene section in Texas. The name Vicksburg group is therefore likely to be misleading. Gueydan group is proposed to designate all strata between the Fayette formation of Eocene age and the Oakville formation of Miocene age. This section is thought to be typically Oligocene, except perhaps the Catahoula, the stratigraphic position of which is still somewhat questionable.

The name Gueydan was first used by Bailey (40, p. 62, 1926) for the clays and tuffaceous strata in southwest Texas now referred to the Catahoula. Gueydan was later dropped in favor of the older name, and it is therefore available and appropriate to apply to all the strata above the Fayette and below the Oakville.

The strata of the Gueydan group are largely pyroclastic sediments consisting of light-colored ash, tuff, and tuffaceous clay interbedded with lentils of light-colored quartzitic sand and conglomerate. The group has been mapped from Sabine River to the Rio Grande along a belt of rough, rolling, and dissected topography about twenty miles wide and situated about eighty miles from the coast, as shown on the map, Plate I.

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[176]Cooke, C. Wythe, The Cenozoic formations: Geol. Survey Alabama, Spec. Rept. 14, p. 279, 1926.

[177]Cook, Carroll, Areal geology of the Catahoula formation in Gonzales and Karnes counties: Univ. Texas Thesis, p. 32, 1932.

[178]Ellisor, Alva, personal communication, November, 1932.

SUBDIVISIONS

The Gueydan group in east Texas comprises only the Catahoula formation. In southwest Texas the thicker section is divided into the Frio formation below and the Catahoula above. In subsurface sections in deep wells along the coast the group is divided, as follows:

4. Catahoula, lower Miocene or upper Oligocene.
3. Unnamed middle Oligocene strata.
2. Frio, middle or lower Oligocene.
1. Vicksburg, lower Oligocene.

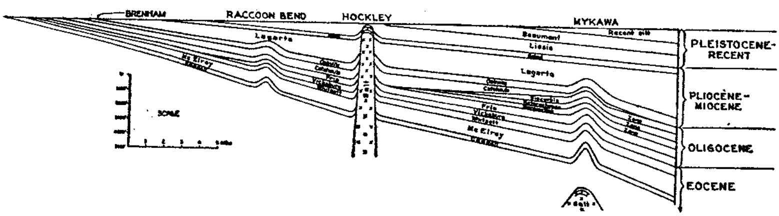

Fig. 47. Section through the upper Cenozoic formations from Brenham to Galveston showing subsurface stratigraphy (adapted from Natl. Oil Scouts Assoc. Amer. Yearbook for 1931, p. 40).

The subsurface middle Oligocene strata may be the down-dip extension of the lower or middle portion of the Catahoula formation in outcrop. The stratigraphic relationships of these Oligocene divisions are shown in the cross-section, figure 47.

SUBSURFACE STRATA OF LOWER OLIGOCENE AGE[179]

Definition.—Marine strata containing minute fossils that are regarded as similar to those in the lower Oligocene strata of Louisiana and Mississippi have been recognized by many paleontologists in a large number of oil-well sections just above the Whitsett division of the Fayette. No such strata have been discovered at the surface in Texas, and it is concluded that these marine Oligocene beds are overlapped by the Frio and Catahoula formations. The strata containing the fossils lie upon the Fayette formation and are overlain by strata correlated with the Frio. The graphic section (fig. 47) shows the relationship. No name has been assigned to these

[179]LITERATURE—The geology of the Gulf Coast area of Texas and Louisiana: Texas Gulf Coast Oil Scouts Assoc. Bull. 1, p. 42, 1930. Ellisor, Alva, Jackson formation in Texas with notes on the Frio: manuscript presented at meeting of Soc. Econ. Pal. Min., March, 1931. Cook, C. E., Areal geology of the Catahoula formation in Gonzales and Karnes counties: Univ. Texas Thesis, pp. 32–34, 1932.

strata in Texas, but Miss Ellisor has referred them tentatively to the Vicksburg group of Mississippi.

Regional geology.—Strata carrying fossils thought to be of lower Oligocene age have been reported[180] from the following areas:

LOCALITY	COUNTY	THICKNESS *Feet*
Moss Bluff oil field	Chambers	500
Raccoon Bend oil field	Washington	300
Barbers Hill oil field	Chambers	400
Humble oil field	Harris	247
Pierce Junction oil field	Harris	?
Hockley oil field	Harris	545
Welder No. 1, near Nursery	Victoria	424

The thickness of this section varies from 200 to 550 feet.

Lithology.—The lower Oligocene beds consist of about 90 per cent clay and 10 per cent very fine sand or sandy clay. The clay is similar to that of the Frio formation and comprises light-gray, greenish-gray or green, argillaceous, slightly calcareous clays that grade in places into sandy clays. The sands are composed of fine, angular and subangular quartz and chert grains mixed with a little volcanic glass. Some of the chert grains are black.

Paleontology and correlation.—These lower Oligocene strata in places carry a rich foraminiferal fauna. Miss Ellisor has identified[181] from this zone more than sixty forms that occur also in the Byram strata in Mississippi and a large number that occur in the Red Bluff clays of the Oligocene in that same state. A typical list from this zone furnished by Miss Ellisor is as follows:

Textularia mississippiensis Cushman
Textularia warreni Cushman and Ellisor
Textularia tumidula Cushman
Clavulina byramensis Cushman
Robulus rotulatus (Lamarck)
Lenticulina vicksburgensis (Cushman)
Nonionella tatumi Howe
Siphonina advena Cushman
Cibicides floridanus (Cushman)
Eponides byramensis (Cushman)
Eponides vicksburgensis Cushman and Ellisor
Cassidulina crassa d'Orbigny
Globigerina bulloides d'Orbigny
Anomalina mississippiensis Cushman

Some geologists[182] believe that these strata represent the deep-water marine facies of the Frio or the lower Frio formation. Others regard these marine strata in well sections as a separate member

[180]Texas Gulf Coast Oil Scouts Assoc. Bull. 1, pp. 42–44, 1930.

[181]Ellisor, Alva, personal communication, 1932.

[182]Applin, E. R., Ellisor, Alva, and Kniker, H. T., 32, p. 107, 1925.

that is overlain and overlapped by the Frio clays. The strata are correlated on the basis of their foraminiferal content with the Vicksburg strata of Mississippi.

FRIO FORMATION[183]

Definition.—The name Frio was assigned by Dumble (**478**, p. 554, 1894) to dark-colored, greenish-gray clays above the Fayette sands in south Texas. He did not define clearly the upper limit of his formation. He states, "The clays are dark colored, greenish gray, red or blue, usually massive, with quantities of gypsum and with calcareous concretions arranged in lines." He specified that typical strata are exposed along Frio River in Live Oak County. Twenty years later he described again the weathered clays as "a chalky looking mass of dazzling white" and stated that the formation outcropped on Atascosa River southwest of Fant City and along the escarpment south of Comanche Creek in Atascosa County. Bailey (**40**, p. 45, 1926) described and mapped under the name Gueydan a series of sandstones, clays, and ash beds which he found to be approximately equivalent in age to, and continuous with, the Catahoula sandstone formation in northeast Texas, but which included also much of the section assigned by Dumble to the Frio formation. Bailey (**40**, p. 44, 1926) restricted the name Frio to the strata beneath the volcanic tuffs of his Gueydan formation and above the Fayette formation. This restricted Frio formation did not include the strata at the type locality of the Frio on Frio River nor the strata southwest of Fant City described by Dumble. Bailey's proposal, therefore, was regarded as too drastic a restriction to be acceptable to the United States Geological Survey according to the rules of nomenclature. Gardner and Trowbridge (**572a**, p. 470, 1931) found it preferable to assign a new name, Yeager clay, to the strata between the Gueydan and Jackson and to abandon the name Frio. Members of the San Antonio Geological Society, however, (**572a**, p. 967, 1931) suggested that the new name Yeager would lead only

[183]LITERATURE—Dumble, E. T., **478**, pp. 554–555, 1894; **494**, pp. 953–956, 1903; **497**, p. 51, 1911; **510**, p. 434, 1924. Hayes, C. W., and Kennedy, Wm., **692**, pp. 22–23, 30–66, 1903. Trowbridge, A. C., **1610**, pp. 97–98, 1923; **1613a**, pp. 156–165, 1932. Deussen, A., **421**, pp. 91–95, 1924. Bailey, T., **40**, pp. 44–52, 1926. Gardner, Julia, and Trowbridge, A. C., **572a**, p. 470; discussion, pp. 967–970, 1931. Ellisor, A. C., Jackson formation in Texas with notes on the Frio: MS. of paper presented at San Antonio meeting of Soc. Econ. Pal. and Min., March 1931. Cook, C. E., Areal geology of the Catahoula formation in Gonzales and Karnes counties: Univ. Texas thesis, pp. 32–34, 1932.

to more confusion and regarded Bailey's restricted use of Frio as preferable. They further objected that the name Yeager was so similar to the name Yegua, that confusion in telegrams and written notes would be a likely consequence. The United States Geological Survey (**970d**, p. 101, 1932) with some hesitancy therefore agreed to the restricted definition of the Frio formation and have assigned the name to the strata included by Bailey in his definition, as shown on their new geologic map of Texas (**396c**, 1932).

Neither Bailey nor the San Antonio Geological Society Committee on geologic mapping has designated a new type locality for the restricted Frio formation. Bailey (**40**, p. 46, 1926) describes 15 feet of creamy-gray to greenish, plastic clay in a cut on the San Antonio, Uvalde and Gulf Railroad one mile northwest of Fant City in Live Oak County. This might be taken as the type locality for the Frio as now recognized.

Regional geology.—The outcrop of the Frio formation is a generally featureless plain, known as the Frio plain, covered by mesquite, cactus, and thorny chaparral. It extends from the southeast corner of Atascosa County southwestward across McMullen County to a point near Aguilares in Webb County, thence southward along the eastern border of Zapata and western Jim Hogg counties to the Rio Grande at Rio Grande City. The width of the outcrop in Live Oak County is about one mile. It widens in McMullen County to two to four miles, and in Zapata, Jim Hogg, and Starr counties it is from eight to ten miles wide. The strata dip beneath younger formations and are penetrated in deep wells throughout southwest Texas as far as the coast.

The thickness of the formation in outcrop varies from 150 feet in Live Oak County to 800 feet in Jim Hogg County. Beneath the surface its thickness ranges from 250 to 600 feet in wells. The following table shows thicknesses in various districts:

LOCALITY	COUNTY	THICKNESS *Feet*	AUTHORITY
Warren No. 7, Humble Oil Co., Hockley salt dome	Harris	560	Ellisor
E. B. Wilson No. 1, Humble Oil Co., Raccoon Bend oil field	Washington	260	Ellisor
Welder No. 1, Humble O. & R. Co., near Nursery	Victoria	424	Ellisor

LOCALITY	COUNTY	THICKNESS *Feet*	AUTHORITY
U. S. I. Realty Co., Fant City	Live Oak	390	Deussen[a]
Hicks No. 1, well drilled by H. Coquat et al, 1 mi. W. of Simmons	Live Oak	270	Bailey
Laas No. 1, Lavaca Oil Co., eastern part of county	Lavaca	322	Bailey
Average thickness of outcrop	Webb	300	Trowbridge

[a]Revised slightly to agree with the new nomenclature.

Stratigraphy.—The Frio strata lie conformably upon sand and sandy shales of the Fayette formation and are overlain unconformably by beds of tuff and volcanic ash of the Catahoula formation. The base is marked by the contact of greenish-gray clays with light-gray, thin-bedded, sandy clays and sand of the Fayette. The top of the formation is established where the greenish-gray clays are in contact with decidedly tuffaceous and ashy beds. In Karnes County a layer of sand and conglomerate and coarse detritus marks the upper contact. In most places where exposures are good, it is easy to identify the Frio strata by its characteristic greenish-gray, massive clay. A typical section is described as follows:

Log[184] of a well drilled by the U. S. I. Realty Company at Fant City, Live Oak County.

	Thickness *Feet*
Catahoula formation—	
Clay, gray, gritty, plastic	65
Lime and volcanic ash, pinkish gray	35
Frio formation—	
Clay, green	40
Clay, green, gritty	15
Clay, green, calcareous, sandy	10
Clay, green, gritty, calcareous	195
Clay, green, sandy	21
Marl, green, containing calcareous nodules	39
Limestone, green, argillaceous, interbedded with green, brittle clay	44
Limestone, green, sandy, argillaceous	26
Total thickness of Frio formation	390

Sedimentology.—The Frio deposits appear to represent a continuation of Fayette conditions of sedimentation. The much larger por-

[184]Described by A. Deussen, 421, p. 93, 1924 (formational interpretation revised).

tion of clays suggest that the adjoining land areas were low and more nearly at base level. There may have been also less rainfall and less river water to transport coarse sediments. The absence of fossils and lack of even stratification in the clays suggests that some of the material may have been of fresh-water origin. The absence of carbonaceous matter and the presence of much gypsum also suggest nonmarine deposition.

Lithology.—The Frio formation is composed of over 95 per cent clay, about 4 per cent sand and sandy silt, and 1 per cent concretions. The clay is nearly everywhere creamy-green or buff green. The silt is gray, extremely fine grained, noncalcareous, and very gypsiferous. The sand grains are subangular to angular and range from one-sixth to one-quarter of a millimeter in diameter. The following composition of a typical washed sample from an outcrop one mile south of Whitsett, Live Oak County is given by Bailey (40, p. 47, 1926):

	Per cent
Light minerals—	
Gypsum	90
Plagioclase feldspar	3
Orthoclase feldspar	1
Quartz	5
Chert	1
Calcite	Trace
Heavy minerals—	
Microcline	Rare
Barite	Trace
Magnetite	Trace
Green hornblende	Trace
Titanite	Rare

Paleontology and correlation.—The age and correlation of the Frio formation are uncertain. The strata are younger than the Fayette which is definitely Eocene, and older than the subsurface strata, now thought to be middle Oligocene. Dumble (494, p. 953, 1903) believed that the Frio fossils indicated Eocene age. Deussen (421, p. 92, 1924; p. 97, 1930 ed.) on the authority of the paleontologists of the United States Geological Survey stated that the fauna "may indicate . . . either late Eocene or early Oligocene age . . . but until further evidence is available the formation is classified as of late Eocene (Jackson) age." Bailey (40, p. 51, 1926) noted that beds contain *Ostrea georgiana* Conrad and are therefore "more probably of Eocene age." Miss Ellisor, as quoted by E. H. Finch (572a, p. 970, 1931), believes that "the Frio clays contain a few lower Oligocene or Vicksburg foraminifera." Miss Kniker[185] believes that possibly the Frio clay is a southern facies of the lower Catahoula sand of central and northeast Texas and is therefore the same age as the Catahoula.

Recent detailed subsurface correlation of strata in oil wells by geologists of the Humble Oil and Refining Company and the United Gas Company indicates that the Frio formation lies beneath strata assigned to middle Oligocene age and above strata assigned to the Vicksburg (fig. 47).

SUBSURFACE STRATA OF MIDDLE OLIGOCENE AGE[186]

Definition.—The subsurface deposits, commonly referred to by Texas geologists as Oligocene or middle Oligocene, consist of dark, olive-green and gray, faintly calcareous, fossiliferous clays, fine, olive-gray sands that carry oil on many domes, and thick lentils of limestone in the form of coral and foraminiferal reefs. The total thickness of these strata varies from 400 to 1100 feet, as shown by the following table:

LOCALITY	COUNTY	THICKNESS *Feet*	AUTHORITY
Hull oil field	Liberty	550	Applin, Ellisor, and Kniker
Batson oil field	Hardin	600	Do
Pierce Junction oil field	Harris	450	Do
Goose Creek oil field	Harris	600–1150	Do
West Columbia oil field	Brazoria	425	Do
Damon Mound oil field	Brazoria	313	Do
Miller-Vidor No. 1, Gulf Prod. Co., E. Lewis Survey	Orange	356	M. A. Hanna
Keeran No. 1, Bunte et al, M. de Leon Survey	Victoria	601	M. A. Hanna

Stratigraphy.—The details of the stratigraphy of the Oligocene beds are shown in the following described sections:

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[185] Personal communication.

[186] LITERATURE—Applin, E. R., Ellisor, A. C., and Kniker, H. T., 32, pp. 102–111, 1925. Ellisor, A. C., 522, pp. 976–985, 1926. Anonymous, The geology of the Gulf Coast area of Texas and Louisiana: 1833d, pp. 41, 42, 1931. Ellisor, A. C., The stratigraphy of the Jackson of Texas with notes on the Frio: MS. 1931.

Section[187] *of strata penetrated by Lovejoy No. 1, Humble Oil and Refining Company, West Columbia oil field, Brazoria County.*

	Thickness Feet
3. Clay, light gray, and light greenish-gray, shaly, containing very fine, angular sand grains and small lime nodules	100
2. Limestone, gray, chalky in places and varying from cryptocrystalline to porous, coarsely crystalline texture, containing lentils of green clay. Portions of the limestone are made up almost wholly of *Heterostegina* cf. *antillea* Cushman and *Amphistegina lessonii* d'Orbigny, bryozoa, corals, and ostracods. Other parts are devoid of fossil remains	225
1. Clay, light greenish gray and bluish gray, calcareous, sandy, and shaly, containing foraminifera	100
Total thickness	425

Details of the strata represented by the second division of the above section are shown in the following descriptions of beds penetrated by another well in the same field.

Section[188] *penetrated by Gallagher No. 2, Humble Oil and Refining Company, West Columbia, Brazoria County.*

	Depth Feet
Limestone, blue, cryptocrystalline, fossiliferous, made up of masses of *Heterostegina*, *Lithothamnium*, and some *Porites*, and containing veins of coarsely crystalline calcite	2977
Limestone, made up of great quantities of foraminifera and a few quartz sand grains cemented by chalky calcite into a firm mass, containing *Heterostegina* cf. *antillea* Cushman and *Amphistegina lessonii* d'Orbigny, *Gypsina* sp., *Pecten* sp., and ostracods	2994–2996
Limestone, blue, cryptocrystalline, containing veins of calcite and many foraminifera, among which *Heterostegina* cf. *antillea* Cushman *Amphistegina lessonii* d'Orbigny, and *Gypsina* sp. can be recognized	3000–3008
Limestone, light gray, cryptocrystalline, made up almost entirely of the coral *Porites* with a few foraminifera and ostracods between the coral branches	3043
Limestone, white, chalky, made up largely of the coral *Porites* and containing veins of crystalline calcite	3059–3078

Lithology.—The middle Oligocene beds consist of shaly clays, sandy clays, fine sands, and lentils of coral and foraminiferal lime-

[187]Described by Applin, Ellisor, and Kniker, 32, p. 109, 1925.
[188]Modified slightly from a description of the cores by Miss Ellisor, 522, p. 978, 1926.

stone. The clays are greenish gray, calcareous in some places, noncalcareous in others, sandy in some layers, and generally fossiliferous. The sands are composed of very fine and angular to medium-sized and subangular quartz grains. Glauconite occurs in some zones.

The limestone lentils in the Oligocene section are especially noteworthy. They consist of massive, crystalline limestone from one to several hundred feet thick, and their fossil content shows that they were originally coral reefs. These reefs occur only on salt domes where water was shallow enough for the reef-forming animals to live. According to Miss Ellisor (**522**, pp. 976–977, 1926), the upper part of the reef is composed almost wholly of *Heterostegina antillea* Cushman; the lower portion is massive, cryptocrystalline coral limestone built up of the massive species *Porites.*

Distinguishing characteristcs.—The Oligocene strata in well sections are distinguished mainly by their foraminiferal content and by the massive limestone lentils containing corals.

Paleontology and correlation.—The subsurface Oligocene strata have been divided by Applin, Ellisor, and Kniker (**32**, p. 102, 1925) into three fossil zones: *Discorbis* zone at the top, *Heterostegina* zone in the middle, and *Marginulina* zone at the base.

3. *Discorbis* zone. This series of strata is characterized by the foraminifer *Discorbis* cf. *D. vilardeboana* d'Orbigny. The strata consist of bluish-gray, calcareous, shaly clay, dark-gray, calcareous, sandy clay, and lentils of fine-grained sand. The thickness averages about 100 feet.
2. *Heterostegina* zone. This zone consists of reefs or lentils of limestone containing *Heterostegina* cf. *antillea* Cushman. The reefs are confined to areas around salt domes where the Oligocene sea was shallow. The rock consists of gray limestone composed of fine, angular grains cemented into a solid mass containing nodules and streaks of white, chalky limestone. Gray, calcareous and noncalcareous clays are interbedded in places with the limestones. The thickness of this rock varies from 100 to 225 feet. It has been encountered on the following salt domes: Damon Mound, West Columbia, Nash, Bowling, Barbers Hill, Pierce Junction, Batson, Hull, Humble, Stratton Ridge, Sour Lake, and others.
1. *Marginulina* zone. This zone is characterized by the foraminifer *Marginulina* cf. *M. philippinensis* Cushman. The strata consist of bluish-gray, calcareous clay containing layers of cal-

careous and noncalcareous fine-grained sandstone and a little glauconite. The thickness of this series of strata varies from 100 to 350 feet.

The fauna is regarded by Miss Ellisor (**522**, p. 977, 1926) as middle Oligocene in age and correlative with the Antigua formation of the West Indies. Carefully constructed cross-sections indicate that these middle Oligocene strata coalesce up dip with upper Catahoula strata.

CATAHOULA FORMATION[189]

Definition.—The formation now named Catahoula was first designated Grand Gulf sandstone for Grand Gulf on Mississippi River in Claiborne County, Mississippi, by Wailes[190] in 1857. In 1860 Hilgard[191] used the name Grand Gulf group for all the beds in Mississippi between the Vicksburg and recent coastal clays. Hilgard[192] in 1869 also recognized the same strata in Louisiana and traced them across the state to the Texas line. Two years later[193] he presented a map showing their extent across southeast and south Texas. The Grand Gulf mapped by Hilgard included the present Yegua, Fayette, Frio, Catahoula, Oakville, and Lagarto formations. Loughridge (**1017**, pp. 47–58, 1884) published the first descriptions of the Grand Gulf strata in Texas. After the publications of Hilgard and Loughridge, however, the name Grand Gulf was used with so

[189]LITERATURE—Roemer, F., **1327**, p. 359, 1846. Hilgard, E. W., Summary of results of a late geologic reconnaisance of Louisiana: Am. Jour. Sci., 2nd ser., vol. 48, pp. 337, 338, 1869. Loughridge, R. H., **1017**, p. 679, 1884. Knowlton, F. H., Description of two species of Palmoxylon, one new, from Louisiana: U. S. Nat. Mus. Proc., vol. 2, pp. 89–91, pl. 20, 1888. Penrose, R.A.F., **1189***, pp. 47–58, 1890. Dumble, E. T., **470***, pp. 154–157, 1892; **478***, pp. 549–567, 1894; **493***, pp. 670–671, 1902; **494***, pp. 913–918, 1903; **501***, pp. 465–476, 1915; **506***, pp. 187–218, 1918. Kennedy, Wm., **906***, pp. 45, 46, 1893; **911***, pp. 95, 96, 1895. Hayes, C. W., and Kennedy, Wm., **692***, pp. 21–61, 1903. Deussen, A., **415***, pp. 68–72, 1914; **421**, pp. 95, 96, 1924; and Dole, R. B., **416**, pp. 68–72, 1916. Goldman, M. I., **596**, pp. 261–287, 1915. Berry, E. W., **101**, pp. 227–251, 1916. Matson, G. C., **1061a**, pp. 209–226, 1916. Udden, J. A., Baker, C. L., and Böse, E., **1652**, p. 88, 1916. Applin, E. R., Ellisor, A. E., and Kniker, H. T., **32**, pp. 100–106, 1925. Bailey, T. L., **40**, pp. 62–164, 1926. Stephenson, L. W., Logan, W. N., and Waring, G. A., Ground-water resources of Mississippi: U. S. Geol. Survey Water-Supply Paper 576, pp. 55–56, 1928. Sherer, H. K., Geology of Catahoula Parish, Louisiana: Am. Assoc. Pet. Geol. Bull., vol. 14, pp. 435–436, 1930. Cook, C. E., Areal geology of the Catahoula formation in Gonzales and Karnes counties: Univ. Texas thesis, pp. 1-61, 1932. Sayre, A. N., Ground-water resources of Duval County: U. S. Geol. Survey Press Rpt., Feb. 12, 1933.

*Includes also some Fayette and Oakville strata.

[190]Wailes, B. C. L., Agriculture and geology of Mississippi, p. 216, 1857.

[191]Hilgard, E. W., Report on agriculture and geology of Mississippi, pp. 147–154, 1860.

[192]Hilgard, E. W., Summary of results of a late geologic reconnaissance of Louisiana: Am. Jour. Sci., 2d ser., vol. 48, pp. 337–338, 1869.

[193]Hilgard, E. W., On the geologic history of the Gulf of Mexico: Am. Jour. Sci., 3d ser., vol. 2, pp. 391–404, 1871.

many different meanings by Smith and Aldrich,[194] Dall,[195] Hilgard,[196] and others, that much confusion arose. Accordingly, when the geological survey under E. T. Dumble was organized in Texas, Penrose (**1189**, p. 47, 1890) and Kennedy (**905**, pp. 60–61, 1892) preferred to use a new name Fayette for the strata above the marine Eocene beds. Kennedy (**905**, p. 60, 1892) used the name Fayette sands to designate what is now Fayette and Catahoula. The prominent sandstone ledge in his Fayette series, which is now in the base of the Catahoula, he named Corrigan sandstone for the town of Corrigan in northern Polk County. Hayes and Kennedy (**692**, pp. 21–23, and map, pl. 1, 1903) referred the basal strata of what is now Catahoula to Dumble's Fayette formation and the upper beds together with some of the strata now named Lagarto to their "Frio" formation. Their "Frio" was younger than the Frio named by Dumble in south Texas. Veatch (**1691**, p. 42, 1906) realizing the confusion in the various definitions in vogue among geologists for the Grand Gulf in Mississippi and Louisiana and for the Fayette in Texas proposed the name Catahoula for the upper sandstone member of Hilgard's Grand Gulf strata. He regarded the Catahoula as Oligocene and as the equivalent of Wailes' original Grand Gulf sandstone of Grand Gulf, Mississippi, and correlated it with Dumble's Oakville formation of south Texas.

Veatch's map and descriptions of localities indicate, however, that he included in his Catahoula the upper strata of what is now called Fayette formation. Deussen (**415**, pp. 68–70, 1914) used Veatch's name Catahoula for the same strata in east Texas, but he included also some strata now mapped as Oakville. Dumble regarded Veatch's definition as applicable to only the coarse sandstone in the basal part of the present Catahoula and above the fossiliferous Fayette strata (as now defined). Catahoula appeared to him to be a synonym for Kennedy's older name Corrigan. He (**501**, p. 465, 1915; **506**, p. 187, 1918) proposed to use Kennedy's name Corrigan for the strata above the Fayette (as now defined) and below the Fleming (Oakville and Lagarto). The strata at the same stratigraphic position in south Texas he referred to his Frio formation.

[194]Smith, E. A., and Aldrich, T. H., The Grand Gulf formation: Science, new ser., vol. 16, pp. 825–837, 1902; Science, new ser., vol. 18, pp. 20–26, 1903.

[195]Dall, W. H., The Grand Gulf formation: Science, new ser., vol. 16, pp. 946–947, 1902; Science, vol. 18, pp. 83–85, 1903.

[196]Hilgard, E. W., Science, new ser., vol. 18, pp. 180–182, 1903.

Udden, Baker, and Böse (**1652**, p. 88, 1916) also used Corrigan in the same way. Matson (**1061a**, pp. 209–210, 1916), working in Mississippi and Louisiana, used the name Catahoula but restricted it to include only nonmarine deposits equivalent to those found at the type locality at Grand Gulf, limiting the formation to the strata above the marine Vicksburg in Mississippi and below the Hattiesburg clay or its equivalent. His Catahoula was a synonym for Dumble's Corrigan. Deussen (**421**, p.95 and map, pl.1,1924) mapped the Catahoula to a point about 5 miles southwest of La Grange in Fayette County, and separated it from the Fayette below and Oakville above following Matson's definition. The strata below the Oakville and above the Fayette south of La Grange he mapped as Frio. Bailey (**40**, pp. 1–179, 1926) mapped and studied in detail the strata between the Fayette and Oakville formations in south Texas. He divided the strata in this section into two formations: (1) volcanic tuffs, conglomerates, and noncalcareous ash beds above, which he named Gueydan; and (2) yellowish-green, calcareous clays below, to which he applied Dumble's name Frio in a restricted sense. He regarded the Gueydan formation to be equivalent, in part at least, to the Catahoula. Cook[197] traced the Catahoula formation southwestward from La Grange in Fayette County to Frio River in Live Oak County and established the equivalency of the Catahoula sandstone to the lower part of the clays which Dumble had designated the type locality of his Frio (now lower part of Bailey's Gueydan formation). Three synonymous names are therefore now in use to designate the strata between the Fayette and Oakville in south Texas and between the Fayette and Lagarto in east Texas: Corrigan and Catahoula in east Texas, and Gueydan in south Texas. The name Corrigan was given in 1892, Catahoula in 1906, and Gueydan in 1926. Corrigan should have precedence over the others, but the Corrigan formation was not clearly defined by Kennedy. In fact, the present meaning of the name was not defined until Dumble's work on east Texas was published in 1915 and 1918. On the other hand, Catahoula was described by Deussen, Matson, Berry, Trowbridge, and Goldman in publications that are read widely so that the latter name came into common usage. The term Gueydan was given to the volcanic tuffs and ash beds by Bailey because he was

[197]Cook, C. E., Areal geology of the Catahoula formation in Gonzales and Karnes counties: Univ. Texas thesis, p. 10, 1932.

not certain of the correlation of the formation with the Catahoula and thought the difference in facies of the strata in the south from those in the northeast was sufficient to warrant another name. The United States Geological Survey on the new geologic map of Texas (**396c**, 1932) has decided to name the sandstone strata in east Texas Catahoula sandstone and the ash beds in south Texas Catahoula tuffs. Bailey (**40a**, p. 259, 1932) has agreed to the substitution of Catahoula tuff for Gueydan formation and the name is likely to stand.

No type locality for the Catahoula was established by Veatch. The formation was named for Catahoula Parish, Louisiana, where according to Sherer[198] the sandstone strata cover the northwestern part of the parish. Matson regarded the type locality as the outcrop at Grand Gulf, Mississippi, where the Grand Gulf was originally described by Wailes. Excellent exposures of the sandstone in Texas occur along the International and Great Northern Railroad just south of Riverside in Walker County. The type locality of the Catahoula tuff facies (Bailey's Gueydan formation) is on the Gueydan ranch in the Gueydan Survey in southeast McMullen County where the upper part of the formation is well exposed.

Regional geology.—The Catahoula outcrop may be conveniently divided into two areas for purposes of description, the east Texas outcrop and the southwest Texas outcrop.

The east Texas outcrop comprises the Catahoula sandstone and interbedded ash beds and consists of a belt of rugged, rocky, tree-covered territory extending from Sabine River at the northeast corner of Newton County westward across northern Tyler, northern Polk, northern San Jacinto, central Walker, central Grimes, northern Washington, central Fayette, and southern Gonzales counties to Guadalupe River.

The south Texas outcrop comprises the Catahoula tuff and occupies a belt of rolling, moderately dissected, more or less improved and cultivated farm land in south-central Texas and pasture land in south Texas which extends from southern Gonzales County, through northern Karnes, northern Live Oak, and northwestern Duval counties to eastern Webb County, then bends southward across

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[198] Sherer, H. K., Geology of Catahoula Parish, Louisiana: Am. Assoc. Pet. Geol. Bull, vol. 14, p. 437, 1930.

eastern Webb County and disappears beneath younger formations in Zapata County (fig. 49).

The width of the outcrop of the Catahoula sandstone in east Texas varies from four to six miles. It narrows in central Texas to one mile or less. The outcrop of the Catahoula tuff in central Texas is from one to two miles, but it widens in south Texas to eight and ten miles in McMullen and Duval counties. The Catahoula formation extends beneath the surface as far as the coast and is an important oil-producing horizon on salt domes and in some of the south Texas fields.

The Catahoula formation varies in thickness from 300 to 600 feet in east Texas to 150 to 200 feet in central Texas and thickens to 800 to 1000 feet in south Texas. Its thickness in various sections is shown in the following table:

LOCALITY	COUNTY	THICKNESS *Feet*	AUTHORITY
Outcrop, 4 mi. NE. of Flatonia	Fayette	120	L. Bowling
Sandies Creek valley	Gonzales	200	C. E. Cook
Brazos River valley	Washington	200	A. Deussen
Guadalupe River valley	Gonzales	190	T. L. Bailey
Generalized section	Karnes	350	Do
Generalized section	Live Oak	600	Do
Generalized section	McMullen	650	Do
Generalized section	Duval	850	Do
Hicks No. 1, H. Coquat and Associates (section incomplete)	Live Oak	350+	Do
Santo Domingo No. 1, Alcorn Oil Company	Starr	629	Do
Peters well, 9 miles NW. of Moglia	Webb	870–790	Do

Matson, (1061a, p. 220, 1916) determined the thickness of the Catahoula in a well at Monticello, Mississippi, to be 420 feet, and Sherer[199] found it to be 844[200] feet thick in The Texas Company well near Jonesville, Catahoula Parish, Louisiana.

Stratigraphy.—The Catahoula formation overlies the Fayette and Frio formations unconformably and is overlain unconformably by the Oakville and Lagarto formations. In east Texas the basal contact is marked by the plane between coarse-grained sand and

[199]Sherer, H. K., Geology of Catahoula Parish, Louisiana: Bull. Am. Assoc. Pet. Geol., vol. 4, p. 449, 1930.

[200]Includes a little recent surface sand.

conglomerate in places cemented to form a quartzitic ledge and the light-colored tuffaceous and highly siliceous clays and thin-bedded, light-colored sandstones of the underlying Jackson. In south Texas the tuff beds of the Catahoula rest upon green and greenish-gray nontuffaceous clays of the Frio. According to Cook[201] the basal Catahoula tuffs in northern Live Oak County are so heavily impregnated with silica that they stand out above the underlying soft, unindurated Frio clay as a conspicuous cuesta known as "chalk bluffs" which can be followed and mapped readily. The upper contact of the Catahoula is distinguished easily in most places. In east Texas where the Catahoula is in contact with Lagarto clay the clay can be distinguished by its darker color, higher calcareous content and larger amount of colloids. The Catahoula beds below are light colored, tuffaceous, gritty, noncalcareous, and less colloidal. In central Texas where the Oakville sandstone rests upon the Catahoula, the contact is marked by a cuesta of brownish-gray, calcareous Oakville sandstone rising above white and buff tuffaceous clays of the upper Catahoula. The basal beds of the Oakville vary in lithology along the contact and in those places where typical Oakville sandstone is absent the Oakville clays can be distinguished by their darker color, greater calcium carbonate content, and smaller amount of volcanic material. The clays of the Oakville resemble more closely the Lagarto than the Catahoula.

The Catahoula formation in east Texas has been divided into two subdivisions or members on a basis of lithology, as follows:

2. *Onalaska.*—Dumble gave the name Onalaska to the strata above his basal sandstone member (now called Chita) and below the base of the Fleming (now called Lagarto and Oakville). The beds consist of tuffaceous shales, sandy clays, and cross-bedded, lenticular sandstones in places cemented by opal. The type locality comprises the exposures in Rocky Creek east of Onalaska, Polk County. There are good exposures also in Kickapoo Creek in Polk County and in Harmon Creek north of Huntsville.
1. *Chita.*—The new name Chita member is introduced to include the coarsely textured, and in places conglomeratic, basal sands of the Catahoula exposed at Chita and Corrigan in east Texas. Kennedy gave the name Corrigan to this sand, and Dumble (506, p. 188, 1918) referred to it as Catahoula member of the Corrigan formation. Since Dumble, Udden, Baker, and others

[201]Cook, C. E., Areal geology of the Catahoula formation in Gonzales and Karnes counties: Univ. Texas thesis, p. 44, 1932.

have used Corrigan for the whole Catahoula formation, it is confusing to use the name again in its original restricted sense, and it seems best to drop the name. The Chita sand is 10 to 80 feet thick, has white, polished grains called "rice sands," and is in places solidly cemented to a hard quartzite with sileceous cement. In most places the layer forms a persistent cuesta. The type locality comprises the exposures along the north-facing escarpment near the town of Chita in Trinity County.

The strata in south Texas have been divided on lithology into three members:

3. *Chusa.*—The Chusa member is named for La Chusa mesa in southeastern McMullen County, where a good section is exposed beneath the Oakville sandstone capping the mesa. The series of strata consists of unindurated, tuffaceous clays and unstratified tuffs, and it resembles in every way the fine-grained materials interstratified with and separating the conglomerate beds of the Soledad member. The tuff is described by Bailey (40, p. 91, 1926) as "an unstratified, noncalcareous to marly, very poorly consolidated, pisolitic or lumpy bentonitic clay . . . which commonly outcrops in vertical facies like loess. The clay . . . shows a prominent pisolitic or pseudo-pisolitic structure." The clay in some places contains spheroidal or lobate clay concretions from one-fourth of an inch to six inches in diameter. The thickness is estimated to be from 160 to 200 feet.
2. *Soledad.*—The Soledad conglomerate lentil is named for the Soledad hills in western Duval County, where a typical section is exposed. It includes conglomerate lentils in the Catahoula in south Texas between the top of the Fant member and the base of the Chusa. This series of strata comprises volcanic conglomerate, sandstone, and tuff. The well-rounded pebbles of the conglomerate consist of reddish- and grayish-brown trachyandesite, trachyte, cobbles, chert, pumice, and tuff, and they range from a fraction of an inch to a foot or more in diameter, and these are cemented by milky-white, translucent opal. Interbedded with the conglomerate layers are lenses and beds of impure tuff. In places the conglomerates are thin and are separated by thicker beds of tuff, clay, and sandstone. The sandstone is brownish-gray and greenish-gray, tuffaceous, more or less indurated, and of uneven texture, ranging from very fine grains to coarse pebbles. The conglomerate layers occur at several horizons in the Soledad member and form a series of ridges especially noticeable in McMullen County.
1. *Fant.*—The Fant member is named for the town of Fant City in northern Live Oak County. This division includes all the strata in south Texas from the top of the Frio formation to the base

of the Soledad member. The series of strata consist of volcanic ash and tuff interbedded with some clay. The tuff is characteristically white, fairly well indurated, massively bedded, somewhat vesicular and fine textured, and classified by Bailey as a trachyte.[202] The beds are cut by joint cracks and break down readily into small angular fragments. The white tuffs are interbedded in places with light-gray and yellowish-gray, very friable, soft tuff resembling the sand and less commonly with grayish-brown, mottled, bentonitic clay. The total thickness of the Fant member is about 200 feet.

All three members are present in south Texas. The Fant member extends as far south as Gonzales and Lavaca counties, where it is interbedded with a number of siliceous sandstone beds and takes on a sandy facies. The exact relationships of the beds in east Texas with those in south Texas have not been satisfactorily determined. It is thought, however, that the strata in east Texas consist of the lower

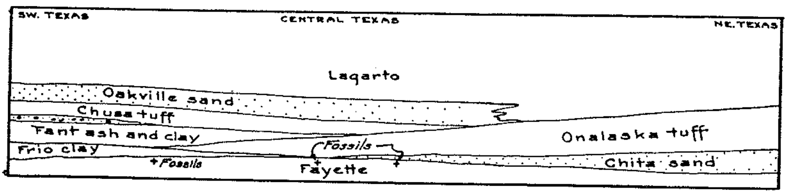

Fig. 48. Diagrammatic sketch showing the stratigraphic relationships of the members of the Catahoula formation and the overlying Oakville sand. The fossils indicated near the top of the Fayette formation are those found at and near Flatonia, Fayette County, and near Fashing in Atascosa County.

beds only and that the upper members are not present in east and central Texas due to overlap by the Oakville sandstone and Lagarto clay. The supposed relationships are indicated in the diagram, figure 48.

The upper portion of the Catahoula formation in east Texas is characterized by beds of volcanic ash, fuller's earth, and tuffaceous clays similar to those described above and resembling closely clays and tuffs in the Fant member of the Catahoula tuff beds in south Texas. The lower portion is characterized by beds of coarse, cross-bedded sandstone in places cemented with white, porcellaneous opaline silica. Details of the stratigraphy in east Texas are shown by the following described sections:

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[202]Light-colored igneous rock composed largely of orthoclase feldspar. All its mineral constituents, except the phenocrysts, are megascopically unrecognizable.

Section[203] *of a portion of the lower Catahoula formation at Devils Bend on Neches River, one-quarter of a mile southeast of the mouth of Shawnee Creek in northern Tyler County.*

	Thickness *Feet*
5. Sandstone, fine to coarse grained, containing plant fragments and balls of clay. The sand grains are set in a white porcellaneous matrix of opaline quartz	8
4. Clay, yellowish green to greenish brown, weathering yellow to cream-colored, thin bedded, partially indurated and breaking in cubical blocks	15
3. Clay, greenish brown to chocolate-brown, weathering dirty brown, the upper 6 inches solidly indurated so that it stands out as a ledge	4
2. Lignite	8
1. Sand and clay, greenish brown to bluish green, weathering to cream-color and containing an abundance of small ferruginous concretions formed around plant nuclei	5
Total thickness of section measured	40

Section[204] *of a hillside on Moscow-Trinity road, a quarter of a mile west of Moscow R. R. station, Polk County.*

	Thickness *Feet*
6. Clay, light green, very calcareous, imperfectly laminated, containing concretions of white, fine-textured limestone 1 foot or less in diameter	6
5. Fuller's earth, creamy white, laminated, nonplastic, gritty toward the top	10
4. Sand, light yellow, weathering white, fine-textured, laminated, cross-bedded, containing thin seams up to one-fourth inch in diameter of cream-colored clay	3½
3. Clay, light gray or greenish drab, weathering cream-color	3
2. Fuller's earth, creamy white, laminated, nonplastic	½
1. Clay, light gray to light greenish drab, weathering cream-color	3
Total thickness of section measured	26

Details of the Catahoula strata in south Texas are shown in the following sections:

[203]Measured by C. L. Baker, 506, p. 198, 1918.
[204]Measured by C. L. Baker, 506, p. 206, 1918.

Section[205] *of Catahoula formation west of the Simmons-Wentz road, 2½ miles northwest of Simmons, Live Oak County.*

	Thickness Ft.	in.
Soledad member—		
13. Sandstone, light grayish pink, friable, containing volcanic glass grains	3	
12. Tuff, light gray and pink, mottled, coarse-textured, porous, containing an abundance of bluish gray, rounded pumice pebbles, most of which are between one-eighth and one-half inch in diameter. A number of red and brownish gray, rounded pebbles and cobbles of extremely vesicular or honey-combed andesite up to 9 inches in diameter are found included in the tuff	30	
Fant member—		
11. Tuff, very porous, rather friable, light gravity, made up of trachyte or trachyandesite and containing small, bluish pumice pebbles or lapilli. The tuff is finer grained and more argillaceous toward the base	3	6
10. Clay or altered tuff, creamy gray, closely jointed, bentonitic. Fresh surfaces have many small pisolite-like bodies which are probably altered glass bubbles	2	
9. Tuff, light gray or white, weathering white, showing many vesicular cavities and having the appearance of a mud flow. The appearance is due to a large number of tuff lumps and some weathered pumice pebbles or lapilli which are included in the finer textured, slightly darker matrix	2	4
8. Clay or altered tuff, creamy gray, closely jointed, containing small pisolitic bodies	6	10
7. Clay, light pink and light green variegated, massive, rather tough, plastic, much jointed. One foot above the base the clay is green and somewhat sandy. The clay is stained black by manganese oxide along many of the joint planes and contains whitish, yellowish gray, pink, and light green, rounded or elliptical concretions composed of a mixture of opal, chalcedony, and argillaceous matter, also smaller, whitish, dense, calcareous concretions and streaks of calcite	11	4
6. Tuffaceous sand, greenish white, soft, friable, laminated, argillaceous, composed mainly of slivers and plates of volcanic glass	1	4
5. Clay, mottled, light purplish pink and grayish green, stiff, imperfectly laminated		8

[205]Described by T. L. Bailey, 40, p. 76, 1926.

	Ft.	In.
4. Tuffaceous sand, light grayish green, soft and friable, massive bedded, somewhat argillaceous		10
3. Tuffaceous clay, light creamy green, sandy, unstratified, soft, much jointed, easily eroded, containing many spicular fragments of volcanic glass. Near the surface the bed is cut by stringers of caliche	5	11
2. Tuffaceous sand, grayish white to light green, massive to platy bedded, composed almost entirely of megascopic volcanic glass fragments. The bed contains rounded and irregular sandy, calcareous concretions up to 3 inches in diameter	5	9
1. Tuff, white, somewhat indurated, containing many roundish yellow spots or irregular splotches due to spheroidal, earthy, limonite concretions one-fourth inch in diameter, which form the centers of such spots. The base is not exposed	5	
Total thickness of section measured	78	6

Sedimentology.—The Catahoula formation is a series of continental sands, clays, and pyroclastics interbedded with fluviatile sediments. Pyroclastic materials predominate in the south Texas area. In north Texas floods from the great east Texas rivers brought down much sand and deposited coarser sediments than the shorter rivers of the south Texas area. The Jackson sea withdrew at the end of the Jackson epoch, but the volcanic activity in the western mountains that characterized the marine epoch continued with even more intensity. Clouds of dust were spread over the coastal plain, picked up by the streams, and concentrated in the depositional areas. The exact location of the craters from which the billions of tons of ash were ejected is not known. Probably there were many craters. Some were located in or near the southwestern part of the state because in south Texas the volcanic material is thickest and coarsest. Boulders, pebbles, and chunks of lava, porphyry, and pumice are common in McMullen, Duval, and Starr counties. All these are of a type that could have been ejected by tremendous explosions. Yet most of them are but little water worn, and many are so large that it seems impossible that they could have been thrown by eruptive forces from any of the known centers of volcanic activity in the western mountains and transported to their present resting place. They were doubtless ejected from some volcanic source not far distant from the south Texas syncline. Some of the ash and lighter materials drifted in the air and traveled longer distances before falling. It may have come from the Davis Mountains and other volcanic centers in Trans-Pecos Texas. Bailey (40, pp. 154–164, 1926) studied the problem of the source of some of the volcanic material in the Catahoula and concluded provisionally that the source of some of the material at least must have been in southwestern McMullen County or western Duval County. He found many large, subangular, acid, andesite boulders in McMullen County, some of which measured over two feet in diameter. These he believed could not have been transported many miles. He found that the tuffs were thickest in McMullen and Duval counties and that there was evidence of mud flows in the clays. Mud flows can, of course, occur on steep river banks and delta slopes. But the Duval flows are widespread and contain so many chunks of pumice and other volcanic ejecta and have so many sun cracks and wavy bedding planes that Bailey believed they were most likely deposited fairly near a volcano.

Lithology.—The Catahoula formation contains about 60 per cent pyroclastic material, 20 to 30 per cent sandstone, 10 to 20 per cent argillaceous clay, and minor amounts of conglomerate. The pyroclastic material is largely ash or tuff. At least 5 per cent of the tuff has been altered to fuller's earth and bentonitic clay. The percentage of sand and sandstone is less, and the percentage of tuff is more in south Texas than in east Texas. Conglomerate, however, occupies as much as 10 per cent of the section in Duval County, and the pebbles and cobbles in it are larger than the conglomerate pebbles in east Texas.

The tuff beds in the Catahoula are white, light gray, dirty gray, and greenish gray, fine textured, massively bedded, range in thickness from eight inches to two feet, and are interbedded with tuffaceous clay and tuffaceous sand. The tuff, according to Bailey (40, pp. 66–67, 1926) is represented by at least six types of rock as follows:

1. Pisolitic tuff. This type contains silky pumice fragments, platy filamentous glass grains, and angular fragments of feldspar grains. In many places the tuff has a distinctly pisolitic appearance due to minute rounded bodies of tuff in the bed.
2. Lumpy tuff. The lumpy type of tuff contains rounded and irregular pieces of tuff in the massive beds. The lumps are composed of the same kind of tuff as the matrix and indicate simply a breaking up and redeposition of an original tuff bed by mud flowage

or stream action. Bailey thinks that some of the small lumps are pumice bubbles.

3. Silicified or "porcellanite" tuff. The silicified tuff is silicified to a very dense textured, chertlike "porcellanite" rock. The rock has a hardness of 6 and breaks with a conchoidal fracture resembling chert. In most places due no doubt to temperature change the surface is cut by closely spaced joint cracks and breaks down on weathering to small fragments. Much of the "porcellanite" rock is in platy beds like chert. Baker[206] has suggested that this silicified rock forms by solution of silica in warm alkaline waters, that in a dry climate the solution reaches the surface by capillary action, the water evaporates, and the silica is deposited exactly the same as caliche forms from lime carbonate in silts and sands where the ground waters are saturated with bicarbonate of lime. He has suggested the name "silice" to designate siliceous rocks of this type.
4. Fluffy, granular tuff. The granular type is very friable and made up of individual grains of volcanic glass of fine to coarse sand texture and classified by Bailey as a sand of probably eolian origin. About 25 per cent of the tuffs of the Fant member, according to Bailey, belong to this type.
5. Altered or bentonitic tuff. This type is creamy gray to grayish green, compact, poorly bedded, and thought to be a tuff which has been redeposited by streams and partly hydrated by water to bentonite.
6. Fuller's earth. Beds of fuller's earth occur at several horizons in the Catahoula formation. The beds are creamy white, yellowish, greenish, and in some places brownish white, a few inches to 6 feet thick, compact, somewhat kaolinitic in appearance, soft and greasy to the touch, exceedingly fine grained and compact. Fuller's earth is in every respect similar to bentonite and probably has a similar origin.

The mineral composition of the tuffs as determined by Bailey (**40**, p. 117, 1926) is as follows:

Primary silicate minerals—	
Volcanic glass	10% to 85%
Soda lime feldspar / Alkali feldspar	1% to 10%
Quartz	Rare
Primary ferromagnesian minerals	Less than 1%
Augite, diopside, or biotite	Trace

[206]Baker, C. L., personal communication, 1932.

Accessory minerals—

Apatite	0 to 1%
Zircon	Trace
Magnetite	1%
Ilmenite	Trace
Tridymite	0 to 5%

Secondary minerals—

Montmorillonite	10% to 60%
Barite	?
Calcite	?
Limonite	?
Chlorite	Trace
Opal, silicified type may contain as much as	65%

The chemical composition of typical samples of tuffs from the Catahoula formation determined in the Bureau of Industrial Chemistry under the direction of E. P. Schoch (40, p. 111, 1926) is as follows:

LOCALITIES[a]	SiO_2	Al_2O_3 Fe_2O_3	MgO	CaO	Na_2O	K_2O	SO_2	H_2O
1. 2½ mi. NW. of Simmons, Live Oak County	55.89	16.44	1.35	0.16	1.03	0.36	2.93	14.43
2. 4 mi. W. of Three Rivers, Live Oak County	57.05	21.04	1.09	1.64	2.11	0.38	2.35	12.70
3. 6 mi. NNW. of Mirando City, Webb County	67.13	11.91	1.42	3.11	2.36	0.28	1.53	11.55
4. 2½ mi. NW. of Simmons, Live Oak County	46.15	12.02	0.78	15.10	2.87	0.43	2.38	14.75
5. 4 mi. SW. of Simmons near McMullen County line	58.90	18.23	1.48	2.51	3.03	1.20	4.03	10.34
6. White Creek, 2½ mi. SE. of Simmons, Live Oak County	59.38	16.75	0.43	1.47	2.29	0.56	3.20	13.07

[a]Samples No. 1 and No. 2 are ordinary vesicular tuff; No. 3 is the siliceous type tuff; No. 4 and No. 5 are the granular light-weight types; and No. 6 is the altered or bentonitic type.

The sandstone beds in the Catahoula consist of gray, brownish-gray, and buffish-gray, medium- and coarse-grained, cross-bedded, quartz sandstone. The most characteristic feature of the rock is its content of opaline cement. In many places the sand grains are solidly cemented by opaline silica into hard quartzite. The opal is bluish white, translucent, vitreous, and takes a beautiful polish. The distribution of the opal is irregular both vertically and horizontally. In a vertical section some ledges are firmly cemented and others are unconsolidated. A quartzitic ledge may change horizontally to loose, unindurated sand in a short distance.

The texture and mineral composition of typical washed samples of the sandstone from south Texas had the following texture, shape, and mineral composition as determined by Bailey (40, p. 145, 1926):

	Sample No. 1[a] *Per cent*	Sample No. 2[a] *Per cent*
TEXTURE		
½ mm. to 1 mm.	Trace	
¼ mm. to ½ mm.	50	
⅛ mm. to ¼ mm.	35	
1/16 mm. to ⅛ mm.	15	
SHAPE		
Well rounded	About 5	10
Subangular, more or less worn	95	90
MINERAL COMPOSITION		
Quartz	30	65
Plagioclase	28	1
Chert	25	5
Opal (cement)	11	24
Orthoclase and sanidine	4	5
Microcline	1	---
Magnetite	Trace	Trace
Biotite	Trace	---
Muscovite	Trace	---
Zircon	Trace	Trace
Glass	Trace	---
Tourmaline	---	Trace

[a]Sample No. 1 is from a quarter of a mile northwest of Rockland, Tyler County. Sample No. 2 is from 5 miles southeast of Smiley, Gonzales County.

Samples from Fayette County examined by Wendler[207] yielded the following heavy minerals in addition to those listed by Bailey above:

Epidote	Rare	Garnet	Rare
Rutile	Rare	Spinel	Rare
Pyrite	Common	Hornblende	Rare
Limonite	Abundant	Titanite	Very rare
Staurolite	Rare	Anatase	Very rare
Monazite	Rare	Kyanite	Rare

Many of the sand grains in the samples from Trinity County are highly polished as if subjected to a sand blast. Goldman (596,

[207]Wendler, A. P., Heavy minerals of the Catahoula, Fayette County, Texas: Univ. Texas thesis, 1932.

pp. 261–287, 1915) thought that this character might indicate an arid climate. The cement between the grains of sand consist of a mixture of opal, chalcedony, and argillaceous material which probably originated from solution of the fine volcanic dust by alkaline underground waters.

The argillaceous clay beds in the Catahoula are gray or dark brownish gray and in some places blue, and they weather to variegated colors. They are tuffaceous, in places carbonaceous, and locally contain plant leaves and siliceous concretions. They are tough and plastic in most places in south Texas and more sandy and friable in east Texas. On the whole the argillaceous clays are less abundant in the outcrop than the tuffs or sandstones. The tuff is most prominent in south Texas, the sandstone in central and east Texas. In subsurface sections south of the outcrop the sands and tuffs thin and argillaceous clays and silts thicken.

Conglomerate beds occur at the base of the Catahoula formation in central Texas and near the middle of the Catahoula tuff beds (Soledad member) in south Texas. The conglomerates in south Texas consist of reddish-brown and dark brownish-gray pebbles, cobbles, and in some places small boulders of trachyandesite, andesite, trachyte, pumice, and chert set in a matrix of light colored, bluish-white, translucent opal and chalcedony. The pebbles are water worn, well rounded to subrounded, and measure from one-tenth of an inch to 2 feet in diameter. The common range is between 1.2 and 8 inches.

Distinguishing characteristics.—The Catahoula formation can be distinguished from other formations by the following criteria:

1. Preponderance of volcanic tuffs. Beds of tuff, volcanic ash, and pyroclastic materials occur in larger quantities in the Catahoula than in other formations. Such materials occur also in the Fayette and Frio. In the Catahoula, however, they greatly predominate.
2. Opaline cement. The sandstones, conglomerates, and in some places the tuff are solidly cemented by opal and chalcedony. Opal occurs also in the Jackson beds but in minor amounts. In the Catahoula it is the predominating cementing material and in some places in south Texas occurs in veins.
3. Glass: Minute grains or spherules of glass occur in the Catahoula, are absent or rare in the Fayette, and absent in the Oakville.

4. Coarse texture and irregular bedding. The sandstones in the Catahoula, especially in northeast Texas, are coarser textured and contain more pebbles than the Jackson strata. The sands and clays are more massively bedded, and the sands are more cross-bedded and more lenticular than those of the Jackson.
5. Polished, rounded sand grains. The lower sandstone beds in north Texas contain many beautifully polished, rounded grains that have suggested to geologists the name "rice sands." These polished ricelike grains set in a matrix of opal cement are especially characteristic of the Catahoula formation in east Texas.
6. Absence of calcareous cement and calcareous concretions. Calcareous cement and calcareous concretions are rare in the Catahoula and common in most other formations.
7. Scarcity of fossils. Fossils are rarer in the Catahoula than in the Jackson.

Paleontology and correlation.—The Catahoula formation in most places is poor in fossil remains. Shells of brackish-water Unios belonging to the genus *Amblemoidea*, discovered by Leslie Bowling north of La Grange in central Fayette County, were described[208] recently by F. S. MacNeil. Poorly preserved shells have also been found by Lyman C. Reed nine miles south of Bryan, Brazos County.

Remains of fossil plants have been found in the Catahoula at a number of places. Plants, however, are not so common as in the Fayette strata. The following list records the more common and typical forms that come from localities known to be Catahoula, as defined by the new geologic map of Texas (396c, 1932):

Palmoxylon microxylon Stenzel (1)
Palmoxylon cellulosum Knowlton (1)
Palmoxylon remotum Stenzel (2)
Palmoxylon lacunosum Felix (4)
Lygodium mississippiense Berry (3)
Acrostichum smithi Berry (3)
Burserites catahoulensis Berry (5, 6)
Cearela jacksoniana Berry (5)

Localities recorded in above list—
1. Northern Rapides Parish, Louisiana.
2. Three miles north of Waynesboro, Mississippi.
3. King, Mississippi.
4. One mile east of Galbraith, Louisiana.
5. Striker, Polk County, Texas.
6. Harmon's Creek, Walker County, Texas.

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[208]MacNeil, F. S., A new genus of fresh-water mussel from the Catahoula sandstone of Texas; manuscript read at Oklahoma City meeting, Am. Assoc. Pet. Geol., March, 1932.

The great abundance of palms *(Palmoxylon)* in the flora indicates, according to Berry (**101**, pp. 229, 1916), a tropical climate. According to Stenzel, they are closely related to either *Corypha* or *Cocus*, which are found among the fossil wood collected from Oligocene beds in Antigua, a decidedly tropical country today and probably tropical also during the Oligocene period. The fern, *Acrostichum*, today inhabits coastal swamps associated with mangroves and nipa palms. The flora so far studied is not large enough to enable paleobotanists to determine the exact age and correlation of the Catahoula strata. Berry (**101**, p. 229, 1916) believes that the basal beds of the Catahoula in east Texas from which the few plant fossils were collected are Oligocene. Stephenson[209] believes that the stratigraphic relation of the Catahoula sand in Mississippi to the underlying Vicksburg strata indicates that the Catahoula can be either Oligocene or Miocene. The final solution of the age of the Catahoula must await further more convincing evidence.

Miocene and Pliocene Systems

FLEMING GROUP[210]

DEFINITION

The clays and thin sandy strata above the Catahoula sandstone in east Texas and Louisiana were named Fleming by Kennedy (**905**, pp. 62–63, 1892) from exposures near Fleming, a station on the Missouri, Kansas, and Texas Railroad east of Corrigan in Polk County. Kennedy included in his division all the strata above the Corrigan sandstone (now Catahoula) and below sand deposits then referred to the Lafayette. He stated that the strata occupy a belt 15 to 25 miles wide. Dumble (**494**, pp. 956–983, 1903), and Veatch (**1691**, pp. 43–44, 1906) used Kennedy's name for about the same strata. Deussen (**415**, pp. 72–77, 1914) limited the Fleming to about 200 feet of clay strata occupying an outcrop about 7 miles wide above the Catahoula sandstone in east Texas and introduced a

[209]Personal communication.

[210]Literature.—Kennedy, W., **905**, pp. 62–63, 1892; **911**, pp. 93–95, 1896. Harris, G. D., **665a**, pp. 28–32, 1902. Maury, C. J., A comparison of the Oligocene of western Europe and the southern United States: Bull. Am. Pal., vol. 3, p. 390, 1902. Veatch, A. C., **1688a**, pp. 135–137, pp. 141–144, 1902; **1691**, pp. 43–44, 1906. Dumble, E. T., **494**, pp. 956–983, 1903; **501**, pp. 467–472, 1915; **504**, pp. 1632–1634, 1915; **510**, pp. 435–440, 1924. Hayes, C. W., and Kennedy, Wm., **692**, p. 53, 1903. Deussen, A., **415**, pp. 72–77, 1914; **421**, pp. 97–102, 1924. Udden, J. A., Baker, C. L., and Böse, E., **1652**, pp. 89, 90, 1916.

new name, Dewitt formation, to include a series of beds occupying in south Texas about the same stratigraphic position as the Fleming. Udden, Baker, and Böse (**1652**, p. 89, 1916) followed Kennedy's and Dumble's terminology.

The name came into general use to designate the strata in east Texas between the Catahoula and Lissie (Pleistocene beds). The same sequence of strata in south Texas that Deussen named Dewitt was divided by Dumble (**478**, pp. 556–559, 1894) into three formations, Oakville, Lapara, and Lagarto. Deussen (**421**, p. 97, 1924) and Trowbridge (**1610**, p. 98, 1923) later abandoned the name Dewitt and used Dumble's south Texas names, Oakville, Lapara, and Lagarto. The United States Geological Survey in preparing a new geologic map of Texas mapped the sandy strata above the Catahoula from Nueces River to the Brazos as Oakville sandstone. They decided, however, to use Dumble's name Lagarto for the beds above the Oakville and dropped the names Fleming and Lapara. The Oakville is really a sandy facies of the lower and southwestern portion of the Fleming. It grades laterally and vertically into the clay. In view of the difficulty of separating the Oakville and Lagarto beds in Texas east of the Brazos, it seems preferable to retain the name Fleming as a group name to include all the strata above the Catahoula formation and below the sands of the Citronelle group and to apply the names Oakville and Lagarto to formational divisions of the Fleming group.

The strata of the Fleming group consist of yellow and green clays, gray sandy clays containing layers of pink and brown clay, in some sections a thin layer of chalky limestone, and lentils and layers of cross-bedded sand. Small calcareous and ferruginous nodules are common. Toward the base in the portion of the section corresponding to the Oakville the clays are dark greenish gray streaked with brown and purplish-gray shades. They contain much more sand than the upper beds. All the strata are calcareous and contain redeposited Cretaceous foraminifera, chara fruit, calcareous nodules, and aragonite prisms thought to have been derived from *Inoceramus* plates. The subsurface strata near the coast are interbedded with several marine layers of well bedded sandy clay 50 to 200 feet thick containing marine Miocene fossils. The total thickness of the Fleming group in the oil fields is 2000 to 2700 feet.

The beds lie unconformably upon the Oligocene strata in the subsurface sections and lie unconformably upon the Catahoula formation on the outcrop. They are overlain conformably by Pliocene strata.

The type locality for the Fleming group comprises the exposures along the Missouri, Kansas, and Texas Railroad east of Corrigan and near the station of Fleming in Polk County. The section as described by Kennedy (692, p. 52, 1903) at this place is as follows:

Section of the Fleming strata along the Missouri, Kansas, and Texas Railroad near Fleming in the eastern edge of Polk County.

	Thickness *Feet*
6. Sand, gray	½
5. Sand, brown, mottled	2-4
4. Sand, gray, stratified, containing fossil palm wood in great abundance and pebbles of quartz and jasper	20
3. Clay, blue, partially stratified, showing a tendency to break into conchoidal blocks, and containing numerous calcareous nodules	50
2. Clay, red, having same structure as bed above, but containing no concretions	10
1. Sand, yellow	4
Total thickness measured	**88½**

SUBDIVISIONS

The outcrop of the Fleming beds in central and south Texas has been divided into the two following formations, which are described in stratigraphic order:

2. Lagarto
1. Oakville

OAKVILLE FORMATION[211]

Definition.—The Oakville sandstone was differentiated from the Fayette group of beds by Dumble (478, pp. 556–559, 1894) and assigned to the Miocene.[212] Dumble described the formation as

[211]Literature—Dumble, E. T., 478, pp. 556-559, 1894; 494, p. 957, 1903; 501, p. 476, 1915; 506, pp. 228–243, 1918. Deussen, A., 415, pp. 74-76, 1914; 421, pp. 97–99, 1924; and Dole, R. B., 416, p. 156, 1916. Bailey, T. L., 38; pp. 95, 96, 1923; 40, pp. 52–58, 1926. Trowbridge, A. C., 1610, p. 98, 1923; 1613a, pp. 165–181, 1932. Applin, P. L., 33, pp. 21–23, 1925. Böse, E., and Cavins, O. A., 135, pp. 128–133, 1927. Sayre, A. N., Ground-water resources of Duval County: U. S. Geol. Survey Press Rpt., p. 7, Feb. 12, 1933.

[212]The announcement of the discovery of extensive Miocene strata in Texas was first made by Shumard (1474, p. 140, 1863) based on the determination of fossil bones identified by Leidy (980, p. 416, 1861).

sandstone, grits, gritstone, and silt interbedded with clay making up a section of strata between the Frio clay (now Catahoula formation) and the overlying Pliocene clay. He thought the formation was confined to south Texas and correlated it with the lower half of the Fleming clays of east Texas. Deussen (**421**, p. 97, 1924) described the formation in more detail, but did not change essentially Dumble's definition. Bailey (**38**, pp. 52–53, 1923) followed Dumble's definition in describing the Oakville formation in the Colorado River valley in Fayette County, but later in describing the strata in south Texas he (**40**, pp. 52–58, 1926) restricted the Oakville as mapped by Deussen and included the basal strata in his Gueydan formation (now Catahoula). Trowbridge in two papers (**1610**, p. 98, 1923; **1613a**, pp. 165–181, 1932) used the name about as originally defined by Dumble. The United States Geological Survey in their preliminary map of Texas (**396c**, 1932) used the definition of Dumble and Deussen in mapping the formation in south Texas and have differentiated its outcrop as far east as Brazos River.

The Oakville formation is now made to include all the strata of Miocene age above the Catahoula formation and below the Lagarto clay. The type section comprises the exposures on Nueces River in the vicinity of Oakville, Live Oak County.

Regional geology.—The Oakville formation as now delineated extends in a continuous outcrop about 8 miles wide from Navasota in Grimes County through Washington, Fayette, northwestern Lavaca, De Witt, Karnes, and Live Oak counties to the southwest corner of Duval County (figs. 49, 50). From Duval County southward it is overlapped throughout most of the area by Pliocene deposits. It occurs, however, in a few isolated spots, for example, near Torrecillas in Webb County, on Mulato Creek in the northeast corner of Zapata County, and north of Rio Grande City in Starr County. It occurs also on the Mexican side of the Rio Grande.

In southeast Texas from northeast of Navasota in Grimes County eastward the Oakville formation has not been differentiated from the Lagarto clay. It is thought that it is not overlapped by the younger deposits as in south Texas, but that east of Brazos River the Oakville sands change to a clay facies and merge with the lower part of the Lagarto formation and cannot be, or at least have not been, distinguished from the Lagarto. Miocene vertebrate fossils similar to vertebrate fossils in the Oakville have been discovered near Cold Spring in San Jacinto County and at Red Bluff on Trinity River. The formation changes also southward beneath the surface. About 50 miles south of the outcrop the Oakville beds merge with and are interbedded with marine Miocene clays and sands, and become important oil-producing zones in the salt dome oil fields.

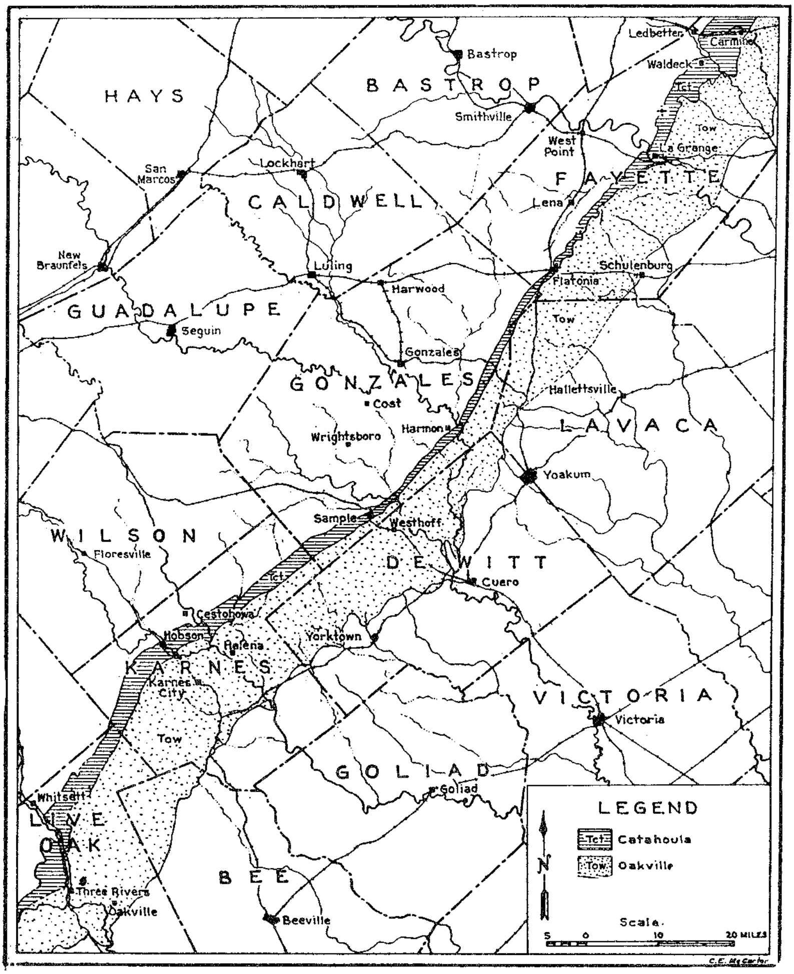

Fig. 49. Outcrops of the Catahoula and Oakville formations in south-central Texas (compiled from Univ. of Texas theses by Carroll Cook and A. P. Wendler).

The thickness of the Oakville formation varies along the strike of the outcrop from 200 feet in northeast Texas to 500 feet or more in south Texas. Its thickness increases also beneath the surface toward the coast line, as shown in the following table:

LOCALITY	COUNTY	THICKNESS *Feet*	AUTHORITY
Brazos River section	Washington	200	A. Deussen
Deep well at Galveston	Galveston	720+[a]	G. D. Harris
Colorado River section	Fayette and Colorado	495–550	T. L. Bailey
Stratton Ridge salt dome	Brazoria	1000+[b]	P. Applin
Niels-Esperson well, 15 miles east of Brownsville	Cameron	175+	Julia Gardner
Nueces River section	Live Oak	300	A. Deussen
Outcrop	Duval	500	A. N. Sayre

[a]Bottom of Miocene strata not reached.

[b]The thickening of the Oakville toward the coast is due somewhat to actual thickening of the strata, but also to a large extent to the fact that the basal portion of the Lagarto clay cannot be differentiated from the marine Oakville beds, and the two divisions are measured together.

Stratigraphy.—The Oakville formation overlies the Catahoula unconformably and in turn is overlapped unconformably by the clays of the Lagarto formation (fig. 48). In some places the basal contact is marked by a conglomerate made up of rolled water-worn Cretaceous fossils and pebbles. In other places the contact is between coarse-grained sand above and greenish- or yellowish-white, tuffaceous clay below. The Oakville formation is wholly continental in origin at its outcrop. It is of more or less uniform composition and has not been subdivided into mappable members. The northeast portion of the outcrop contains a larger proportion of clay than the southwest district. In other respects the Oakville is generally uniform in character throughout its outcrop. The following sections compiled from literature give a good idea of its stratigraphic features:

Section[213] of Oakville formation exposed at Hidalgo bluff on Brazos River in Washington County.

	Thickness *Feet*
Oakville—	
9. Sandstone and clay, light gray to yellow, generally coarse grained, but ranges from very fine to coarse, irregularly bedded. The beds are from 2 to 6 feet thick, massive in some places and laminated in others	29

[213]Measured by W. W. Kelley, 506, p. 239, 1918.

	Thickness *Feet*
8. Clay, dirty yellow or grayish, calcareous, weathers to produce badland forms	16
7. Sand, unconsolidated, medium grained, containing several lentils of consolidated sand, rolled and redeposited Cretaceous fossils, and one fragment of a bone	11
6. Clay, dirty yellow or gray, containing calcareous nodules and a lentil of yellowish sand	17
5. Sand, unconsolidated except the upper 6 inches, which is indurated. The sand contains rolled Cretaceous fossils, fragments of silicified wood, and a layer of pebbles at its base	5
4. Sandstone, gray to yellow, cross-bedded, ranging in texture from a conglomerate made up of sandstone pebbles to a fine sand	26
3. Coquina, white or gray, composed of small fragments of Cretaceous fossils mixed with a little fine sand. The fossils are rolled and water worn	5
Catahoula?—	
2. Clay, buff or dirty yellow, fine grained, sandy, standing up to exhibit a vertical section	20
1. Clay, light bluish gray, containing streaks and nodules of calcareous matter, less calcareous at the base, partly covered by detritus	54
Total thickness measured	183

Section[214] of Oakville formation on a hill just east of Santa Cruz ranch 5 miles southeast of Rio Grande City, Starr County.

	Thickness *Feet*
6. Clay, pink	23½
5. Clay, hard, nodular, forming a protruding ledge	1
4. Clay, pink	2½
3. Sandstone, gray, massive, irregularly bedded	11
2. Clay	3
1. Sandstone, hard, blocky. The sandstone at a locality nearby contains pellets of clay believed to have been derived from underlying Frio which weather out leaving round cavities in the sandstone	4–5
Total thickness measured	46

Sedimentology.—The sediments of the Oakville were deposited by streams on a gently inclined coastal plain along the border of a

[214]Measured by A. C. Trowbridge, 1613a, p. 171, 1932.

sea and merged seaward with marine deposits.[215] The physical geography of the Oakville epoch was somewhat unusual. Conditions must have favored rapid deposition of material derived from sources comparatively near at hand by streams that established enormously wide flood plains. Large quantities of redeposited Cretaceous shells prove that the sediments were derived largely from Cretaceous outcrops, carried across the older Tertiary areas, and deposited in great quantities in the form of broad alluvial sheets or aprons. A very large mass of Cretaceous marl must have been transported to secure in places so rich a concentration of Cretaceous shells. Perhaps the deposition of so much volcanic ash during the preceding Catahoula epoch so changed the character of the soil that much of the land flora disappeared on the Cretaceous uplands. Before a new flora became adjusted to the new environment produced by a mantle of ash, the barren uplands eroded easily and water unobstructed by plant life ran off rapidly causing great floods after each rainy period. Only by rapid erosion and great quantities of water in rivers constantly shifting over a featureless plain can such thick and extensive sheets of redeposited Cretaceous shells, coarse-grained, lenticular, cross-bedded sand beds, and bone-bearing clay beds be explained.

Lithology.—The strata of the Oakville formation consist of about 40 per cent sand, 30 per cent sandy and ashy or bentonitic clay, 20 per cent marl, 5 per cent redeposited Cretaceous shells, and 5 per cent gravel. The sand is light gray in most places, friable, medium grained, intricately cross-bedded, calcareous, and in places more or less indurated. Bailey (40, pp. 55, 1926) found that a typical washed sample had the following mineral composition:

	Per cent
Quartz	40
Calcite (largely cement)	25
Chert	20
Orthoclase	6
Plagioclase	7
Water-worn shell fragments	2

Traces of microcline, biotite, magnetite, limonite, zircon, barite, chalcedony, and reworked foraminifera.

[215] Bailey, T. L., 38, pp. 95–96, 1923.

At some exposures the sand grains are cemented with chalcedony or opal in place of calcite. The siliceous rock is exceedingly hard, breaks with a conchoidal fracture, and resembles quartzite in every way. The sand grains are subangular to angular, made up of quartz, feldspar, and calcite, and have according to Trowbridge (**1613a**, p. 176, 1932) the following texture analysis:

DIAMETER OF GRAINS *mm.*	*Per cent*
¼ to ½	45
⅛ to ¼	35
1/16 to ⅛	11
1/32 to 1/16	½
1/64 to 1/32	½
Smaller than 1/64	8

The clay is gray or dirty yellow, compact in most places, poorly laminated, calcareous, containing in places much marly material, reworked foraminifera, and oyster and other shells derived from the Cretaceous deposits. In other places the clay contains much redeposited volcanic ash derived from the Fayette and Catahoula formations. In a few places in south Texas the ash is so pure that it is thought to be original and derived from volcanic sources during Oakville times. In the places where the ash is particularly abundant it is cemented in places into hard lentils of chalcedony by infiltrating siliceous waters. The indurated siliceous clay, according to Trowbridge (**1613a**, pp. 178–179, 1932), is an extremely hard, grayish to brownish-gray, fine-grained siltstone resembling chert. It may occur in the form of concretions, as thin lenticular seams, or as pipes.[216] A thin-section under the microscope reveals minute angular quartz grains less than one-eighth of a millimeter in diameter set in a brownish-gray clay matrix together with some calcitic cementing material, limonite aggregates and streaks, and minor amounts of chalcedony in veins and segregations. Trowbridge thinks that the material in one part of the section was cemented originally with calcite and that in another part with chalcedony. Most of the rock is now cemented with silica, which in the form of chalcedony has replaced the calcite.

[216]The pipes, according to Lonsdale, are possibly ancient volcanic vents filled with silica. Deussen has thought these siliceous deposits might be associated with fault or fracture lines and produced by ascending siliceous waters.

Distinguishing characteristics.—The Oakville formation is distinguished from the Lagarto clay above and the Catahoula formation below by the following criteria:

1. Redeposited Cretaceous fossils. The Oakville strata contain in many places, both in outcrop and in core samples obtained from wells, water-worn Cretaceous fossils and fragments of shells and foraminifera redeposited from the Cretaceous marls. The Catahoula does not contain such redeposited material. The Lagarto clay has much less sand, thinner lentils of sand, and fewer redeposited shells.
2. Intricate cross-bedding. The sandstone strata in the Oakville are more intricately and persistently cross-bedded than the Lagarto sand.
3. Chalcedony. The Oakville strata in south Texas contain more lentils, veins, and pipes of chalcedony in the form of siltstone than the Lagarto or Catahoula. The Catahoula has much opaline cement but less chalcedony in the form of separate aggregates.
4. Vertebrate bones. The clays in some places contain bones of mammals that distinguish the strata from the Lagarto and Catahoula. Similar bones occur in the Lagarto, but they are of Pliocene age.
5. Lithology. The Oakville contains a much larger percentage and thicker, more massive beds of sand than the Lagarto. It contains less ash and more sand than the Catahoula of south Texas. The sand grains are more angular and less polished than the sand grains in the Catahoula.
6. Clay balls. The rapidly deposited sands of the Oakville have balls, nodules, and small lentils of clay imbedded in the grit. These clay balls are not common in the Catahoula sand.
7. Prominent escarpment. In many places the Oakville is sufficiently indurated to produce a prominent cuesta. In south Texas the formation forms the Bordas escarpment.

Paleontology.—The Oakville formation contains no marine fossils on the outcrop. In well sections in the salt dome oil fields it yields a rich marine fauna that distinguishes it easily from the formations above and below.

The following fossils have been identified from the lower Fleming strata at Stratton Ridge salt dome, Brazoria County, by Mrs. Applin (**33**, pp. 25–29, 1925):

Mulinea lateralis Say
Ostrea sp.
Balanus sp.
Pecten sp.
Chione cancellata (Linné)
Natica cf. N. eminuloides (Gabb)
Corbula cf. C. seminula Dall
Corbula inaequalis Dall
Arca transversa var. busana Harris
Arca incongrua Say
Nassa trivittata Say
Leda sp.
Mactra lateralis Say
Mactra quadricentennialis Harris
Glycimeris sp.
Cerithiopsis sp.
Olivella sp.
Cylichna bidentata var. galvestonensis Harris
"Pleurotoma" cf. P. calvertensis Clark
Strombina sp.
Rotalia beccarii (Linné)
Cibicides americana (Cushman)
Elphidium sp.
Quinqueloculina sp.

A collection of these fossils was studied by Olsson,[217] who reported them to be definitely Miocene in age probably representing middle Miocene assemblages.

The following fossils have been identified from the Miocene strata in the Niels-Esperson well, 15 miles east of Brownsville, by Miss Gardner (**1613a**, p. 182, 1932):

Nucula sp. indet.
Leda sp. cf. L. proteracuta Gardner
Leda sp. indet.
Pecten aff. P. eboreus Conrad
Pecten? sp.
Cardium (Cerastoderma) sp. indet.
Tellina sp. indet.
Corbula (Caryocorbula) cf. C. (C.) nasuta Dall
Corbula sp. indet.
Dentalium sp. indet.
Cadulus? sp.
Adeorbis sp.
Architectonica? sp.
Natica (Cryptonatica) cf. N. (C.) pusilla Say
Polynices sp.
Turritella sp. cf. T. terebriformis Dall
Alectrion? sp.
Oliva cf. O. literata Say
Cancellaria n. sp.
Cancellaria? sp.
Drillia n. sp.

Miss Gardner did not determine the exact position in the Miocene section of the collection from the Brownsville well but recognized a prominent Chipola factor in the fauna indicating a lower or middle Miocene age.

A number of bones have been discovered in the Oakville formation. These have been studied and identified by Cope,[218] Leidy,[219] Matthew,[220] and Stock,[221] and the following species have been reported:

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[217]Olsson, A., personal communication.

[218]Cope, E. D., quoted by E. T. Dumble, **494**, p. 957, 1903.

[219]Leidy, J., **980**, p. 416, 1861.

[220]Matthew, W. D., quoted by E. T. Dumble, **506**, pp. 231, 233, 237, 1918.

[221]Stock, Chester, quoted by Applin, **33**, p. 22, 1925.

ANIMAL	NAME	AGE	LOCALITY
Camel	Alticamelus? sp.	Middle Miocene or lower Pliocene	1
Camel	Procamelus?	Middle Miocene	7
Camel	Procamelus? or Protolabis?	Middle Miocene or Pliocene	3
Camel	Blastomeryx sp.	Middle or upper Miocene	2
Cervid	Dromomeryx?	Middle Miocene or lower Pliocene	1, 8
Horse	Hystricops sp.	Middle to upper Miocene	2
Horse	Protohippus sp.	Middle Miocene to Pliocene	4
Horse	Merychippus cf. M. seversus (Cope)	Late middle Miocene	1, 2, 3, 6, 8
Horse	Protohippus medius Cope	Loup Fork Miocene	9
Horse	Protohippus perditus Leidy	Loup Fork Miocene	9
Horse	Protohippus placidus Leidy	Loup Fork Miocene	9
Rhinoceras	Coenopus sp.	Miocene	10
Rhinoceras	Teleoceras? or Aphelops?	Middle Miocene or lower Pliocene	1, 8
Rhinoceras	Aphelops meridianus Leidy	Loup Fork Miocene	9
Rhinoceras	Aphelops?	Middle Miocene or lower Pliocene	1, 8
Mastodon	Trilophodon cf. T. euhypodon (Cope)	Middle or upper Miocene	1, 2
Oreodont	....	Miocene or lower Pliocene	2

Localities recorded in above list—

1. Two miles west of Cold Spring, San Jacinto County.
2. One and one-quarter miles north of Cold Spring, San Jacinto County.
3. Two and one-quarter miles north of Navasota, Grimes County.
4. Red Bluff, Trinity River, San Jacinto County.
5. Shallow well at old Washington, Washington County.
6. Boggs No. 1 oil test, Stratton Ridge salt dome, Brazoria County.
7. Smith Ferry, Neches River, Tyler County.
8. Two miles north of Cold Spring, San Jacinto County.
9. Type locality for Oakville sandstone on Nueces River, near Oakville, Live Oak County.
10. Small creek on Derrick farm, about 3½ miles west of Burton, Washington County.

Correlation.—Matthew (506, p. 237, 1918) concludes that the vertebrate faunas from Navasota and Cold Spring are the same and that they represent an age not earlier than middle Miocene nor younger than lower Pliocene. Absence of all characteristically upper

Miocene or lower Pliocene mammals points to middle Miocene as the probable age of the strata.

Middle Miocene beds with which the Texas section approximately correlates are Pascagoula clay in Mississippi and Alabama, Chipola formation in Florida, Gatun formation of Panama, and San Fernando beds of Mexico.

Economic resources.—The principal resource of the Oakville formation lies in its oil-bearing sands. Up to 1931, sands of Miocene age had produced about 60 per cent of the oil in the Gulf Coast area (about 446,000,000 barrels). It is estimated that about 12 per cent of the oil (about 4,000,000 barrels per year) is obtained from the Miocene sands (**1833d**, p. 41, 1931). The following table shows the depths of the Miocene oil sands in the more important salt dome oil fields (**1833d**, p. 46, 1931):

DOME	COUNTY	DEPTH *Feet*
Allen	Brazoria	5350–5384
Barbers Hill	Chambers	5500
Blue Ridge	Fort Bend	4300
Brenham	Washington	1194–1400
Esperson	Liberty	2276–3330
Fannett	Jefferson	4380+
Goose Creek	Harris	4600±
Hankamer	Liberty	2676
High Island	Galveston	5034–6017
Hull	Liberty	?
Humble	Harris	1100–1500
Nash	Brazoria	3700–4700
North Dayton	Liberty	4100–5134
Mykawa	Harris	4188–9333
Orange	Orange	2600+
Pierce Junction	Harris	3400+
Port Neches	Orange	4144–4412
Saratoga	Hardin	2669–3117
Sour Lake	Hardin	2000–4378
Spindletop	Jefferson	2900–3811
West Columbia	Brazoria	2700–3250
Refugio (gas)	Refugio	3600
McFadden (gas)	Refugio	3750
White Point (gas)	San Patricio	3750

LAGARTO FORMATION[222] (emended)

Definition.—The Lagarto formation was named by Dumble (478, p. 560, 1894) for Lagarto Creek in Live Oak County. He divided the strata between the Oakville sandstone and the Pleistocene deposits into two divisions:

2. Lagarto, the upper division, composed of calcareous clay and a little sand.
1. Lapara, or lower division, was named for Lapara Creek in Live Oak County, and comprises mostly cross-bedded sand and gravel containing fragments of bones thought to be of Pliocene age.

Dumble did not map his new divisions nor describe their contacts. He simply referred lower sands containing Miocene fossils to the Oakville, the sands on Nueces River containing Miocene or Pliocene bones to the Lapara, and the clays below the Reynosa and above the Lapara to the Lagarto. Deussen (421, p. 100, 1924) believed that the Lapara was exposed only on Nueces River and stated that if it extended farther east, it was entirely overlapped by the Lagarto. Later work by Richardson[223] indicated that the Lapara is a more or less continuous layer of sand and gravel, 15 to 20 feet thick, that can be traced across central Texas.

Between the top of the Oakville sand and the base of the Lapara is a prominent clay section from 500 to 1000 feet thick. This clay has been regarded as a part of the original Lagarto clay of Dumble for so long, that the name Lagarto has come into good usage to designate it. Recently it has been shown that the Lapara sand is separated from the clay beneath by a prominent unconformity (fig. 50), and consequently the Lapara has been separated from the Lagarto and placed in a new formation, the Goliad, which is a division essentially equivalent to the Reynosa, as used by Deussen (421) and Trowbridge (1613a). The name Lagarto is hence restricted to the clay underlying the Lapara sand and does not include the Lapara nor the

[222]LITERATURE—Harris, G. D., 659, pp. 115–119, 1893; 661, pp. 83–114, 1895. Dumble, E. T., 478, pp. 559–560, 1894; 494, pp. 973–975, 1903. Udden, J. A., Baker, C. L., and Böse, E., 1652, p. 90, 1916. Bailey, T. L., 38, pp. 66–96, 1923. Deussen, A., 421, pp. 100–102, 1924. Applin, E. R., Ellisor, A. E., and Kniker, H. T., 32, pp. 79–100, 1925. Applin, P. L., 33, pp. 21–23, 1925. Suman, J. A., 1569, pp. 266–276, 1925. Trowbridge, A. C., 1613a, pp. 182–184, 1932.

[223]Richardson, R. T., Memorandum on the Goliad formation: MS. presented at conference of committee on state geologic map, Austin, October 8, 1932.

overlying clay. This is a drastic emendation of the original definition, since Dumble's type locality for the Lagarto is in Lagarto Creek in southern Live Oak County and lies within the Goliad formation above the Lapara sand. The change can be justified only on a basis of usage. The clays above the Oakville have been called Lagarto by so many geologists for so many years, that the introduction of a new name would be awkward and much more confusing than correcting the old definition to conform to present widespread usage.

The type section for the emended Lagarto comprises the exposures along the Brenham-Houston highway just west of Brazos River bridge, Washington County (**1833d**, p. 41, 1931).

Regional geology.—The Lagarto formation outcrops south of the Oakville sandstone in a broad belt that extends from Sabine River to the Rio Grande, except where obscured by terrace deposits or patches of Pleistocene gravel. It has been mapped across Newton, Jasper, Tyler, Polk, San Jacinto, northern Montgomery, Grimes, Washington, Austin, Colorado, Lavaca, De Witt, northern Goliad, Bee, and Live Oak counties to the southeast corner of McMullen County (fig. 50). From McMullen County to the Rio Grande it is covered for the most part by Pleistocene gravel. It has been recognized, however, in the Rio Grande valley west of Samfordyce by Trowbridge (**1613a**, p. 183, 1932).

The average width of its outcrop is 15 miles. The formation dips toward the southeast and passes beneath younger deposits. It is penetrated in oil wells as far south as the coast.

Along its outcrop from northeast to southwest its lithologic character is remarkably uniform, and in subsurface sections it exhibits the same characteristics to within 40 to 50 miles of the present coast. In deep wells drilled near the coast line it is found in a marine facies carrying a marine fauna. It is recognized in wells as dominantly a clay section containing lentils of sand and marine shells, and it occurs just below the thick water-bearing Goliad sands.

The thickness of the Lagarto formation varies. It is thickest in east Texas and thinnest in the Rio Grande valley. It is also thicker in deep wells along the coast than in shallow wells drilled near its outcrop. The thickness in various sections is shown in the following table:

LOCALITY	COUNTY	THICKNESS Feet	AUTHORITY
Tolar and Dannenbaum No. 9, Freeport Sulphur Co., Stratton Ridge	Brazoria	2500	P. L. Applin
Hull oil field	Liberty	2000	Applin, Ellisor, and Kniker
Brazos River section northeast part of county	Colorado	1250	T. L. Bailey
Well section near Eagle Lake	Colorado	1184	T. L. Bailey
Section near west county line	Colorado	1270	T. L. Bailey
Singer No. 4, Humble Oil Co.	Duval	1575	D. C. Barton
Palangana salt dome, wells Nos. 3 and 4, National Oil Co.	Duval	1150	D. C. Barton
Raccoon Bend oil field	Austin	1800	1833d, p. 44, 1931
Well near Deer Park	Harris	2200	1833d, p. 45, 1931
McFadden No. 2, Rycade Oil Co., Spindletop salt dome	Jefferson	2115	D. C. Barton
Saratoga oil field	Hardin	700-1200	J. R. Suman
West No. 2, Humble Oil Co., Blue Ridge oil field	Fort Bend	1132	D. S. Hager and E. Stiles

Stratigraphy.—The Lagarto formation lies conformably upon the Oakville sandstone or strata of equivalent age and is overlapped unconformably by Pliocene and Pleistocene sand and gravel deposits. The base of the Lagarto formation from Brazos River to the Nueces is taken as the contact of yellowish-gray, cross-bedded sand with colloidal, yellow, poorly bedded, calcareous clays containing lentils of calcareous, coarse-grained, pebbly sandstone. The top is drawn at the contact of silty calcareous clays with overlying orange sands or with beds of gravel more or less cemented by calcareous matter. East of the Brazos where the Oakville sands merge into sandy clays the basal contact is difficult to distinguish, and the Oakville and Lagarto are mapped together as the Fleming group of beds. The characteristics of the Lagarto formation in various areas are shown by the following described sections:

Section[224] of upper Lagarto formation on west bluff of Cummins Creek 1 mile northwest of the mouth of Redgate Creek, Colorado County.

	Thickness *Feet*
Terrace gravel—	
6. Gravel, red, coarse, containing many flint pebbles	0–3
Lagarto formation—	
5. Sandstone, whitish gray and yellowish white, greatly cross-bedded and irregularly bedded, containing conglomerate interbedded with layers of dull yellow sand	10–30
4. Marl, ocher-yellow, laminated, containing calcareous concretions	0–5
3. Clay, buff to bright yellow, gray-splotched, containing calcareous concretions up to 3 inches in diameter	20–40
2. Clay, unexposed	20
1. Sandstone, yellowish white, cross-bedded	10–20
Total thickness section measured	118

Section[225] of lower Lagarto formation on west bank of Colorado River, one-half mile below Fayette County line, Colorado County.

	Thickness *Feet*
7. Soil, black sandy loam	0–3
6. Sandstone, yellowish gray, weathering to brownish buff, medium to fine grained, finely laminated, hard, calcareous	10
5. Clay, green above and magenta red below, unstratified, jointed without recognizable lime nodules	6
4. Clay, yellow and pale greenish or bluish gray mottled, jointed, massive, full of calcareous nodules 2 inches or less in diameter and containing thin lenticular beds of argillaceous, yellow sandstone one-quarter to 2 inches thick	15–23
3. Clay, dark gray to black, massive, jointed, soapy	0–2
2. Clay, pale green, bluish and pink variegated, jointed, unstratified, containing a little calcium carbonate but no calcareous nodules	4–8
1. Sandstone, grayish buff, irregular bedded and cross-bedded, medium grained, calcareous	0–15
Total section measured	60

Sedimentology.—The seaiments of the Lagarto formation were deposited by streams on a low coastal plain in the same manner as the Oakville except at a time when the rivers were nearer to base

[224]Measured by T. L. Bailey (38, p. 78, 1923), slightly modified.

[225]Measured by T. L. Bailey, 38, p. 68, 1923.

level and were carrying finer sediments. Perhaps there was more vegetation on the uplands and less torrential rainfall. The rivers gathered their loads largely from the Cretaceous marls and limestones and transported mostly calcareous mud. They spread broadly over the flat coastal plain and built up natural levees over which the waters overflowed periodically, spread broadly, dropped ooze over the land, and built up thick deposits of calcareous clay which merged seaward with delta deposits. During dry periods the wind played a part in sorting the fine material and in adding new material picked up in the areas left without a forest covering. Bailey (38, p. 95, 1923) points out that the beautiful rounding of some of the sand grains in contrast to the subangularity of most of them, and the freshness of many of the feldspar grains indicates work of wind. The Lagarto shore line with its deltas and bays was not far from the present Beaumont-Lissie contact. Oil wells located on the Beaumont plain penetrate brackish water and marine sediments below the base of the Lissie. Thick bodies of very fine sand and sandy silt occur near the base of the Lagarto in the wells drilled near the coast. Many cores obtained from these beds show beautiful examples of delta bedding. Bailey (38, p. 96, 1923) shows that during the Lagarto epoch the deltas were built farther seaward extending the land. The streams were continually changing their courses, working back and forth across the whole plain many times, and thus covering it with a thick mantle of fine river-laid deposits that now constitute the Lagarto formation.

Lithology.—The Lagarto formation is made up of about 75 per cent marl, 15 per cent sand, and 10 per cent silt. The marl is typically yellow, gray, and green colloidal joint clay, weathering to produce a thick black soil, which resembles the soils from the Upper Cretaceous formations more than those of other Tertiary strata. In places the clay is slightly silty and contains numerous small ferruginous and calcareous concretions.[226] In other places the strata contain thin seams of fine silty sand more or less consolidated and small lentils of sand and gravel. For the most part, the clay is massive and laminated, jointed, sticky, tough, breaks with a

[226]Minute concretions from the Lagarto in oil-field sections have been studied by Moore (1126, pp. 77–79, 1914). They are dark gray, range in size from 1.25 to 3 mm. in diameter, have a distinctly oolitic or pisolitic structure, and are made up largely of barite mixed with some calcium and strontium sulphate.

conchoidal fracture, and has a soapy texture. When wet, it forms thick, sticky mud which dries out into small, crumbly chunks. The chemical composition of the Lagarto clay is shown in the following analysis by Ries (1320, p. 211, 1908) of a typical sample from near Brenham, Washington County.

	Per cent
Silica (SiO_2)	51.30
Alumina (AlO_3)	14.40
Ferric oxide (FeO_3)	6.20
Lime (CaO)	10.30
Magnesia (MgO)	Trace
Soda (Na_2O)	4.10
Potash (K_2O)	Trace
Titanic acid (TiO_2)	0.80
Water (H_2O)	4.90
Carbonic acid (CO_2)	7.60
Sulphuric acid (SO_3)	Trace
Total	99.60

The sand in the Lagarto formation is brown, gray, reddish gray or mottled, medium grained to coarse, friable, calcareous, very cross-bedded, and lenticular. It is more or less cemented by calcium carbonate to produce a silty sandstone and in some places contains some siliceous cement. In some places the sand grades into a pebble conglomerate or may contain lentils of conglomerate. In other places the sand contains lumps of buff-colored clay and rolled water-worn fragments of Cretaceous fossils. Occasionally spots are noted in which bone fragments or bits of fossilized wood are mixed with the sand. The bones, although discovered at a number of localities, are comparatively rare.

Bailey (38, p. 90, 1923) found that an average sample of sandstone had the following mineral analysis:

	Per cent
Quartz	37
Feldspar	12
Calcite	27
Chert	12
Clay	5
Shell fragments	5
Rare minerals	2

The rare and uncommon minerals are apatite, barite, biotite, chalcedony, chlorite, diopside, dolomite, epidote, fluorite, garnet, glauconite, gypsum, hematite, hornblende, ilmenite, limonite, magnetite, monazite, muscovite, opal, pyrite, rutile, staurolite, strontianite, titanite, tourmaline, zircon, and zoisite. The feldspar is mostly microcline and orthoclase, and is characteristically pink. Some colorless plagioclase is present. The quartz grains are pink or pale gray and subangular to subround. Most of the grains are between ¼ and 1/16 mm. in diameter. Calcite occurs in irregular crystalline masses forming a part of the cement of the rock, as small round pisolitic grains, and as minute angular granules. The chert is a common mineral. It occurs in various colors and shapes. Some dark-gray to black grains, probably came from the Paleozoic sediments, and beautiful translucent grains of chalcedony were undoubtedly derived from the Catahoula sandstone.

The size analysis[227] of the average of a number of samples of Lagarto sandstone is as follows:

DIAMETER OF GRAINS *mm.*	*Per cent*
Larger than 1	9
1–½	24
½–¼	24
¼–⅛	23
⅛–1/16	16
Less than 1/16	4

The chemical composition[228] of a sample of Lagarto sandstone is as follows:

	Per cent
Silica	51.40
Alumina	5.18
Ferric oxide	0.77
Calcium carbonate	24.57
Magnesia	0.00
Sodium oxide	1.29
Potassium oxide	0.92
Water	15.43
Total	99.56

[227]Determined by T. L. Bailey, 38, p. 89, 1923.

[228]Analysis by J. E. Stulken, Bureau of Industrial Chemistry, University of Texas (38, p. 92, 1923).

Distinguishing characteristics.—The Lagarto formation can be distinguished by the following criteria:

1. Calcium carbonate content. The Lagarto has a high percentage of calcareous matter which gives the clay its compact, colloidal, sticky, "gumbo"-like character and makes it resemble more nearly the Taylor marl than most Tertiary formations. The marl has a characteristic yellowish-gray color and weathers to form thick, black soils like those of the Navarro or Taylor.
2. Concretions. The Lagarto has numerous small, hollow, botryoidal, gray, calcareous concretions from the size of a pinhead to the size of an egg.
3. Redeposited Cretaceous fossils. The Lagarto, like the Oakville, contains in many places traces of Cretaceous fossils, especially foraminifera.
4. Thin, cross-bedded, brown sandstone. Thin beds of intricately cross-bedded, fine grained, very calcareous sandstone are interbedded with the marl in many of the exposures. Many of the sandstone layers are not over ½ to 1 mm. thick, others are thicker. Some are very lenticular in shape.

The Lagarto is very similar in character to the Oakville. It is distinguished by its greater proportion of clay. The clay beds are thicker and more massive; the sand beds are thinner and less massive than those of the Oakville. The Lagarto and Oakville are distinguished from the Fayette and Catahoula by the greater proportion of calcareous matter and smaller proportion of volcanic ash. They have much more limestone, less gravel, and finer sediments than the Lissie. They have many more rolled Cretaceous fossils than any other formation. They can be distinguished further by their vertebrate fossils, if teeth or determinable bones can be located.

Paleontology.—The Lagarto formation contains three types of fossil remains:

1. Bones of land vertebrates and rarely shells of land invertebrates in the clays and sands along the outcrop.
2. Redeposited and water-worn invertebrate shells derived mainly from the Cretaceous marls and redeposited in the Lagarto. These are found in both the surface and subsurface deposits.
3. Marine and brackish-water invertebrate shells found in cores and cuttings from oil wells drilled through the Lagarto along the Gulf Coast.

The following vertebrate fossils have been reported in the Lagarto:

SPECIES	AGE	LOCALITY
Protohippus perditus Leidy	------------	1
Protohippus sp.	------------	2
Protohippus? (upper molar)	Late Miocene or early Pliocene	3
Protohippus? (fragment of lower molar)	------------	4
Merycodus (fragment of femur)	------------	4
Hipparion cf. H. lenticulare (Cope)	Late Miocene or early Pliocene	4
Teleoceras? (tibia)	Late Miocene or early Pliocene	3

Localities recorded in above list—

1. Dripping Springs, 1½ miles northeast of Borden, Colorado County.
2. One-quarter mile west of Borden, Colorado County.
3. One-half mile east of Burkville, Newton County.
4. From 400 to 600 feet in Jordit No. 262, Rio Bravo Oil Company, Saratoga oil field, Hardin County.

The following shells of brackish-water forms have been collected from the Lagarto in an excavation one mile southeast of Burkville in Newton County. The identifications were made by Dall (415, p. 73, 1914), who believes the fauna indicates the strata to be of Pliocene age.

Ostrea virginica Gmelin
Anomia sp.
Potamides matsoni Dall
Potamides matsoni var. gracilior Dall
Cerithiopsis burkevillensis Dall
Pachycheilus anagrammatus Dall
Pachycheilus satillensis Aldrich
Pachycheilus sauvis Dall
Paludestrina curva Dall
Neritina sparsilineata Dall

The following marine fossils have been collected from well cores obtained from Lagarto strata along the Gulf Coast:

Stratton Ridge, Brazoria County. Species identified by Mrs. E. R. Applin (32, p. 21, 1925)—

Rotalia beccarii (Linné), var.
Polystomella galvestonensis n. sp. (MS.)
Polystomella striato-punctata (Fichtel and Moll)
Polystomella craticulata (Fichtel and Moll), var.
Rangia cuneata Gray
Ostracods

Saratoga oil field, Hardin County, well No. 346 B. B. B. & C., Rio Bravo Oil Co., from 922 to 1159 feet. Species identified by Dorothy K. Palmer (1569, pp. 272–273, 1925), who believes they point to correlation with the Oak Grove Miocene of Florida—

Divaricella? chipolana Dall
Corbula cf. C. swiftiana C. B. Adams
Corbula radiatula Dall
Arca sp.
Cancellaria sp.
Nassa? sp.
Terebra sp.
Terebra cf. T. dislocata Say
Natica cf. N. canrena (Linné)
Turritella subgrundifera Dall
Chione cf. C. glyptocyma Dall
Strigillia sp.
Chama sp.
Phacoides cf. P. sphaeriolus Dall
Phacoides (Parvilucina) crenulatus (Conrad)
Astarte sp.
Cardium sp.
Donax sp.
Cerithium? sp.
Solarium sp.

The following redeposited Cretaceous fossils have been reported from the Lagarto:

Orbitulina walnutensis Carsey (from Walnut formation)
Exogyra arietina Roemer (from Del Rio formation)
Gryphaea sp.
Globigerina spp.
Anomalina sp.
Nodosaria sp.
Cristellaria sp.
Pulvinulina sp.
Guembelina spp.

The fossils, so far as they have been studied, do not offer conclusive evidence of the age of this formation. According to Matthew, the vertebrates can be regarded as either Miocene or lower Pliocene. The invertebrates are not very diagnostic but suggest lower Pliocene. The Lagarto formation is therefore placed tentatively in the lower Pliocene and is correlated with the lower beds of the Panhandle formation in northwest Texas and with the upper part of the Pascagoula formation of Alabama and Mississippi.

Economic resources.—The economic resources of the Lagarto formation are: (1) rich alluvial soils that furnish some of the best farming and grazing land in the Gulf Coast area; (2) colloidal clays suitable for brick but as yet undeveloped extensively; and (3) oil-bearing sands that produce from shallow horizons in nearly all the Gulf Coast oil fields.

Pliocene System

CITRONELLE GROUP

DEFINITION

The name Citronelle is proposed as a group name to include the beds of Pliocene age between the Lagarto clay below and the Lissie sand above. Citronelle has been used by Matson (**1061**, p. 168, 1916) as a formational name for sands thought to be of Pliocene age in Alabama, Mississippi, and Louisiana. These sands extend into east Texas and are essentially equivalent to the upper Pliocene sands in this state, and therefore the name is appropriate and has been applied by a number of geologists in east Texas. The need for Citronelle as a group name arises from the recent differentiation and mapping in Texas of the new Pliocene unit, the Goliad formation, which outcrops in southwest Texas between the Lagarto clay and the Lissie sand as far northeastward as Colorado River. East of Colorado River the Goliad formation is obscured by sands thought to be Pliocene in age and as yet unnamed. The upper Pliocene in Texas is thus represented by two sets of beds, one prominent in east Texas and another somewhat older and equally well developed in southwest Texas. In forested areas where both units are present it is difficult to distinguish the two. In the eastern area the Goliad, if present, is covered, and all the upper Pliocene sands are mapped under the name Citronelle.

The Citronelle group of strata rests unconformably upon the Lagarto formation and is overlain by the Lissie sand. It covers the belt of rolling and maturely dissected more or less tree-covered country between the Lagarto black-land prairies and the flat and nearly featureless Lissie plain. Its base is marked by a bed of gravel or coarse sand, and its upper contact by a discordance in dip and a slight change in texture to the overlying Lissie. The Citronelle exhibits undulating, rolling topography; the Lissie is a flat featureless plain.

SUBDIVISIONS

The Citronelle group consists of two divisions:

2. Unnamed Pliocene? sand.
1. Goliad sand formation.

GOLIAD FORMATION

Definition.—The Goliad formation was named by I. K. Howeth and P. F. Martin.[229] These geologists, while engaged in mapping the coastal counties of south Texas, discovered that the persistent beds of sandstone outcropping along San Antonio River at Goliad

[229]Howeth, I. K., and Martyn, P. F., The Goliad sandstone formation of southwest Texas: MS. presented at annual meeting of San Antonio Geological Society, Corpus Christi, Feb. 27, 1932.

comprised a mappable unit that could be separated easily from the Lissie. They mapped the outcrops and named the division the Goliad formation, which comprises the strata from the top of the Lagarto clay, as now emended, up to the base of the typical Lissie. This definition includes most of the strata that had been placed in the Reynosa by Deussen (**421**, pp. 102–105, 1924) and Trowbridge (**1613a**, pp. 184–203, 1932). The old name Reynosa is regarded as invalid for this series of strata, because the gravels at the type locality for the Reynosa at Reynosa, Mexico, are terrace gravels and are the same age or younger than Lissie. The Goliad strata are below and older than the Lissie. Deussen writes:

> I have had the opinion for a long time and still believe, in view of recent studies, that the caliche at the town of Reynosa is a stream-terrace deposit, which is Lissie in age and should be correlated with the Lissie rather than with what Dumble later described as the Reynosa. For this reason it raises a serious question as to whether or not the name Reynosa ought not to be abandoned and the two units Goliad sandstone and these Starr County conglomerates redefined. (Letter to E. H. Sellards, July 12, 1932.)

The name Goliad accordingly has been accepted by the San Antonio Geological Society, by the Houston Geological Society, and by the Bureau of Economic Geology. The San Antonio committee[230] on geologic mapping, however, decided to include the Lapara sand in the new Goliad formation and to draw the line at the base of the Lapara gravel beds. Richardson[231] has pointed out that the unconformity at the base of the Lapara gravel beds is the most prominent break, the most easily distinguishable horizon, and therefore the most natural division point in the upper Cenozoic section. Some geologists, including Howeth and Martyn, regarded this as too drastic a revision, because if the base of the Lapara gravel is made the plane of division between the Goliad and the underlying formations, the Goliad formation will include the type locality for the Lagarto formation. The new classification, however, because of its obvious practical advantages, was finally accepted by the Bureau of Economic Geology and by the Houston Geological Society.

[230]Ed. W. Owen, Charles H. Row, Herschel H. Cooper, Fred Shayes, W. A. Maley, and T. J. Galbraith.

[231]Richardson, R. T., Memorandum on the Goliad formation: MS. presented at the conference of committees on the state geologic map, Austin, Oct. 8, 1932.

The Goliad is now made to include all the strata in the San Antonio River section from the base of the Lapara gravel and sand beds up to the base of the Lissie sands of the flat, featureless coastal plain. The base of this division lies about 250 feet above the top of the Oakville. The graphic section and map, figure 50, show the divisions. The type locality for the Goliad formation comprises the exposures along San Antonio River at Goliad in Goliad County. Another excellent and more complete section is exposed at Mt. Lucas about three miles south of Mikeska, Live Oak County.

Regional geology.—The outcrop of the Goliad formation covers a belt about fifteen miles wide bordering the Lissie formation on the north, as shown by figure 50. It has been mapped from the southwest corner of Lavaca County through De Witt, Goliad, Bee, and Live Oak counties to Duval County. Northeast of the southwest part of Lavaca County it is covered for the most part by a surface sand that is difficult to distinguish from the Lissie. This sand is thought to be older, however, than the Lissie, since it is much more deeply dissected. South of Duval County the Goliad formation is obscured by Recent wind-blown sand and can not be mapped in detail. It has been recognized,[232] however, as far south as Mission in Hidalgo County. It is thought that it outcrops also in the Colorado River bluffs in southern Colorado County where recent erosion by Colorado River has removed the overlying sand.

The average thickness of the Goliad formation is estimated to be about 250 feet. Its exact thickness in well sections is not definitely known because it is so difficult to separate it from the overlying Lissie that its upper contact can not be determined in most well sections. It is known to be thicker in east Texas than in southwest Texas and thicker in well sections located near the coast than at the outcrop.

Stratigraphy.—The Goliad formation in central Texas can be divided into three members, as follows:

3. *Labahia beds.* The beds of this unit are typically exposed along San Antonio River near La Bahia Mission south of Goliad. Howeth and Martyn[233] have divided these beds into three subdivisions, as follows:

[232]Howeth, I. K., and Martyn, P. F., *op. cit.*

[233]Howeth, I. K., and Martyn, P. F., The Goliad sandstone formation of south Texas: MS. presented at the annual meeting of the San Antonio Geological Society, Corpus Christi, Feb. 27, 1932.

c. Upper sandstone bed. This unit consists of grayish-white, medium- to fine-grained sandstone, which is cross-bedded in some places and massive in others. This sandstone weathers to form rough-surfaced bluish-black ledges.

b. Middle marl member. This is a greenish-gray, pink, or reddish calcareous clay containing white calcareous nodules.

a. Lower sandstone bed. This sandstone is grayish-white, medium to coarse grained, in places grading into calcareous, cross-bedded, conglomerate lentils that change laterally into massive and poorly bedded layers. The cobbles that make up the conglomerate are coarse, hard, and consist mostly of chert and quartz pebbles. The sand contains numerous grains of red and brown jasper and also in many places balls of green clay derived from the Lagarto.

2. *Lagarto Creek beds.* These clays were named Lagarto by Dumble (478, p. 560, 1894; 494, pp. 60–63, 1903) for Lagarto Creek in Live Oak County. He included in his Lagarto all the strata between the Oakville and Lissie formations. These Lagarto Creek beds include only that part of the section between the Lapara sand and the Labahia, or upper Goliad, sand. According to Richardson[234] the outcrop in Lagarto Creek is a clay zone consisting of pinkish-brown and reddish mottled limy clay resembling the clays below the Lapara, but in most places having more pastel shades and a higher calcium carbonate content. The thickness of this unit is about 50 feet.

1. *Lapara sand.* This division was named by Dumble (478, pp. 559–560, 1894; 494, pp. 44–60, 1903) for Lapara Creek in Live Oak County. The member is typically exposed on Nueces River southeast of Mikeska, on Manahuilla Creek four to five miles northeast of Goliad, and on Guadalupe River southeast of Cuero. According to Richardson[235] it can be traced and mapped from Nueces River to Guadalupe River, as shown on the map, figure 50. The member consists of conglomerate, cross-bedded sand, and limy clay. The conglomerate is composed of cobbles that range up to six inches in diameter, clay balls, sand, and much reworked material, such as bone fragments and bits of fossilized wood. It lies unconformably under the Lagarto Creek beds. The sand is coarse, friable, and con-

[234]Richardson, H. T., Memorandum on the Goliad formation: MS. presented at the Austin meeting of committees on geologic mapping, Oct. 8, 1932.

[235]Richardson, H. T., *op. cit.*

tains clay pebbles, calcareous concretions, and lentils of red and green clay. The clay is irregularly bedded and contains pebbles and nodules similar to those in the conglomerate. The type locality comprises the exposures along Lapara Creek in Live Oak County.

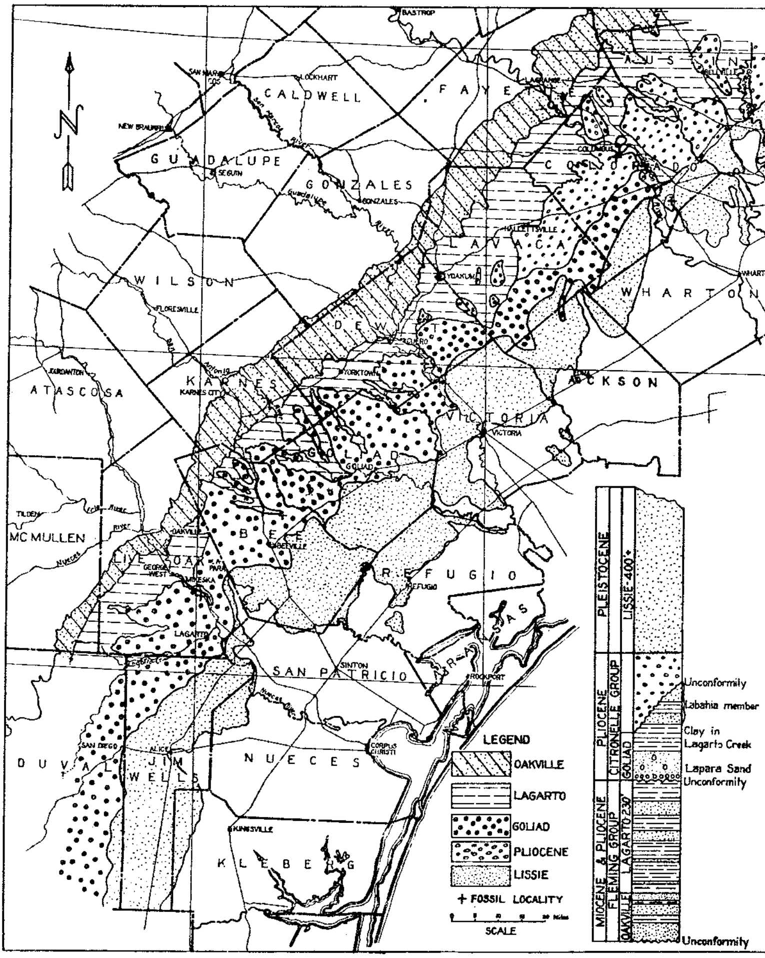

Fig. 50. Outcrops of the Oakville, Lagarto, Goliad, and Lissie formations in southwest Texas. (Map furnished by Ed. W. Owen, C. R. Row, Herschel Cooper, Fred Shayes, W. A. Maley, and T. J. Galbraith, Committee on Geologic Mapping, San Antonio Geological Society.) The Goliad outcrop northeast of San Marcos River is modified from maps furnished by L. W. Stephenson.

The following table gives the thicknesses of typical sections:

LOCALITY	COUNTY	UPPER MEMBER	MIDDLE MEMBER	LOWER MEMBER	THICKNESS TOTAL
San Antonio River, 1 mi. S. of Goliad[a]	Goliad	10	40	25	75
Lagarto Creek, ½ mi. NE. of Lagarto[a]	Live Oak	5–10	20–30	10–30	35–70
Near Meyersville[a]	De Witt	0–5	0–40	10–60	105
Mt. Lucas, 3 mi. S. of Mikeska	Live Oak	-------	-------	-------	200±
Bunte, Kennan No. 1	Victoria	-------	-------	-------	390

[a]Howeth, I. K., and Martyn, P. F., *op. cit.*

The Goliad gravel deposits in south Texas have been described by Dumble (478, pp. 560–563, 1894; **494**, pp. 976–983, 1903), Udden, Baker, and Böse (**1652**, p. 93, 1916), Trowbridge (**1610**, pp. 98–100, 1923; **1613a**, pp. 102–108, 1924), and Deussen (**421**, pp. 102–108, 1924) under the name Reynosa. The outcrop of the Reynosa at its type locality opposite Hidalgo, Texas, is typical terrace gravel cemented into a white limestone deposit known commonly as caliche,[236] a surface deposit formed in semi-arid climates by the evaporation of surface waters carrying calcium bicarbonate in solution, leaving calcium carbonate precipitated in the interstices of the sand and gravel. This caliche deposit, which in some areas is composed of over 30 per cent calcium carbonate, mantles broad areas of the country along the outcrop of both the Goliad and Lissie formations and gives to these formations an aspect quite different from that of the loose sands exposed in northeastern portions of the state.

The local characteristics of the Goliad formation are shown in the following typical sections:

[236]Literature on caliche—Blake, W. P., Eng. Min. Jour., vol. 72, pp. 601–602, 1901; Min. Sci. Press, vol. 82, p. 294, 1901; The caliche of southern Arizona; an example of deposition by the vadose circulation: Am. Inst. Min. Met. Eng. Trans., vol. 31, pp. 220–226, 1902. Udden, J. A., The rim rock of the High Plains: Am. Assoc. Pet. Geol. Bull., vol. 7, pp. 72–74, 1923. Wanless, H. R., The stratigraphy of the White River beds of South Dakota: Am. Phil. Soc. Proc., vol. 62, pp. 190–269, 1923. Price, W A., Caliche and pseudoanticlines: Am. Assoc. Pet. Geol. Bull., vol. 9, pp. 1009–1017, 1925. Lonsdale, J. T., The occurrence of caliche in Oklahoma: Okla. Acad. Sci. Proc., vol. 5, pp. 132–136, 1926. Twenhofel, W. H., Surface and subsurface efflorescence of salts: Treatise on Sedimentation, pp. 479–486, 1932.

Section[237] *of Goliad formation along south bank of San Antonio River near La Bahia Mission, Goliad, Goliad County.*

	Thickness *Feet*
9. Sandstone, gray, medium coarse grained	10
8. Marl or clay, gray, calcareous	8
7. Clay? not exposed	8–10
6. Sandstone, gray, fine grained, in part calcareous but grading to noncalcareous layers	8
5. Sandstone, gray, medium coarse grained, indurated, stands up to form a vertical cliff	10
4. Clay or marl, grayish yellow, chalky	1
3. Sandstone, gray, medium coarse grained	½
2. Clay, gray, chalky	½
1. Sandstone, gray, medium coarse grained, fairly well indurated, in places cross-bedded, and containing small dark-colored sand grains and small pink grains (Base of Goliad)	2
Total thickness measured	50±

Section[238] *of the Goliad formation along bank of San Antonio River near railroad bridge at Goliad, Goliad County.*

	Thickness *Feet*
8. Sandstone, gray and yellow, medium coarse, uniformly grained, well indurated sand containing numerous small dark sand grains and also numbers of pink grains	7
7. Sandstone, gray, medium coarse, well indurated, unevenly grained, containing pebbles up to one-half inch in diameter, and balls of gray and yellow clay mixed with the sand grains	11
6. Clay? unexposed	11
5. Sand, chalky gray, fine grained, containing considerable calcareous matter	5
4. Clay? unexposed	6
3. Sandstone, gray, medium coarse, fairly well indurated, containing minute pink grains	1–2
2. Sand, pink, chalky, argillaceous	2
1. Clay, pink, containing calcareous nodules	8
Total thickness strata exposed	42

Sedimentology.—The sediments of the Goliad formation record the beginning of the climatic conditions which prevailed during the glacial period. In the south increased rainfall swelled streams to

[237]Measured by Willis Clark, Amerada Petroleum Corporation, Sept., 1930.
[238]Measured by Willis Clark, Amerada Petroleum Corporation, Sept., 1930.

torrents, increased greatly the size of rivers, and spread floods of water over lowlands. The swollen streams spread a mantle of gravel and sand over the coastal plain from Alabama to Mexico.

Two opinions regarding the climate of the Goliad epoch are held. Some geologists believe that increased rainfall began in the late Pliocene over the northern hemisphere. The increase in precipitation in the form of rain in the south and of snow in the far north brought on the early Pleistocene glaciation. Other geologists believe that increased low temperature of the early Pleistocene was the chief cause of the glaciation in the north and of increased rainfall in the south. The presence of the early ice cap they believe further depressed the temperature, which caused greatly increased precipitation in the south due to the more sudden cooling of the moisture-laden winds from the gulf area. These geologists believe that the Goliad and associated sands are really contemporaneous with the formation of the glacial cap in the north and that the Goliad sand deposits are contemporaneous with early glaciation and should be placed in the lower Pleistocene. They point out that the evidence in the remains of Pliocene animals is not conclusive, since similar animals may have existed longer in the south and have lived on into glacial time long after they were exterminated by the cold climates of northern areas. The problem is an interesting and important one for paleontologists and glacialogists and has not received the attention it deserves. The fossil evidence is discussed in later paragraphs.

Caliche occurs in the Goliad and is encountered in some places in shallow wells, and it is thought to have formed, in part at least, during Goliad times. Since caliche is produced today only at the surface and in areas in which evaporation is in excess of rainfall, its presence indicates epochs of semi-aridity during Goliad times. The observations contradict the idea of heavy rainfall and serve to indicate the complexity of the problem of the Goliad sediments and Goliad climates. The observations are not, however, incompatible with early Pleistocene history in the northern provinces, where deeply leached layers, old soils, and even forest layers are interbedded in places with the earlier glacial tills.

The sediments for the most part, however, are more similar to Pliocene strata of the Panhandle and elsewhere than to Pleistocene deposits. The basal strata of the Goliad, for example, are coarse grained, contain rounded cobbles, much gravel, clay balls, fragments of wood, and have the irregular bedding of river-bottom deposits. The upper strata are finer grained, contain less gravel, and indicate that the streams of this later epoch had less transporting power. The ancient flood plains were aggraded toward the end of the epoch, river water was spread more broadly over the alluvial flats, and currents were less swift.

Lithology.—The strata of the Goliad formation consist of about 80 per cent sand, 5 per cent gravel, 10 per cent clay, and 5 per cent calcium carbonate. In south Texas the sand and gravel are impregnated with much caliche. In places this amounts to as much as 20 to 35 per cent of the volume of the sample. The sand is whitish gray or pinkish gray. In places it contains so many black chert grains that it has a pepper-and-salt appearance. In other places it contains many pink grains. It is sufficiently well cemented by calcium carbonate to form conspicuous ledges and enable it to be used locally for building stone. The indurated beds are lenticular and erratic in extent and average 10 to 15 feet in thickness. The grains vary in shape from subround to subangular and in size from medium fine to quite coarse. A size analysis[239] of a typical sample is given below.

SCREEN NO.	MESH SIZE	MINERAL GRAINS
	mm.	*Per cent*
Larger than 20	.84	.3
30	.59	.9
40	.42	1.60
50	.297	6.80
60	.250	12.40
80	.175	39.80
100	.102	20.00
200	.074	14.90

The grains of this sample are made up of the following minerals:

Clay, grayish white
Chert, gray, pink, red, black
Quartz, white, transparent, and translucent varieties
Feldspar, pink and white

The gravel deposits in the Goliad vary in color from white to red. The prevailing color is a pinkish gray mottled with spots of red. The pebbles vary from the size of a pea to the size of a hen's egg. They occur in streaks and lentils everywhere mixed with some clay and contain nodules of green and pink clay. In the southern area

[239]Sargent, E. C., Jan., 1933.

the pebbles are cemented by white caliche, and the indurated rock is nearly white except where the color is modified by numerous dark-colored chert pebbles. The sand grains mixed with the gravel are more or less rounded or subround in shape, composed of translucent and transparent white quartz, and set in a matrix of amorphous white caliche. The pebbles are largely chert with some quartz and a few fragments of a pink calcareous rock, probably redeposited caliche. Bailey (38, Table 4, 25th sample in list, 1923) gives the following mineral composition for a sample of Goliad conglomerate from Colorado County.

	Per cent
Clay (caliche in part)	50
Quartz	25
Feldspar	14
Pegmatite	5
Chert	5
Limonite	1
Cassiterite, epidote, hematite, ilmenite, magnetite, muscovite, titanite, tourmaline, and zircon	Traces

The mineral associations indicate that some of the sediments of Colorado River valley were derived from crystalline rocks of Llano Mountains and prove that the Cretaceous strata had been removed from that area before the Goliad epoch.

The clay is greenish gray, in places mottled with red and brown streaks and blotches. It is highly calcareous and resembles in most respects the clays of the Lagarto formation. In south Texas calcium carbonate occurs in many layers in the form of concretions, nodules, and stringers, which in some places coalesce to form hard nodular limestone.

Distinguishing characteristics.—The Goliad formation is one of the most difficult of the coastal formations to define definitely. Its upper layers resemble closely, and grade up into, Lissie sands in central Texas and into other sands probably of Pliocene age in the area east of Colorado River. Its basal layers are difficult to distinguish from the sand and gravel lentils in the Lagarto clay. The lentils in the Lagarto, however, are browner and in most places more evenly textured. Although no features can be regarded as exclusively characteristic of the Goliad, the following criteria are useful in identifying the formation:

1. Topography. The Goliad formation has been eroded into ridges, valleys, and cuestas, whereas the Lissie in much of the Coastal Plain area is flatter or only gently undulating and has a more featureless topography.
2. Cementation. In southwest Texas the Goliad is in general more indurated than the Lissie and stands up as resistent ridges. In some places it is hard enough to be used for building purposes.
3. Chert content. The Goliad formation contains a larger percentage of chert and feldspar than the Lagarto. Much of the chert is black, so that in places the sand is speckled. The black grains are not so noticeable in the Lissie.
4. Texture. The Lissie sands in most places are somewhat finer textured and contain less conglomerate than the Goliad, and the average size of the conglomerate pebbles in the Lissie is somewhat smaller than the average size of those in the Goliad. The Goliad contains more balls and nodules of clay than the Lissie.
5. Structure. The dip of the Goliad is steeper than that of the overlying Lissie.

Paleontology and correlation.—Fragmentary vertebrate remains and invertebrate shells have been found in the Goliad formation. The vertebrate fossils include bird bones, horse teeth, a rhinoceras, and a camel. Many of these remains are water worn and indicate that the fossils may have been redeposited from the Oakville or the Lagarto formation, so the presence of a Miocene or Pliocene tooth is not necessarily significant of the age of the beds in which it is found. Teeth that are associated with bones in place in the sand are thought to be diagnostic. The jaw of a large rhinoceras and teeth of a small horse have been collected by Alexander Deussen and identified by Gilmore[240] as *Teleoceras cf. T. fossiger* (Cope) and *Hipparion ingenum* (Leidy). All the specimens have come from the lower conglomerate member of the Goliad on Medio Creek about seven and one-half miles north ten degrees east of Beeville, Bee County. These forms are regarded as Pliocene in age.

Invertebrate fossils are rare in the Goliad. The best collection was obtained from the banks of Guadalupe River in south-central De Witt County by I. K. Howeth and were identified by W. B. Marshall (**1056**, pp. 1–6, 1929). All are extinct today. The list is as follows:

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[240]Personal communication from Alexander Deussen to E. H. Sellards, July, 1932.

Pliconaias popenoei Marshall
Eonaias reynosenica Marshall
Antediplodon dewittensis Marshall
Polygyra myersi Marshall

UPPER SANDS OF THE CITRONELLE GROUP

Sands of undetermined age outcrop along a sandy and gravelly ridge covered by a post oak forest between the Lagarto and the Lissie formations east of Colorado River in east Texas. These sands occur along the eastward extension of the belt of the terrain occupied by the Goliad sand south of San Antonio River but appear to be younger in age and to cover or overlap on the Goliad in De Witt and Colorado counties. These beds have been described as Lafayette gravel by Dumble (**506**, p. 246, 1918), as part of the Dewitt and the lower part of the Lissie formations by Deussen (**415**, pp. 74–80, 1914), as Lafayette-Reynosa by Kennedy[241] in 1915, as lower Lissie or post oak belt by Bailey (**38**, pp. 18–20, 1923), and as undifferentiated Lissie and Reynosa formations by the United States Geological Survey (**396c**, 1932). These sands overlie the typical Goliad in Colorado County; east of Brazos River they cover completely the Goliad formation, if it is present in the section, and rest unconformably upon the eroded surface of the Lagarto. The supposed relationships of the sand are indicated in the section, figure 50.

These unnamed sands are all of nonmarine origin and are regarded by some geologists as the eastward extension of the Goliad sand and to be the same age as the Goliad, though of different lithologic character and derived probably from a different source. Other geologists regard them as Pleistocene and as representing upstream deposits laid down during Lissie times, while the Lissie was being deposited upon the flat coastal plain. Others believe that they are upper Pliocene deposits somewhat younger than the Goliad but older than, and dipping under, the Lissie.

These upper Citronelle? sands are coarser in texture, lighter in color, and more forested than the Lissie. They are less consolidated, more irregularly distributed, and contain less calcareous matter than the Goliad. So far as known, they carry no vertebrate fossils. The surface outcrop is discontinuous. The sands occur on divides as

[241]Kennedy, William, Report on that portion of southern Texas lying between the Brazos and Colorado rivers: unpublished manuscript, 1915.

patches or outliers on the Lagarto clay. In some places they take on the aspect of ancient upland terrace sands and gravels. In other places they constitute a belt about fifteen miles wide of sandy and gravelly ridges so thickly wooded with post oak and underbrush, that the outcrop is prominent in airplane photographs. Typical outcrops of these strata are described in the following sections:

Section[242] of upper Pliocene? strata on Cummins Creek near the bridge about 6 miles east of Fayetteville, near the Colorado-Fayette county line.

	Thickness *Feet*
Sand, gray	4–6
Gravel in irregular pockets from 1 to 4 feet thick	3–6
Clay, brown	2
Clay, dark grayish brown weathering to snuff-colored	2–10
Total section measured	24

Section[243] of upper Pliocene? strata in the western part of Austin County.

	Thickness *Feet*
Sand, brown or red, with 2- to 6-inch bands of white calcareous matter	10
"Lime," white	10
Clay, yellow, calcareous, with bands of gray calcareous sandstone from 6 inches to 1 foot thick	?
Total section exposed	21

Section west of Altair, Colorado County.

	Thickness *Feet*
Gravel	1–2
Sandstone, white, calcareous, stratified, in hard and soft layers containing nodules of calcareous clay or calcite, also small light yellowish-gray flint pebbles from 1 to 4 inches in diameter Toward the bottom the beds are more regular, but in places are thin layers of light red, coarse sand interbedded with the gray and white limestones	30–50
Clay, sandy, with lentils of sand containing gravel composed largely of flint pebbles	3
Total section exposed	55

[242]Kennedy, William, Report on that portion of southern Texas lying between the Brazos and Colorado rivers: unpublished manuscript, 1915.

[243]Kennedy, William, *op. cit.*

The total thickness of these upper Pliocene? strata is estimated to range from 0 to 350 feet.

No age determinations or exact correlation of these strata have been made. They are probably somewhat older than the Lissie and tentatively placed in the upper Pliocene as a part of the Citronelle group.

The gravel deposits at the base of these beds are the chief source of gravel for road building and concrete construction in the Gulf Coast area. A large number of gravel pits are located along the outcrop of this unit.

PLIOCENE STRATA OF WEST TEXAS[244]

HISTORY OF GEOLOGIC INVESTIGATIONS

Pliocene strata occur as a continuous deposit over the Llano Estacado or Staked Plains province of northwest Texas, as outliers in intermontane valleys in the Davis and other Trans-Pecos mountains, and as isolated patches of gravel and sand on the stream divides in many spots in north-central and northwest Texas. The west Texas Cenozoic strata were first studied by Shumard (**1476a**, pp. 179–195, 1853). In 1855 Jules Marcou crossed the High Plains, collected fossils, and published a description of his observations (**1037**, pp. 125–128, 1855; **1038**, pp. 808–813, 1855; **1039**, pp. 121–164, 1865). Cummins (**342**, pp. 431–435, 1891; **343**, pp. 128–223, 1892; **346**, pp. 177–238, 1893), geologist for the Geological Survey of Texas, made an investigation in northwest Texas and published

[244]LITERATURE—Cummins, W. F., **342**, pp. 431–435, 1891; **343**, pp. 127–223, 1892; **346**, pp. 177–238, 1893. Cope, E. D., **306**, pp. 251–258, 1892; **308**, pp. 49–50, 1892; **310**, pp. 131–132, 1892; **316**, pp. 63–68, 1894. Hay, Robert, Water resources of a portion of the Great Plains: U. S. Geol. Survey, 16th Ann. Rpt., pt. 2, pp. 569–573, 1895. Johnson, W. D., **881**, pp. 604–741, 1901. Hatcher, J. B., **672a**, pp. 113–131, 1902. Gidley, J. W., **582**, pp. 617–635, 1903. Darton, N. H., Preliminary report on the geology and underground water resources of the central Great Plains: U. S. Geol. Survey Prof. Paper 32, pp. 169–179, 1905. Fisher, C. A., Preliminary report on the geology and underground waters of the Roswell artesian area, New Mexico: U. S. Geol. Survey, Water-Supply Paper 158, pp. 8–9, 1906. Gould, C. N., **614b**, pp. 1–64, 1906; **615**, pp. 1–70, 1907. Osborn, H. F., **1165b**, pp. 360–366, 458, 1910. Carter, Wm. T., Reconnaissance soil survey of the Panhandle region of Texas: U. S. Dept. Agric., Bur. Soils Field Operations for 1910. Baker, C. L., **42**, pp. 1–225, 1915. Patton, L. T., **1180**, pp. 1–180, 1923. Udden, J. A., **1661**, pp. 72–74, 1923. Matthew, W. D., **1070**, pp. 221–222, 1924; Observations on the Tertiary of the Staked Plains: MS. submitted to Amer. Mus. Nat. Hist., 1924; **1074a**, pp. 411–480, 1932; and Stirton, R. A., **1073**, pp. 349–396, 1930. Hoots, H. W., **841**, pp. 38–126, 1925. Gould, C. N., and Lonsdale, J. T., Geology of Texas County, Oklahoma: Oklahoma Geol. Survey Bull. 37, 1926. Reed, L. C., and Longnecker, O. M., Jr., **1288a**, pp. 1–98, 1932. Baker, C. L., Conjectures on the Cenozoic history of the Texas Plains: MS. submitted to Bur. Econ. Geol., Aug., 1932. Stirton, R. A., **1546b**, pp. 147–168, 1932.

the first connected account of the geology of the area. His publications drew the attention of paleontologists to the region, and Cope (**305**, p. 177, 1892; **308**, pp. 49–50, 1892) and Gidley (**582**, pp. 617–635, 1903) made extensive collections of vertebrate fossils and recorded observations on the stratigraphic sequence. Gidley gave names to three divisions of the section, and C. N. Gould (**614b**, pp. 1–64, 1906; **615**, pp. 1–70, 1907) published comprehensive reports on the geology and the water supplies of the Panhandle of Oklahoma and Texas. Lull (**1028**, p. 117, 1913; **1026**, pp. 327–385, 1915) led an expedition for Yale University into the Panhandle area, made collections of vertebrate fossils, and both he and his assistant, Troxell (**1614**, pp. 613–638, 1915) published descriptions of some of them. Baker (**42**, pp. 1–225, 1915) studied and described the geology and underground waters of the Llano Estacado and contributed much to the knowledge of west Texas. Eight years later Patton (**1180**, pp. 1–180, 1923) described the geology of Potter County, and Udden (**1661**, pp. 72–74, 1923) published additional descriptions of the rim rock of the High Plains. Matthew,[245] just before his untimely death, prepared a manuscript setting forth his observations of the Tertiary geology of the northern Staked Plains in Texas. Hoots (**841**, pp. 33–126, 1925) studied and described the strata in eastern New Mexico and western Texas and published a comprehensive bulletin describing the surface and subsurface section. More recently Matthew and Stirton (**1072**, pp. 171–216, 1930; **1073**, pp. 349–396, 1930) have identified a large collection of vertebrate fossils from Pliocene sands northeast of Miami in western Hemphill County. Finally, Reed and Longnecker (**1288a**, pp. 1–98, 1932) published a detailed account of the geology of Hemphill County, and Baker has completed a manuscript on the geologic history of the Texas High Plains. Altogether more than forty articles have been written on the geology and paleontology of the Cenozoic deposits of west Texas.

DEFINITION

The Pliocene strata include all the deposits above the Triassic and Cretaceous rocks and below the Pleistocene stream and terrace sands. The strata rest upon the Dockum beds of Triassic age in

[245] Matthew, W. D., Observations on the Tertiary of the Staked Plains: MS. submitted to American Museum of Natural History, 1924.

the northern and western part of the Llano Estacado and upon upper Comanchean strata in the southern portion. The beds consist of a basal conglomerate overlain by 200 to 650 feet of sand, sandy clay, sand containing lentils of clay, a little volcanic ash, and some fine wind-blown sand and silt.

SUBDIVISIONS

The Cenozoic strata of the Llano Estacado have received the following names in geological literature:

Loup Fork beds. This name was used by Cummins (346, pp. 203–208, 1893) to designate the oldest Tertiary strata in the Panhandle thought then to be of Miocene age.

Blanco beds. The term Blanco division was used by Cummins (342, p. 431, 1891; 346, pp. 200–201, 1893) and made to include the strata that outcrop along the rim of the Llano Estacado from Double Mountain Fork of Brazos River on the south to Paloduro Canyon on the north. These beds have a thickness of about 160 feet.

Panhandle formation. This name was proposed by Gidley (582, pp. 634–635, 1903) to include the finer clay deposits of the High Plains above the Mesozoic and Paleozoic beds and below the Recent sands. This unit as originally defined appears to be more or less equivalent to the Blanco beds of Cummins.

Clarendon beds. These beds were named by Gidley (582, pp. 632–634, 1903) to denote strata that occur north and northeast of Clarendon in Donley County. These beds had previously been called Loup Fork by Cummins, as he regarded them as equivalent to the type section in Nebraska, but they are now known to be lower Pliocene in age and therefore younger than the Loup Fork.

Goodnight beds. This name was given by Cummins (346, pp. 201–203, 1893) to sands outcropping at the head of Mulberry Canyon and thought by Cummins to be older than the Blanco beds. Matthew and Stirton have since confirmed this opinion (1073, pp. 365–366, 1930).

Potter formation. This name was proposed by Patton (1180, p. 78, 1923) for the coarsely stratified and more or less consolidated sand and gravel above the Dockum beds and below the Coetas formation exposed along Canadian River in Potter County.

Coetas formation. This formation was named by Patton (1180, p. 80, 1923) and made to include the slightly consolidated sand and sandy limestone strata above the Potter formation and below the surface silts and marls occupying the surface of the Llano Estacado. The formation has a thickness of about 200 feet. The type locality is along Coetas Creek in eastern Potter County.

Hemphill beds. This name was given to the upper-lower Pliocene strata in the Canadian River valley by Reed and Longnecker (1288a, p. 20, 1932). The formation includes all the strata in Hemphill County above the Triassic formations. It is thought by Matthew to be older than the Blanco division and probably younger than the Clarendon. It is quite possible that the Hemphill beds are equivalent to the Goodnight beds of Cummins.

Most of these names apply to local areas only and can not be used to separate the Cenozoic deposits of the High Plains into stratigraphic divisions outside the respective areas in which they were named. Gould pointed out (**614b**, p. 27, 1906) that it is impossible to separate the deposits of this area into mappable divisions that can be traced and designated as stratigraphic units. Matthew[246] used Gidley's name Panhandle formation to apply to the entire Cenozoic section in the west Texas plains. On a basis of his large collections of vertebrate fossils he was able to determine three divisions, as follows:

Panhandle formation—
3. Blanco beds, middle Pliocene.
2. Hemphill (Goodnight) beds, upper-lower Pliocene.
1. Clarendon beds, lower Pliocene.

The age relationships of these beds are discussed by Matthew and Stirton (**1073**, pp. 365–366, 1930), as follows:

1. The Hemphill fauna, especially the equids, is a later phase than Clarendon, so far as the latter can be judged from described material.
2. The four equid species agree quite closely with the four types of Equidae distinguished by Cope in the "Goodnight" beds. So far as published material shows they do not agree closely with Clarendon specimens referred to these species by Gidley.
3. The typical Clarendon species are nearly allied to those from Hemphill, although more primitive, and they may well have been comparatively direct ancestral stages or mutations.
4. The Blanco fauna in turn is more advanced than the Hemphill, the Equidae carrying on two of the four types into further divergence (*Plesippus simplicidens, Hipparion phlegon*), the *Borophagus* with a larger species, the Proboscidea with *Stegomastodon* in place of *Rhyncotherium*, rhinoceroses absent and

[246]Matthew, W. D., Observations on the Tertiary of the Staked Plains: MS. submitted to the American Museum of Natural History, 1924. Matthew, W. D., and Stirton, R. A., **1073**, pp. 364–367, 1930.

glyptodonts present. The gap between Hemphill-Goodnight and Blanco appears to be wider than between Hemphill and Clarendon.

PANHANDLE FORMATION[247]

Definition.—The main body of the banded "clays" that underlie the Staked Plains were named Panhandle formation by Gidley (582, pp. 634–635, 1903). The unit was defined more definitely by Matthew[248] and made to include all the strata on the Staked Plains above the Cretaceous and Triassic formations below and the Recent surface deposits.

Regional geology.—The Panhandle formation overlies unconformably the variegated green and purple clays and sandstones of the Triassic Dockum formation, and it is overlain by the buff sands of the Recent wind-blown deposits. It extends from Crosby County northward into Oklahoma and Kansas. Southward from Crosby County the formation grades into the Recent wind-blown sand. According to Baker[249] no fossiliferous Cenozoic beds have been found on the Llano Estacado south of the headwaters of Brazos River, and consequently it has been impossible to correlate the strata of the southern part of this area with the fossiliferous beds farther north.

The Panhandle formation is best known from exposures around the east-facing escarpment of the Llano Estacado and in canyons that cut back into the escarpment. Its thickness has not been determined in many places. In Hemphill County Reed and Longnecker (1288a, fig. 2, 1932) found the thickness of the lower Pliocene strata to be about 550 feet, which is the maximum thickness so far measured. Their Hemphill strata, according to Matthew, represent only the middle portion of the Panhandle section. The thicknesses determined by Reed and Longnecker are as follows:

LOCALITY	COUNTY	THICKNESS *Feet*	AUTHORITY
Generalized section	Hemphill	550	Reed & Longnecker
Jones No. 1, Gibson Oil Co.	Roberts	512	Do
George No. 1, Fisher Oil Co.	Hemphill	465	Do

[247]LITERATURE—Gidley, J. W., 582, pp. 617–635, 1903. Baker, C. L., 42, p. 32, 1915. Matthew, W. D., Observations on the Tertiary of the Staked Plains: MS. submitted to the Amer. Mus. Nat. Hist., 1924. Udden, J. A., Baker, C. L., and Böse, E., 1652, p. 91, 1916.

[248]Matthew, W. D., Observations on the Tertiary of the Staked Plains: MS. submitted to the Amer. Mus. Nat. Hist., 1924.

[249]Baker, C. L., personal communication.

Stratigraphy.—The character of the formation is shown by the following described section that outcrops in Hemphill County:

Composite section[250] *of Pliocene strata exposed in Hemphill County.*

	Thickness *Feet*
"D" member—	
Sand, buff, fine grained, unconsolidated, covering the surface and containing in places much white or grayish-white caliche	75
Sandstone (key bed No. 1–A), gray, friable, faintly laminated, cemented at the surface in most places by white caliche to form the cap rock exposed along the tops of escarpments	10
"C" member—	
Clay, sandy, brown, unconsolidated	15
Sandstone (key bed No. 1), notably very light gray to white, calcareous and clayey, contains volcanic ash locally. This sandstone constitutes a persistent bed that caps the next to the highest escarpment and mesas in western Hemphill County	10
"B" member—	
Clay, brown, sandy in some places	45
Sandstone (key bed No. 2), gray, laminated, friable, containing some gravel and clay pebbles	10–25
Clay	30
Sandstone, buff, massive	15–50
Sandstone (key bed No. 3), gray, massive, indurated to friable, containing a little gravel and some vesicular lava boulders from 3 to 6 inches in some places	5–25
"A" member—	
Sand, buff, slightly resistant, massive, containing stringers of calcareous material	4
Sand, buff, soft to well indurated, weathering to form blocks, shows fine laminations	8
Sandstone, light buff, very fine grained, loesslike	15
Sand, reddish to buff, fine grained, loesslike, massive, weathers to form steep bluffs and contains a little clay as a matrix in the lower part of the bed	22
Clay with little grit, dark brown, containing few calcareous nodules	6
Sand, reddish buff, massive, medium grained, contains a little clay and numerous calcareous nodules	32
Sand, coarse, made up of irregularly sized grains in a matrix of reddish-brown clay, contains abundance of calcareous nodules	5
Clay, brown, mottled with greenish tints	3
Sand, dark brown, medium to coarse grained	6

[250]Compiled from descriptions by Reed and Longnecker, 1288a, fig. 2, pp. 16–39, 1932.

Sandstone, brown or dark buff, massive, coarse-grained, made up of much arkosic grit from .5 to 3 mm. in diameter	60
Clay, brown, sandy	5
Clay and brown silty sand	20
Sand, white to greenish, calcareous	10
Section unexposed	50
Sandstone, grayish brown, friable, coarse grained, in places containing few thin clay partings	16
Section unexposed	25
Sandstone and conglomerate, gray to buff, well indurated in places, containing clay balls and other material derived from the underlying red beds	15
Average thickness of lower Pliocene section	550

Sedimentology.—The sediments of the Panhandle formation represent a broad piedmont alluvial apron that was laid down on a gently inclined plain by streams that flowed eastward from the Sangre de Cristo and Sierra Grande uplift of New Mexico. Deposition took place during an epoch when rainfall in western Texas and eastern New Mexico was heavy. Streams swollen by heavy rains flowed swiftly down the mountain slopes and debouched abruptly on the nearly flat treeless plain of the mountain foreland (fig. 51). As a result of the sharp slacking of the flow of the streams on reaching the gentle gradient of the plain, large amounts of their loads of sediments were deposited. Fans were built outward until they coalesced to produce the broad alluvial apron represented now by the thick mantle of alluvial deposits that constitutes the present Cenozoic deposits of the High Plains. During epochs or intervals of little rainfall, when the streams carried little coarse sediment, the larger rivers were able to erode and to deepen their channels. Wind also became an agent of sorting and in redepositing finer material that produced beds of loess and silt. With renewed rains, channels were again filled and finer material in the form of mud was washed into the depressions between alluvial ridges and became the clay lentils. Showers of volcanic ash contributed some of the finer sediments. Thus, the remarkable sheet of continental deposits was slowly built up. Streams in west Texas and eastern New Mexico are at present carrying much less water than they did during the Pliocene and Pleistocene epochs. Erosion is now in excess of deposition, and the larger streams, like Canadian River, have cut deep channels through

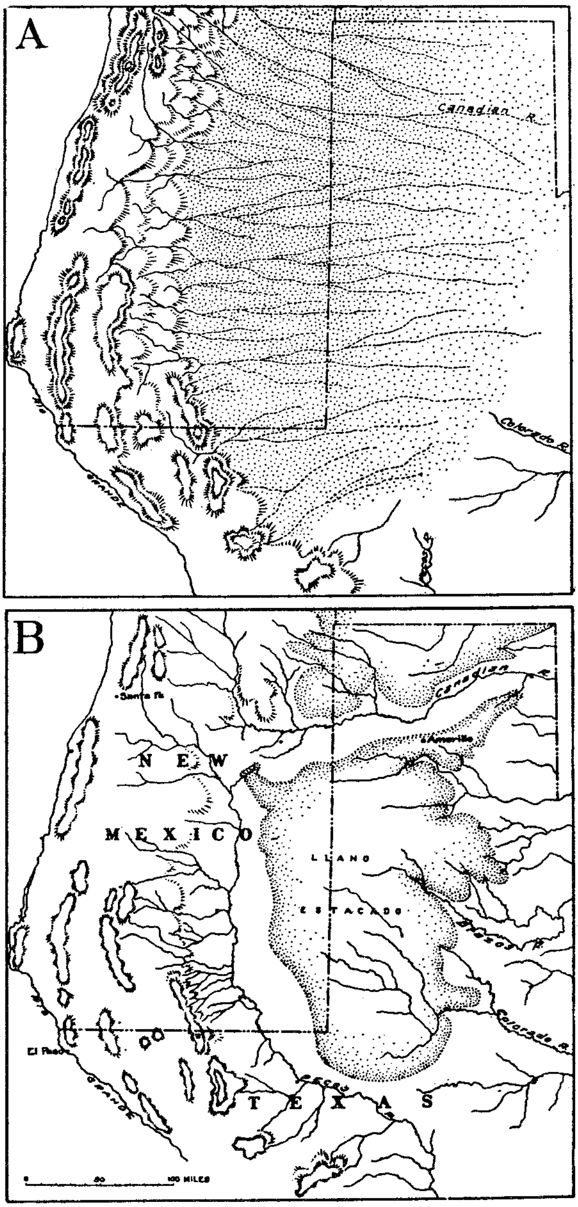

Fig. 51. Evolution of the physiography of northwest Texas and southeastern New Mexico. A, Area during Pliocene times showing alluvial deposits east of the high mountains in New Mexico. B, Area during present epoch showing capture of eastward-flowing streams of Pliocene times by the head-waters of Pecos River.

the sand deposits of the Llano Estacado. The surface strata too are cemented by caliche and other forms of calcium carbonate to form a hard cap rock, so that the strata form steep escarpments and canyon walls.

The greater breadth of the ancient river channels compared with those of present streams and the presence of so much caliche in the Recent surface sands and its absence in the lower beds indicates a somewhat more arid climate now than during Pliocene times. Baker believes that the larger streams of past epochs were caused by much higher mountain ranges in New Mexico during Pliocene times. The greater altitudes induced greater precipitation, and the steeper gradients intensified erosion of the mountain slopes and deposition on the surrounding plains. The original mass of Cenozoic sediments in the Llano Estacado is estimated to have been at least 6000 cubic miles, an amount equal to a mountain mass 300 miles long, 20 miles wide, and 5,000 feet high. Although uplift and erosion may have been contemporaneous, it is probable that the great amount of denudation during and since Pliocene times has lowered New Mexico elevations considerably

Marked changes in stream courses have taken place since the Pliocene epoch. The southward-flowing streams, which have the shortest course to the Gulf of Mexico and consequently the steepest gradient, have an advantage in this valley-cutting process and have eroded their valley heads farther back and have captured many of the former eastward-flowing streams. Thus Sulphur Draw, headwater tributary of the Colorado, was beheaded by the Pecos. Later the upper Portales River was cut off by the Pecos and diverted southward into the Rio Grande. Fans are no longer forming, and the Llano Estacado, once the site of so much deposition, is now being slowly cut away[251] by slow recession of the great eastern escarpment and the downward and lateral erosion by the streams that have cut deep canyons into this great alluvial formation.

Lithology.—The sediments of the Panhandle formation consist on the average of about 60 per cent sand, 23 per cent clay, 10 per cent arkosic grit, and 7 per cent gravel and conglomerate. The sand is gray, coarse to medium grained, contains in some places lentils and balls of red clay and in some places lentils of gravel. The grains

[251]Baker, C. L., Conjectures on the Cenozoic history of the Texas Plains: MS., 1932.

in most places are subangular and are made up largely of quartz with some feldspar, a little magnetite, phlogopite, biotite, and a trace of epidote. The largest portion of the grains (about 65 per cent) range between 0.5 and 2 millimeters in diameter, as shown by the following mechanical analyses:

Mechanical analyses[252] *of four typical samples of the Panhandle formation from Hemphill County.*

SCREEN MESH NO.	SCREEN SIZE	SAMPLES 5	6	7	8
	mm.		*Per cent*		
10	2½	4	0	2	0
10- 20	2½-1¼	15	7	12	2
20- 40	1¼-5/6	18	9	15	8
40- 60	5/6-5/8	12	10	10	6
60- 80	5/8-5/12	15	18	13	10
80-100	5/12-5/16	14	16	12	14
100-120	5/16-¼	5	8	5	10
120-140	¼-5/24	4	7	4	9
140-160	5/24-5/28	2	3	3	5
160-180	5/28-5/36	1	1	2	2
180-200	5/36-⅛	6	11	10	24
200	⅛-	4	10	10	16

The clay is brown or buff. In many places it is poorly bedded, in others it is laminated with thin silty partings that produce thin bedding planes. The beds are lenticular and grade in short distances into sandy clays and sand.

The conglomerate in most places occurs in the basal part of the section where it constitutes a basal conglomerate. The material consists of rounded and subrounded pebbles, cobbles, and in some places boulders derived partially from the underlying red beds and in part from distant sources. The pebbles are composed of metamorphic, igneous, and sedimentary rocks, of which quartz, chert, and quartzite are the most common, although in places igneous pebbles are present in appreciable proportion. The sizes vary from small pebbles to cobbles of quartz that range from two to three inches in diameter. A few vesicular lava boulders are a foot or more in diameter. In many exposures the gravel contains waterworn Cretaceous shells.

[252]Reed, L. C., and Longnecker, O. M., Jr., 1288a, p. 44, 1932.

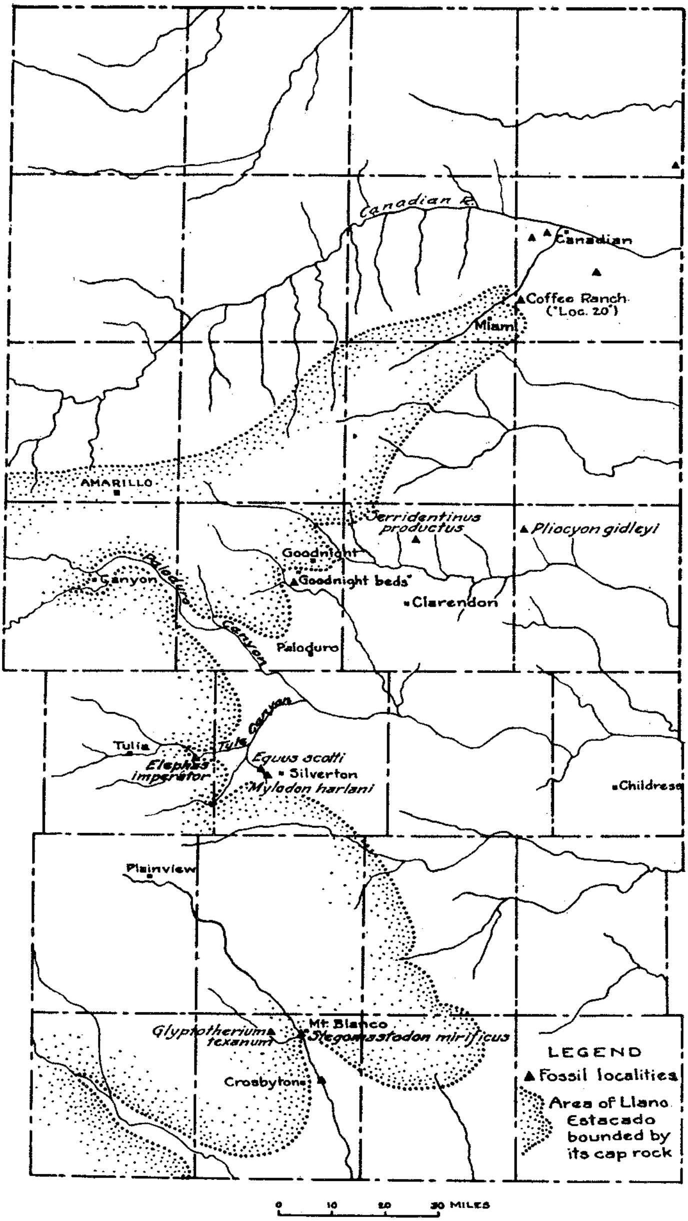

Fig. 52. Area of the High Plains (Llano Estacado) showing well-known fossil localities in the Panhandle and Tule formations.

The arkosic sand is brown, cross-bedded, and contains in its upper portion a little clay. The sand is composed of quartz, feldspar, jasper, magnetite, phlogopite, and minor amounts of rarer minerals.

Paleontology and correlation.—The Panhandle formation contains the largest variety of vertebrate remains of any Cenozoic formation in Texas. Fossil-hunting expeditions have explored the wild canyons of the High Plains since the pioneer trips of Shumard and Marcou. Many have been richly rewarded. The more common and best-known specimens recorded and the localities where they occurred are presented in the following lists.

Fauna[253] *of the Clarendon beds*

Pliocyon gidleyi (Matthew)
Machaerodus? sp.
Teleoceras fossiger (Cope)
Protohippus perditus? Leidy
Protohippus placidus? Leidy
Pliohippus pachyops (Cope)
Hipparion cf. H. lenticulare (Cope)
Hipparion cf. H. occidentale? (Leidy)
Serridentinus productus (Cope)
Serridentinus serridens (Cope)
Megatylopus gigas M. & C.
Camelidea sp. indet.
Pliauchaenia sp.
Blastomeryx sp.
Synthetoceras tricornatum Stirton

This fauna, according to Matthew, is lower Pliocene in age and correlates with the upper Snake Creek fauna and the Valentine fauna of Nebraska.

Fauna[254] *of the Blanco beds*

Canimartes cumminsii Cope (1, 2)
Borophagus diversidens Cope (1)
Glyptotherium texanum Osborn (1)
Megalonyx leptostomus Cope (1)
Plesippus simplicidens (Cope) (1, 2)
Hipparion phlegon (Hay) (1)
Stegomastodon mirificus (Leidy) (1)
Rhyncotherium? sp. (1)
Platygonus bicalcaratus Cope (1)
Platygonus texanus Gidley (1)
Leptotylopus percelsus (1)
Megatylopus spatula (Cope) (1)
Camelids indet.

[253]Matthew, W. D., MS., 1924.
List from Cope and Gidley with some revised identifications by W. D. Matthew (MS. 1924).
[254]List recorded by Cope and Gidley and revised by W. D. Matthew (MS., 1924).

Localities recorded in above list—

1. North side of Crawfish Draw, a small tributary to the south side of Blanco Canyon about 10 miles north of Crosbyton, near R. B. Smith ranch house, now known as the "old rock house," Crosby County.
2. East side of Blanco Canyon due east of Crosbyton, Crosby County.

Matthew regarded the fauna of the Blanco beds as middle Pliocene in age.

Fauna of the Hemphill beds

Canidae (2, 3)
Leptocyon sp. (20)
Procyon sp. (28)
Borophagus cynoides (Martin) (20)
Aelurodon sp. (24)
Hyaenarctos sp. (20)
Sthenictis sp. (20)
Pseudolaelurus sp. (20)
Machaerodus catocopsis Cope (20)
Mylagaulus cf. M. monodon Cope (6, 20)
Teleoceras sp. (5, 18, 24)
Aphelops mutilis Matthew (20)
Aphelops sp. (24)
Pliohippus interpolatus (Cope) (19, 20)
Pliohippus sp. (5, 6, 9, 11, 15, 24, 25)
Protohippus ansae Matthew and Stirton (20)
Hipparion eurystyle (Cope) (19, 20)
Hipparion lenticulare (Cope) (2, 6, 15, 16, 19, 20, 25)
Hipparion occidentale (Leidy) (15)
Hipparion sp. (3, 11, 24)
Merycodus sp. (16)
Prosthennops cf. P. crassigensis Gidley (20)
Miolabis sp. (20)
Paracamelus arenicola nom. nov. (20)
Paracamelus n. sp. (20)
Dyseomeryx sp. (20)
Docameryx optimae Matthew (20)
Stegomastodon sp. (26)
Rhyncotherium sp. (20)
Mylodon sp. (26)

Localities recorded in above list (locality numbers of Reed and Longnecker (1288a) retained)—

2. Three and one-half miles west of Canadian, between Red Deer Creek and Canadian River, near mouth of Red Deer Creek in eastern half of W. W. Langham Survey, Hemphill County.
3. East and south side of an isolated mesa in western portion of eastern half of W. W. Langham Survey, Hemphill County.
5. First bluff on north side of Red Deer Creek west of east line of Hemphill County.
6. Three miles southwest of Mendota, one-half mile west of east line of Hemphill County north of Red Deer Creek.
9. Northwest side of Red Deer Creek, 3 miles northwest of Mendota in southeast corner of Lout Survey, Hemphill County.
11. East side of a valley in northeast corner of section 194, Block C, Hemphill County.

15. South-central portion of section 132, Block 42, Hemphill County.
16. Northwest corner of section 26, Block 43, Hemphill County.
19. Northwest corner of section 18, Block 1, on slopes of mesa fronting Red Deer Creek, Hemphill County.
20. Northeast corner of section 59, Block A–2, 500 feet north of Amarillo-Canadian highway, 20.3 miles by road from Canadian, 9 miles northeast of Miami on Coffee Ranch, western Hemphill County.
24. West side of a creek in the northwest corner of Lipscomb County, one-fourth mile west of the east line and 3 miles north of the south line.
25. Northeastern part of section 128, Block 41, on north side of Canadian River.
26. Two miles north of Canadian, north of Canadian River bridge, Hemphill County.
28. Northeast corner of section 161, Block 41, north of Canadian River and about 1½ miles northeast of the Conatser ranch.

Matthew and Stirton have stated that the Hemphill fauna is younger than the typical Clarendon and older than the Blanco (1073, p. 365, 1930). They regarded it as upper-lower Pliocene, whereas the Blanco is middle Pliocene.

LATE PLIOCENE OR EARLY PLEISTOCENE STRATA

DEFINITION

Deposits of late Cenozoic age occur in the form of ancient stream terraces and upland interstream gravel deposits in many places in central and north-central Texas, east and southeast of the Llano Estacado. These sands and gravels were deposited during the late Pliocene and early Pleistocene epochs upon surface strata of various ages. They represent the last chapter in Cenozoic continental deposition north of the Gulf Coast.

SUBDIVISIONS

The late Cenozoic deposits of the interior areas of Texas have been classified into two geographic divisions, as follows:

Uvalde gravels. These comprise upland gravels and interstream deposits that occur on divides and ancient upland surfaces south of the Balcones fault zone and north of the Pliocene deposits of the Gulf Coast.

Seymour sand and gravel. The upland sands and gravels and interstream gravel deposits found on divides in north-central and central Texas north of Llano Mountains and east of the Llano Estacado. These deposits are best developed in the Permian areas of Baylor, Haskell, Jones, Fisher, Scurry, and adjoining counties.

UVALDE DEPOSITS[255]

Definition.—The name Uvalde was given by Hill (**770**, p. 368, 1891) to the upland gravel deposits of central and south Texas. The name is appropriate, applicable, and well defined. It was not generally accepted by geologists for a long time, however. Penrose (**1189**, p. 63, 1890) had named the gravel and caliche deposits along the Rio Grande Reynosa for the town of Reynosa, Mexico. As previously explained, these Reynosa gravels are now thought to be of Pleistocene age and younger than the Uvalde gravel of Hill. Nevertheless, many preferred to use Penrose's name. Dumble (**478**, p. 560, 1894; **494**, pp. 976–983, 1903) adopted it. Kennedy[256] used the name Lafayette-Reynosa. Udden, Baker, and Böse (**1652**, pp. 91–93, 1916) used the old name Lafayette. Deussen (**415**, pp. 77–78, 1914) used Uvalde but changed to Reynosa in 1924, although he questioned (**421**, p. 102, 1924) the appropriateness of correlating the upland gravels with the river terrace deposits at Reynosa. Sellards (**1402**, p. 65, 1919) and Liddle (**992**, p. 93, 1918) accepted Hill's name Uvalde, but Trowbridge (**1610**, pp. 98–100, 1923; **1613**, pp. 455–462, 1926; **1613a**, pp. 184–203, 1932) followed Dumble's usage and retained Reynosa. Adkins and Arick (**16**, p. 66, 1930) also preferred Reynosa. The United States Geological Survey in the preliminary edition of the geologic map of Texas retained the name Reynosa for these gravels. No fossils have been found in the upland interstream deposits. The topographic position and general physiographic relationships of these deposits indicate so clearly that they antedate the river terraces, that Hill's name must take precedence over others.

Regional geology.—The gravels of the Uvalde deposits occur on the stream divides, and in many places they cap the highest hills in the area south of the Edwards Plateau. They rest upon formations

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[255]LITERATURE—Penrose, R. A. F., **1189**, p. 63, 1890. Hill, R. T., **770**, pp. 366–370, 1891; **803**, pp. 347–349, 1901; and Vaughan, T. W., **795**, pp. 244–247, 1898; **794**, p. 3, 1898. Dumble, E. T., **478**, p. 560, 1894; **494**, pp. 976–983, 1903. Vaughan, T. W., **1686**, p. 3, 1900. Deussen, A., **415**, pp. 77–78, 1914; **421**, pp. 102–108, 1924. Trowbridge, A. C., **1610**, pp. 98–100, 1923; **1613**, pp. 455–462, 1926; **1613a**, pp. 184–203, 1932. Sellards, E. H., **1402**, pp. 65–69, 1919. Liddle, R. A., **992**, pp. 93–96, 1918. Adkins, W. S., **11**, pp. 83–84, 1923; and Arick, M. B., **16**, pp. 66–67, 1930.

[256]Kennedy, Wm., Geology and oil prospects of the lower Brazos River Valley: Unpublished MS.

of various ages from Lower Cretaceous to Miocene. They are especially prominent in the area between the Brazos and Devils rivers and occur in even greater thickness in northern Mexico.

The Uvalde deposits consist of gravel composed almost entirely of rounded flint cobbles with pieces of limestone and quartz and flint pebbles set in a matrix of chalky marl and caliche. The marl matrix weathers to a black soil and the land covered by the deposits is in many areas cultivated, although the fields are everywhere strewn with large numbers of cobbles. The larger percentage of the cobbles are less than an inch in diameter, but many measure up to three or even six inches in diameter. The material is in most places well assorted, distinctly cross-bedded, and some is well cemented by calcium carbonate. The thickness of the gravel deposits ranges from a very thin covering to 25 or 30 feet. The average thickness is probably from 15 to 20 feet.

The material composing these deposits is believed by Hill and Vaughan (795, p. 244, 1898) to have been derived from the Edwards limestone of the Edwards Plateau and to have been spread over the area to the south by streams.

The gravel is distinguished from the Lissie and later stream terrace gravels by its higher topographic position on divides and interstream ridges and by the large size of its cobbles and by its larger proportion of chert, and by its smaller proportion of calcareous material.

The Uvalde deposit is composed almost entirely of flint cobbles and pebbles derived from Lower Cretaceous formations. The gravel of the lower terraces has been derived from various pre-Cretaceous rocks and consists largely of quartz, black flints from the Bend group, igneous rocks, and redeposited pebbles from Strawn conglomerates together with a mixture of some Cretaceous material.

Paleontology and correlation.—No fossils of diagnostic value have ever been found in the gravels, so far as known. Doubtless bones will sometime be discovered. In absence of any definite information the Uvalde is assigned to the Pliocene, because it is topographically higher and is more weathered and more eroded than the well-known oldest terrace deposits along river valleys. Vertebrate fossils are common in the terrace sands, and some of the specimens are known to be early Pleistocene, according to Hay

(682, p. 116, 1923). Since the Uvalde is older than these early Pleistocene stream terraces, it is placed in the late Pliocene or oldest Pleistocene and correlated with the upper Pliocene sands of the eastern Gulf Coast or the basal Lissie of south Texas, and possibly with the Seymour beds of north-central Texas.

Economic resources.—The Uvalde deposits constitute the chief source of gravel for road ballast and concrete work. Its wide distribution, easy accessibility to highways and towns, the ease with which it can be handled with steam shovels, and the hardness and durability of its cobbles are noteworthy characters that make these strata valuable in building operations.

SEYMOUR DEPOSITS[367]

Definition.—The Seymour deposits were named by Cummins (346, p. 181, 1893) for the town of Seymour in Baylor County. The formation is exposed typically in the area between the Brazos and Big Wichita River in Baylor County and also near Benjamin in Knox County. It occurs in places over much of the area east of the Llano Estacado in northwest Texas.

Regional geology.—The Seymour deposits consist of beds of stratified sand, sandy clay, and lentils of gravel resting unconformably upon Permian strata. The basal layers in most places are sand and gravel. The well-rounded pebbles are mainly chert and quartz, but some are limestone cobbles. The majority of the pebbles are quartz, and most of them are less than an inch in diameter. In many exposures the deposit is made up entirely of sand and sandy clay containing some water-worn Cretaceous fossils. According to Cummins the thickness of the beds ranges from a few to fifty feet.

Paleontology and correlation.—The exact age and correlation of these west Texas upland deposits has not been definitely established. Cummins (346, p. 182, 1903) collected a few fragments of *Mastodon?* and *Equus?* bones at a locality fourteen miles east of Benjamin and others on Groesbeck Creek west of Quanah. Singley (346, pp. 186–190, 1893) identified a number of land shells from the same beds and referred them to the Pleistocene.

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[367]Literature—Cummins, W. F., 346, pp. 181–182, 1893. Singley, J. A., 346, pp. 186–189, 1893. Patton, L. T., 1185, p. 53, 1930.

The exact age of the main portion of the Seymour beds is doubtful the following reasons:

1. The exact location of the fossils collected by Cummins and regarded as Pleistocene by Singley is uncertain. The localities are along stream lines and may belong in terrace deposits younger than the true Seymour.
2. No fossils from the Seymour beds have been studied recently by experts.
3. Most of the Seymour deposits occupy divides and appear to correlate with the Uvalde gravel, thought by some geologists to be Pliocene.
4. Some of the Seymour is thought to be derived from the Panhandle formation and therefore must be younger and most probably post-Pliocene.

Pleistocene System

HOUSTON GROUP

DEFINITION

Houston is a new group name proposed to embrace the Pleistocene strata of the flat Gulf coastal plain from the top of the Pliocene sands of the Citronelle group to the base of the Recent coastal silts and wind-blown sands overlying the Pleistocene deposits in some areas.

The Houston group of strata outcrop along the coastal border of the Gulf of Mexico. They are bounded on the north by the Hockley escarpment and equivalent rolling ridgeland and on the south by the beach and wind-blown sands that occur along the present shoreline

The strata of the Houston group consist of fine, gray and reddish-orange sand, yellow and gray clay, and silt. Sands predominate in the lower portion of the section and clays in the upper part. The sediments are unconsolidated, alluvial, deltaic, and brackish-water or lagoonal deposits. Their average thickness is about 1500 feet. The formation is named for the city of Houston, the largest metropolis on the Texas coastal belt, which is located in the middle part of the Pleistocene section at about the contact of the upper clays with the lower sands. Good exposures occur in drainage ditches south and west of the city.

SUBDIVISIONS

The strata of the Houston group are divided into the two following formations:

2. Beaumont clay.
1. Lissie sand.

LISSIE FORMATION[258]

Definition.—The Lissie formation was named by Deussen (**415**, p. 78, 1914) for the town of Lissie in Wharton County. Previously, Pleistocene deposits of the Gulf Coast had been classified under various names. Wailes[259] in one of the earliest reports written on the younger deposits referred to them as "Diluvium" or "Northern drift." Safford[260] in 1856 named the deposits Orange sand. His name was used by Harper,[261] Hilgard,[262] and many other geologists during the next 50 years. In 1891 McGee[263] described the Pleistocene deposits of the Atlantic slope under the name Lafayette formation. McGee's monograph was widely read and his name has been much used. In fact it was adopted in many text books and used in most geological reports until it became a sort of "catch all" to designate all sorts of surficial deposits ranging in age from Tertiary gravel to Recent silt. It was employed by Smith, Johnson, and Langdon,[264] Hayes and Kennedy (**692**, p. 26, 1903), Veatch (**1691**, p. 44, 1906), and others to designate the Pleistocene sediments of the Gulf Coast. As used by these southwestern geologists, the Lafayette included the Lissie, Leona, and Uvalde or Reynosa formations of recent reports.

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[258]Literature—Cope, E. D., **302**, pp. 160–165, 1889; **304**, pp. 912–913, 1891. McGee, W J, The Lafayette formation: U. S. Geol. Survey 12th Ann. Rpt., pt. 1, pp. 384–408, 1891. Dumble, E. T., **478**, pp. 563–564, 1894; **494**, pp. 976–987, 1903; **502a**, pp. 192–193, 1915; **506**, pp. 246–269, 1918. Hayes, C. W., and Kennedy, W., **692**, pp. 26–66, 1903. Veatch, A. C., **1691**, pp. 44–50, 1906. Deussen, A., **415**, pp. 78–80, 1914; **421**, pp. 108–110, 1924. Udden, J. A., Baker, C. L., and Böse, E., **1652**, pp. 91–95, 1916. Matson, G. C., **1061**, pp. 177–192, 1916. Berry, E. W., 101, pp. 227–251, 1916. Trowbridge, A. C., **1610**, p. 100, 1923; **1613**, pp. 455–462, 1926; **1613a**, pp. 203–207, 1932. Bailey, T. L., **38**, pp. 97–113, 1923. Applin, E. R., Ellisor, A. C., and Kniker, H. T., **32**, pp. 81, 85, 1925. Applin, P. L., 33, pp. 20–21, 1925. Marshall, W. B., **1056**, pp. 1–6, 1929.

[259]Wailes, B. L. C., Report on agriculture and geology of Mississippi: Mississippi Geol. Survey, p. 245, 1854.

[260]Safford, J. M., Geological reconnaissance of Tennessee, p. 148, 1856.

[261]Harper, L., Preliminary report on the geology and agriculture of the state of Mississippi, pp. 5–46, 1860.

[262]Hilgard, E. W., Geology and agriculture of the state of Mississippi, pp. 5–45, 1860.

[263]McGee, W J, The Lafayette formation: U. S. Geol. Survey Twelfth Ann. Rept., Pt. 1, pp 384–408, 1891.

[264]Smith, E. A., Johnson, L. C., and Langdon, D. W., Jr., Report on the geology of the Coastal Plain of Alabama: Geol. Survey Alabama, p. 66, 1894.

Dumble (478, p. 563, 1894), as the result of the discovery of fossil horse bones in some of the Pleistocene sands along the coast, named these coastal sands "Equus beds." Hayes and Kennedy (692, p. 26, 1903) named the sands of Pleistocene age in east Texas the Columbia sands. Deussen believed that the Columbia sands of Hayes and Kennedy might not be the same as Dumble's "Equus beds" and therefore proposed the name Lissie to include the section in southeast Texas above the strata now classified as Lagarto and below the Beaumont clay. The type section of the Lissie comprises the exposures along the Southern Pacific Railroad near the town of Lissie in Wharton County.

The gravel beds cemented by caliche and lying upon the Lagarto clays in south Texas were referred to by Dumble (506, 1894) as Reynosa limestone (now Goliad). These caliche deposits were correlated with the Uvalde upland gravels by Trowbridge (1610, p. 99, 1923) and made to include all the beds between the Lagarto clay below and the Beaumont clay above, so that the name Reynosa as defined by Trowbridge is essentially equivalent to the Lissie as defined by Deussen. Deussen (421, p. 106, 1924), however, restricted the name Reynosa mainly to upstream terrace deposits. He stated, "These upstream Reynosa deposits lie unconformably upon beds ranging in age from Upper Cretaceous to middle Pliocene. They are in general not covered by later deposits." Yet he regarded them as correlative with the older subsurface gravels, for he says (421, p. 108, 1924) that the Lissie gravel lies unconformably above the Reynosa formation (now Goliad) and is overlain by the Beaumont clay. In the final classification of the United States Geological Survey (1613a, pp. 184–208, 1932) the lower and coarser part was referred to the "Reynosa" (now Goliad) and the upper and finer sands were called Lissie. The two divisions are separated by an unconformity.

The Lissie is now made to include all the strata above the Goliad and other sand and gravel beds of Pliocene age and below the Beaumont clay. It is intended to include in this formation only Pleistocene strata that outcrop north of the Beaumont Plain and south of the Hockley Ridge and the rolling topography of the Pliocene terrain.

Regional geology.—The Lissie formation outcrops in a belt about 30 miles wide parallel to the present coastal plain at a distance about 50 miles from the coast. The beds extend from Sabine River to the Rio Grande. The outcrop is shown on the map, Plate I, and in figure 50. Northward from the coastal belt upland gravels and older terrace deposits, which are more or less equivalent in age to the Lissie, extend up the principal drainage lines and overlap older deposits. In fact the Pleistocene deposits occupy the largest areal outcrop of any group of strata younger than the Cretaceous. Southward from its outcrop the Lissie dips beneath the Beaumont clay of the coastal prairies and becomes an important underground water sand for the cities of Houston, Beaumont, Bay City, and other towns located south of its outcrop.

The thickness of the Lissie ranges from 600 feet at its outcrop in east Texas to 400 feet in south Texas. The thickness of the Lissie formation in Brazoria and Matagorda counties is shown in the following table:

LOCALITY	COUNTY	THICKNESS *Feet*	AUTHORITY
Water well at Chenango	Brazoria	245	Wm. Kennedy
Hoskins Mound	Brazoria	530	Wm. Kennedy
Roxana Pet. Co., Seaburn No. 3, Stratton Ridge	Brazoria	325	F. B. Plummer
Oil well on NE. side of Markham oil field	Matagorda	501	Wm. Kennedy
Oil field near Bay City	Matagorda	390	Wm. Kennedy
Thompson Station, 12 mi. S. of Richmond	Fort Bend	265	Wm. Kennedy

Stratigraphy.—The Lissie formation lies unconformably upon the Goliad sand or other sands of Pliocene age and is overlain unconformably by the Beaumont clay. It is composed of thick beds of sand containing lentils of gravel and is interbedded with clay and silt. In places near the coast line the Lissie contains layers of marine clays in or between thick strata of sand. It has not been divided into separate members or zones.

The character of the Lissie formation is shown in the following described section:

Section[265] *of the Lissie formation in west bank of Colorado River, one-fourth mile north of Garwood, Colorado County.*

	Thickness Feet
4. Sand, pale yellowish or pinkish, slightly calcareous, medium grained, unconsolidated, greatly cross-bedded, and containing near the middle a thin layer containing pinkish, calcareous concretions up to 3 centimeters in diameter	8
3. Gravel, brownish red to orange, medium grained, arenaceous and argillaceous, noncalcareous, containing a number of large, rounded clay lumps	3
2. Sand, coarse, cross-bedded, gravelly, with a few streaks of slightly calcareous red clay	5
1. Gravel, sandy, containing pebbles up to 2 inches in diameter, and with a few lenses up to 8 inches thick of brownish-red, laminated clay	6
Total thickness section measured	22

Sedimentology.—The sediments of the Lissie formation on the outcrop are partly continental deposits laid down as flood-plain deposits along rivers and creeks as they deployed over the flat, featureless marine plain and partly delta sands, bottom silts, and muds laid down at the mouths of rivers as they reached the bays and lagoons. The deposits originated during the Glacial epoch. The atmospheric changes brought about by the ice sheet undoubtedly induced increased rainfall; floods of water were poured down the drainage lines, filled the valleys, and spread over the flat coastal plain. Cobbles up to six or eight inches in diameter were transported a hundred miles or more, were rounded, and left as evidence of the force and size of the Pleistocene floods. Animals driven south by the ice sheets were engulfed in the currents and their bones buried in the sands. The onrushing waters seem to have been somewhat more violent in south Texas than in northeast Texas. A widespread alluvial apron of sand and gravel was spread over the land. In Mexico boulders a foot or more in diameter and transported many miles from their source are common. Some of the quartz pebbles can be traced back to outcrops in the mountains of west Texas and New Mexico. The only hypothesis adequate to explain the widespread sheet of gravel of the Pleistocene is floods of water. Remnants of old abandoned stream channels still existing

[265]Measured by T. L. Bailey (38, p. 102, 1923).

in the late Pleistocene surface indicate that some of the late Pleistocene river channels were more than five times as wide as the present rivers. Barton (70, p. 382, 1930) cites examples of two large ancient rivers in the Trinity and Neches delta plain. The rivers in earlier Pleistocene epochs when the gravel was deposited must have been at flood stage to have transported so much detritus. There is no evidence of any local uplifts during the Pleistocene period along the Balcones fault line or along any of the central Texas structural lines of sufficient magnitude to have furnished gradients steep enough to have brought out widespread sand deposition without greatly increased amounts of water. It seems certain that the floods in the south occurred during the advance and retreat of the ice sheet in the north. The floods were terrific and exceeded even the transporting power of water flowing out from the melting ice sheet itself.

Lithology.—The Lissie formation is made up of about 60 per cent sand, 20 per cent sandy clay, 10 per cent gravel, and 10 per cent clay. The sand and gravel is red, orange, or mottled red and gray on the outcrop and bluish and greenish gray in subsurface sections. In north Texas the gravel occurs in lentils a few inches to 5 feet thick, rarely thicker. In south Texas the lentils of gravel are thicker, the pebbles are much coarser, and the beds at the surface are cemented by caliche.[266] The bedding is irregular, and the texture is variable. The pebbles are composed of chert, quartz, quartzite, pegmatite, granite, porphyries, schists, silicified wood, chalcedony, and water-worn fossils. In central Texas the chert pebbles are largest and most numerous. In most samples at least 90 per cent of the pebbles are chert. Of the remainder, 5 to 6 per cent are white, yellow, and pink quartz, and the rest are chalcedony or igneous rocks. In south Texas the percentage of igneous pebbles increases. The pebbles vary greatly in size in the same exposure and also to a greater extent from one exposure to another. The pebbles average much larger in the outcrops in south Texas than in the sections of east Texas. Most of the pebbles are subround.

[266]Caliche, according to W. A. Price, is found under 12 inches of soil in western Hidalgo County and has been encountered in core tests in the Saxet gas field, Nueces County, at depths between 85 and 100 feet. This latter occurrence may be the base of the Lissie. (See H. W. Hawker, A study of the soils of Hidalgo County and the stages of their soil accumulation: Soil Science, vol. 23, No. 6, pp. 475–485, June, 1927. W. A. Price, Reynosa problem of south Texas and origin of caliche: Amer. Assoc. Pet. Geol., vol. 17, May, 1933.)

The sand varies between red and gray and varies greatly in texture from very fine sand to gravel. Most of the small grains are subangular to angular and average perhaps one-sixteenth of a millimeter in diameter. The composition of a typical sample (Bailey, 38, table 4, 28th from top of list) is shown in the following table:

Clay	22%
Quartz	63%
Chert	10%
Chalcedony	3%
Feldspar	1%
Limonite	1%
Ilmenite	frequent
Magnetite	abundant
Hematite	common
Epidote	frequent
Tourmaline	frequent
Zircon	abundant

Distinguishing characteristics.—The Lissie formation can be distinguished by the following criteria:

1. Topography. The outcrop of the Lissie is a nearly featureless plain bounded on the north by a ridge known as the Hockley escarpment. Streams meander broadly across this flat belt in broad, shallow valleys bordered by a slight ridge of sand deposited as a natural levee. The outcrop of the Goliad and the upper Pliocene sands have more maturely dissected rolling uplands and normal stream profiles.
2. Vegetation. The Lissie supports a more or less open prairie forested in most places by only patches of oak or having fringes of trees along its stream courses. The Goliad and upper Pliocene strata are more heavily forested with post oak and underbrush.
3. Color. The Lissie is distinctly red, orange red, or pinkish buff. The Goliad and upper Citronelle sands are grayish buff and have in most places much lighter shades than the Lissie.
4. Texture. The Lissie is finer textured and carries less gravel than the Pliocene strata.

Paleontology.—Fossils are rare in the Lissie formation. A few bones have been found, and rare land snails and fragments of plant leaves. In a few wells drilled close to the shoreline marine and brackish-water fossils have been recovered. In general, however, the Lissie formation is barren ground for the fossil hunter. The following vertebrates have been identified from the Lissie:

Trucifelis fatalis Leidy (7)
Canis sp. (3)
Cistudo marnockii Cope (3)
Megatherium sp. (2)
Bison latifrons (Harlan) (6)
Mastodon serridens Cope (4)
Glyptodon petaliferus Cope (3)
Elephas columbi Falconer (6)
Elephas primigenius (Blumenbach) (3)
Elephas imperator Leidy (6)
Equus complicatus Leidy (7)
Equus francisci Hay (5)
Equus crenidens? Cope (3)
Equus tau? Owen (3)
Equus semiplicatus Cope (3)
Equus excelsus Leidy (3)
Equus occidentalis? Leidy (3)
Camelid (3)
Ox (2)
Tapir (2)

Localities from which above fossils were collected—

1. Two feet above base of gravel at La Loma de la Cruz, Mexico, 3 miles east of Rio Grande City, Starr County.
2. Banks of Brazos River; no exact localities recorded.
3. Taranchua Creek, a branch of San Diego Creek, near San Diego, Duval County (erroneously recorded as Nueces County in old reports by Cope).
4. East Texas; no exact locality given by Cope.
5. Shallow well in northern Wharton County, depth 25 feet.
6. Bee County; no exact locality given.
7. Hardin County; no exact locality given.

BEAUMONT CLAY[267]

Definition.—The Beaumont clay was named by Hayes and Kennedy (**692**, p. 27, 1903) for the exposures in the vicinity of Beaumont, Jefferson County. Previously these clays along the Gulf Coast had been referred to as Port Hudson formation by Hilgard[268] and Loughridge (**1017**, pt. 1, p. 680, 1884) and as coast clays by Dumble (**478**, p. 564, 1894). Hayes and Kennedy (**692**, pp. 27–29, 1903) defined the Beaumont as the clay deposits between the Columbia sands (now Lissie sands) and the overlying Port Hudson silt of recent age. The name has been used in the same way by all later writers. The Beaumont is unique among Cenozoic formations of Texas in maintaining one geologic name during the last three

[267]Literature—Hilgard, E. W., Summary of results of a late geological reconnaissance of Louisiana: Am. Jour. Sci., 2nd ser., vol. 48, pp. 332–333. 1869. Loughridge, R. H., **1017**, vol. 5, pt. 1, p. 680. 1884. Dumble, E. T., **478**, pp. 564–566, 1894; **506**, pp. 269–272, 1918. Hayes, C. W., and Kennedy, W., **692**, pp. 27–29, 1903. Fenneman, N. M., **537**, pp. 13–16, 1906. Deussen, A., **415**, pp. 80–81. 1914; **421**, pp. 110–113, 1924. Udden, J. A., Baker, C. L., and Böse, E., **1652**, pp. 94–95, 1916. Trowbridge, A. C., **1610**, p. 100, 1923; **1613a**, pp. 208–218, 1932. Bailey, T. L., **38**, pp. 113–117, 1923. Barton, D. C., **70**, pp. 359–382. 1930; **74**, pp. 1301–1320, 1930.

[268]Hilgard, E. W., Summary of results of a late geological reconnaissance of Louisiana: Am. Jour. Sci., 2d ser., vol. 48, pp. 331–346, 1869.

decades. Geologists are in general agreement regarding its definition. It consists of 400 to 900 feet of clay and marl interbedded with lentils of clay between the Lissie formation and surface silts, surface terrace, and alluvial deposits. The type locality is regarded as the shallow well sections in the vicinity of Beaumont. The surface soil at Beaumont is terrace material deposited by the waters of Neches River. Beneath these silts the drill encounters 400 feet of clay mixed with a little sand. The section of a well drilled at the Gulf, Colorado and Santa Fe Railroad station at Beaumont is as follows:

	Depth *Feet*
Recent—	
Clay and soil	0-6
Sand	6-8
Beaumont clay—	
Clay, blue	8-45
Sand, containing shells	45-49
Clay, blue, containing thin streaks of sand	49-120
Thickness penetrated	112

The Beaumont clay is well exposed in most of the deeper drainage ditches around Houston, Harris County, Beaumont, Jefferson County, and along the bluff of the bay shore at Corpus Christi, Nueces County.

Regional geology.—The Beaumont clay occupies a flat, featureless, treeless coastal plain extending in a belt about 40 miles wide about 10 to 15 miles from the coast from Sabine River on the east to Olmos Creek in southern Kleberg County on the south. In the Rio Grande valley in Hidalgo and Willacy counties it is covered by recent and wind-blown sand and silt, but it is reached at slight depths in all wells. It is essentially a late coastal plain formation that stretches from the Mississippi delta to Tamaulipas Range in northeastern Mexico. Along the Gulf Coast the Beaumont clay is overlain by recent wind-blown river and beach deposits. It dips southeastward and extends beneath beach sand and waters of the Gulf as far as the continental shelf. Its thickness is fairly uniform, ranging from 450 to 900 feet with an average of about 700 feet, as shown in the following table:

LOCALITY	COUNTY	THICKNESS *Feet*	AUTHORITY
Roxana Pet. Co., Seaburn No. 3, Stratton Ridge	Brazoria	930	F. B. Plummer
Northwest side of Bryan Heights salt dome	Brazoria	567	Wm. Kennedy
Water well at Chenango	Brazoria	830	Do
Water well at Amsterdam	Brazoria	822	Do
Water well at Thompson, 12 mi. S. of Richmond	Fort Bend	186	Do
Well ½ mi. N. of Markham oil field	Matagorda	541	Do

Stratigraphy.—The Beaumont clay lies unconformably upon the Lissie formation and is overlain unconformably by stream deposits and wind-blown sands. It has not been subdivided into smaller units. Throughout its extent it is more or less a unit of plastic, poorly bedded, clay interbedded with lentils and more or less continuous layers of sand. Details of its stratigraphy are best illustrated by the following described section:

Section[269] *of the Beaumont clay in a well (from 6 to 370 feet) on the V. E. Damstron farm, three-fourths of a mile north of Olivia, Calhoun County.*

	Thickness *Feet*
Clay, mottled, pink and green, calcareous	24
Clay, light green, calcareous	30
Shell bed, containing fragments of oysters, barnacles, clams (*Rangia* sp.)	10
Clay, green and pink, calcareous	50
Clay, green and reddish pink, fairly hard calcareous clay	20
Clay, pink, hard, calcareous	20
Clay, green, calcareous, medium hard	40
Clay, blue, noncalcareous, medium hard	30
Clay, reddish pink, medium hard	20
Clay, blue, plastic, medium hard	35
Shell bed, containing fragments of oysters and other shells, and thin layers of light brown sand	20
Clay, pink, calcareous, containing fragments of oyster shells	15
Clay, green and pink, calcareous, medium hard	32
Sand, light brown, calcareous, coarse grained	18
Total thickness measured	364

[269]Measured by Alexander Deussen 421, p. 112, 1924.

Section[270] *of Beaumont clay exposed on Brazos River near the former wagon bridge at Richmond, Fort Bend County.*

	Thickness Feet
Recent—	
Sand, grayish red, river sand	15
Beaumont clay—	
Sand, red, with gray patches, and indurated sufficiently to form a bench	10
Clay, bluish gray, sandy, containing calcareous nodules, exposed at water's edge	15
Total thickness measured	40

Sedimentology.—The Beaumont sediments were deposited largely by rivers in the form of natural levees and deltas which coalesced by shifting of the river mouths along the coast, and to a less extent by marine and lagoonal waters in the bays and embayments between stream ridges and delta banks. As the river mouths, and hence the levees and delta levees, shifted, the marine and lagoonal deposits of the interdelta areas were buried beneath the deltaic sediments. The resulting formation is largely deltaic interbedded in places with marine and lagoonal beds. Northward these delta beds are contemporaneous and continuous with the later terraces that occur along all the drainage lines north of the Beaumont clay outcrop. Barton (70, pp. 359–382, 1930) has described admirably the depositional process and points out (74, p. 1309, 1930) that sand was deposited on the terraces and on the crests of the natural levees close to the old stream channels, sandy clays on the flanks, and compact clays in the black bottoms between stream lines. By mapping the sands he has worked out traces of many of the ancient stream lines in the present Beaumont clay surface and found that Beaumont clay soils grade from fine sandy loams on the crests of the ridges into clay loams and from clay loams into clays in the depressions. Near the coast the black clays in places contain marine fossils. A knowledge of the method of deposition of the Beaumont clay, where the ancient ridges, delta bedding, and shifting of stream channels can be observed, enables one to understand better the origin of similar Gulf Coast formations of earlier age.

[270]Measured by William Kennedy, Geology and oil prospects of the lower Brazos River valley: Unpublished manuscript.

Much of the sandy clay of the Wilcox, Cockfield, Catahoula, and Lagarto undoubtedly owes its origin to processes of deposition similar to those exhibited in the Beaumont formation.

Lithology.—In the northeast Gulf Coast area the Beaumont formation consists, according to information derived from well sections, of about 60 per cent clay, 20 per cent silt, and 20 per cent sand. In the central Gulf Coast the formation in some sections is 80 per cent to 90 per cent clay. In the Rio Grande valley the proportion of sand and gravel appears to be much larger, and the formation contains 75 or 80 per cent sand with considerable gravel and some limestone originally deposited as caliche. The sands of the Beaumont are light gray or bluish gray, medium to fine grained, and range in size from one-fourth to one-sixteenth of a millimeter in diameter down to minute grains of silt one-sixty-fourth of a millimeter, with a large part of the sand below one-eighth of a millimeter in diameter. The sand is made up largely of quartz and chert grains together with fragments of recent shells, a small amount of pyrite, and flakes of mica and the usual list of rare, heavy minerals similar to the list given for the Oakville formation. Some of the samples from south Texas differ in containing a larger percentage of grains derived from igneous rocks such as red and pink feldspar, rose quartz, granite, and magnetite.

The clay is bluish gray, yellowish gray, pinkish gray, purple, and some shades of red. It is in most places calcareous in composition and contains calcareous nodules, rarely calcareous concretions, and fragments of more or less decomposed wood. In most places the clay is highly colloidal, and when wet forms a thick, very sticky mud difficult to traverse with car or wagon in the rainy season. These clays are characterized by their low content of lime and comparatively high silica content. The analyses undoubtedly represent the nonmarine portion of the Beaumont clay. Other deposits, particularly some of those containing oyster beds, have a higher percentage of lime. The following analyses reported by Ries (**1320**, p. 241, 1908) show the chemical composition of typical samples of Beaumont clay in Harris County:

	HOUSTON	HARRISBURG	CEDAR BAYOU
Silica (SiO_2)	89.0	80.84	85.60
Alumina (Al_2O_3)	3.69	8.09	6.71
Ferric oxide (Fe_2O_3)	1.65	2.25	1.44
Lime (CaO)	0.47	1.44	Tr.
Magnesia (MgO)	0.65	0.26	0.43
Soda (Na_2O)	0.06	0.10	0.65
Potash (K_2O)	Tr.	Tr.	0.50
Titanic acid (TiO_2)	0.84	0.78	1.00
Water (H_2O)	1.62	6.00	3.10
Total	97.98	99.76	99.43

Distinguishing characteristics.—The Beaumont clay can be recognized by the following criteria:

1. Flat, featureless surface. The surface of the Beaumont is a flat, featureless, treeless plain undissected by broad valleys. The streams, except the large rivers, flow in narrow channels bordered with sand and silt built up slightly above the plain surface. In all clay formations north of the Beaumont the main streams have broad valleys.
2. Soils. The surface soil derived from the Beaumont is typically dark, heavy clay soil, exceedingly sticky when wet and hard when dry and known as the Lake Charles soil. The soil of the Lissie formation below and recent silts above are light silt loams.
3. Water holes or pitted prairies. The surface of the Beaumont clay has in many places small hollows 10 to 15 feet in diameter, locally known as "blow outs" or "hog wallows." These are small spots of poor drainage where a slight excess of alkali prevents or hinders growth of grass and weeds. During dry periods the wind removes dust and after a time forms a slight hollow. Rain water fills the depression and after evaporation leaves the bottom covered with mud cracks and films of dried up alkaline silt which is removed by the next dry wind storm, so that the pits in uncultivated areas are gradually deepened to depths of 20 to 30 inches. The pits occur also on the Lissie plain and other poorly drained areas where clay is the surface formation. They are, however, more common and more characteristic of the Beaumont plain.
4. Pimple prairies. Small knolls 10 to 25 feet in diameter and 1 to 4 feet high occur in clusters or belts over the flat surface of the Beaumont plain in certain areas where patches of silt occur. These pimple-like knolls are especially common along the sandy belts produced by minor levees of former temporary streams.

They occur also on the Lissie formation and on other silty formations in east Texas and Louisiana. They are especially noticeable, however, on the Beaumont plain, where any slight elevation is noticeable in contrast to the generally featureless surface. These knolls were formed by the action of wind at a time when the soil was not fixed by so heavy a vegetation as at present and are thought to be ancient, small dunes now nearly obliterated by weathering and erosion. They are composed of silt and superimposed on an old soil line of clay or hard, silty clay. Veatch and others[271] have discussed the origin of these interesting features in much detail.

5. Wood and partly decomposed organic matter. The Beaumont clay contains much organic detritus in the form of cypress logs, rotten and partly decomposed tree trunks, peat, and plant detritus of various kinds. None of this is mineralized or lignitized as is the wood in the older formations.
6. Invertebrate fossils. The Beaumont clay contains in a few places near the coast oyster and clam shells and rarely a shell bed made up of large numbers of *Ostrea virginica* Gmelin and *Rangea cuneata* (Gray).

Paleontology and correlation.—The Beaumont clay contains few fossils along its outcrop. In a few places brackish-water and marine shells have been found and rarely a bone or tooth of a vertebrate. Shells in this formation are likely to belong to one or two species that occur in large numbers. The most common is *Rangia cuneata* (Gray), a small smooth-surfaced clam, that occurs, in reefs or banks from 3 to 15 feet thick extending laterally for 30 to 75 feet. Such concentrations of shells in piles has been explained as the work of Indians, who undoubtedly lived on the animal. Charred wood, arrow heads and in some places Indian bones have been found in the shell heaps. Pearce,[272] who has examined them critically, however, believes that the piles of shells are not kitchen middens, that they antedated the Indian remains, and served merely as temporary camp sites. He believes that these shell deposits are simply small "reefs" formed by wave and river action. The shells are deposited

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[271]Veatch, A. C., **1689**, pp. 310–311, 1905; **1690**, pp. 350–351, 1905; **1691**, pp. 55–59, 1906; **1692**, pp. 34–36, 1906. Udden, J. A., **1624**, pp. 849–851, 1906. Hill, R. T., **813**, pp. 704–706, 1906. Campbell, M. R., **193**, pp. 708–717, 1906. Wentworth, I. H., **1729**, pp. 818–819, 1906. Farmsworth, **533**, pp. 583–584, 1906. Hobbs, W. H., **835**, pp. 245–256, 1907. Dumble, E. T., **506**, pp. 272–274, 1918. Bailey, T. L., **38**, pp. 24–30, 1923. Hannemann, M., **647d**, pp. 218–224, 1928. Melton, F. A., **1089**, pp. 184–185, 1929.

[272]Pearce, J. E., The archaeology of east Texas: Amer. Anthrop., vol. 34, pp. 671–672, 1932.

originally in the silt and clay, and later they are washed out by river currents. When the stream falls, the waves beat upon the exposed shells and wash them up into beach ridges along the head of the bay or near the mouth of the stream. This process is cumulative until a "reef" is formed. Such "reefs" are found at Grigsby's Bluff on Neches River, Shell Bluff near the mouth of Sabine River, around the head waters of Trinity Bay on Oyster Creek, and along San Jacinto River in Texas. They occur also in the low bluffs along Black Lake near Hackberry Island in Cameron Parish, Louisiana. The shell deposits differ from the ordinary beach barrier ridges in that they are parallel to the old stream beds and are formed by the combined action of the streams and waves instead of by shore currents and waves. *Ostrea virginica* Gmelin occurs also in the Beaumont formation, both singly and in beds of from six inches to a foot in thickness. The oyster beds can be traced in some places for several miles. Oyster beds of this type, however, are rare in Texas. Near Lake Charles, Louisiana, such a layer has been mapped halfway across the parish. Rarely the tooth of an elephant, mammoth, or horse is reported in this clay. One good specimen from the mammoth *Elephas imperator* Leidy was found by the writer on Big Creek 8 miles south of Richmond, Brazoria County. Another large specimen was discovered by August Isle in the Beaumont clay 9 miles south of Garwood in Wharton County. Fossils recorded from the Beaumont clay are as follows:

Rangia cuneata (Gray) (1)
Ostrea virginica Gmelin (1, 3)
Astrangia sp. (3)
Mellita sp. (3)
Terebra protexta Conrad (3)
Terebra dislocata Say var. (3)
Mangilia cerinella Dall (3)
Cancellaria sp. (3)
Oliva literata Lamarck (3)
Olivella mutica Say (3)
Nassa acuta Say (3)
Anachis avara Say (3)
Anachis obesa Adams (3)
Purpura floridana Conrad (3)
Pyramidella sp. (3)
Cerithium floridanum Mörch (3)
Cerithium muscarum Say var. (3)
Scala humphreysi Kiener (3)
Turritella sp. (3)
Littorina littorea Say (3)
Cryptonatica pusilla Say (3)
Neverita duplicata Say (3)
Natica sp. (3)
Leda acuta Say (3)
Arca pexata Say (3)
Arca incongrua Say (3)
Arca transversa Say (3)
Diplodonta semiasper Philippi (3)
Cardium magnum Linné (3)
Tellina (Angulus) texana Dall (3)
Strigilla flexuosa Say (3)
Chione cancellata Linné (3)
Anomalocardia rostrata Savage (3)
Abra aequalis Say (3)
Petricola pholadiformis Linné (3)
Pholas costata Linné (3)
Donax texasiana Philippi (3)
Mulinia lateralis Say (3)
Corbula barrattiana C. B. Adams (3)
Corbula swiftiana C. B. Adams (3)
Elephas imperator Leidy (2)

Localities recorded in above list—
1. Well 4 miles southwest of La Ward, Jackson County.
2. Robstown, Nueces County.
3. Depth of 370 feet in a well near Alligator Head, Calhoun County (species identified by T. W. Vaughan).

Economic resources.—The only features of economic value in the Beaumont clay are its highly colloidal black or dark-gray, acid soils classified by Carter[273] as Lake Charles soils, and its brick clays. The principal type of soil on this formation is clay of the calcareous character. It produces open-prairie grasslands, which characterizes the coastal plain. This grassland constitutes the grazing areas of south Texas, and thousands of head of Brahma cattle are raised along this belt annually. Near the cities and towns the soil is intensively cultivated and supports extensive truck gardens and fig orchards. In Matagorda, Jackson, and Jefferson counties, where water for irrigation is available, rice is raised on a large scale. Most of the Beaumont clay is too calcareous and has too high a shrinkage coefficient to produce a high grade of brick. Small brick yards, however, are in operation near the town of Sheldon 12 miles east of Houston, at Harrisburg, and at Cedar Bayou, Harris County. At Beaumont in Jefferson County a fair quality of common yellow pressed brick is manufactured.

PLEISTOCENE STREAM DEPOSITS

DEFINITION

Strata of Pleistocene age occur in the form of terraces along all the principal stream courses north and northwest of the outcrop of the Lissie formation, in bolsom deposits in the intermontane valleys of the Trans-Pecos Texas, and in ancient stream valleys cut in the surface beds of the Llano Estacado of northwest Texas.

SUBDIVISIONS

Two Pleistocene deposits north of the Gulf Coast have been named, as follows:

Leona formation.
Tule formation.

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[273]Carter, W. T., The soils of Texas: Texas Agric. Exper. Sta. Bull. 431, p. 23, 1931.

LEONA FORMATION[274]

The name Leona was given by Hill and Vaughan (795, pp. 253–254, 275–276, 1898) to include terrace deposits along the principal streams of Texas. The deposits are composed of red and reddish-gray silt and fine gravel. The terraces range from 20 to 120 feet above the present water level and have widths ranging from a few feet to several thousand feet along the larger rivers. The deposits are widest on the south sides of the east-flowing streams. Vertebrate remains and fresh-water mollusks are common in these sand and silt layers. The following forms are typical:

Mollusks

Bulimulus dealbatus Schiedeanus
Helecina tropica Pfeiffer
Pampsilis purpuratus Lamarck?
Planorbis tricarinatus Say
Polygyra texasiana Mori
Unio tetralasmus var. camptodon Say
Unio tetralasmus var. manubius Gould

Vertebrates

Testudo francisci Hay (8)
Glyptodon petaliferus Cope (13, 15)
Mylodon harlani Owen (1, 7)
Nothrotherium texanum Hay (14)
Neochoerus pinckneyi (Hay) (15)
Camelops aransus Hay (15)
Camelops hesternus Leidy (2)
Mammut americanum Kerr (1, 5)
Elephas columbi Falconer (2, 3, 7, 12, 15)
Elephas imperator Leidy (2, 4, 7, 8)
Elephas boreus Hay (6)
Anancus brazosius Hay (1)
Anancus ovarius Hay (15)
Anancus defloccatus Hay (15)
Equus semiplicatus Cope (7, 15)
Equus francisci Hay (7)

Localities from which vertebrates are recorded—

1. Hog Creek, 3 miles northwest of Speegleville, McLennan County.
2. White Rock sand pits above Waco, upper terrace of Brazos River, McLennan County.
3. Second terrace of Brazos River at Third and Bosque streets, Waco, McLennan County.
4. Moore gravel pit in second terrace, Brazos River, near Waco, McLennan County.
5. J. B. Warner gravel pit, 1½ miles east of Belton, 100 feet above Leon River, McLennan County.
6. McGregor gravel pit, one-half mile north of ford over Leon River east of Belton, Bell County.
7. Midway gravel pit halfway between Belton and Temple, Bell County.
8. Gravel pit, 1 mile east of courthouse at Fort Worth, Tarrant County.
9. Medina River, near Frio road crossing south of San Antonio, Bexar County.

[274]LITERATURE—Hill, R. T., and Vaughan, T. W., 795, pp. 253–254, 275–276, 1898. Dumble, E. T., 506, pp. 264–269, 1918. Ashley, G. H., 36, p. 252, 1919. Sellards, E. H., 1402, pp. 69–72, 1919. Winton, W. M., and Adkins, W. S., 1789, p. 84, 1919; and Scott, G., 1790, p. 33, 1922. Adkins, W. S., 11, pp. 83–85, 1923; and Arick, M. B., 16, pp. 66–69, 1930. Trowbridge, A. C., 1610, p. 101, 1923. Deussen, A., 421, pp. 114–119, 1924. Patton, L. T., 1185, p. 53, 1930.

10. White Rock shoals, Trinity River.
11. Forks of Harvey Creek, 3 miles northeast of Weimar, Colorado County.
12. Colorado River terrace, 1 mile south of Columbus, Colorado County.
13. Along middle Sulphur Creek about nine feet below surface in gravel bed overlain by clay, near Wolfe City, Hunt County.
14. Dug well in Wheeler County.
15. West bank of Aransas River, 1 mile north of bridge on which St. Louis and Brownsville R.R. crosses the Aransas near Sinton, San Patricio County.

The vertebrate remains, according to Hay (**682**, p. 116, 1923) are indicative of early Pleistocene time and are approximately equivalent to the Sheridan beds of Nebraska.

TULE FORMATION[275]

The name Tule was given by Cummins (**346**, pp. 199–200, 1893) to exposures of Pleistocene deposits in Tule Canyon on the east side of the Llano Estacado in Swisher County. The formation includes the strata in valleys overlying the Blanco beds of Blanco age. With the exception of recent wind-blown deposits, these sands are the youngest strata in the Llano Estacado and range in thickness from 0 to 150 feet. They do not outcrop, so far as known, along the rim of the High Plains. The Tule formation has been called also Rock Creek beds and Equus beds by other authors.

The fauna of the Tule beds has been studied by Cope (**314**, pp. 75–87, 1893), Gidley (**582**, pp. 622–624, 1903), Lull (**1026**, pp. 325–385, 1915), Troxell (**1614**, pp. 613–638, 1915), and Matthew (unpublished manuscript, 1924).

Fauna[276] of Tule beds

Arctotherium sp.
Canis cf. C. dirus Allen
Canis cf. C. priscolatrans Cope
Palaeocyon texanus (Troxell)
Mylodon harlani Owen
Equus scotti Gidley
Equus semiplicatus Cope
Elephas columbi Falconer
Platygonus sp.
Camelops cf. C. hesternus (Leidy)
Camelops cf. C. kansanus Leidy
Holomeniscus macrocephalus Cope
Preptoceras mayfieldi Troxell

Localities where above species have been collected—

1. Near head of Tule Canyon, about 10 miles east of Tulia in Swisher County.
2. Gulches in badlands and along small side canyons one-half mile east of Tule Canyon, Swisher County.

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[275]LITERATURE—Cummins, W. F., **346**, pp. 199–200, 1893. Cope, E. D., **314**, pp. 75–87, 1893. Gidley, J. W., **582**, pp. 622–624, 1903. Lull, R. S., **1026**, pp. 325–385, 1915. Troxell, E. L., **1614**, pp. 613–624, 1903. Matthew, W. D., Ms. 1924; **1288a**, pp. 69–70, 1932.

[276]Matthew, W. D., Observations on the Tertiary of the Staked Plains: MS., 1924.

3. Rock Creek, a lateral canyon 3 miles long running into Tule Canyon from the south about 6 miles from its head, Swisher County.

According to Matthew, the fauna of the Tule beds is decidedly different from that of the Blanco and Clarendon beds. The difference "represents a considerable lapse in time accompanied by extensive migration and extinction of many animals." The horses, peccaries, and camels may be regarded as approximately direct descendants of certain Blanco species, but as the rest of the fauna consists of migrant types, it is not unlikely that these are also newcomers from some other region. Matthew believed the Tule beds to be younger than any other strata in the Panhandle formation and observed that they were deposited apparently in valleys in the surface of some of the earlier sediments of the Panhandle formation. He placed the Tule fauna in the lower Pleistocene and correlated it with the Sheridan fauna of Nebraska.

The correlation of the faunas of the Staked Plains with Pliocene and Pleistocene faunas of the Gulf Coast is not clear, as so few species are common to the two areas.

Volcanic Rocks of Cenozoic Age[277]

Investigations.—The first mention of igneous rocks in west Texas in scientific publications is to be found in the early reports of United States army engineers who explored the Southwest to establish boundary lines and to select routes for trains and transcontinental roads. Marcy (**1054**, p. 200, 1850), William P. Blake (**120**, pp. 1–50, 1856), James Hall (**643**, pp. 107, 109–111, and 120–121, 1857), and C. C. Parry (**1178**, pp. 49–61, 1857) in Major Emory's report all describe briefly volcanic rocks of different sorts, minerals, and ores in west Texas. The first extended investigation of the geology of the Trans-Pecos country was made by von Streeruwitz

[277]Literature—Streeruwitz, W. H. von, **1560**, pp. 217–226, 1890; **1561**, pp. 665–701, 1891; **1566**, pp. 141–159, 1893. Osann, C. A., **1160**, pp. 341–346, 1893; **1161**, pp. 123–138, 1893; **1162**, pp. 394–456, 1896. Turner, H. W., **1617**, pp. 453–455, 1895. Lord, E. C. E., **1014**, pp. 90–95, 1900. Udden, J. A., **1623**, pp. 42–44, 1904; **1626**, pp. 70–75, 1907. Richardson, G. B., **1312**, pp. 6–7, 1909; **1314**, pp. 6–7, 1914. Baker, C. L., and Bowman, W. F., **44**, pp. 141–146, 1917. Schoch, E. P., **1378**, pp. 67–73, 184–187, 1918. Udden, J. A., Baker, C. L., and Böse, E., **1652**, pp. 100–101, 1919. Lonsdale, J. T., and Adkins, W. S., **1007**, pp. 256–259, 1927. Baker, C. L., **46**, pp. 34–37, 1927; **53**, pp. 79–82, 1929. Lonsdale, J. T., **1010**, pp. 449–450, 1928; **1012**, pp. 26–32, 1929. King, Phillip B., **936**, pp. 99–103, 1931.

(**1560**, pp. 217–226, 1890; **1561**, pp. 665–701, 1891; **1566**, pp. 141–159, 1893). Von Streeruwitz traveled over the country, made many observations and collected large numbers of specimens of minerals and volcanic rocks. His collections were studied by C. A. Osann (**1161**, pp. 123–138, 1893; **1160**, pp. 341–346, 1893; **1162**, pp. 394–456, 1896), who identified and described the specimens and later made an excursion into the region himself. The next important contribution to the petrography of the volcanic rocks was made by Lord (**1014**, pp. 90–95, 1900) who described the rocks in the vicinity of San Carlos and Chispa in Culberson and Jeff Davis counties. A few years later Udden (**1623**, pp. 42–44, 1904; **1626**, pp. 70–75, 1907) published brief accounts of the volcanic rocks in the Shafter mining district, Presidio County, and Chisos Mountains in Brewster County, and Richardson (**1312**, pp. 6–7, 1909; **1314**, pp. 6–7, 1914), aided by experts in the United States Geological Survey, published a report on the rocks in the Van Horn and El Paso quadrangles. In recent years Baker (**44**, pp. 141–146, 1917; **46**, pp. 34–37, 1927; **53**, pp. 79–82, 1929), Lonsdale (**1007**, pp. 256–259, 1927; **1010**, pp. 449–450, 1928; **1012**, pp. 26–32, 1929), and King (**936**, pp. 99–103, 1931) have all made important contributions to the knowledge of vulcanism in west Texas. Most of the field work has been of a reconnaissance character. The area is vast, and the igneous masses are scattered and represent a large number of types so that much detailed mapping and much painstaking petrographic work is necessary before an authoritative treatise of the geology of the igneous rocks can be undertaken. This account is merely a summary of what has been written up to this time about the younger volcanic rocks of Texas.

Regional geology.—Igneous rocks of Cenozoic age occur in the Big Bend district of the Trans-Pecos area of west Texas. The principal outcrops cover the greater portion of Jeff Davis, the south corner of Reeves, the northwest portion of Brewster, and all the eastern half and portion of the northwestern part of Presidio counties. In addition there are many isolated areas of igneous rock thought to be of Cenozoic age in southern Brewster, southern Culberson, and southern El Paso counties. In general igneous rocks occur along the belt of intense folding and faulting characteristic of the Cordilleran structure which crosses the extreme western portion of Texas.

Lithology.—The igneous rocks of west Texas occur in a large variety of forms, although the intrusives predominate. Porphyries in the form of dikes, plugs, and sills are common. Laccolithic bosses of granite, syenite, and diorite cover large areas. Extrusions of lava, tuffs, agglomerates, and ash are found throughout the area. Associated with the intrusives are minerals formed by the contact of the igneous with the sedimentary beds and metamorphic rocks produced by action of heat on the sediments in contact with the intrusives. Conglomerates, sandstones, and fine-textured pond and lake deposits are interbedded with the lava and ash beds. In some places the sedimentary beds contain fresh-water mollusks, plant leaves, and mammalian bones that help to establish the geologic age of the deposits. Altogether, west Texas presents a rich variety of igneous, metamorphic, and contact rocks and minerals in such variety of forms and so beautifully exposed as to interest and delight every petrographer who is so fortunate as to make an excursion through the Big Bend country.

The most widespread group of igneous rock is the porphyry. This group includes rhyolite porphyry, granite porphyry, andesite porphyry, trachyte porphyry, basalt porphyry, and syenite porphyry. The rhyolite is a light-colored, pinkish-buff rock made up of phenocrysts of orthoclase feldspar and quartz in an indeterminable ground mass. It is widespread over the volcanic areas of west Texas in the form of near-surface sills, dikes, and lava flows. The granite porphyry is of similar light color but more distinctly crystalline. It consists of distinct phenocrysts of quartz and feldspar set in a granular ground mass of the same minerals. It occurs in laccoliths and deep-seated formations. The andesite porphyry is a light-colored rock consisting of phenocrysts of plagioclase feldspar with no quartz set in an undeterminable ground mass. The rock is less common than the rhyolites and granites. According to Baker,[278] it occurs in flows and dikes especially in the area around Chispa Mountain. The trachyte porphyry is similar to the rhyolite but

[278]Baker, C. L., Cenozoic igneous rocks of Trans-Pecos: MS. submitted to Bureau of Economic Geology, 1932.

contains no quartz. The basalt porphyry is a dark-colored, fine-grained, dense rock containing phenocrysts of plagioclase feldspar in a black, indeterminable ground mass. It occurs in dikes. The syenite porphyry is similar to the granite porphyry except that it contains no quartz. It also contains traces of biotite, hornblende, and pyroxene, either as phenocrysts or in the ground mass. The syenites occur as stocks and plugs. They have domed up sedimentary rocks and older lavas in a number of places. Diorite intrusives occur in the Diablo Plateau. The diorite is a dark-colored rock composed of phenocrysts of plagioclase feldspar, hornblende, biotite, and pyroxene either separately or together in a determinable ground mass of the same minerals.

Basalt, next to the porphyries, is most common. It occurs on the surface as the most recent deposit in some places. In others it is interbedded with tuffs, tuff-breccias, agglomerates, and other sediments. The flows range in texture from obsidian through pitchstone and vitrophyre to porphyritic basalt. Basalt is common in Van Horn Mountains, in the area south of Wylie Mountains, south of Malone Mountains, in Tierra Vieja Mountains (Rim Rock country), and in the Presidio district. The basalt in west Texas is dark colored, mainly black, and so fine grained that no crystals can be seen with a lense. Some of it is cellular or scoriaceous, and in some places the cavities contain fillings of zeolites and chlorite. The rock grades into coarse-grained granular porphyries. The most common rock of this type is the olivine-basalt or diabase. In texture it falls between the basalt porphyry and the dense cryptocrystalline black lava.

The tuff occurs in most of the igneous areas. In most places it is interbedded with other sediments or volcanic flows. It is light colored, white, pink, buff, pale brown, or variegated. This tuff is fine grained, light in weight, and has a chalky consistency. It is, however, less calcareous and more gritty than chalk.

Volcanic breccia and agglomerate occur in the Davis Mountains and doubtless in other of the volcanic ridges of west Texas. The breccia in most places is a mixture of rounded volcanic bombs, cobbles, and chunks of lava and fragments of sedimentary rocks held together in a matrix of volcanic mud.

The occurrence of the different types of igneous rocks is shown in the accompanying table[279] (footnotes by author)

Types of igneous rocks in west Texas

LOCALITY	COUNTY	FORM	ROCK
Barilla Mts.	Reeves and Jeff Davis	Lava flow	Rhyolite
		Ash bed	Tuff
Big Hill Canyon	Presidio	Dikes	Essexite[a]
East flanks of Carmen Range near junction of Maravillas Creek and Rio Grande	Brewster	Lava flows	Basalt
Chinati Mts.	Presidio	Lava flows	Rhyolite and basalt
		Dikes and sills	Andesite and syenite
Chisos Mts. and neighboring ranges	Brewster	Lava flows	Rhyolite Basalt Obsidian Felsite
		Dikes and sills	Dacite Phonolite Grorudite[b] Andesite porphyry
Chispa Mts. (north of Chispa)	Jeff Davis-Culberson	Dikes and sills	Syenite porphyry Rhyolite Andesite porphyry
		Lava flows	Basalt
Cienega Mt.	Brewster	Laccolith	Granite
Davis Mts.	Jeff Davis	Dikes and sills	Nephelite-syenite Eleolite-syenite Phonolite Trachyte Andesite
		Lava flows	Paisanite[c] Basalt Rhyolite
Eagle Mt.	Hudspeth	Ash beds	Rhyolite
		Lava flows	Basalt
		Agglomerate and breccia beds	Tuff and tuff breccias
Finlay Mts.	Hudspeth	Intrusions	Syenite porphyry Hornblende porphyry
Franklin Mts.	El Paso	Laccolith	Granite
Hueco tanks, Hueco Mts.	El Paso	Dikes	Syenite porphyry
Iron Mt. north of Marathon	Brewster	Plug	Syenite porphyry
Mount Ord Range	Brewster	Laccolith	Granite
		Dikes	Syenite
		Lava flows Tuffs	Rhyolite porphyry

[a]Essexite is intermediate between a diorite, gabbro, and nephelite syenite. It contains labradorite, some orthoclase, and in some cases nephelite.
[b]Grorudite is a fine-grained porphyry composed of alkali feldspars rich in soda, quartz, aegirite, and sometimes hornblende and mica.
[c]Paisanite is a variety of quartz porphyry composed of soda orthoclase and quartz which phenocrysts of the same minerals.

[279]Baker, C. L., Cenozoic igneous rocks of Trans-Pecos: MS. submitted to Bureau of Economic Geology, 1932.

LOCALITY	COUNTY	FORM	ROCK
Quitman Mts.	Hudspeth	Laccolith	Granite
		Intrusives	Syenite Aplite Augite porphyry
		Lava flows	Keratophyre
Santiago Range	Brewster	Sills	Pulaskite[d]
Sierra Blanca	Hudspeth	Lava flows	Rhyolite and trachyte
		Plugs	Phonolite?
Sierra Bofecillas	Presidio	Lava flows	Augite andesite
Sierra Diablo	Culberson-Hudspeth	Laccolith	Diorite Quartz-diorite
Tierra Vieja Mts.	Presidio-Jeff Davis	Intrusives	Syenite porphyry
		Dikes	Olivine-diabase
		Lava flows	Nepheline-tephrite[e] Quartz-pantellerite[f] Rhyolite Latite
Solitario	Presidio-Brewster	Intrusions	Felsite and diabase
Van Horn Mts.	Culberson-Hudspeth	Dikes	Andesite
		Lava flows	Rhyolite Basalt
Wylie Mts.	Culberson	Lava flows	Andesite Basalt
East of Santiago Range, south and southeast of Marathon	Brewster	Plugs	Porphyry Basic intrusives
South of Wylie Mts.	Culberson	Plugs	Syenite porphyry

[d]Pulaskite is composed of soda-orthoclase, a subordinate amount of hornblende and biotite, little diopside, nephelite, sodalite, and some accessory minerals. It is a syenite with trachytic texture containing a little nephelite.

[e]Nepheline tephrite resembles basalt but differs in its composition that includes both plagioclase and nepheline.

[f]Pantellerite is intermediate in composition between dacite and liparite and is more or less trachytic in texture.

Relationship of igneous rocks and sedimentary strata.—The Cenozoic igneous rocks rest upon Upper Cretaceous strata along the eastern escarpment of the central igneous plateau between the northeastern Davis Mountains on the north and the southern margin of Green Valley on the south. The underlying Cretaceous strata are thought by Baker[280] to be equivalent to the Navarro or possibly somewhat younger (Laramie). The volcanic rocks along the "Rim Rock" area of western Presidio County rest upon the Rattlesnake beds, also of Upper Cretaceous age. Northward along the "Rim Rock," according to Baker, the volcanics overlie successively older Cretaceous sediments. At Chispa Summit, for example, they rest upon the Eagle Ford. Southward from San Carlos Basin the same relationship exists as on the north side. The igneous rocks rest upon the Taylor in the vicinity of Capote Ranch, on the Edwards at Silver

[280]Baker, C. L., Cenozoic igneous rocks of Trans-Pecos: MS. submitted to the Bureau of Economic Geology, 1932.

Dome Mountain, and on the Word formation of Permian age in Pinto Canyon. The volcanic rocks in the northern part of the Trans-Pecos lie upon faulted and eroded Lower Cretaceous rocks. The Cretaceous strata were overthrust toward the northeast, some of the folds and faults were peneplained, and igneous rocks poured out from both Sierra Blanca and Eagle Mountain upon the acutely deformed strata.

The volcanic rocks are overlain in valleys by sand and gravel thought to be equivalent to some of the Pliocene or lower Pleistocene deposits of the High Plains. Thus the main body of the igneous rocks of Jeff Davis and Presidio counties appears to be younger than Upper Cretaceous (Navarro) and older than upper Pliocene (late Panhandle).

Age of the igneous rocks.—The volcanic rocks are of many types and represent probably a number of different epochs of eruption that may have begun in the late Mesozoic and continued spasmodically through the greater portion of the Cenozoic era. Baker[281] points out that volcanic ash and its alteration product bentonite are found in all Gulf Coast sediments from the Woodbine to the Goliad. The Woodbine, Eagle Ford, Navarro, Midway, Carrizo, Yegua, Jackson, Catahoula, Oakville, Lagarto, and Goliad all contain some ash and tuff, but especially the Jackson and Catahoula. Basalts, according to M. B. Arick,[282] are interbedded with lacustral beds in the Rio Grande valley in southern Presidio County. The lake beds are thought to be of Pliocene or Pleistocene age. It is possible that eruptions in Texas occurred as late as the Quaternary, since late flows are known to have taken place in New Mexico. Since no remains of craters or other evidence of very late activity has been found, most geologists are inclined to assign an earlier age to the flows. This is true particularly for the Davis and Barilla Mountains area where the volcanic rocks are gently folded and faulted. Basal tuffs in the Barilla Mountains contain fossil plant leaves which E. W. Berry (**104**, pp. 1–4, 1919) has identified and correlated with the flora of the Raton and Denver formations of lower Eocene age. The rhyolitic tuffs in Eagle Mountains, Hudspeth County, have yielded bones of late Tertiary land tortoises. A tuff bed on the

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[281]Baker, C. L., Cenozoic igneous rocks of Trans-Pecos: MS. submitted to the Bureau of Economic Geology, 1932.

[282]Quoted by C. L. Baker, idem.

Casey ranch on the northeast flank of the Davis Mountains and 11 miles west of Balmorhea yielded also a few land snails resembling *Planorbis* and vertebrate bones. The horizon is about 200 feet above the base of the volcanic section. The most important specimen was determined by R. A. Stirton[283] to be the tooth of a lower or middle Oligocene rhinoceras belonging to the genus *Hyracodon.* Land snails belonging to the genus *Helix* have been collected by Nelson from tuff beds on O2 Ranch located 20 miles southwest of Alpine in the Davis Mountains. These were identified by Junius Henderson[284] and compared by him with similar fossils from either the Puerco or Torrejon formations in New Mexico.

Baker[285] believes that the volcanic activity in the southwest portion of Trans-Pecos may be somewhat younger than that in the northeast portion of the province. He concludes that the rhyolites, tuffs, and tuff-breccias of the eastern part of the Trans-Pecos represent the earliest igneous activity. These were succeeded by widespread eruptions of syenite-trachytes and phonolites. The syenite porphyries were the most extensive. Andesite eruptions followed, especially in the area around Chispa and the Big Bend. Latest of all seem to have been the basalts of Van Horn Mountains, the area south of Wylie Mountains, and in the Presidio country south of Malone Mountains. Basalt porphyries and augite-basalt porphyries cut other intrusives in Quitman Mountains. Olivine basalt porphyries cut all older strata and other igneous rocks in the "Rim Rock" area of the Big Bend. With the exception of these important observations by Baker, the geologic history of the volcanic rocks of west Texas has not been worked out in detail. Tertiary geologic history of the Trans-Pecos remains one of the many interesting and complicated problems that challenge the enterprise of future geologists and petrographers.

Economic resources.—The economic resources of the volcanic rocks of west Texas are the picturesque scenery of its rugged mountains, deep canyons, and cactus-adorned slopes, its numerous deposits of ore-bearing rocks, and its pasture lands. Each year increasing numbers of tourists travel into the Big Bend country to

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[283]Stirton, R. A., letter to C. L. Baker.

[284]Quoted by W. S. Adkins, this paper, p. 514.

[285]Baker, C. L., Cenozoic igneous rocks of Trans-Pecos: MS. submitted the Bureau of Economic Geology, 1932.

enjoy the life in the beautiful resort towns. The ore deposits of the Trans-Pecos country have been known, prospected, and mined more or less actively for fifty years. The principal deposits are silver and mercury minerals. Silver[286] has been produced at Shafter in Presidio County for more than fifty years, and has enriched the State by eight to ten millions of dollars. The silver ore is cerargyrite (silver chloride) associated with galena (lead sulphide), calcite, and hematite. The ore occurs in irregular pockets or lodes from a few feet to a hundred feet in length along the contact of igneous intrusions with metamorphosed limestones (Cibolo) of Permian age. Mercury mines[287] are in operation near Terlingua in Presidio County, where the ore has been known since 1900. The mercury occurs chiefly in the form of cinnabar in Lower Cretaceous limestone and to a less extent in the Eagle Ford clays of the Upper Cretaceous. The ore is found in fissures, veins, mineralized fault lines, and as underground placer deposits. The lodes are cut by igneous dikes, sills, and faults. All the deposits are in the general vicinity of some igneous body. The cinnabar is associated with granular calcite and a pinkish earthy mass of insoluble calcium, aluminum silicate. It is mined, crushed, and refined by roasting in retorts.

Lead,[288] following silver and mercury, is the third most important metal in west Texas. Lead prospects are located near Altuda and north of Van Horn Mountains in Culberson County, in the Quitman Mountains in Hudspeth County, and in the Chinati Mountains and near Shafter in Presidio County. Mines and prospects from which lead, copper, and silver have been obtained are given in the table on page 808.

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[286]LITERATURE—Dumble, E. T., 459, pp. lxvii-lxviii, 1891. Udden, J. A., 1623, pp. 32–44, 1904. Phillips, W. B., 1219, pp. 202–203, 1914.

[287]LITERATURE—Turner, H. W., 1618, p. 64, 1900; 1619, pp. 265–281, 1906. Hill, Ben F., 722, pp. 1–74, 1902. Moses, A. J., 1143, pp. 253–263, 1903. Phillips, W. B., 1202, pp. 160–161, 1904; 1208, pp. 155–162, 1905. Hillebrand, W. F., and Schaller, W. T., 831, pp. 259–274, 1907; 832, pp. 1–174, 1909. Udden, J. A., 1648, pp. 1–30, 1918. Lonsdale, J. T., 1013, pp. 626–631, 1929.

[288]LITERATURE—Phillips, W. B., 1203, p. 364, 1904; 1219, pp. 14–15, 1914. Paige, Sidney, 1171, pp. 75–77, 1911; 1172, p. 14, 1912.

Minerals[a] associated with Cenozoic igneous rocks

NAME	COMPOSITION	LOCALITY	COUNTY
Agate	SiO_2	Chinati Mts.	Presidio
Amethyst	SiO_2	Sierra Blanca	Hudspeth
Amphibole		Quitman Mts. Carrizo Mts. Van Horn Mts.	Hudspeth and Culberson
Argentite	Ag_2S	Hazel Mine, Sierra Diablo Mts.	Hudspeth
Azurite	$2CuCO_3$ $Cu(OH)_2$	Sierra Diablo Mts. Carrizo Mts.	Hudspeth
Calomel	Hg_1Cl_1	Terlingua district	Brewster
Cassiterite	SnO_2	Quitman Mts. Franklin Mts.	Hudspeth and El Paso
Cerargyrite	AgCl	Chisos Mts.	Brewster
Chalcocite	Cu_2S	Carrizo Mts. Hazel Mine	Hudspeth
Chalcopyrite	$CuFeS_2$	Hazel Mine	Hudspeth
Christophite		Quitman Mts.	Hudspeth
Chrysocolla	$CuSiO_32H_2O$	Sierra Diablo	Hudspeth
Cinnabar	HgS	Terlingua	Brewster
Cuprite	Cu_2O	Boracho Mts. Quitman Mts.	Culberson-Jeff Davis
Galena	PbS	Quitman Mts. Carrizo Mts. Mt. Ord Range	Hudspeth and Brewster
Gold	Au	Quitman Mts. Carrizo Mts.	Hudspeth
Hematite	Fe_2O_3	Sierra Blanca Quitman Mts. Carrizo Mts.	Hudspeth
Magnetite	Fe_3O_4	Carrizo Mts.	Hudspeth
Malachite	$CuCO_3$ $Cu(OH)_2$	Quitman Mts. Sierra Diablo Sierra Blanca Franklin Mts. Carrizo Mts.	Hudspeth and El Paso
Molybdenite	MoS_2	Rare, north of Van Horn in Sierra Diablo	Hudspeth
Opal	SiO_2 $(H_2O)_x$	Van Horn wells	Culberson
Pitchblende		Hunter district in Quitman Mts.	Hudspeth
Psilomelane	MnO_2	Sierra Blanca Quitman Mts.	Hudspeth
Pyrolusite	MnO_2	Sierra Blanca Quitman Mts.	Hudspeth
Siderite	$FeCO_3$	Sierra Blanca Quitman Mts.	Hudspeth
Silver, haloids, and argentiferous galena	Ag, etc.	Shafter district Chinati Mts.	Presidio
Stromeyerite	CuAgS	Hazel mine	Hudspeth
Tetrahedrite	$4Cu_2S\text{-}Sb_2S_3$	Diablo Mts. Hazel mine Carrizo Mts.	Hudspeth
Torbernite	$Cu(UO_2)_2\text{-}(PO_4)_2\text{-}BH_2O$	Hunter mine	Hudspeth
Turquoise	$H(Al_2OH)_2\text{-}PO_4$	Quitman Mts.	Hudspeth
Wolframite	$(FeMn)\text{-}WO_4$	North of El Paso North of Van Horn	El Paso and Culberson
Wulfenite	$PbMoO_4$	Quitman Mts. Garlin mine	Hudspeth

[a]All the minerals are ore minerals except opal and amethyst, which are ornamental, and agate, which is used for ornament, marbles, and mortars. All the minerals are contact minerals except magnetite, amethyst, and amphibole, which occur in igneous rocks, and agate, which occurs in vugs and cavities in contact rocks.

Mines and prospects that have produced lead, copper, zinc, and silver.

MINE	LOCALITY	COUNTY	METAL
Hazel mine	North of Van Horn	Culberson	Silver, copper, and lead
Bonanza mine	Northern part of Quitman Mountain	Hudspeth	Zinc, copper, silver, lead
Alice Ray mine	Northern part of Quitman Mountain	Hudspeth	Zinc, copper, silver, lead
Sierra Blanca prospect	Intrusive sill, 1 mi. SW. of Sierra Blanca	Hudspeth	Copper
Plata Verde prospect	West foot northern Van Horn Mountains	Culberson	Copper, silver
Dick Love prospect	West side of Eagle Mountain	Hudspeth	Silver

Most of these mines are not worked at present. In favorable years, however, as much as 320 tons of lead valued at more than $28,000 have been obtained.

Supplies of building stone, china clay, and underground waters are other outstanding economic resources. The syenites of the Quitman Mountains, Iron Mountain, and Wylie Mountains are desirable building stones. The rhyolite tuffs in many places are easily cut by saws, they withstand weathering very well, and have attractive colors. The contact metamorphic marbles of the Cienega and Sierra Diablo mountains are also noteworthy. China clay, in the form of ancient hot springs deposits, occurs, according to Baker, in considerable quantity north of the Fort Davis-Valentine road, sixteen miles from Fort Davis and also in other places in Trans-Pecos. Underground water is found in the bolson deposits of the intermontane valleys. Wells are most productive at the mouths of long draws and where branch valleys approach the outer foothills of the range.

Some of the commonest ore minerals that are associated with Cenozoic volcanic rocks in west Texas are shown in the table on page 807.

EXPLANATIONS OF PLATES VII TO X

SOME NOTEWORTHY CENOZOIC FOSSILS

Life evolved rapidly during the Cenozoic era. The faunas from most of the zones, if studied closely, can be easily distinguished from the faunas of the overlying and underlying zones. Certain fossils, because they are common, because they have distinctive ornamentation, and because they evolved more rapidly than others, constitute better guide fossils. These are shown on Plates VII to X.

The forms illustrated, all of which were marine in habitat, are only a few of the great number of Texas Cenozoic species selected as especially useful in stratigraphic studies. In addition, the land was occupied by a land and fresh-water flora and fauna. During this era the great mammalian faunas developed, for whereas mammals originated in Mesozoic time they did not become dominant until Cenozoic time. Coincident with the development of the mammals was the development of herbage suitable to the requirements of the herbivorous forms. Limitation of space prevents illustration or description of even the most striking of the Cenozoic mammals, many of which existed in the Texas region. Lists of species of vertebrates will be found under the formations in which they occur.

The foraminifera, minute miscroscopic unicellular animals, are illustrated in Plate VII. These very low forms of life have existed in the oceans from the Cambrian to the present. They developed a multitude of shell forms, and the shape and ornamentation of the shell changed from one epoch to another, so that these minute animals have proved to be of greatest help in identifying formations from well samples, where it is impossible to obtain large fossils. The diversity and complexity of the minute foraminiferal shells are well shown in the plate.

A characteristic and very common genus of bivalves, *Venericardia*, is illustrated by several species on Plate VIII. This group ranges from the lowest Eocene to recent times. The sculpture of the shell consists of radiating ribs that increased in number and complexity of ornamentation as the animal developed. Two main groups of species are recognized, planicostate shells that have wide flat radials and alticostate shells that have narrow, serrate, and noded ribs. The latter group, which is the easier to differentiate, is illustrated in the plate.

Forms of *Volutocorbis*, beautiful spindle-shaped snails, are shown on Plate IX. They are slightly less common than the turritellids but equally variant from one zone to another and therefore excellent zone fossils. They are more likely to be found in clay deposits than the turritellids, which liked shallow water and sandy bottoms and limestone reef zones.

Species of *Turritella*, tall turreted gastropods, which range from the Lower Cretaceous to Recent, are illustrated on Plate X. They were common during the Eocene in Texas. The group comprises a series of beautiful, ornamented shells that vary in details of sculpture from one epoch to another as the animal evolved and adapted itself to changing environments.

The nautiloids, best exemplified today by the pearly *Nautilus* of the southern seas, were common during the Eocene in Texas. Two genera are represented, *Hercoglossa* Conrad and *Aturia* Bronn. The former was especially plentiful in the Midway seas, and in places the shells form a nautiloid bed a foot or more thick and traceable for several miles. The latter appears to be confined to the Claiborne and later strata. An interesting example of *Hercoglossa* from the Kerens member of the Wills Point formation in the Midway group is illustrated in figure 53, page 817.

Only the commonest and most noteworthy species of these groups of fossils are illustrated. Most of these can be identified by referring to the figures on the plates and to the tables in which the common measurements and characteristics of each shell are summarized.

PLATE VII

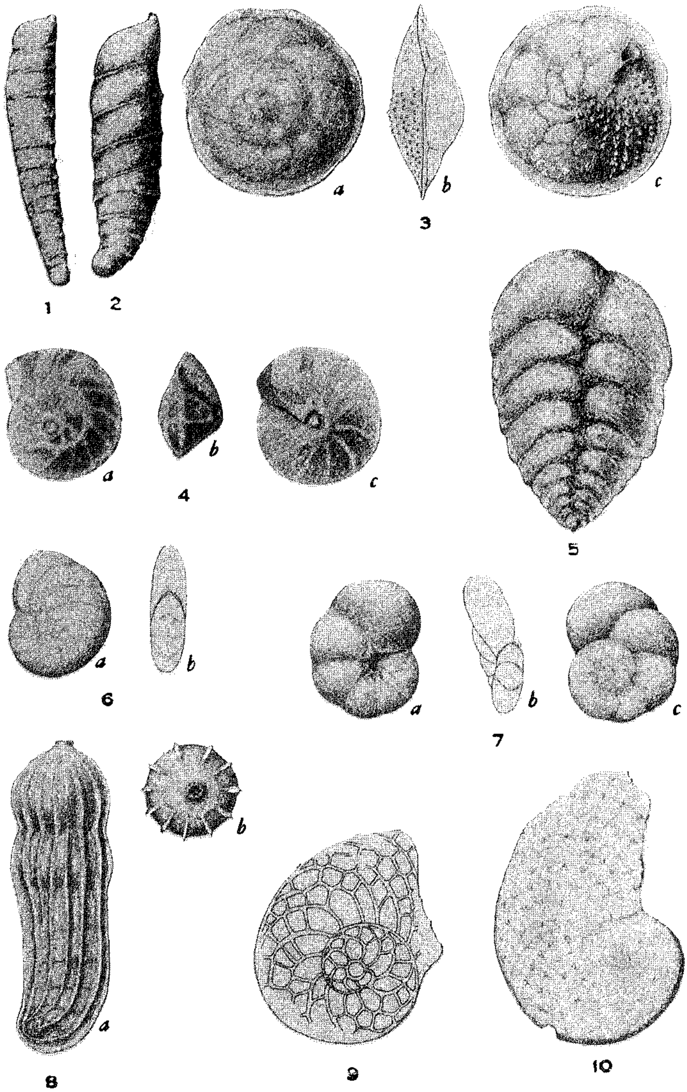
SOME CENOZOIC FORAMINIFERA

Figures—

1. *Vaginulina gracilis* H. J. Plummer, × 25, holotype from roadside ditch on Commerce-Paris road, 0.7 miles by road northeast of Commerce, Hunt County. This species is restricted to the Kincaid formation.
2. *Vaginulina robusta* H. J. Plummer, × 25, holotype from the clay pit in the west edge of Mexia, Limestone County. This species is diagnostic of the Wills Point formation of the Midway group and is especially abundant in the Mexia clay member.
3. *Asterigerina texana* (Stadnichenko), × 40, from type locality and from original collection of material made by Miss Julia Gardner at Evergreen Crossing on Elm Creek, 5 miles north of Giddings, Lee County; Crockett formation. *a*, Dorsal view; *b*, peripheral view; *c*, ventral view. This species is characteristic of the Weches and Crockett formations of the Claiborne group.
4. *Eponides yeguaensis* Weinzierl and Applin, × 50, holotype from core at depth of 4015 feet in the Bissonett No. 2, Humble oil field, Harris County. *a*, Dorsal view; *b*, peripheral view; *c*, ventral view. This form, especially characterized by its relatively flat dorsal face, is common in the Yegua formation of the Claiborne group.
5. *Textularia hockleyensis* Cushman and Applin, × 40, from core at depth of 4475 feet in the Renn No. 1, Humble Oil and Refining Company (specimen contributed by Miss Alva Ellisor); Fayette formation. This species is characteristic of the McElroy division of the Fayette formation.
6. *Nonion whitsettensis* (Cushman and Applin), × 40, from core at depth of 1495 feet in the Ruckman No. 1, Adams and Lyle, Karnes County; upper part of Fayette division (specimen contributed by Miss Alva Ellisor). *a*, Side view; *b*, peripheral view. This species, characterized by its compressed test, its subcircular peripheral outline, and its exceedingly minute spinose apertural face, is diagnostic of that part of the Fayette formation above the McElroy division.
7. *Discorbis* cf. *D. vilardeboana* d'Orbigny, × 50, from core at depth of 4305 feet in the S. Smith No. 74, Humble Oil and Refining Company, Goose Creek oil field, Harris County (specimen contributed by Miss Alva Ellisor). *a*, Ventral view; *b*, peripheral view; *c*, dorsal view. This species characterizes the upper part of the Oligocene section on the salt domes of the southern Gulf Coast.
8. *Marginulina* cf. *M. philippinensis* Cushman, × 50, from core at depth of 2593 feet in Lovejoy No. 1, Humble Oil and Refining Company, West Columbia oil field, Brazoria County (specimen contributed by Miss Alva Ellisor). *a*, Side view; *b*, apertural view. This species characterizes the lower part of the Oligocene section on the salt domes of the southern Gulf Coast.

9, 10. *Heterostegina* cf. *H. antillea* Cushman, from core at depth of 4765 feet in the Harrell No. 4, Humble Oil and Refining Company, Goose Creek oil field (specimens contributed by Miss Alva Ellisor). This species is diagnostic of the middle part of the Oligocene section on the salt domes of the southern Gulf Coast.

   9. Section through a megalospheric test showing chambers and chamberlets, × 25.
   10. Side view of a typical specimen, × 15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IDENTIFICATION TABLE FOR EOCENE SPECIES OF VEN :RICARDIA

Family CARDITIDAE Gill

Genus VENERICARDIA Lamarck

Formation	Species	Altitude	Latitude	No. of radials	No. radial nodes per 10 mm.	Distinguishing Characters
Crockett	*V. flabellum* Harris, var. ***kingi*** **Plummer n. var.** (Pl. 8, fig. 9)	17 5	18	23	18	Larger number of radial nodes than *V. rotunda*
Weches	*V. flabellum* Harris (Pl. 8, fig. 8)	20	21.5	22	18	Larger number of radial nodes than *V. rotunda*
	V. rotunda Lea (Pl. 8, fig. 7)	15	17	22	10	Fewer radial nodes per cm. than *V. flabellum*
	V. texalana Gardner (Pl. 8, fig. 5)	19	19	23	10	Fewer radial nodes per cm. than *V. flabellum*; much lower umbones than *V. natchitoches*
	V. natchitoches Harris (Pl. 8, fig. 6)	19.5	19.5	16	8	Small number coarsely notched radials
Wills Point	*V. wilcoxensis* Dall (Pl. 8, fig. 3)	32	32	22	4	Like *V. bulla* but with fewer and simpler radials
	V. bulla Dall (Pl. 8, fig. 2)	35	33	31	2.5	Extreme convexity; secondary radials on both sides of radials
Kincaid	*V. smithii* Aldrich (Pl. 8, fig. 4)	41	41.5	28	9–10	Large number of radial nodes
	V. eoa Gardner n. sp. (MS.) (Pl. 8, fig 1)	36.5	35	16	3	Small number of radials; coarse sculpture

PLATE VIII

EOCENE SPECIES OF VENERICARDIA

Figures—

1. *Venericardia eoa* Gardner n. sp. (MS.), × .75, roadside exposure 2 miles northeast of Cedar Grove and 5 miles due north of Cobbs, about one-half mile west of the Kaufman-Van Zandt county line, Kaufman County; Kincaid formation.
2. *Venericardia bulla* Dall, × .75, from creek banks 5 miles southwest of Elgin and 2 miles southeast of Littig, Bastrop County; base of Wills Point formation.
3. *Venericardia wilcoxensis* Dall, × .75, Matthews Landing on Alabama River, Alabama; Naheola formation (middle Wills Point) formation.
4. *Venericardia smithii* Aldrich, × .75, from photographs of Aldrich's cotypes, taken by Miss Julia Gardner (MS.).
5. *Venericardia texalana* Gardner, × 1.5, roadside exposure 20.7 miles by road east of Nacogdoches on the San Augustine road, Nacogdoches County; Weches formation.
6. *Venericardia natchitoches* Harris, × 1.5, at side of road 2.3 miles west of San Augustine, San Augustine County; Weches formation.
7. *Venericardia rotunda* Lea, × 1.5, bank of Colorado River, at bridge in Smithville, Bastrop County; Weches formation.
8. *Venericardia flabellum* Harris, × 1.5, on Colorado River just north of the bridge in Smithville, Bastrop County; Weches formation.
9. *Venericardia flabellum* Harris, var. *kingi** Plummer n. var., × 1.5, Shipps Ford on Colorado River just north of the Bastrop-Fayette county line, Bastrop County; Crockett formation.

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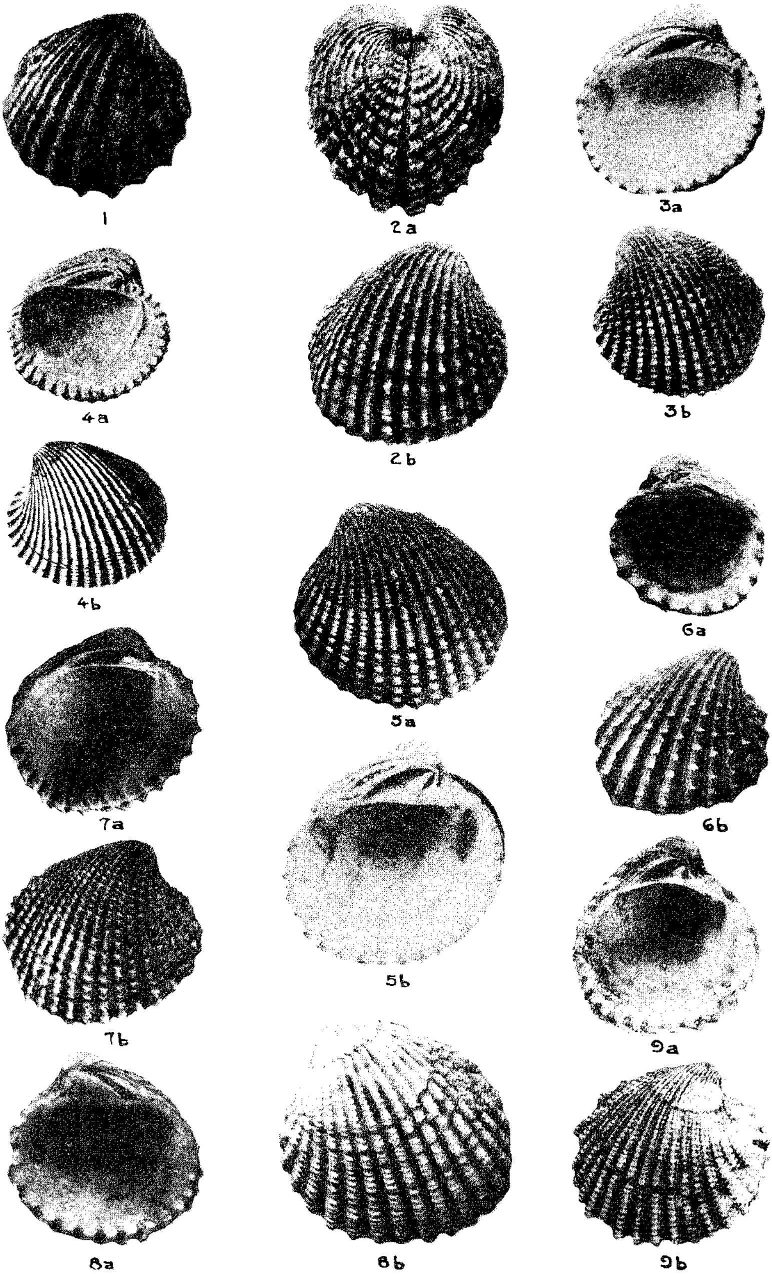
*Named in honor of R. H. King.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3a
4a
2b
3b
4b
6a
5a
7a
6b
5b
7b
9a
8a
8b
9b

IDENTIFICATION TABLE FOR EOCENE SPECIES OF VOLUTOCORBIS

Family VOLUTIDAE Gray

Genus PLEJONA Bolton

Subgenus VOLUTOCORBIS Dall

Formation	Species	Apical angle	Altitude	Maximum diameter	No. longitudinal ribs, next to last whorl	No. transverse ribs, last whorl	Development of whorls
			mm.	*mm.*			*See key below*
Crockett	*V. lisbonensis* (Aldrich), var. *crockettensis* Plummer, n. var. (Pl. 9, fig. 19)	71°	30	14.5	20	5	B, E
Crockett	***V. wheelockensis*** **(Cossman) var.** *sabinensis* Plummer, n. var. (Pl. 9, figs. 20, 21)	61°–63°	24	11	13	4	B, F
Weches	*V. wheelockensis* (Cossman) var. *bastropensis* Plummer n. var. (Pl. 9, fig. 16)	55°	26	11	16	4 or 5	B, F
Weches	*V. lisbonensis* (Aldrich), var. *wechesensis* Plummer, n. var. (Pl. 9, figs. 17, 18)	61°	21	10	18	4	B, E
Weches	*V. dalli* (Harris), var. *smithvillensis* Plummer n. var. (Pl. 9, fig. 14)	59°	31	14	28+	5	C, E
Weches	*V. dalli* (Harris), var. *smithvillensis* Plummer n. var. (Pl. 9, fig. 15)	65°	21	11	40–50	3	C, E
Reklaw	*V. stenzeli* Plummer, n. sp. (Pl. 9, figs. 12, 13)	64°	20	10	40	4	A, F
Seguin	*V. olssoni* Plummer, n. sp. (Pl. 9, fig. 11)	60°	12.5	6	35	5	A, F
Wills Point	*V. rugatus* (Conrad) (Pl. 9, fig. 9)	49°	30	15	10	5	B, F
Wills Point	*V. saffordi* (Gabb) (Pl. 9, fig. 10)	41°	32	12	13	4	B, F
Wills Point	*V. kerensensis* Plummer, n. sp. (Pl. 9, fig. 8)	41°–48°	24.5	10	26–30	5 or 6	B, F
Wills Point	*V. limopsis* (Conrad) (Pl. 9, figs. 6, 7)	45°	25	12	19–21	4	B, F
Wills Point	*V. texana* Gardner, n. sp. (MS.), var. C (Pl. 9, fig. 5)	52°	23	11.5	13–14	4 or 5	B, F
Kincaid	*V. texana* Gardner, n. sp. (MS.), var. B (Pl. 9, figs. 3, 4)	62°	20	10	10–12	3 or 4	B, F
Kincaid	*V. texana* Gardner, n. sp. (MS.), var. A (Pl. 9, figs. 1, 2)	66°	20-26	10–13	12–13	3	B, F

A, Transverse ribs about equal in height to longitundinal ribs.
B, Transverse ribs much larger than longitudinal ribs.
C, Transverse lines nearly as prominent as longitudinal ribs.
D, Five fine transverse ribs.
E, First 4 smooth, 5th and 6th ribbed.
F, First 3 smooth, 4th and 5th ribbed, others cancellate.

PLATE IX

EOCENE SPECIES OF VOLUTOCORBIS

Figures—

1, 2. *Volutocorbis texana* Gardner n. sp. (MS.), var. A, × 1.5, 7 miles from Lytton Springs, Caldwell County; Kincaid formation.

3, 4. *Volutocorbis texana* Gardner n. sp. (MS.), var. B, × 1.5, Santa Clara Creek 2 miles south of Marian, Guadalupe County; Kincaid formation.

5. *Volutocorbis texana* Gardner n. sp. (MS.), var. C, × 1.5, bank of branch flowing into Tehuacana Creek, 3 miles north of Mexia, Limestone County; basal Mexia clay member of Wills Point formation.

6, 7. *Volutocorbis limopsis* (Conrad), × 1.5, Matthews Landing on Alabama River, Alabama; Naheola formation (middle Wills Point).

8. *Volutocorbis kerensensis* Plummer n. sp., × 1.5, bluff on Trinity River near old Humble pumping station, about 5½ miles east-northeast of Kerens, Navarro County; Kerens member of Wills Point formation.

9. *Volutocorbis rugatus* (Conrad), × 1.5, 1 mile west of Oak Hill, Alabama; near top of Naheola (upper Wills Point) formation.

10. *Volutocorbis saffordi* (Gabb), × 1.2, 1 mile west of Oak Hill, Alabama; near top of Naheola formation (upper Wills Point).

11. *Volutocorbis olssoni* Plummer n. sp., × 1.5, bank of Solomon's Creek about 5½ miles south-southwest of Elgin, Bastrop County; Seguin formation.

12, 13. *Volutocorbis stenzeli* Plummer n. sp., × 1.5, from dump at side of old copper prospect, 4½ miles northeast of Harwood, Caldwell County; Reklaw formation.

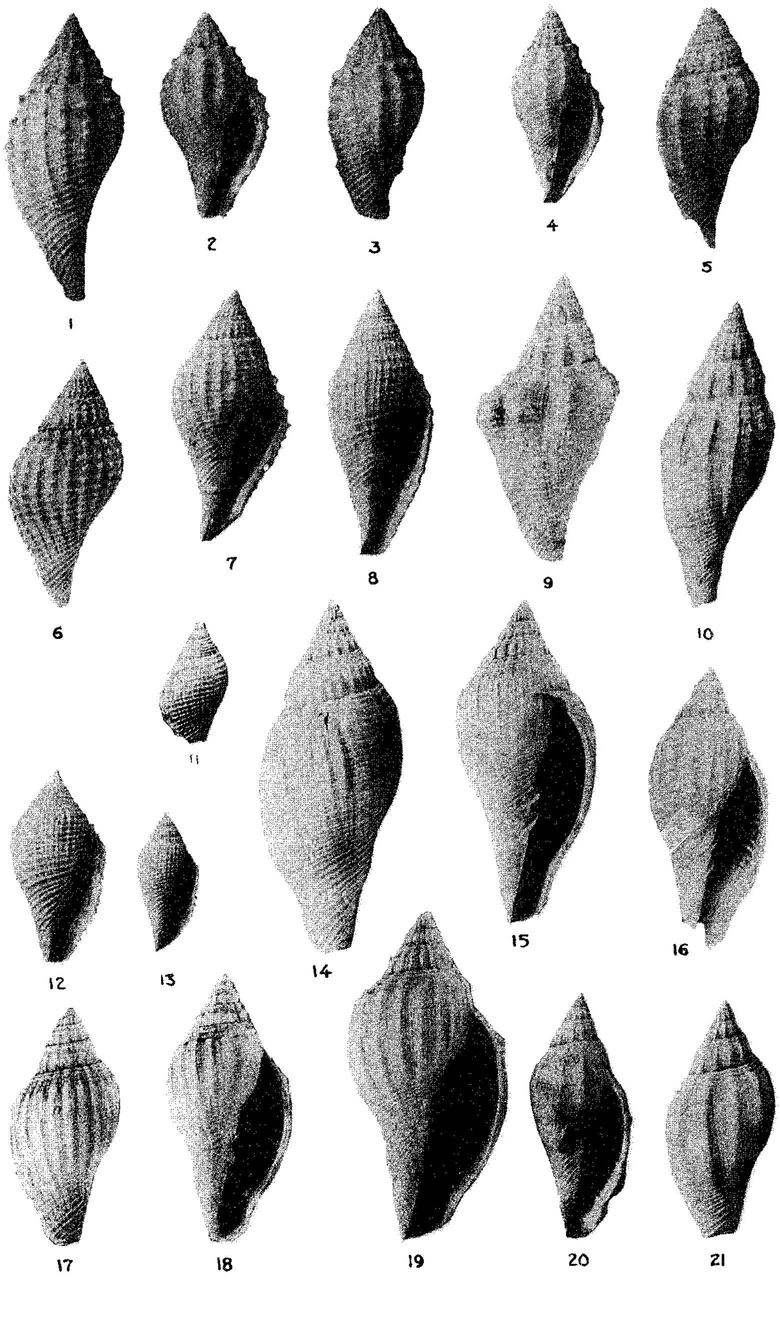
14, 15. *Volutocorbis dalli* (Harris), var. *smithvillensis* Plummer n. var., × 1.5, Colorado River, just north of bridge, Smithville, Bastrop County; Weches formation.

16. *Volutocorbis wheelockensis* (Cossman), var. *bastropensis* Plummer n. var., × 1.5, bank of Colorado River, just north of bridge, Smithville, Bastrop County; Weches formation.

17, 18. *Volutocorbis lisbonensis* (Aldrich), var. *wechesensis* Plummer n. var., × 1.5, bank of Colorado River, just north of bridge, Smithville, Bastrop County; Weches formation.

19. *Volutocorbis lisbonensis* (Aldrich), var. *crockettensis* Plummer n. var., × 1.5, right bank of Brazos River, at bridge on Highway No. 1 (Moseley's Ferry), Burleson County.

20, 21. *Volutocorbis wheelockensis* (Cossman), var. *sabinensis* Plummer n. var., × 1.5, 2 miles west of Columbus, Louisiana, on the Texas side of Sabine River; Crockett formation.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IDENTIFICATION TABLE FOR EOCENE SPECIES OF TURRITELLA

Family TURRITELLIDAE

Genus TURRITELLA Lamarck

Formation	Species	Apical angle	Sculpture	Whorl shape
Crockett	*T. nasuta* var. *houstonia* Harris (Pl. 10, fig. 11)	12.0°	9 faintly crenulate spirals of nearly equal size	Strongly and evenly convex; greatest diameter near center
	T. nasuta Gabb (Pl. 10, fig. 12)	11.0°	6 smooth spirals of equal size	Nearly flat, greatest diameter anterior
Weches	*T. femina* Stenzel	13°	7 fine spirals of equal size	Gently convex; fine growth lines prominent between spirals
Reklaw	*T. turneri* Plummer, n. sp. (Pl. 10, fig. 10)	17.5°	5 unequal spirals, anterior spiral largest	Strongly convex, posterior whorl slope slightly longer than anterior
Tuscahoma (Alabama)	*T. bellifera* Aldrich (Pl. 10, fig. 7)	10.5°	5 or 6 strong, sharp, smooth spirals, posterior largest	Flat or slightly convex, diameter at top and bottom nearly equal
	T. sp. (Pl. 10, fig. 9)	12.5°	3 strong, smooth, equal-sized spirals	Flat
Sabinetown	*T. mortoni* Conrad, var., (Pl. 10, fig. 8)	23 0°	Smooth, unornamented	Strongly convex with longer posterior slope
Seguin	*T.* cf. *abrupta* Conrad (Pl. 10, fig. 6)	15.5°	11 subequal, narrow spirals	Sharply convex, with longer posterior slope
Wills Point	*T. alabamiensis* Whitfield (Pl. 10, fig. 5)	12.5°	14 or 15 fine lirae crossed by fine growth lines forming finely beaded sculpture	Slightly concave, greatest diameter anterior
Kincaid	*T. kincaidensis* Plummer n. sp. (Pl. 10, fig. 3)	12.5°	14 finely beaded lirae	Convex with greatest diameter anterior
	T. levicunea Harris (Pl. 10, fig. 4)	21.5°	10 to 12 finely crenulate lirations per whorl	Whorls separated by a raised notched ridge
	T. ola Plummer, n. sp. (Pl. 10, fig. 2)	18.0°	2 narrow, high spirals and faint posterior spiral line	Whorls separated by a fine, nearly invisible lira
	T. saffordi Gabb (Pl. 10, fig. 1)	20°	No spiral lines, very fine, curving growth lines	Flat whorls separated by narrow grooves

PLATE X

EOCENE SPECIES OF TURRITELLA

Figures—

1. *Turritella saffordi* Gabb, × .75, quarry south of Ola, Kaufman County; Kincaid formation.

2. *Turritella ola* Plummer n. sp., × .75, quarry south of Ola, Kaufman County; Kincaid formation.

3. *Turritella kincaidensis* Plummer n. sp., × .75, quarry south of Ola, Kaufman County; Kincaid formation.

3a. *Turritella kincaidensis* Plummer n. sp., × 3.7, ¼ mile south of the mouth of Dry Creek on right bank of Colorado River, Bastrop County; Kincaid formation.

4. *Turritella levicunea* Harris, × 1.5, ¾ mile downstream from mouth of Dry Creek on right bank of Colorado River, Bastrop County; top of Kincaid formation.

5. *Turritella alabamiensis* Whitfield, × .9, Matthews Landing on Alabama River, Alabama; Naheola formation. *a*, 12th and 13th whorls, × 3.7.

6. *Turritella* cf. *T. abrupta* Conrad, × 2, Solomon's Creek, 5½ miles south-southwest of Elgin, Bastrop County; Seguin formation.

7. *Turritella bellifera* Aldrich, × .75, Bells Landing on Alabama River, Alabama; Tuscahoma formation. *a*, about the 6th and 7th whorls, × 3.7.

8. *Turritella mortoni* Conrad, × .75, Pendletons Bluff on Sabine River, Sabine County; Sabinetown formation.

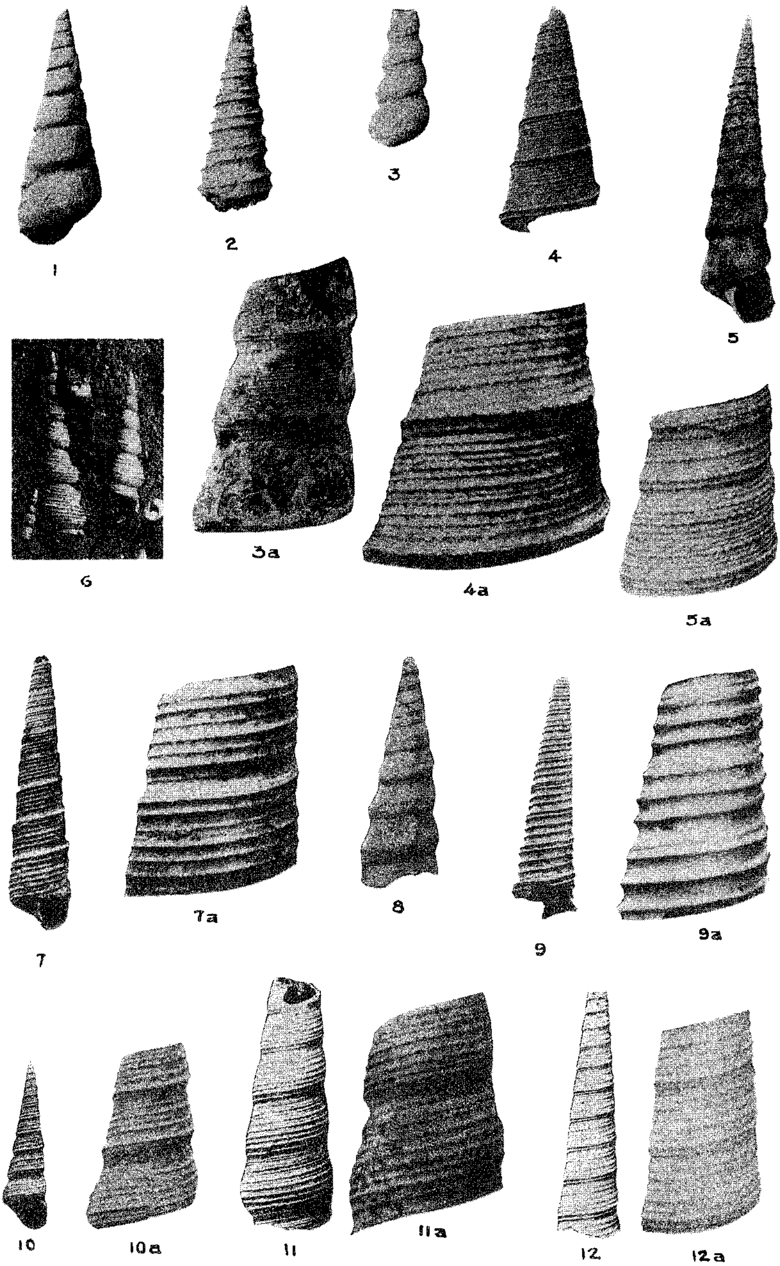
9. *Turritella* sp., × .75, Bells Landing on Alabama River, Alabama; Tuscahoma formation. *a*, About the 4th to 6th whorls, × 3.7.

10. *Turritella turneri* Plummer n. sp., × 1.5, old copper prospect 4½ miles northeast of Harwood, Caldwell County; Reklaw formation. *a*, 10th to 12th whorls, × 3.7.

11. *Turritella nasuta* Gabb, var. *houstonia* Harris, × 1.5, 13th to 17th whorls, roadside exposure 3 miles east of Melrose on the San Augustine road, Nacogdoches County; Weches formation. *a*, 14th and 15th whorls, × 3.7.

12. *Turritella nasuta* Gabb, × 1.5, 9th to 17th whorls, right bank of Brazos River at bridge on Highway No. 21 (Moseley's Ferry), Burleson County; base of Crockett formation. *a*, 14th to 16th whorl, × 3.7.

Turritella femina Stenzel, measurements of which are included in the table and which is characteristic of the Weches, unfortunately is not shown. It is illustrated, however, in Univ. Texas Bull. 3101, Pl. VI, Fig. 14.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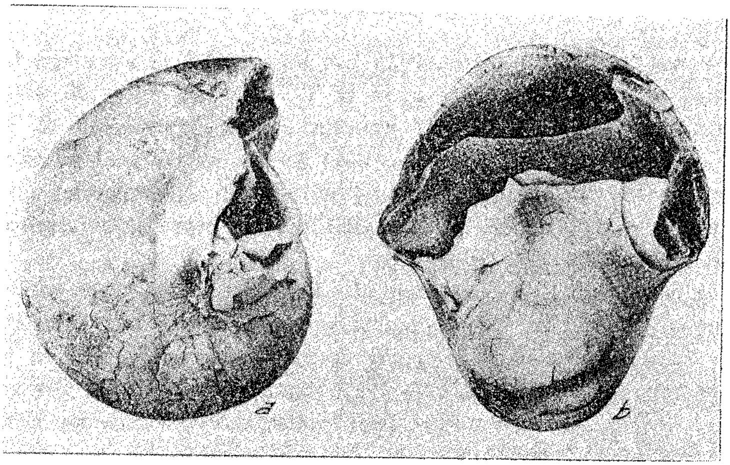

Fig. 53. *Hercoglossa vaughani* Gardner, × .7. This unusually thick and beautifully preserved specimen of a nautiloid occurs in the uppermost Wills Point formation on Trinity River 5½ miles east-northeast of Kerens, Navarro County. (Collected by Gene Ross.)

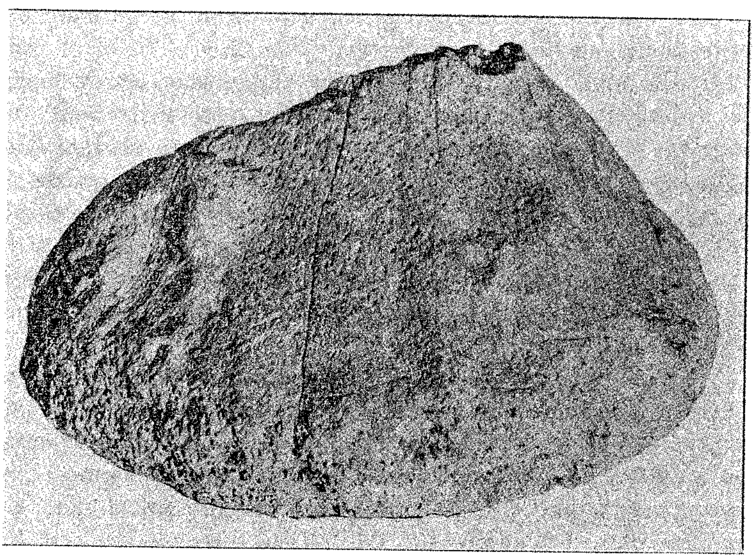

Fig. 54. *Palmoxylon* sp., × .17, a fossil palm from town of Dime Box, Lee County; Yegua formation. (Identified by G. R. Wieland; collected by H. C. Fountain; photographed by Joe Barber.) Palm stumps are characteristic of strata of Yegua age.

Conclusions

A vast amount of information has been collected since the first review of the geology of Texas by R. T. Hill (734, pp. 1–95, 1887) forty-five years ago. Hill's bulletin contains references to 110 articles representing all that has been written on the geology of the State at that time. Now at the end of 1932 the accompanying bibliography (Pt. 4 of this publication) carries over 1900 references that concern the geology of Texas.

In reviewing all the accumulated information since the pioneer summation by Hill, one is impressed not so much by the bulk of the literature, which is imposing, as by the large number of yet-unanswered questions, unsolved problems, and extent of the still unstudied areas. New undescribed faunas in the Eocene are awaiting treatment. The stratigraphy of the Pliocene strata in southwest Texas needs much more concentrated attention. The Claiborne in southwest Texas requires a large amount of field work to make clear its relationships with the divisions of this group farther northeast. The problem of glacial climates in Texas and the correlation of the southern Pliocene and Pleistocene sediments with the northern deposits should challenge glaciologists. The igneous rocks of west Texas constitute a virgin field for the enthusiastic petrographer. The undeveloped ore minerals in the western part of the State, the lignites in the central part, and the iron ores in the east should intrigue many mining engineers. Finally in the broad stretches of the coastal belt, undiscovered oil pools and domes of salt and sulphur still exist to attract petroleum geologists for many years to come. No geologic province having so many and so diverse natural resources is so little known scientifically as the forests, prairies, and mountains of Texas.

The large number of unsolved problems and the extent of the unknown areas make it certain that geologists during the next forty years will discover as many new resources and advance the geologic knowledge of this area as much as in the past equal period. This present account will soon be superseded by more detailed and more complete data. If, meanwhile, this review serves to indicate the unstudied areas and unsettled problems and to inspire others to supply corrections, additions, and new geologic data, then a final and more complete account of the geology of Texas may be written.

Part 4

BIBLIOGRAPHY AND SUBJECT INDEX OF TEXAS GEOLOGY

E. H. SELLARDS

The following bibliography and subject index, containing papers relating to Texas geology through December, 1932, have been prepared to accompany Volume I of the Geology of Texas. In order to keep the bibliography within reasonable limits it has been necessary to omit publications relating to explorations with only incidental mention of geology, textbooks containing only limited reference to Texas, publications issued through daily or weekly newspapers, and brief references in trade journals. Comments or contributions by persons other than the author or authors, appearing as inclusions in a listed paper, are not separately entered in the bibliography. Such contributions are, however, cited under the name of the contributor in the subject index which follows the bibliography. Reviews of papers and articles are listed under the publication reviewed and not under the name of the reviewer. The date of publication given is ordinarily that found on the title page of the publication; however, in some cases a second date is added in brackets indicating the year in which the publication is known to have actually appeared. An asterisk following an entry indicates that the publication is to be found in some one of the libraries at The University of Texas. It has been found necessary, likewise, to restrict the subject index. Thus in paleontologic references it has been necessary to omit, in the main, citation of families, genera, and species, and some larger groups.

It is recognized that both the bibliography and the subject index are necessarily incomplete. Nevertheless, it is believed that both will be found useful in locating the widely disseminated literature on the geology of the State.

Among those who, in addition to the geologists of the Bureau Staff, have given valuable help in the tedious work of assembling the bibliography and abstracting the publications for the subject index are Miss Josephine Casey, Secretary, and Assistants Velma Morrison, Faye Ricketts, Wayne Wilson, Ralph King, Gilbert Hart, Gene Ross, Leo Hendricks, and M. N. Broughton, to all of whom the authors of this volume are greatly indebted.

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SUBJECT INDEX

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