University of Texas Bulletin

No. 2901: January 1, 1929

CONTRIBUTIONS TO GEOLOGY

Bureau of Economic Geology

J. A. Udden, Director **E. H. Sellards, Associate Director**

PUBLISHED BY
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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. . . . It is the only dictator that freemen acknowledge and the only security that freemen desire.

Mirabeau B. Lamar

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The "Contributions to Geology" includes shorter papers of which in addition to other Bureau publications, usually, one volume per year will be issued, this volume being the second of the series. Each volume of the "Contributions" bears a bulletin number and is thus a part of the series of University of Texas bulletins issued from the Bureau of Economic Geology.

E. H. SELLARDS,
Associate Director.

DEPOSITIONAL HISTORY OF THE RED BEDS AND SALINE RESIDUES OF THE TEXAS PERMIAN

BY

CHARLES LAURENCE BAKER

INTRODUCTION

When the writer first began the study of Permian problems twenty years ago, it was generally thought that red beds must have been deposited under conditions of aridity for the reason that they were interbedded with saline residues. The writer's preliminary review of the problem convinced him that red beds *per se* were in all probability not deposited in either arid or cold climates but in warm and at least seasonally moist climates **(1)**. It was then thought that the Permian was a period of surprising severity of climate, arid and cold, practically throughout the world, a conception that proved to be based on lack of knowledge. At that time only the deposits of northwestern Europe and the interior United States which are poor in fossils were known. Since then Permian deposits rich in fossils have been found to be even more widespread than are those poor in fossils or lacking fossils altogether.

Up to the present time saline residues have been held by all to imply aridity. However, the writer has discovered by his observations in Mexico and Texas that salt and calcium sulphate are today being deposited where the annual rainfall is from 20 to 35 inches. It is thus not necessary to have an arid climate for the deposition of these salts. Other problems of the Permian are to account for the very great thickness and areal extent of the saline residues now demonstrated by borings, and for the "Big Lime" of the southwestern end of the great interior Permian Basin of the United States. In the writer's view it is no more difficult to account for the great volume of the saline residues than for an equivalent amount of marine limestone. The writer

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thinks, also, that it is possible to explain the "Big Lime" as a necessary part of the saline residue assemblage without recourse to either an unconformity at its top or to an epoch of folding occurring between its deposition and that of the overlying Permian. There remains the problem of the correlation of the strata exposed on the borders of the saline residue basin. Even on this matter he hopes to have made some progress in setting forth some reasons why ordinary correlation methods have proved so difficult.

ACKNOWLEDGMENTS AND REVIEW OF LITERATURE

The recognition of true Permian deposits in North America has come only after a protracted controversy lasting for half a century. The pioneers of Permian invertebrate paleontology were Shumard, Cummins, Prosser, and Beede and the battleground was Texas and Kansas. Girty **(55)** verified Shumard's opinion **(112)** that the Guadalupian series of Trans-Pecos Texas contained many elements of old-world Permian. Böse, however, in his monograph of the ammonoids of the Glass Mountains **(5)** was the first to satisfactorily correlate new-world Permian with the old-world fauna. Subsequently, Beede, one of the pioneers of Kansas Permian **(21)** proved that the *Schwagerina* zone could be widely correlated throughout the continents of the northern hemisphere and that this zone is everywhere very close to if not, indeed, the base of the Permian wherever it may be found. The vertebrate fauna of the Lower Permian was first made known through the efforts of Cummins and Cope. The work of Williston demonstrated the Texas Lower Permian vertebrate fauna to be the most extensive yet known. Cummins's stratigraphic and paleontologic work placed the stratigraphic succession on a firm basis. At present it is coming to be recognized that the Trans-Pecos Permian of Texas and New Mexico is the fullest, most normal, and most typical marine section known.

The discovery of Permian rocks in the southwest is to be attributed to B. F. Shumard who as early as 1858 correctly assigned the strata in the Guadalupe Mountains to the Permian. The great name in Texas Plains Permian will probably ever be W. F. Cummins who collected the first fossils, both invertebrate and vertebrate, made the subdivision of the strata still in use and who persisted in calling the strata Permian at the time the great weight of authority was opposed. N. F. Drake, the associate of Cummins, made the first detailed subdivision of the lower part of the system (on the Colorado River) and made the first accurate map of the outcropping members in that part of the State.

Although considerable vertebrate collecting was done in the Wichita and Clear Fork of Wichita and Baylor counties, Texas, by Cummins, Cope, Boll, Sternberg, Von Huene, and perhaps others, the world owes most of its knowledge of the richest known assemblage of Permian reptiles and amphibians to S. W. Williston, Paul C. Miller, and E. C. Case. The richest locality was discovered by accident on the last day of a collecting trip by the present writer. David White has studied the fossil plants and C. A. White was one of the first to describe Permian invertebrates from the Texas plains.

Within recent years the most fundamental and important work in the Texas Plains Permian both stratigraphical and paleontological, has been done by J. W. Beede, who with W. E. Wrather was the first to emphasize the significance of the San Angelo conglomerate. Beede also continued into the higher horizons the detailed subdivision of the strata in the Colorado River valley, begun by Drake, and published areal maps and reports on Coke, Runnels, and Foard counties, Texas. Beede was the first to establish a definite line around the eastern basin margin between Pennsylvanian and Permian all the way from northern Kansas to Trans-Pecos Texas. His work has by no means been confined to the Texas plains. He has studied all but one or perhaps two of the known Permian localities in Trans-Pecos Texas and some of the New Mexico outcrops. Permian stratigraphy and paleontology in Kansas and Oklahoma owe more to him than to any other one man. Dr. Beede has very obligingly reviewed the present paper and made some additions and corrections to it.

J. A. Udden first called attention to the possibility of commercial deposits of potash **(126)**, and inaugurated the present extensively pursued study of well cuttings, which has already added much to our knowledge of the underground Permian. He was the first to describe and subdivide the Permian strata in the Glass Mountains of Trans-Pecos Texas, an area which appears destined to become the type for the marine Permian of the world **(128)**. He also discovered the Permian of the Chinati Mountains.

The first areal mapping of the Trans-Pecos Permian was done by George B. Richardson **(99)**. G. H. Girty described many of the fossils from the Guadalupian series but was unfortunate in referring the Hueco limestone farther west and southwest to the Pennsylvanian, whereas this limestone, as originally defined, contains strata ranging from Mississippian to Permian in age, as first shown by Beede **(21)**.

Emil Böse in his monographs on the ammonoids and *Richthofenia* of the Glass Mountains succeeded in making definite correlations with the old world Permian and was the first to emphasize the extremely early Permian age of the Wolfcamp formation. J. P. Smith has recently determined that the lower Wolfcamp fauna is the oldest true Permian yet known and is a development probably without important time break or without any hiatus whatever, from the uppermost Pennsylvanian of Texas and adjoining areas. Philip B. and Robert E. King have recently made a valuable contribution to the stratigraphy of the Glass Mountains **(83)** confirming very closely Udden's earlier studies.

In the part of New Mexico with which we deal Willis T. Lee did the pioneer work on the Permian **(86)**. His work has been followed by N. H. Darton who has recently issued an excellent areal map of New Mexico.[1]

[1] Published by the United States Geological Survey. See also "Red Beds" and Associated Formations in New Mexico with an outline of the Geology of the State, N. H. Darton. U. S. Geol. Surv., Bull. 794, 1928.

Böse, from a study of fossils collected in company with the present writer, has shown that at least the lower Abo, in at least one locality, is of upper Pennsylvanian age **(6)**. Gould has been the main contributor in Oklahoma.

The literature on the origin of red beds, salt, gypsum, anhydrite, and potash, is far too extensive to attempt to review or summarize here. Some of the most important and fundamental papers were published by Van't Hoff and associates and comprise more than fifty separate articles, beginning in 1887, and to be found in the "Zeitschrift für physikalische Chemie" and the proceedings of the Royal Prussian and the Imperial Viennese Academies of Science. Condensed summaries are given by Van't Hoff in "Zur Bildung der Ozeanischen Salzablagerungen, Erstes Heft," Braunschweig, Friedrich Vierweg und Sohn, 1905, and in "Physical Chemistry in the Service of the Sciences," University of Chicago Press. Grabau's volume on the "Principles of Salt Deposition," McGraw-Hill Book Company, New York, 1920, is a reference work in English. Most of the papers on deep borings will be found in the publications of the American Association of Petroleum Geologists.

Since 1909 the writer has studied all border regions of the Permian Basin with the exception of the Oklahoma area. He has also personally studied samples from a large part of the borings cited. In the preparation of the section on correlation of marginal outcrops he has depended greatly on the paleontologic work of J. W. Beede, Emil Böse, and J. P. Smith.

DISTRIBUTION OF NORTH AMERICAN PERMIAN

Permian rocks in North America extend from Nova Scotia, New Brunswick, and Prince Edward Island on the northeast, from Alaska and the Banff, Alberta, area of the Canadian Rockies on the northwest, southwards to Guatemala or beyond in Central America. In Ohio and adjoining states the Permian is represented by the Dunkard red bed series. It is possible that originally the Permian area of deposition was flanked on the east by the Appalachian Mountain folds. If so, the Permian was the last bedrock formation deposited in the basin of the upper Mississippi, and being the surficial formation during Mesozoic and Tertiary times could have been almost entirely removed by erosion. Permian, partly marine and partly red bed facies, extends into southwestern Montana and probably the Black Hills of South Dakota and covers large parts of the states of Wyoming and Colorado.

Relatively little is known of the Permian in Mexico. Marine Permian is known at Las Delicias; in southwestern Coahuila; near Ciudad Victoria in Tamaulipas; in northern Sonora; and in Guatemala. Red beds and gypsum of unknown age, but possibly Permian, occur in the eastern Mexican Cordillera from the Nuevo Leon-Tamaulipas boundary southwards to the Isthmus of Tehuantepec. Red beds are found beneath the Jurassic within a few miles of the Gulf of Mexico in a boring near Altamira in southeastern Tamaulipas. Red beds and gypsum are also found near the Pacific Coast of Mexico in the State of Colima.

The deposits although nearly everywhere remnantal in the remaining outcrops would, if solidly connected, cover an area equivalent to between one-third and one-half of the continent. The saline residues occupy approximately middle the distance between the farthest marginal outcrops, extending from Nebraska on the north to Trans-Pecos Texas on the south and from central Kansas, Oklahoma, and Texas on the east to southwestern Utah and southern Nevada on the west. The marine Permian of the United States is largely confined to the eastern, southern, and western margins of the saline residues and red beds.

LIMITS OF THE SOUTHWESTERN PERMIAN BASIN

The basin of deposition of the southwestern Permian appears to have been originally formed in the main by Hercynian folding and uplift. The southeastern and eastern boundary was defined by the mountain folds known to extend from the Big Bend of the Rio Grande in a general eastward direction to the Central Mineral Region of Texas, thence northeastward by way of the Balcones Fault Zone in the general vicinity of which borings have reached basement rocks beneath the Cretaceous in various localities between the Rio Grande near Del Rio northeastward to the northeast corner of Texas, thence eastwards at the foot of the north flanks of the Massern and Ouachita mountain folds of southeastern Oklahoma and southwestern Arkansas. It was bounded on the west by the ancestral Rocky Mountains which now correspond with the eastern Front Range of the Cordillera in southern Colorado and northern New Mexico. South of central New Mexico calcium sulphate deposits continue westwards across New Mexico and northern Arizona to beyond the Utah-Nevada boundary line. On the south the basin was flanked by a normal sea at least in Trans-Pecos Texas and probably near the Arizona-Sonora boundary as well. In the extreme southwest in Arizona and Utah, strictly marine deposits predominate and in California and Sonora, so far as known, and in most of Nevada and Utah only marine Permian is known.

The basin is now a great structural syncline in which the greatest thickness of known Permian on the continent has been preserved, partly through the great downwarp and partly by being covered with later deposits. Its longer axis extends from north of the Kansas-Nebraska boundary to the mountain ranges of Trans-Pecos Texas, if we except the western exposures within the present Cordilleran province, where saline residues are less developed. The entire area of the desiccation deposits is between 150,000 and 200,000 square miles. The maximum thickness of the Permian is found in the southwestern part of the main basin in the drainage basin of Pecos River, where it reaches to between seven and eight thousand feet in thickness and extends in places to perhaps 5,000 or more feet beneath present sea-level. On the outcrop 8,900 feet of Permian are found in the Glass Mountains.

New Data Revealed by Recent Borings.—The most important of the new data revealed by recent borings may be briefly summarized:

1. The surficial red color of the red beds is apparently original, extending downwards beneath the surface to the base of the terrigenous Permian. Light greenish or grayish mottling also persists downwards.
2. In the southeastern part of the Texas Panhandle proper if not elsewhere, the color of red beds underground becomes lighter in a westward direction away from the source of the sediments. This may have come about by (a) wearing of the original red surface films of the interstitial grains by the abrasion of longer transportation or (b) removal of part of the red coloring matter by chemical action, either before, during or after deposition.
3. The gypsum present in surface outcrops changes underground to anhydrite, showing hydration to gypsum at and near the surface.
4. Anhydrite, salt, and potash salts have been found in greater volumes underneath the basin than in the surface bordering outcrops because (a) the marginal outcropping saline residues were at some places thinner originally, and (b) there has been a large amount of solution of these substances at or near the surface.
5. Deposition of saline residues began very near the beginning of the Permian[2] in the eastern and western margins of the basin and continued to near the top of the deposits now known within the basin. In the western part of the eastern half of New Mexico, two general epochs of saline residue deposition are separated by a marine limestone which thins at least to the northeast. So far all the saline residues known in the southwestern part of the basin are in the higher Permian. Deposition of the saline minerals therefore began earlier in the northern and eastern area at a time when normal marine sediments were formed on at least the southwestern margins.
6. In the southeastern Panhandle, marginal deposits of anhydrite were laid down in apparent contemporaneity with rock salt beds farther west and quite probably in the same body of water. The same condition appears to have been present on the southwestern margin in Reeves County, Texas.
7. In Coke County, Texas, marine sediments were deposited to the southeast only a few miles away from contemporaneous anhydrite. Here, again, there is strong suspicion that this transition took place in the same body of water.

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[2]The lowest gypsum in the Kansas section, according to Beede, is somewhat more than 100 feet above the Neva limestone, being found at Blue Rapids.

8. A thick limestone, more or less magnesian, was laid down in the Pecos River drainage basin either contemporaneous with or possibly shortly before the deposition of saline residues there. This limestone, or at least a similar one, outcrops in the Guadalupe-Delaware-Apache, the Wiley, the Glass, and the Chinati mountains.

TENTATIVE PERMIAN CORRELATION—KANSAS, NEW MEXICO AND TEXAS

Kansas	New Mexico	Mountain area of Trans-Pecos Texas	North-Central Texas
Cimarron	Guadalupian- Pecos Valley Red Beds	Capitan-Gilliam- Vidrio-Tessey- Castile-Apache- Rustler-Top Yellow Limestone of Cibolo Guadalupian- Pecos Valley Red Beds Word-Delaware- Mountain-Cibolo (except top yellow limestone) Leonard?	Double Mountain with San Angelo at base.
WIDESPREAD UNCONFORMITY AT LEAST AROUND BORDERS			
Wellington	Absent (?)	Leonard ? Hess	Clear Fork
Marion Chase-Neva	Manzano San Andres Yeso Upper Abo?	Manzano of Diablo Plateau and Hueco Mountains-Wolfcamp- Cieneguita of Glass and Chinati Mountains	Wichita

CORRELATION OF PERMIAN STRATA

A tentative correlation of the Permian of Kansas, New Mexico, and Texas is herein proposed supported by a somewhat limited fauna and by an unconformity within the

Permian. The fauna of the Manzano group of New Mexico, especially of its highest member, the San Andres limestone, is apparently very close to that of the middle Wichita series of Texas. The fauna of the Guadalupian which rests unconformably on the Manzano is an entirely different and more advanced fauna which extends also into the higher Permian of the Delaware, Apache, Glass, and Chinati mountains. In the Glass Mountains of Texas, the Guadalupian is underlain by an extensive older Permian marine fauna in a thick succession of strata. The ammonoids and fusilinoids have proved the most satisfactory horizon markers. *Schwagerina* is found in the older Permian of the Glass and Chinati mountains, in the basal Wichita of central Texas, in the Neva and Florence formations of Kansas, and probably from at least one locality in New Mexico. The same ammonoids that occur in the Glass Mountains (upper Wolfcamp) are found in the upper Wichita of Texas. Fossils in the middle Wichita of the Colorado River basin of central Texas are well represented in the San Andres limestone of New Mexico. The Kansas fauna of Wichita age contains, perhaps, a larger percentage of holdovers (relicts) from the Pennsylvanian although such forms are common in all faunas of the Wichita stage. The equivalent Wolfcamp of Trans-Pecos Texas contains the largest percentage of new forms. This older Permian of the Glass Mountains also contains *Richthofenia* and *Lyttonia,* and according to Böse and J. P. Smith, an assemblage of ammonoids of a pre-Artinsk stage but younger than any known Pennsylvanian (Uralian) forms; in fact, it is the oldest known Permian. This oldest Permian contains a number of new or immigrant forms which apparently did not reach into Kansas, New Mexico, or central Texas. Ammonoids in the upper Wichita of Baylor County, apparently belong in the Hess or Leonard of the Glass Mountains and those from the Clear Fork of western Runnels County apparently are found in the Leonard. Upper Leonard or more likely Word ammonoids have been found in the Double Mountain stage of north-central Texas at the falls of Salt Croton Creek, Kent

County, near Quanah, Hardeman County, and probably occur three miles east of Guthrie, King County. Such is the faunal evidence for correlation of the marginal strata of the Permian Basin. It is admittedly incomplete.

Another basis for marginal correlation is an unconformity separating lower and higher Permian. There is some doubt just where this unconformity comes if at all in the Glass Mountains section. It may come within the succession of strata referred to the Leonard or it may come at the junction of the Leonard and Word where there appears to be a break in the ammonoid succession. The lower two-thirds of the Leonard contain considerable conglomerate. In the Chinati Mountains, near the Rio Grande in Presidio County, Texas, the horizon of the unconformity is most likely represented by the 3,500-foot section of Alta beds—non-fossiliferous or at least very sparsely fossiliferous shales and sandstones. The strata next above the Alta contain the Word-Delaware Mountain fauna. Elsewhere in Trans-Pecos Texas—in the Guadalupe and Finley mountains and in the Diablo Plateau—there is angular unconformity between probable Leonard and the overlying Delaware Mountain. The unconformity on the east side of the basin has not been proved to be angular. The San Angelo formation—Duncan sandstone which is separated by an erosional unconformity from the underlying Clear Fork, has been traced from south of the Colorado River in Tom Green County, Texas, northward to Kansas. The writer has found an unconformity between Wellington and Cimarron in Sumner County, southern Kansas.

This unconformity, which agrees with the available faunal evidence, is taken as the dividing line between the lower and the higher Permian. Saline residue deposits are present in both divisions but in the lower are not known in the southwestern part of the basin. The lower series is marine in part around the entire margin but not in the heart of the basin. The upper series is prevalently marine only to the southwest of the Pecos River and contains a great thickness of saline residues north of a line approximately

50 miles southwest of and parallel to the course of the Pecos. A few widely separated marine fossils have been found in the upper series as far north as Red River. There is not much information concerning the nature of the lower series underneath the drainage basin of the Pecos but what little we know indicates that it is probably marine and contains little or no saline residues.

DESCRIPTION OF SEDIMENTS

THE WICHITA STAGE

There is wide variation in Wichita stage sediments as thus correlated. These sediments are marine in the Trans-Pecos Texas mountains. They consist almost entirely of marine limestone in the Diablo Plateau and Hueco Mountains of northern Trans-Pecos Texas where they are obviously clear water sediments deposited far from land, but a short distance north in New Mexico they begin to pass in the lower division into red beds, gypsum, and thin, not typically marine, limestones of the Yeso formation. The San Andres of central and southern New Mexico is a typical marine limestone but in northeastern New Mexico only a few thin limestones are present and the predominant rock is sandstone. The Yeso in the latter region contains heavy beds of sandstone, salt, and anhydrite. The sandstones in both formations extend far out into the plains area east of the mountain outcrops. The underlying formation, the Abo red beds, the upper part of which may prove to be Permian, contains in the same area a large proportion of arkose. Evidently, therefore, in latest Pennsylvanian and Wichita time the shore lines of the Ancestral Rocky Mountains were not far distant from the present outcrops in central-northern New Mexico. Wichita age in Kansas and northern Oklahoma was characterized by marine conditions with the fauna perhaps more isolated and relict than elsewhere. The Wichita outcropping strata in northernmost Texas, and southernmost Oklahoma (mainly red bed clays and sandstones) were deposited in a fresh-water delta containing the greatest assemblage of amphibians and reptiles known from the Permian. The middle of the sequence was probably very shallow littoral marine sediments. Westwards from the outcrops marine limestones become more frequent in the sequence and still farther westward—in the southeastern corner of the Texas Panhandle—some marine limestone may be present at the base, but most of the Wichita contains anhydrite. Very few red beds are found in the marine and desiccation portion of the Wichita here. The deltaic deposits grade southwards on the outcrop to a marine facies. The outcropping Wichita of central Texas (Colorado River basin) consists of marine clays and limestones, nearly no red beds and but 1 per cent of sandstone. Underground to the westward, anhydrite appears.

CLEAR FORK STAGE

The Wellington of Kansas consists of gray and greenish-gray clays, heavy salt beds in the lower part, anhydrite, and a few thin, fine-grained desiccation limestones, some of which are caliche and tufa domes. It contains only a minor amount of red beds. The Oklahoma section is not greatly different. The Clear Fork in northernmost Texas is in its lower part vertebrate-bearing land deposits. On the outcrop near Red River the entire stage appears to be deltaic. Westwards from the outcrop the red beds thin and large amounts of salt and anhydrite appear. The Clear Fork of central Texas outcrops are largely marine red beds, limestone and dolomite. Northwestward and westward from the outcrop there are anhydrite, dolomitic limestone, and clays.

The Hess of the Glass Mountains, which is believed to be of Clear Fork age, consists of a basal conglomerate, marine limestone, and dolomite. It lies upon the Wolfcamp with angular unconformity, probably formed by renewed uplift of the Marathon Mountains.

A widespread unconformity separates the Clear Fork stage from the overlying Double Mountain stage and its equivalents, a fact that has been recognized only in very recent years. On the eastern side of the basin, the Clear Fork was partly eroded and is overlain unconformably by conglomerates, sandstones, and clays known as the San Angelo formation in Texas and the Duncan sandstone in Oklahoma. At the south the conglomerate consists of well-rounded and highly polished pebbles of quartz and Cambro-Ordovician chert.

DOUBLE MOUNTAIN STAGE

This stage begins with the San Angelo conglomerate or its various equivalents but its upper limit has not been defined. Its top is concealed from view in the deepest part of the basin and elsewhere, at least, the top has been eroded. Whether or not the Quartermaster beds of the Panhandle should be included in this stage is uncertain. They appear at least in places to have an unconformity at the base. It is not entirely certain that the Quartermaster is Permian. Nor is it certain to which stage of the Old World Permian the Double Mountain is to be referred. Possibly it is Lower Permian.

The true Double Mountain—named for the higher strata of central Texas—is not definitely known to have more than one definitely marine fossil horizon. From this ammonoids have been collected which appear to be nearly the same as those from the Word (perhaps from the Leonard) formation of the Glass Mountains. Higher dolomite beds (Whitehorse) have a poorly preserved fauna which apparently is truly marine. Most of the stage in central Texas, Oklahoma and Kansas is barren of fossils but careful and skillful search may yield faunas.

The Double Mountain proper consists of upwards of 4,000 feet at a maximum of red beds consisting of clays and fine sands with thick deposits of salt, anhydrite, potassium and magnesium salts, and some limestone and dolomite. In the deepest part of the basin, in the lower Pecos River drainage basin, the upper strata are red beds but it is not certain that these may not have contained saline residues, later removed by solution. In this particular area, most of the stage is made up of saline residues with only a minor amount of red beds. The thickest section of the saline residues amounts to 4,375 feet and is found in eastern Reeves County, Texas. These saline residues contain important adjacent, interlying, and underlying limestones more or less magnesian. In Reagan County, Texas, the underlying limestone is 900 feet thick, and in the adjoining county of Upton is more than 2,700 feet thick. The lower part of this limestone series is, however, perhaps Clear Fork but this is by no means certain.

The more typically marine equivalent of the Double Mountain occurs in the Trans-Pecos region where a very extensive fauna is known. The section is limestone, shales, and sandstones passing laterally in the upper part in the flanks of both the Guadalupe and Glass mountains into some layers of red beds and gypsum; the different facies dovetail into each other. In all three areas of outcrop the pure limestones and dolomites form the upper half of the stage; the detrital sediments are confined very largely to the lower half.

The total thickness of the marine Permian section in both the Glass and Guadalupe mountains is 7,000 to 9,000 feet. It is quite possible that there is an equivalent thickness in the deepest part of the Salt or Pecos Basin. The Wichita stage is the only one that is largely marine, although it has important saline residues in the areas centering in the Texas Panhandle and extending from the Colorado River of Texas to Nebraska underneath the basin and contains a lower succession of saline residues and red beds throughout New Mexico and most of Arizona except the southernmost part. West of the Pecos River in New Mexico, Arizona, southwestern Nevada, southwestern Utah, Idaho and the surrounding regions the Wichita may be the only definitely known stage of the Permian.

The Double Mountain stage is prevalently marine only in the mountains of Trans-Pecos Texas and in the vicinity of Las Delicias, Coahuila, Mexico. In other words, the normal sea of that stage lay to the south and southwest.

Saline residues are found in the higher Permian series throughout the deeper parts of the Permian Basin (from northern Kansas to the mountain flanks of Trans-Pecos Texas) but it is not yet known whether saline residues in important amounts occur in the lower series in the southernmost part of the basin.

With the exception of the Van Horn dome and Hueco Mountains of Texas and an area in central New Mexico where Permian overlaps older formations, the Lower Permian appears to be everywhere conformable with the uppermost Pennsylvanian. Land areas which were sources of Permian sediments lay to the east and northwest of the basin. The full marine succession is present on the southwest side of the basin in Trans-Pecos Texas. Only three exposures of Permian gypsum are known west of the Front Range in Trans-Pecos Texas. One occurs in the Malone Mountains, a second in the northeastern Diablo Plateau, and a third in the Delaware-Apache Mountains, where the Castile gypsum grades stratigraphically into the Capitan limestone. Gypsum, however, reaches into the flanks of the outermost Front Ranges in this area and extends far to the westward north of the Texas line.

The terrigenous sediments in the heart of the basin consist of fine-grained clays and sandstones, red, blue-gray or green-gray in color, interbedded with various precipitates comprising more or less magnesian "rauchwacke" limestone, anhydrite, rock salt, and various compounds of potassium and magnesium. The terrigenous sediments are fine-grained indicating that they may largely have been transported by the wind. At the most they are current-transported and very analgous to blue clay oceanic deposits laid down fairly distant from land.

The so-called "Big Lime" found in the heart of the basin along the Pecos River is not a definite stratigraphic horizon and its top does not represent a definite plane of contemporaneous deposition. In this irregularity it is similar to the other saline residues. Such fossils as are known from it are very poorly preserved, which fact is significant also of its origin. This rock is not of uniform composition but is made up of varying proportions of dolomite, more or less magnesian limestone, anhydrite, and red and non-red sandstone and clays. It appears to contain at least one zone of bentonite and has oolitic, lignitic, and cherty zones. To the eastwards it probably grades into the nearer-shore deposits of the Double Mountain and Clear Fork.

The gradual merging from land-laid sediments through partially marine into saline residues at the same stratigraphic level in a westward direction is well shown along a line passing a few miles south of Red River. To the east on the Wichita outcrop the sediments are deltaic with land amphibians, reptiles, and plant fossils. Farther west marine limestones are intercalated with red and gray clays and sandstones. Still farther west (in southwestern Hardeman County and in Childress and Hall counties, Texas), all but perhaps the lowest part of the Wichita consists predominantly of anhydrite, with chemically-deposited "rauchwacke" limestone and fine clays of gray, green-gray, blue-gray, red, and black colors. Underneath this southeast corner of the Panhandle, the underlying Cisco has changed largely to limestone, especially in the upper part, and the Clear Fork stage, almost entirely red beds on the outcrop to the east, has become an assemblage of saline residues with which some clay is interbedded while to the westward of Hardeman County some of the anhydrite horizons change laterally into rock salt.

Farther south in the basin of the Colorado River of Texas, Beede **(20, 24)** found the Wichita and Clear Fork predominantly marine on the outcrop. Only a small amount of calcium sulphate is found in the upper outcropping strata of the Clear Fork. Fourteen miles to the north of the upper outcropping strata of the Clear Fork that stage contains abundant anhydrite from top to base and the lower Wichita has three zones of anhydrite.

In northeastern New Mexico thick zones of sandstones extend far eastward into the basin of desiccation. These sandstones were derived from erosion of basement complex rocks in the Ancestral Rocky Mountains which were apparently exposed as land areas close to the edge of the general basin undergoing desiccation. There is a western subsidiary basin in which some saline residues were deposited which merges in south-central New Mexico with the main basin we are discussing. Knowledge of the age relationships of Permian in this subsidiary basin is very unsatisfactory and discussion is beyond the scope of the present paper. The northwestern and northern borders of this Permian basin are unknown since their sediments now lie deeply buried.

ORIGIN OF THE PERMIAN RED BEDS

It is an undisputable fact that red residual soils, the source of red bed sediments, are formed only in warm, moist climates, practically never in arctic or truly desert climates. Such soils are formed in uplands where there is fairly good surface drainage, not in bogs, ponds, or swamps. Warm, moist climates practically everywhere are characterized by alternations of moister and drier periods, best exemplified, of course, where part of the year is prevailingly dry and the remainder wet. There is no doubt that fine red sediments of the texture of silts can be transported hundreds of miles by streams without losing their red color. This is shown by present conditions along such streams as Red, Colorado, Pecos, and Brazos rivers of Texas and Colorado River of the West. Red residual soils can be formed in one climate and transported to a different climate. Red beds of primary coloration are deposited in non-marine formations as well as in shallow water, more characteristically shore line littoral marine formations. The Permian red beds contain irregular splotches or layers of greenish or grayish color which is not a modern surficial alteration, since it is found thousands of feet beneath the present surface. In the heart of the desiccation basin, where the saline residues are thick and form most of the succession, the muds and salts are not prevalently red in color but are greenish or grayish. It may be that strong saline solutions have here reduced the iron oxides.

NON-ARID DEPOSITION OF SALINE RESIDUES

COASTAL LAGOONS OF NORTHWESTERN GULF OF MEXICO

Salt and gypsum are now being deposited where annual rainfall varies from 20 to 36 inches but where there are abundant strong winds and also high temperature favoring evaporation, accompanied by a relative scarcity of inflowing fresh waters. These lagoons fringe the northwestern shore of the Gulf of Mexico between Tampico, Mexico, and Corpus Christi, Texas. The lagoons are very shallow, and bordered on the mainland side by extremely low and flat lands miles in width in a direction transverse to the coast. These lagoons are separated from the main Gulf by sand bars over which at rare intervals hurricane winds wash the Gulf waters and sometimes destroy portions of the bars, as happened at Aransas Pass, Texas, about ten years ago. Narrow and shallow passages in a few places permit influx of Gulf waters at normal times. The very extensive delta of the Rio Grande separates the Mexican lagoons from those of Texas. In the Mexican stretch the Soto la Marina and the San Fernando-Conchos are the only two streams of any size which enter the Gulf. Between the mouth of the Rio Grande and Corpus Christi, Texas, no important stream enters the Gulf. The annual rainfall decreases northward from 36 inches at Tampico to 27 inches at Brownsville, Texas. At Corpus Christi it is 25 inches. Inland from the coast between Brownsville and Corpus Christi, the rainfall is less but only one station between the Coast and the latitude of Del Rio records less than 19 inches.

In the southern end of the lagoon a few miles north of Tampico, salt is being deposited and apparently has continued to be deposited since before the Spanish conquest. The landward sides of practically all the lagoons between the Soto la Marina and the Rio Grande deposit sodium chloride and calcium sulphate. These salts are being precipitated in the Laguna Madre and Baffin's Bay on the Texas

Coast. Large crystals of selenite including sand grains were dredged in large quantity from the channel cut between Brazos Santiago and Point Isabel at the southern end of the Laguna Madre. It is to be emphasized that the selenite has formed here in the strait itself which connects the open Gulf with the lagoon under an annual rainfall of 27 inches, which is far from aridity.

An analysis of the water from the landward part of one of these lagoons shows a salinity of 9.14 per cent and a density at 20° C. of 1.062. This water has accordingly 2.6 times the total salinity of the Gulf of Mexico. This lagoonal water has already become so concentrated that more than two-thirds of its calcium carbonate content has been precipitated out. The landward bays of this lagoon are precipitating salt. Fish entering the lagoon from its gulfward connection are killed in great quantity by the excessive salinity within. The annual average rainfall on this particular lagoon is 26 inches.

THE CASPIAN SEA AND THE GULF OF KARABUGAS

The phenomena of the Aralo-Caspian depression and the production of salt from artificial salt pans formed the basis of Ochsenius' famous bar theory of the origin of saline residues, which is the only acceptable theory advanced. The Caspian Sea has at present an area of 169,000 square miles, but old shore lines up to 600 feet above its present level as well as relics in numerous saline lakes indicate that it formerly had a much greater extent. Its present water surface is 85 feet beneath sea-level. The floor of the Aralo-Caspian depression, formerly covered by water, has over twenty-five hundred lakes and playas in which salt is being deposited and into which salts formerly deposited in the sediments around these lakes and playas are being washed. According to Herodotus, the Oxus River, now emptying into the Sea of Aral, 2400 years ago flowed into the Caspian, increasing somewhat its area and raising its level. A rise of 144 feet in the level of the Caspian would connect it with the Aral. The Aralo-Caspian depression is considered to have formerly been connected with the ocean from which it has been separated by deformational movements or by a depositional barrier. The Caspian proper, although less saline than the ocean, has a relict marine fauna. Rivers entering the Caspian from the north, especially the Volga and the Ural, bring in a large supply of fresh water, the mean annual discharge of the Volga alone being nearly one-third that of the Mississippi. The high ranges of the Caucasus on the southeast and the Elburz ranges in northern Persia furnish a considerable water supply. The Aralo-Caspian depression is flanked all along the southern border by high ranges to the north of which little rain falls. Hence the west side of the Caspian in particular has a relatively dry climate. Extensive salt deposits, salt lakes, and salt marshes are found in both the west and north parts of the depression. The Gulf of Karabugas, which has about one-twentieth the area of the Caspian, is on the arid west side of the depression and is connected with the Caspian by a relatively narrow and shallow strait.

The waters of the Caspian, Aral, and Karabugas belong to the sub-group of sulphate-chloride waters, differing chemically from ocean water in their higher proportions of calcium, magnesium, and sulphates. The Caspian has a salinity of 1.294 per cent, being only brackish at the north end near the mouth of the Volga and much more salty in the deeper southern portions. Large amounts of calcium and carbonic acid must have been brought in by streams but have been almost entirely eliminated by precipitation. Much of the salt and gypsum originally present in Caspian water at the time it was cut off from the Black Sea has been deposited on areas now dry land but formerly a part of the Caspian or is left in the salt lakes and marshes formerly connected with the Caspian. The Sea of Aral is higher in sulphate than the Caspian and has a salinity of 1.084 per cent. The salinity of the Gulf of Karabugas varies from time to time, a maximum of 28.5 per cent being given. The Caspian has only a little more than one-third the salinity of the ocean but the salinity of Karabugas Gulf is 22 times that of the Caspian and eight times that of the ocean. A current continually flows from the Caspian into the Karabugas and there is no compensating return current. This current carries 350,000 tons of salt into the Karabugas daily. Therefore the salinity of the latter is continually increasing. Saline deposits are forming upon its bottom, gypsum deposits are forming near its margins and sodium sulphate is deposited towards its center during the winter months.

There is therefore taking place a flushing-out of the salts in the Caspian water into the Karabugas Gulf. If present Caspian level, supply of water from inflowing streams, and climate remain constant and the passage into the Karabugas Gulf remains open ultimately all the saline residues originally derived from the ocean water will disappear from the Caspian and be deposited in the Karabugas Gulf. The Caspian will then become a fresh-water lake and there will be large deposits of saline residues in the Karabugas Gulf. Already, during the time when the Aralo-Caspian basin has been subject to desiccation, large deposits of salt are known to have been formed in minor basins now entirely dried up and in saline lakes and marshes not yet entirely dried up. Either these salt deposits are underlain by anhydrite deposits or the anhydrite was largely deposited in other and perhaps more marginal minor basins within the major depression. Such deposits would be formed either in basins entirely cut off from the main basin or in marginal basins receiving intermittent or more or less constant supply of water from the main basin or would have formed at various localities within the main basin itself.

We can deduce from the above that saline residues are actually being formed from a parent body of water, the salinity of which is only one-third that of the ocean under climatic conditions which are strictly arid only on one side. We do not know the entire history of the Caspian basin. Before it was entirely cut off from oceanic circulation, large deposits of saline residues may have formed through partial or total desiccation and in the aggregate these may be greater in total volume than would be furnished by the actual volume of sea water present in the basin at the time it was entirely cut off from oceanic circulation. If the only source of supply was by way of the Black Sea, with an average salinity of less than two-thirds that of ocean water, provided Black Sea water can be assumed to have had constant salinity during the time of desiccation of the Caspian, we have had an interesting chain of basins including the Caspian, the Black and the Mediterranean. The salinity of the eastern Mediterranean is from 1.1 to 1.2 times greater than that of the ocean, the salinity of the Black Sea is only two-thirds and that of the present Caspian only one-third that of the ocean. Nevertheless, we can safely assume that if the present Caspian was connected with the Black Sea by a relatively narrow and shallow strait, the present Dardanelles, Hellespont, and Straits of Gibraltar being open, saline residues would be deposited in gulfs on the west side of the Caspian Sea at a greater rate than they are being concentrated in the Gulf of Karabugas at present and would be derived from bodies of water at least 400,000 square miles in extent and less saline than waters of the present ocean, the climate for fully three-fourths of the total area of these hydrographic basins being humid and arid only at the far western extremity. This is sufficient reason for disposing of the absolute necessity for marked general aridity over the southwestern Permian Basin in order to account for the deposition of saline residues.

Under the above postulates, the waters of the main Caspian may never have had a salinity as great as that of ocean water but there may have been deposited from them a far greater volume of saline residues than would be present in a body of water which would fill the entire Aralo-Caspian depression even if that water were originally much more saline than normal sea water. The Caspian water itself would need never to have become so concentrated that it would not support abundant organic life, in fact, it could have remained so dilute that it would contain a mingling of the more adaptative marine and fresh-water organisms.

Changes in climate and hydrographic basins would disturb the above conditions. We will mention a few possibilities. The Aralo-Caspian depression may have formerly become entirely desiccated. Connection with the Black Sea may have been entirely cut off relatively suddenly, leaving only the volume of saline residues then within the basin. Or it may have gradually dried up while receiving a more or less constant supply of water from the Black Sea, in which case the amount of saline residues would be greatly augmented. In either of these cases there must have been renewed connection with the Black Sea after total desiccation, else there would be no relict fauna now in the Caspian. Or the Aralo-Caspian basin under a former more humid climate might have overflowed into the Black Sea and lost a part of its salines through flushing-out. The above conditions may have alternated or been repeated a number of times.

The present situation in the Aralo-Caspian basin may repeat what brought deposition of saline residues to an end in the Southwestern Permian Basin after that basin was finally completely cut off from the ocean. Water then in the basin may have gradually freshened by flushing-out of the salines into minor basins undergoing evaporation. Or there may have been complete desiccation progressing continuously to the end or through various stages, depending upon water supply or the lack of it. The average climate of the entire basin may or may not have been arid. All that would be necessary would be a total water supply not greater than the total evaporation, at least for not long enough to permit a total flushing-out into the ocean or another water body of the salines present in the waters of the basin.

MODE OF DEPOSITION OF PERMIAN BASIN SALINE RESIDUES

Only three fundamental assumptions are requisite to account satisfactorily for the immense volume of saline residues in the Permian Basin:

1. A total amount of evaporation greater than the total water supply from all sources. This does not require an arid climate, although it happens also to be the condition in an arid climate.
2. A more or less constant long-continued supply of water from the ocean.
3. A basin of sedimentation the base of which ultimately reached in at least one place (the Glass Mountains) to 8,900 feet beneath the ocean-level. It is possible this basin had reached its original depth when deposition of saline residues began or its area may have sunk more or less gradually during the accumulation of deposits. The border area, except possibly in the Glass Mountains, may have risen above sea-level just previous to the deposition of the San Angelo conglomerate and the equivalent unconformity on the west border, but this does not mean that any great proportion of the area within the peripheries of the exposed unconformity was uplifted above the surface of the water in the basin. If a temporary lowering of water-level took place within the basin, either through increased rate of desiccation or shutting-off of the supply of water from the ocean, marginal deposits would be subject to erosion and the sheet of the San Angelo formation would have been swept over the eroded surfaces.

The great volume of saline residues is remarkable, to be sure, but no more remarkable than an equivalent thickness and volume of any marine sediments, as, for instance, the Cretaceous of Mexico. Nor does the connection or connections between open ocean and desiccation basin present any great difficulty. The main necessity is to keep that connection open most of the time until the final drying-up of the basin. This implies either continued depression in the connecting area or a current flowing through it, like the Gulf Stream between Florida and Cuba, which had sufficient force to prevent deposition in the connecting area. The connecting area need not have been exceptionally narrow nor exceptionally shallow. It appears probable that the site of one connection was between the Glass and Guadalupe mountains of Trans-Pecos Texas, the distance between which totals, including outcrops of the Capitan-Vidrio-Gilliam-Tessey-Apache formations, 170 miles. Not all of this connection may have been open, or there may have been more than one connection in this expanse. The area of the Van Horn dome was, for instance, above sea-level for a part of the Permian. Southwest or west of a line connecting the Guadalupe and Glass mountains, the connecting channel may have been much restricted but the Permian south of the Delaware-Apache mountains is buried from view. The Hercynian folded area, in all probability extending from the vicinity of Marathon to the Solitario near Terlingua, may have continued southwestward into Mexico, forming a land area in the Permian and gaps in these land masses may have been the sites of the connections.

It is quite possible another at least part-time connection existed from the Californian sea by way of Nevada. Possible connections appear to be limited to the southwest or west margins of the Permian Basin. There may have been a return current from the basin to the open ocean. If so it transported less water than the amount of inflow from the ocean, plus drainage from land areas entering the basin, else no great volume of salines could have been deposited.

Evaporation is great in all warm climates where there is a great percentage of clear weather, more especially between the 45th parallels of latitude on both sides of the equator. It is also great wherever there is strong wind movement, as for instance, on the Great Plains or in coastal areas. In bodies of water of sufficient depth so that the deeper water is beneath the zone of agitation by waves, water of the deeper zone is more highly concentrated in mineral salts than the surface zone. Also when waters reach a degree of concentration at which most of the sodium chloride has been precipitated, the remaining solution increases markedly in temperature and this increase in temperature aids loss by evaporation.

Amarillo, Texas, lies in the middle of the Permian Basin of desiccation. The annual rainfall there is 22 inches. The open tank evaporation for the six warmer months is 54 inches and for the entire year must amount to at least between three and four times the rainfall. Lower Amarillo 3,700 feet—to sea-level—and the evaporation would increase because of greater average temperature. Desiccation deposits would then probably form there with a considerably greater rainfall than the present.

SOME DATA ON SUCCESSION OF SALINE RESIDUES

The saline residues are in local beds as will be apparent from the following records of borings, based on samples. In these figures a cycle based on anhydrite overlain by salt is taken as a unit. In some cases, an excessive number of cycles are given since in some instances both minerals are likely to be deposited more or less simultaneously. Gypsum replaces anhydrite at the surface and for a few hundred feet beneath the surface, anhydrite having here been hydrated to gypsum.

Anhydrite-Salt Cycles in Wichita Stage Alone

Number of Cycles	Situation
14	Guadalupe County, New Mexico
9	Chaves County, New Mexico
1 (all anhydrite, interbedded with other rocks)	Hall County, Texas

Anhydrite-Salt Cycles in Upper Series Alone

Number of Cycles	Situation
4	Big Lake Field, Reagan County, Texas
5 (some eroded?)	Northwestern Reeves County, Texas
6	Upton County, Texas
3 (some eroded?)	Near Carlsbad, New Mexico
1 (solid anhydrite, 1,164 ft. thick)	Eastern Culberson and Western Reeves Counties, Texas
26	Loving County, Texas
22	Southern Ward County, Texas
3 (upper part eroded)	Eastern Pecos County, Texas
6	Reeves-Pecos County line, Texas
10	Central Midland County, Texas

Anhydrite-Salt Cycles in both Upper and Lower Series, Northwest Texas

(Some eroded from top, and all, except last, situated in eastern marginal territory)

Number of Cycles	Situation
12	Hall County, Texas
3	Motley County, Texas
5	Childress County, Texas
4	Dickens County, Texas
11	Southern Hale County, Texas

No thickening or repetition of salines caused by the "intrusive" action of salt domes or salt anticlines have ever been noted in the Permian Basin. It is possible that such may be found but the present likelihood is not very great. It may be that salt domes and anticlines are absent for one or more of the following reasons:

1. Intense deformation does not occur.
2. The saline residues were not buried under a sufficient thickness of later deposits.
3. The overlying sediments are more competent than those of salt dome areas.

Detrital sediments, generally relatively thin, are interbedded with the saline residues. In the Manzano series of New Mexico these sediments are thicker, coarser and undoubtedly derived from fairly close land areas. With this exception, the terrigenous detritus in the deeper parts of the basin is fine clays, blue, gray, green-gray, and dark red in color. They are prevailingly of the texture of the oceanic blue muds and were apparently deposited relatively far from the land. The water may have been fairly deep, at least locally, although this is probably not a necessary condition.

There is nothing inherently against the view that the basin clays were largely wind-transported deposits. Current deposition will account for all, most, or a large percentage of them. They sometimes contain admixtures of lime carbonate, anhydrite or salt, as can reasonably be expected.

There appears to be something of a prevalent impression that in the deposition by desiccation of saline residues there is first a time in which all the calcium carbonate is deposited, followed by an interval in which all the gypsum goes out of solution, followed by a time in which nearly all the salt is laid down. Usiglio's evaporation of sea water, however, does not show this. The calcium carbonate is precipitated when sea water is evaporated to two concentrations, the first to 53.3 per cent the original volume and the other to 19 per cent the original volume. At the latter concentration five-sixths as much is precipitated as at the former. But, also, slightly more gypsum is precipitated than calcium carbonate when the solution has been evaporated to 19 per cent original volume. The gypsum is precipitated between the concentration points of 19 and 3 per cent, nearly four-fifths of it going out of solution before the 9½ per cent concentration is reached when sodium chloride, magnesium sulphate and magnesium chloride begin to be precipitated. Seventy-seven per cent of the total salt is precipitated along with the remaining one-fifth of the gypsum. At the same time, one-fourth the total magnesium sulphate is being deposited, as well as one-third the total magnesium chloride. It is possible that at least some of the polyhalite (triple sulphate of potassium, magnesium, and calcium) is precipitated at this stage under certain conditions of temperature and concentration-composition, since this mineral occurs with layers of anhydrite in the Permian Basin, although possibly re-concentration of one or the other has taken place subsequent to original deposition. At greater concentrations common salt forms a more or less mixed deposit with the mother liquor salts of magnesium and potassium and sodium bromide.

The German Upper Permian saline residues contain various eutectic mixtures—of calcium carbonate and anhydrite, of anhydrite and common salt, of common salt with potassium and magnesium. A "salt-porphyry" is fairly common in New Mexico and Texas. This consists of "phenocrysts" of cubical crystals of common salt in a finer "groundmass" of anhydrite. Anhydrite and limestone (often with some percentage of magnesium) are often intimately intermixed. Fairly pure beds of sylvite have been found in New Mexico, which shows concentration to saturation of the mother liquors.

The limestone of the Texas-New Mexico desiccation cycles is generally fine-grained, dirty gray in color and very porous, with small cavities. This is the "rauchwacke" of European geologists. Some of the beds contain magnesium carbonate. It occurs at virtually any and all horizons within the saline residue succession, but in general there is a greater thickness at the base.

Pure laminated anhydrite, 1,164 feet in thickness, forms the Castile formation on the west edge of the basin in Culberson County, Texas. This was deposited in 300,000 years, according to Udden. Anhydrite was here deposited through a total interval of 1,950 feet. Pure and continuous strata of common salt up to at least 370 feet in thickness are known. The thickest individual beds of anhydrite and salt as well as the total greatest thickness of saline residues occur in the deepest part of the basin contiguous to the Pecos River, where one boring found saline residues through a 4,375 foot succession.

There is a remarkable succession of limestone and anhydrite, at some horizons intermingled and forming a "porphyry" and at other horizons interbedded, in the Wichita formation of Hall County, Texas. Anhydrite deposition began at the base of this succession on deposits of limestone and black shale. Anhydrite, limestone, and a small amount of clay form the lower 1,080 feet (Wichita part) of the saline residue section. Then a bed of salt less than 10 feet in thickness was laid down. Then 450 feet of anhydrite, limestone, a small amount of clay, and one bed of salt were deposited. Above this level, thin salt beds and red beds become more numerous and limestone is much less common. This boring began in the succession of saline residues and continued in them until a depth of 3,135 feet was reached. A total of fifteen horizons of salt was found. A remarkable uniformity in salinity of water is indicated by the fact that the only chemical precipitates in the lower 1,080 feet were anhydrite and limestone. During this deposition, the salinity of the water must never have surpassed 27.546 per cent. Traced to the east the salt changes to anhydrite in the same horizons.

There can be little doubt that these saline residues have formed from the evaporation of sea-water. This is indicated by the stratigraphy and the great volume of as well as the composition of the residues. Some older saline residues from which a part of these may have been derived are known in Utah, Colorado, Iowa (?), Michigan, New York, Ohio, Alberta, and other areas, although it is not certain any contribution was made from older deposits.

The basin was virtually surrounded, except perhaps on the north, in the Wichita stage by normal fossiliferous deposits, but in the upper series such are found only on the southwest, although it is quite evident that elsewhere the upper marginal deposits are largely if not entirely destroyed. It may be, however, that except on the southwest normal marine fossiliferous deposits of the upper series never flanked the basin, since it may have been more constricted and more saline than in the Wichita stage. It is important to make this point, since so far as known the very lowest Wichita may be normally marine throughout the basin and the saline residues of the higher Wichita may have been deposited in an area much constricted by evaporation, the marginal deposits of which, of slightly greater age, may have been, at least in the earlier stages, normally marine. Such could have readily occurred if the heart of the basin were fairly deep as compared with the edges, which is perhaps indicated by the pure fossiliferous limestone of perhaps the earlier Wichita overlain by saline residues in the heart of the basin. The earliest known specimen of an ammonoid found in the Double Mountain is in the gypsum while the higher Double Mountain fossiliferous dolomite grades from sandstone at the north into gypsum at the south.

Assuming for the moment there was but a single, continuous salt basin during upper Wichita time, fossiliferous formations might constantly form in that basin in an area close to the intake of water from the normal sea or around its margins where fresh water from the land was added. For instance, the Wolfcamp of the Glass Mountains is fossiliferous throughout and lies in the immediate vicinity of a possible barrier constituted by the folded mountain chain of the Marathon area. Just as in the case of the Gulf of Karabugas an afferent current would bring in abundant organisms the remains of which would be deposited at and near where they were killed by excessive salinity of the basin water.

We note the above in order to meet Grabau's objection: "Many of our older salt deposits which have generally been interpreted as formed under the conditions postulated by the bar theory, show neither organic remains enclosed within the series, nor are there contemporaneous normal marine sediments within reasonable distance of the salt deposits. They therefore can not be interpreted as lagoonal deposits of sea salts" **(73).** That objection does not hold for either the lower or higher series of the Southwestern Permian Basin. Some additional evidence will be presented later on in another connection.

Grabau states also **(73,** p. 142) that "fossiliferous salt beds, representing deposits formed in lagoons or otherwise in close association with the sea, have so far rarely furnished potash or other mother liquor salts." The potash beds of the Southwestern Permian Basin constitute one more exception to that statement. Both Grabau and Walther fail to recognize that potash salts in great amount are so tightly absorbed by clays that they can be dissolved from them only with great difficulty, a fact which Hilgard long since noted in his book on "Soils" and which the United States Geological Survey re-discovered in their borings in the playa lakes of the Great Basin. The saline residues of the Permian Basin are overlain by clays, the basal parts of which do not appear to have been analyzed for possible potash content.

We will observe next that the extent of the Salt Basin of the present is only an undeterminable fraction of the original. To the east—as far as the Atlantic Coastal Plain—we are not sure any higher formation was ever deposited. On the northwest no later deposits are known to have been formed before the Upper Trias. On the north, southeast, south, and southwest, the next later deposits are Cretaceous. An extensive peneplain is known to have been developed on the southeast and south during the post-Double Mountain Permian—pre-Trinity Cretaceous erosion interval. A very large extent of Permian strata has obviously been removed. A large area and volume of water may have originally been concentrated by desiccation before any deposition of saline residues took place, or in other words to one-fifth the original volume before anhydrite began to be formed. The facts previously given are not unfavorable to the likelihood that just such a concentration took place in the Southwestern Permian Basin. It will not, however, account for the great volumes of salines nor is it necessary for them but it would undoubtedly aid in a measure.

DIFFERENCES IN SALINITY IN THE SAME WATER BODY

We have already noted differences in salinity in different parts of the Caspian Sea and of the lagoons on the northwestern Gulf of Mexico coast. We can add almost without limit to these instances but will content ourselves with a few. There is often a marked difference in salinity, both horizontally and vertically, in the same water body and these vary in extent and volume from small ponds to oceans. Thus seas connecting with the ocean, such as the Baltic, Black and Mediterranean, vary in salinity from place to place. Layers of varying depths and of varying situations in the oceans show marked differences in temperature and salinity. Lakes at the eastern base of the Sierra

Nevada are fresh enough at the end where the principal inflowing stream from the mountains enters them to permit mountain trout to live and at the other end are highly concentrated brines. Fresh water, being lighter, floats on salt water very commonly, as for instance, in the Dead Sea and at the mouths of fresh water streams entering the sea. In some lakes, the underlying more saline water is known to have a much higher temperature than the overlying fresher water. In Black Lake, Hungary, for example, the surface temperature was found to be 21° C., while the deeper, dense layer had a temperature of 56° C. The denser, lower layers of brine in some Hungarian lakes have been found to have temperatures of over 70° C.

These facts indicate that circulation by convection and all other causes is very far from complete, even in the very largest bodies of water. It appears, indeed, possible that at least in a local deep trough in a larger water body, the water may be supersaturated and may deposit salts while the surface water is undersaturated. It may be possible, also, that under these conditions, the surface water is not too saline to permit the existence of organisms. In a very large body of evaporating water, connected with the open sea by a strait, an afferent current may bring in a large assemblage of organisms which may live in the surface waters of the current for a distance of many miles beyond the intake. This may partly explain, for example, the occurrence of the San Andres marine fauna, the Double Mountain ammonoid fauna and the "Big Lime" ridge in the vicinity of the Pecos River. If the current be sufficiently strong, organic remains will be swept beyond the locality in which the organisms could live.

Fresh water, brought in by streams to such a basin, may largely remain in the peripheral more shallow places, or, if more extensively spread, may form mainly a surface layer. It is, indeed, possible that little or no salts will be deposited near the shores of such a basin while at the same time extensive salt deposits are forming farther from shore.

The Permian saline residues are of such great thicknesses that the amount of water evaporated must have been of great volume. Bodies of water of extensive area probably in some places dried up to the stage when highly concentrated solutions were left only in local deeper parts of the basin. In the latter final precipitation of the more soluble minerals occurred. In other places and times, limited inflow of water from the sea was added to the basin of evaporation, as Ochsenius has postulated in his bar theory, which can be somewhat modified to fit particular instances. In only the Pecos area are cycles of desiccation known during which hundreds or thousands of feet of a continuous section of anhydrite or salt were laid down but ordinarily there is an alternation of more or less complete desiccation cycles with limestone, anhydrite, salt and sometimes potassium and magnesium minerals following in an upward succession and then the section is again repeated from several to more than a dozen times. Often, at least, one succession is separated from another by beds of well consolidated, dense, impervious clay or shale, grayish-green to gray and blue-gray in color, sometimes red, which resembles physically and texturally the hard-baked surface playa clays of the American Great Basin. Such clay may be partly eolian and partly aqueous deposit. It served, no doubt, in many instances as an impervious capping preventing solution of the underlying salts if fresher water at later dates invaded the site of the former desiccation basin.

Basins would be formed in various ways, certainly by depositional processes, less certainly by deformational processes. Under the former there would be bars, spits, barrier beaches and reefs formed by currents and waves, and by the growth of reef-building organisms. Also, locally a greater supply of land-derived detritus would be furnished from the more highly and broadly uplifted parts of the land surface. For instance, growth of delta promontories from opposite directions towards each other would gradually more and more restrict arms of the sea forming first gulfs, later embayments, and later, more or less enclosed basins. Also, in some instances, eolian deposition of sand and clay would accomplish the same result.

It is sufficiently evident that the gradual withdrawal of the normal sea more and more to the southwest probably was not accomplished absolutely uniformly whether its cause was gradual sedimentation, uplift either uniformly or differentially or by a combination of the two. Some barriers would be destroyed by wave-cutting. Von Humboldt mentions such an event on the coast of Venezuela where a salt pan which had produced for centuries was destroyed in a single hurricane. Erosion, either marine or terrestrial, would locally and temporarily prevail over depositional processes and the converse would be equally true. The stratigraphy shows there was shifting of the basins and recurrence in the same area of basin desiccation more than once.

Another probable source of saline materials has apparently been overlooked. By the time the maximum saline deposition was taking place much of the marginal land area, and especially that nearer the desiccation basins, had been reduced to low relief and was largely a depositional plain. Under such conditions, the runoff in surface streams is considerably less than the precipitation, the difference is absorbed by the soils and evaporated. A very large proportion of the red beds is sandy silts. Even the highest red beds and those deposited in the very heart of the basin, such as those now exposed in the Panhandle, are so absorbent that surface reservoirs will not hold water. A very large proportion of the water so absorbed is lost through evaporation, capillary action, surface tension (adsorption) and absorption. That proportion which freely circulates underground and finally is added to a supply of the basin will dissolve mineral matter from the soils and rocks and saline residues through which it passes in its movement underground. The latter will afford important increment in such a case as this, where the area of the basin is gradually constricted, and shifts in site, so that previously deposited saline residues are subject to solution while precipitation of the same is taking place elsewhere. This would tend to further concentration in the deeper parts of the basin or basins. A certain amount of this underground solution and concentration has gone on constantly from the earliest Permian saline deposition to the present for this basin now occupies the trough of an exceedingly large geosyncline towards which underground waters become increasingly mineralized. This geosyncline was formed by a deformation which occurred before the upper Triassic (Keuper). We know nothing to successfully controvert the possibility that there was gradual geosynclinal downwarping during Permian deposition. The presence of conglomerate zones in both the Pennsylvanian and Permian are perhaps most readily explained by secular earth movements.

Another perhaps not inconsiderable source of saline material is its transportation inland from the coast by winds. It accumulates along shore above low-tide level and a broader area of accumulation is formed by storm waves. The retreating Permian sea left a very flat shore line. Clays and muds of the low shore line deposits would be covered to considerable areal extent during high tide and storm periods, they would absorb a notable amount of salts and some of these would be blown inland when the tidal and storm flat surfaces were exposed to the air.

The great thickness and area of the saline residues do not appear to present any extraordinary difficulties. If the water in the basin of desiccation had already become concentrated to the state in which it could not carry calcium carbonate in solution that substance, derived from inflowing normal sea-water, would be precipitated close to the point of intake. Similarly, if the water of the basin was already so concentrated that calcium sulphate could not remain in solution, anhydrite would be deposited along the course where the normal inflowing current mingled with the more concentrated basin waters. This would afford more or less wedge—or lens-shaped thicker bodies of either limestone or anhydrite grading laterally into either anhydrite or salt or into an alternation of anhydrite and salt. It appears we have a good example of this in the upper Permian deposits. South of the Capitan limestone of the Guadalupe Mountains, there is a very thick formation of anhydrite, hydrated at and near the surface to gypsum, and known as the Castile gypsum. A number of wells have penetrated the Castile formation in Culberson and Reeves counties, Texas. One of these was continuously cored through 1,950 feet of gypsum and anhydrite with a few interbeds of limestone. Heavy salt beds intercalated with anhydrite and limestone occupy farther east apparently the same stratigraphic interval. The Capitan limestone ends abruptly along the southern scarp of the Guadalupe Mountains so far as can be determined, not through faulting but by abrupt change in material deposited. The Delaware Mountain formation contains much sandstone at the south end of the Guadalupe Mountains which rapidly thins both to north and south and apparently also to the east. It is therefore suggested that a connection between the normal sea and the desiccation basin of the later Permian may have been across this area. The abundantly fossiliferous Delaware Mountain formation underlies the Castile gypsum which is overlain by the Rustler limestone, a magnesian carbonate "rauchwacke" chemical precipitate.

The Vidrio-Gilliam-Tessey formations which are the equivalent of the Capitan limestone, apparently pass to the north of the Glass Mountains into thick anhydrite and salt. Between the Glass Mountains and the Apache-Delaware Mountains, for a distance of 70 miles, the Permian is deeply buried, hence we do not know the full extent of the Capitan-Vidrio-Gilliam-Tessey limestone nor of the Castile gypsum. The Castile outcrops in a belt 55 miles long between the Guadalupe and Apache mountains. This may represent the constriction or bottle-neck of a Mediterranean-like basin. No Permian of equivalent age is now present farther west or southwest for a long distance and it may be that in this direction the constriction was narrower. The anhydrite would reasonably be expected to widen out into a fan on the desiccation basin side of the constriction.

Branson's modified bar hypothesis **(25)** is herein quoted since it quite likely applies to the Permian basin:

> "A modified bar hypothesis seems to explain the phenomena of thick gypsum and salt deposits, and the modification consists of supplying the receiving basins with highly concentrated waters instead of normal sea-water. In the drying up of a large interior sea, the waters might come to lie in separate basins if the bottom were uneven. Evaporation over the full expanse of the interior sea might be rapid enough to decrease the depth and area in spite of the inflow of some stream, but when considerable expanse of bottom had become exposed, the total evaporation would have become less and the inflow nearer to the amount of evaporation. Assuming that isolated basins would be formed, separated by low barriers, and that the main streams would enter into the marginal basins, the inflow might be sufficient to cause these basins to overflow and supply the inner basin, that had no direct stream connections, with highly charged waters as fast as their own waters evaporated."

Lakes, the waters of which have a concentration as high as those of the Dead Sea, have the calcium carbonate and sulphate of stream waters precipitated, near the mouth of each stream which enters, as the lake waters are already too highly concentrated to hold these substances in solution.

THE WICHITA FOSSILIFEROUS STRATA BORDERING THE BASIN

The afferent current entering the basin from the normal sea is quite likely to have finally become a marginal current flowing around the borders of a basin of this oval shape. In the Northern Hemisphere such a current would probably be deflected by the earth's rotation in a northeastward direction to the eastern basin borders. Such a current would perhaps bring with it some of the more hardy organisms of the immigrant fauna which would mingle with the relicts still surviving of the Cisco fauna. The border area would contain the less saline waters because it would receive the drainage from the land areas and would have the more normal sea waters brought by the current. It is therefore within the realm of possibility that an adaptable original marine fauna, perhaps more largely molluscan, especially pelecypod, could live in the marginal waters while carbonates and sulphates were being deposited in the more stagnant waters removed some distance from the shore line. In some such way it may be possible to explain the occurrence of the Wichita fauna in the eastern border area of Texas, Oklahoma and Kansas and the western border area of New Mexico (Yeso formation). The next higher formation in New Mexico, the San Andres, may represent a more typical marine incursion from the westward, though this postulate is perhaps unnecessary. In much the same way, perhaps, can be explained the Clear Fork fauna along the Colorado River of Texas. The later very sparse almost wholly pelecypod faunas in the Double Mountain may have a somewhat analogous explanation.

THE PECOS "BIG LIME"

It should be recalled at the outset that the so-called "Big Lime" is by no means all calcium and magnesian carbonate but contains a considerable but as yet immeasurable amount of anhydrite, clay, sandstone and bentonite. We should observe furthermore that the "Big Lime" is found adjacent to the thickest salt and anhydrite strata yet known.

We can at present learn much concerning this "Big Lime" from the surface outcrops of what is either at least a part of it or a formation partly at least analagous. We refer to the Capitan of the Guadalupe Mountains, the Apache of the Apache-Delaware Mountains, and the Vidrio-Gilliam-Tessey of the Glass Mountains, all of which can be seen to dovetail into gypsum and red beds. The most fossiliferous part of the Capitan is in the vicinity of Guadalupe Point and El Capitan Peak, where it contains marine invertebrates and algal reefs. To the northward and eastward fossils are rare and the dolomite has the appearance of being pisolitic and at least largely a non-organic chemical precipitate. To the southeast this dolomite suddenly ends with the very thick Castile gypsum reaching to the base of its cliffs. In the Glass Mountains the Capitan equivalent or a higher formation contains abundant *Fusulina elongata,* at least in certain zones or nests, but has yielded exceedingly few other fossils. The fusulinas are very generally corroded—perhaps were so when deposited. Therefore, this facies may have accumulated by current deposition or as a barrier reef in an area sinking at or about the same rate as deposits accumulated.

There is no definite evidence yet to indicate that this dolomite is not at least a part of the upper "Big Lime." The current entering the basin of water so highly concentrated that carbonates could not remain in solution would be forced to deposit its carbonate content and its organisms would be killed when it reached the concentrated basins. In this way the "Big Lime" may have been deposited as a current delta or current reef contemporaneously with deposition of anhydrite, rock salt and other saline residues immediately adjacent. It is thought that just such deposition would necessarily occur. It is possible the Castile gypsum was deposited in the same way by waters saturated to about the point of precipitation for calcium sulphate meeting waters even more highly concentrated and at least intermittently depositing salt.

The deposition of the "Big Lime" would therefore be the necessary complement to deposition of anhydrite, rock salt, and potassium and magnesian salts in closely adjacent water. If it should be objected that the quantity of carbonate is too great compared with the amount of other saline residues, we would answer (1) that at least one continuous core section from top to base of the "Big Lime" throughout its area for every ten square miles would be necessary to give even a reasonable estimate of the real amount of carbonate, (2) that it is possible that after deposition of the saline residues ceased, the remaining water, very highly charged with sulphates, chlorides, and other compounds, may have been freshened by fresh water incursion, and that (3) part of the sulphates and chlorides originally deposited may have been removed by subsequent erosion or solution.

If this view is correct, the top of the "Big Lime" is apt to be very irregular and by no means a true stratigraphic horizon. Nor would there be any need to postulate an erosional unconformity at its top. Over the top of the Yates oil field where no saline residues overlie the "Big Lime" they may have been removed by solution, certainly indicated by the nature of down-faulting in surface strata towards the summit of the anticline, the highly saline waters of the flanks indicating solution is still operative, and certainly suggested by the nearness of the field to the Pecos along the valley of which much solution is known to have certainly taken place. Also, there may be some possibility that the post-Cretaceous deformation of the field has been of sufficent force to squeeze salt and anhydrite from the summit portion.

THE ORIGINAL SULPHATE MINERAL DEPOSITED

There remains the question whether anhydrite or gypsum was the original sulphate mineral deposited. The answer perhaps cannot now be given. Van't Hoff and Weigert found, however, that in solutions high in chlorides, anhydrite and not gypsum is deposited. There is considerable evidence that the highly concentrated solutions of the particular salts with which we have to deal have an excessively high temperature and high temperature is thought to favor precipitation of anhydrite rather than gypsum. Dehydration of gypsum to form anhydrite is accompanied by a large decrease in volume and processes of anamorphism under pressures of superincumbent sediments take place very much more generally in the direction of decrease of volume. Hence, even granting that gypsum was originally deposited, downward pressure of superincumbent strata, increase of temperature upon burial and by the pressure may have changed original gypsum to anhydrite. With regard to the change of gypsum to anhydrite, Elsden says: "The presence of any substance in solution which lowers the vapor tension of water will lower the inversion temperature of gypsum. . . . . Even solid gypsum . . . . can be changed into anhydrite by a concentrated solution of sodium chloride. .... These facts are of interest as pointing to the possibility of dehydration of minerals in rocks, in contact with salt solutions, at a temperature considerably below the normal inversion point."[3]

Some new data concerning this problem has just been published by Partridge and White, "The Solubility of Calcium Sulphate from 0 to 200°," Journ. Amer. Chem. Soc., Vol. 51, pp. 360–370, February, 1929, from the conclusion and summary of which, the following is abstracted:

"Incomplete experiments indicate that gypsum is converted into hemihydrate ($CaSO_4 \frac{1}{2} H_2O$) in less than one day when in contact with water at 100° C., and that the hemihydrate thus formed is subsequently transformed into anhydrite over longer periods of time. Gypsum and anhydrite are the only stable phases between 0 and 200° C. The transition temperature of gypsum into anhydrite lies near 40° C. (104° F.) Hemihydrate is metastable in the approximate range 90° to 130° C., showing decreasing stability with decrease of temperature below 90° and with increase of temperature above 130°."

A QUANTITATIVE ESTIMATE OF CARBONATES AND SULPHATES

As a test for the hypotheses here presented we will attempt an estimate of the amount of carbonate and calcium sulphate which might be formed from ocean water of present average composition entering a basin of assumed constant capacity of one million cubic kilometers (equivalent to 386,100 square miles with an average depth of 3,280 feet) and concentrated by evaporation until all the calcium sulphate has been deposited, ocean water entering the basin sufficient to maintain constant volume as evaporation takes place. The volume may or may not be excessive for the Permian Basin. It does not appear to be excessive when we recall that saline residues certainly extend from the north line of Kansas to southern Nevada and from central Texas to the Cordillera. If the Mexican red beds, gypsum,

[3]Elsden, J. V., Principles of Chemical Geology, pp. 85–86, 1910. See also Stremme, H., Zur Kentniss der wasserhaltigen und wasserfreien Eisenoxydbildungen in den Sedimentgesteinen. Zeit. für prakt. Geol. Jan. 1910, pp 18–23.

salt, and potash (the latter two occurring in the Tehuantepec region) are Permian, a large additional area must be added. We do not take into account a former greater distribution of saline residues beyond the present borders nor the possibility that a much greater area of water was lessened by evaporation before saline residue deposition began. We further assume for our purposes practically perfect diffusion of mineral content which is by no means so likely as usually supposed.

The average specific gravity of the salts in solution in the present oceans is 2.25 (Clarke). The percentage of salts in solution by mass is 3.5 per cent (Dittmar's average). The volume of the salts is 1.5555 per cent of the total liquid. By volume we have the following percentages:

sodium chloride	1.254 per cent
calcium sulphate	.042 per cent
calcium carbonate	.0045 per cent

All the calcium sulphate will be precipitated when the water is concentrated to three per cent of its original volume (density 1.257). The total volume of the solution entering the basin is 33,333,333 cubic kilometers of which one million cubic kilometers remain when all calcium sulphate is precipitated. There would at that point be the following volume of the three salts within the basin:

1,500 cubic kilometers of calcium carbonate.
14,000 cubic kilometers of calcium sulphate.
418,000 cubic kilometers of sodium chloride.

The above does not include any of the calcium carbonate contributed by the hard parts of organisms brought into the basin from the normal sea. Five-sixths of the calcium carbonate would be brought into the basin after the basin solution had become too concentrated to hold that substance in solution and would be mainly deposited close to the intake from the normal sea and largely be present in the "Big Lime." By the time all the calcium sulphate had been precipitated, two per cent of the total mineral content of the present oceans would be within the basin and, adding the volume of bitterns, one-fortieth the present ocean saline content. After this stage was reached, salines would still continue to enter the basin as long as there was an entering current from the ocean and wastage of water by evaporation balanced or exceeded the total water supply.

COMPOSITION OF THE PERMIAN OCEAN AND ITS POSSIBLE RESULTS

In the foregoing discussion we have limited ourselves to strict uniformitarian principles—conditions of the present day. However, in one respect, probably or, perhaps, certainly, strict uniformitarianism must probably be ultimately abandoned. The normal sea water of Permian time was likely in several essential respects different from present day sea water. In what precise respects it differed we are not certain and the following suggestions should be viewed with caution since they at least border on a field of speculation not yet critically tested. Dr. A. C. Lane has directed attention to the probability that the water of the ocean could very well have varied widely in composition in past geologic ages. In his geologic column summary in the Lefax notebook sheets, he gives the sodium to chlorine ratio in the Pennsylvanian as .49, in the Permian as .53, and in the present day ocean it is .65.

Some additional data supporting Lane's views are afforded by the following four analyses of waters occurring at four different horizons through a vertical succession of 900 feet in the Cisco Pennsylvanian (first three) and probably upper Canyon Pennsylvanian (fourth) underneath Hall County, southeastern corner of the Texas Panhandle. For comparison there is added (fifth) the average percentage composition of the present oceans.

These waters are all under large hydrostatic heads, number four having risen 3,400 feet in the well above the level at which it was found. They are, however, far removed from intake of surface waters in their horizons, a fact also indicated by their composition. The waters are all in cherty limestones in a limestone-shale succession which includes a number of beds of bentonite, the latter occurring at various horizons in both Pennsylvanian and lower Wichita Permian in this area.

ANALYSIS OF WELL AND OCEAN WATERS

	Depth in feet 3345–3397	Depth in feet 3705–3721	Depth in feet 3841–3853	Depth in feet 4270	Present Ocean's Average	
Cl	60.453	60.828	61.446	61.479	55.292	
Br					.188	
So_4	1.315	1.379	.734	.612	7.692	
Co_3	.088	.056	.051	.036	.207	
Na	32.661	31.129	30.476	30.902	30.593	31.699
K					1.106	
Ca	4.338	4.888	5.609	5.405	1.197	
Mg	1.154	1.723	1.678	1.567	3.725	
	100.009	100.003	99.994	100.011	100.000	
Salinity Percentage	14.11	12.95	16.04	22.16	3.5	

The waters are connate and also in part diagenetic. They would be more typical of the true composition of the Pennsylvanian ocean if they occurred in sandstones without adjacent beds of bentonite and limestone. They are so highly concentrated that they have lost a large amount of the carbonate, and also sulphate, which are characteristic of waters of lesser saline content in limestone rocks. It is suggested that the high content of mineral matter has come about from absorption of relatively pure water in the hydration of the bentonite, which mineral has probably been formed from probably acidic volcanic ash blown into the Pennsylvanian sea and in part at least hydrated after deposition. At least one alternative possible hypothesis is that gasses of original organic source have absorbed pure water.

These brines are so highly concentrated that they have lost much of their carbonates and sulphates upon supersaturation, and they now contain as much of these salts as they are able to hold in solution under the conditions of salinity, pressure and temperature in which they occur. Therefore, the other acid radical, the chlorine, has increased in proportion as carbonate and sulphate decreased.

The alkalies have not increased proportionally but part of them are likely to have been absorbed in the shales and the bentonite. This is especially likely with potassium. Magnesium content very likely has decreased through the deposition of magnesium carbonate, which is less soluble than calcium carbonate. The calcium content of these waters is from nearly four to nearly five times as much in proportion as in the present ocean. It appears very doubtful that the increased calcium is of diagenetic origin, derived from the limestone. It appears to be connate and, as Lane maintains, present as calcium chloride.

It therefore appears probable that the normal Permian ocean contained a relatively higher percentage of calcium than the present ocean. This would apparently lead to some far-reaching results. It is perhaps beyond our province to suggest that a higher percentage of calcium in the Pennsylvanian and Permian ocean was one of the reasons for the great amount of limestone deposited in the southern part of the Permian basin. But Branson, and perhaps others, has experienced great and very legitimate difficulty in accounting for the great volumes of calcium sulphate in even the Triassic of Wyoming, very much less in quantity than the Permian calcium sulphate. The present ocean contains 29 6/7 times as much by volume of sodium chloride as calcium sulphate. It certainly would appear that one way of overcoming this difficulty for the sulphate as well as for the carbonate of calcium (the latter making up such a great volume of the "Big Lime") would be by proving a greater proportionate amount of calcium in the Permian ocean water. To account for the large amount of magnesium carbonate in the Permian, we have a suggestion from the following statement of a chemist: "It is entirely possible that the dolomitization of limestone associated with brines is brought about by replacement of calcium of the limestone by magnesium of the brine. This reaction probably accounts for the dolomitization of most of the limestones associated with brines." Putrifying organic matter is also stated to be favorable for the deposition of magnesium carbonate.

We can at least be fairly certain that the average salinity percentage of the Permian ocean was higher at the beginning of the saline residue deposition than at its close. Hardly a plausible guess can now be made of the total volume of saline residues yet existent in the Permian basin of America. There is also a large volume of saline residues yet existing in the Permian of Europe and some in the Himalayas (Spiti) as well as in the Kimberley district of north Australia. Also, a large amount deposited in the Permian has been given back to the oceans in times subsequent to the Permian.

We are of the opinion that a selective precipitation took place during the Permian. There was relatively more calcium carbonate and sulphate abstracted from the Permian ocean than sodium chloride, the former being mostly deposited before the waters became completely saturated for chlorides. A large amount of chlorides in waters which lost all their calcium carbonate and sulphate was never precipitated, or else precipitated in higher strata later destroyed as is indicated by an abnormal proportion of residues of carbonate and sulphate as compared to chlorides in the deposits yet existent. There was, therefore, probably an increase in relative percentage of sodium chloride in the ocean and a corresponding decrease in calcium carbonate and sulphate from the beginning to the end of Permian saline deposition. In other words, the ocean at the end of that period probably approached more nearly its present composition than it did when saline deposition began.

If the percentage composition of the normal ocean water of the Permian was essentially different from the present. with respect at least to percentages and saturation points, instead of using present ocean water in order to explain Permian saline residues we should ascertain as accurately as may be possible the actual nature of the Permian water and base further conclusions upon experimental data derived from the evaporation of water of that composition. It would appear that the most favorable area in which to ascertain the composition of Pennsylvanian marine connate water is beneath the Permian Basin of America, where many borings are now being made. Such waters should, if possible, be collected from sandstones, interbedded with shales, free from chances of contamination with limestone or bentonite, away from oil- or gas-producing areas and free from admixture with surface waters. A little consideration will show that we can not hope to procure normal connate waters from American Permian although they can perhaps be found in the marine Permian of Russia or Siberia or perhaps Australia.

Branson's difficulty in accounting for the great amount of calcium sulphate is matched or exceeded by the apparent great amount of carbonates in the deeper portions of the Permian Basin. In the present ocean the carbonates in solution form less than one-tenth the mass of calcium sulphate, and magnesium sulphate is one and one-third times the mass of calcium sulphate. These difficulties may be at least much lessened by assuming a greater relative content of calcium in the Permian ocean, as discussed above. They are also to be in part discounted by the driller's logging anhydrite in nearly all instances as "lime," by standard tool drilling samples never affording precise thickness of the various materials in the samples, by ordinary drilling methods certainly dissolving much of the sodium chloride, and by the impossibility of detecting from standard tool drilling samples how much of the formation penetrated may be eutectic mixtures in various unknown proportions of sulphate and carbonate and of sulphate and chloride. Even in continuous cores procured by drilling with fluid saturated with magnesium chloride many complete analyses must be made of cores in order to find the exact amounts of various saline residues and then the whole succession of saline residue has seldom if ever been continuously cored from top to base. It has been demonstrated, however, that in short distances the sequence and thickness of the saline residues greatly differ. This fact certainly proves that there was little regular deposition of persistent saline members or even of widespread and uniform saline cycles. Another difficulty is that we have no means of knowing how much of the sodium chloride has been removed in subsequent solution in strata still present and how much has been removed by erosion of the original strata.

We will note one instance of localization out of many we might mention. Two borings within the basin are 45 miles apart. The one nearer the edge, in fact so near the original bounding land mass that it penetrated five thick sandstones interbedded with the saline residues, showed 14 different cycles of anhydrite-salt deposition and a total of over 600 feet of salt and of over 600 feet of anhydrite. The other showed only an inconsiderable total amount of either salt and anhydrite in two cycles, neither of which was complete, the salt occurring below the anhydrite so that water already free from calcium sulphate must have reached that place and began deposition of sodium chloride. Both borings went through the entire saline residue succession, the one with the greater saline residues having also the greater amount of sandstone as well as other detritals (clay and bentonite).

Wherever underground waters from surface sources have had access to the saline residues, a selective solution of the more soluble has occurred. Apparently a large amount of sodium chloride has been removed from near the surface outcrops both from lower beds on the flanks of the basin and from the upper strata in the basin itself. The anhydrite and salt within the basin contains generally little water and when it does, as on the flanks of Yates oil pool the water is a highly concentrated brine with as high as 35 per cent mineral matter in solution. In the "Big Lime" the water carries much sulphate, the gas is sulphurous and the oil contains a considerable percentage of sulphur, all of which indicates considerable quantities of sulphate in the "Big Lime."

There are ways in which chlorides and other compounds of the alkalies can have been lost during saline residue deposition. A large amount would be deposited on the wide shore line, tidal and storm wave zone as is seen on the edges of all salt water bodies today. Upon becoming dry much would be carried away by the winds. Clays absorb a high percentage of alkaline salts, more of the potassium and less but still considerable quantity of the sodium. It is well known that the alkali salts so absorbed can not be again readily leached out. Much of the original chloride is therefore still in the Permian clays.

If magnesian limestone and dolomite is an original precipitate in the Permian Basin the precipitation of magnesium carbonate will release part of the calcium ions. Possibly this calcium absorbed carbon dioxide either from the atmosphere or supplied from organisms killed by excessive salinity and formed more calcium carbonate. Or it might have combined with the sulphate radical and formed more calcium sulphate.

We have now possibly considered most of the important events occurring within the basin itself. But there were perhaps factors operating outside of the basin which had their effects within it. It is therefore necessary to consider some of the more general and even world-wide Permian phenomena.

The Permian red beds and saline residues are distributed widely over North America and Europe and are found in the Spiti Himalayas and in the Salt Range of northwest India, in the latter overlying the glacial beds and underlying the Permian containing the more normal (Tethys) marine fauna. Fossiliferous marine red beds are found in the island of Timor, just north of Australia; and not far away from Timor, in the Kimberley district in the north part of western Australia, red beds, gypsum and rock salt occur. The Timor and northern Australian localities are the only red bed or saline residue Permian deposits apparently yet known in the southern hemisphere. Red beds overlie the glacial deposits in the Salt Range. With this exception they are not known to be associated with Permian glacial deposits. Permian glacial deposits occur in peninsular India, the Salt Range, Australia, South Africa, and South America, but in the northern hemisphere only in India. Permian coal is almost as abundant and widespread as Pennsylvanian coal but in the main it occurs in regions where Pennsylvanian coal is absent. Permian coal is found everywhere where glacial deposits occur and in addition in southern Siberia and in relatively minor amounts only in the Permian red bed regions of Europe and America. Permian fossiliferous limestone is especially characteristic of the Tethys epicontinental trough paralleling on the north the equator from Indo-China westwards through the northern Himalayas and Tibet with a branch southwards into the Salt Range, thence through Persia and Armenia into southern Europe, branching out over most of Europe except the Baltic and other positive shield areas and ending in the North American Southwest. The only region in which marine Permian is interbedded with the glacial deposits is in Australia, and the Australian marine fauna is different from that of the Tethys although it reaches into the Salt Range. The Gondwana land flora occurs wherever there are glacial deposits and in addition reaches into Kashmir, Siberia, and European Russia.

It is thought the above distributional facts are so significant that we advance the possibilities: (1) that red beds and saline residues are not associated with glacial deposits because a glacial climate is too cold for their formation; (2) most of the Permian coal may have been formed in the cooler climates since it is so largely associated with glacial deposits, is mainly derived from cryptogams and gymnosperms more characteristic of the present cooler climates, and coal is not being formed within the present tropics;

and (3) the Australian marine fauna, the only one interbedded with glacial deposits, is different from the other marine faunas because isolated from them.

Many and various are the hypotheses advanced in order to account for the distribution of the Gondwana flora, of similar terrestrial and fresh water reptiles in South America and South Africa during Permian and Triassic, the glaciation, the perhaps isolated marine fauna of the Australian Permian and also the post-glacial, also likely isolated, in part only strictly marine Permian fauna of south Brazil. Our own will be a combination of most of the others without, we trust, dealing too violently with the doctrine of permanence throughout geologic time of the ocean basins and continents.

We assume the existence of land bridges connecting the former Australia-New Zealand land mass with Antarctica, South America with Antarctica, Australia-New Zealand with southeastern Asia and eastermost South America with westermost Africa. So much will meet the needs without a superfluity. The most controversial will be the land bridge between South America and Africa; nevertheless we must somehow get the land vertebrates across into South America and it is just as easy to bring them across the present equatorial Atlantic as from Africa to Antarctica and thence to South America. It is granted at the outset that connection between South America and Africa by land may not be necessary, nor is it entirely requisite to have an entirely solid land bridge between the two continents but only an archipelago, the islands of which were separated by relatively shallow water, sufficient to inhibit or entirely prevent oceanic circulation. This particular land bridge may have been entirely or in part an inheritance from former times.

The necessity for great diastrophic action to form these land bridges is not so apparent. There are rather widespread marine transgressions of epicontinental seas in Europe and North American Permian basins and in the Tethys in the later Pennsylvanian after the Hercynian diastrophism. There was also removal of water from the ocean basins into the Permian ice caps and valley glaciers if these were more extensive than the present Antarctic and Greenland ice caps and other glaciers. The two would lower ocean levels and by just so much would bring shallow water areas above ocean level. Possibly this lowering of level alone was sufficient to bring the Australia-New Zealand-Antarctic and the South America-Antarctic shallow water connections out of water.

The poles may or may not have shifted. If they did it would meet the requirements to place the North Pole south of Alaska and the South Pole south of Africa. By such shifting there would be formed a southern polar ocean out of the present Indian and the south Atlantic. If the poles were in their present situations we could add to the present areal extent of peninsular India and elevate that land mass to the altitude of a high plateau which it would also probably be necessary to do if the poles were shifted as suggested. There does not appear to be any serious objection to this, since Indian glacial deposits are non-marine and the Gondwana system of terrestrial sediments is of great thickness and areal extent and must have been supplied by a large and possibly high land area.

All the other Permian glaciated areas may have had relatively high altitudes as well. Only in Australia are marine and glacial deposits interbedded and here an epicontinental sea or seas connected to the south with the southern colder ocean and flanked by high lands would meet the conditions. All known Permian glacial areas would be grouped about this southern cooler ocean.

Concerning the general refrigeration of the planet there is the view that deposition of abnormal amounts of carbonates and coal in Pennsylvanian and Permian impoverished the atmosphere in carbon dioxide. There is a possibility that glaciation may have lowered the content of water vapor in the atmosphere. Evaporation would be lessened in the colder regions of the ice caps and precipitation would be increased. Great evaporation was taking place in the

Permian basins of Europe and North America. Perhaps one of the causes of this evaporation was the lessening of carbon dioxide and water vapor in the atmosphere making the air in the vicinity of the warmer oceans drier and also warmer than normally since there was less thermal blanketing of the atmosphere over the evaporating basins. Greater radiation conceivably might mean greater evaporation. The general atmospheric circulation would draw moisture away from evaporating areas to the ice caps and colder regions. The warm shallow water epicontinental seas would expose a larger water surface to evaporation.

If a large percentage of the total water was gathered into the ice caps the salinity of the ocean would be increased which would favor extensive deposition of saline residues.

SUMMARY

It is shown in this paper that saline residues are now forming in non-arid climates, and that all that is absolutely necessary for their formation is a sufficiently restricted body of water in which the total evaporation exceeds total supply. Since the red beds flanking on both sides the Permian Basin were in all probability formed under humid climatic conditions, it is much less difficult though not absolutely necessary to consider the associated saline residues as also of non-arid conditions of origin.

There can be no reasonable doubt after a review of the evidence that the saline residues were derived from the evaporation of sea-water. This is sufficiently indicated by the stratigraphy, paleontology, and depositional history. Moreover, the great volumes could have been derived from no other known possible source. The known paleogeographic facts indicate that the saline residues of the main basin were deposited in an elliptical embayment connected by a strait with an open, normal sea on the southwest. During at least a part of the earlier Permian, there existed a broad western arm of this embayment which may or may not have been connected directly with the Pacific sea, but the full history of this arm can perhaps not be written until more exact data are available.

The original floor of the embayment must have either sunk to a maximum of from eight to nine thousand feet beneath then existing sea-level at the time saline residue deposition began or have undergone that amount of total depression before deposition ceased. The connecting strait must have remained for the most part relatively shallow but this could have happened by deposition in it equalling more or less the rate of its depression or current erosion may have maintained its original shallowness.

Various ways of local concentration of the different saline residues are considered but it is sugges'ed that for the most part the various minerals were deposited contemporaneously in the same body or bodies of water, since lack of complete circulation of waters gave rise to great variations locally in percentages of salinity. This view receives important support from actual known conditions in present-day water bodies varying in size all the way from ponds to oceans. Local variations in salinity were probably so extreme that in Wichita time at least organisms lived in some parts of the same body of water in which relatively short distances away anhydrite was being precipitated. It is known that in west-central and northeastern Coke County, Texas, a fossiliferous marine limestone of Wichita age is intercalated between sequences of anhydrite and evaporation carbonates while but a few miles farther east, the whole of the outcropping Wichita is normal marine.

Finally, it is generally admitted that all other hypotheses of the origin of the saline residues of the Southwestern Permian Basin are inadequate to explain satisfactorily the various phenomena now known.

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NOTE ON THE PERMIAN CHINATI SERIES OF WEST TEXAS

BY

CHARLES LAURENCE BAKER

Dr. J. A. Udden published in 1904 a report on "The Geology of the Shafter Silver Mine District, Presidio County, Texas."[1] At the time Udden did his field work, he thought all sedimentary rocks of the district lower than the Cretaceous were Pennsylvanian, but before his report was published Dr. Girty announced the discovery of Permian in the Guadalupe Mountains which caused Udden to suggest that the upper part of the Paleozoic section of the Chinati Mountains might prove to be Permian. Dr. Böse was able to show in 1916 that Udden's suggestion was correct. Nevertheless, we still thought the lower part of the Chinati series, as Dr. Udden named these rocks, or the subdivisions Cieneguita and Alta were Pennsylvanian. This view was based on the Pennsylvanian aspect of the fossils collected by Udden.

During December, 1927, the present writer made a reexamination of the Chinati series, devoting most of his time to the collection of fossils, and was able to determine the Permian age of the Cieneguita and Alta formations. The characteristic lowermost Permian genus *Schwagerina*, was found from bottom to top of the Cieneguita. *Richthofenia*, another characteristic Permian fossil, was found to occur at least in the top of the Cieneguita, and the uppermost beds of the same were found to contain two species of Permian ammonoids.

The Chinati Mountains proper are composed of a very thick series of volcanic rocks comprising lavas, tuffs, and tuff-breccias, with a number of intrusive dikes and at least three larger intrusive masses. One of the intrusives outcrops in the valley of Cibolo Creek at the east foot of the main mountain mass and will be called the Ojo Bonito

[1]University of Texas Bull. 24, 1904.

porphyry. This porphyry is covered on the southwest and south sides by the volcanic series but has been the means of uplifting to the present surface Permian and Trinity Cretaceous rocks on its northwest, north, northeast, east, southeast, and south flanks. It is probable from the situation of the sedimentaries that the Ojo Bonito porphyry underlies the volcanics in the southeast part of the Chinati Mountains proper. It is possible that the Permian was not so greatly uplifted by the intrusion on the southwest flank, since that flank may be bordered by a south-southeast extension of the great Rim Rock fault zone exposed north of the Chinati Mountains.

Another large intrusive outcrops in San Antonio Canyon in the western part of the Chinati Mountains. This may really be a part of the same intrusive mass as that of Ojo Bonito. Just northwest of the Chinati Mountains the Rim Rock fault has a large displacement, which must continue for a considerable distance farther south-southeast and may prove to be the western boundary of the intrusive mass of San Antonio Canyon. There is some reason for thinking the faults noted by Udden west and southwest of Shafter may be a part of the great Rim Rock fault zone since they are tectonically very similar and are situated along a line of possible extension.

Great erosion followed the uplift by intrusive action. This erosion exposed the intrusive mass and flanking sedimentaries. Then came the time of great volcanic action during which the country was buried deep in the volcanic accumulations. At a later time, the volcanic rocks were folded, and then Cibolo Creek excavated a broad deep valley, removing the volcanic cover from the area where the intrusive and sedimentary rocks are now exposed.

The upper part of the Permian Chinati series and the Trinity Cretaceous are exposed at the north base of the Chinati Mountains in a large anticline bounded on the west by the Rim Rock fault zone and overlain on the other sides by the volcanic series. The strata are exposed along Pinto Canyon and will subsequently be studied in detail.

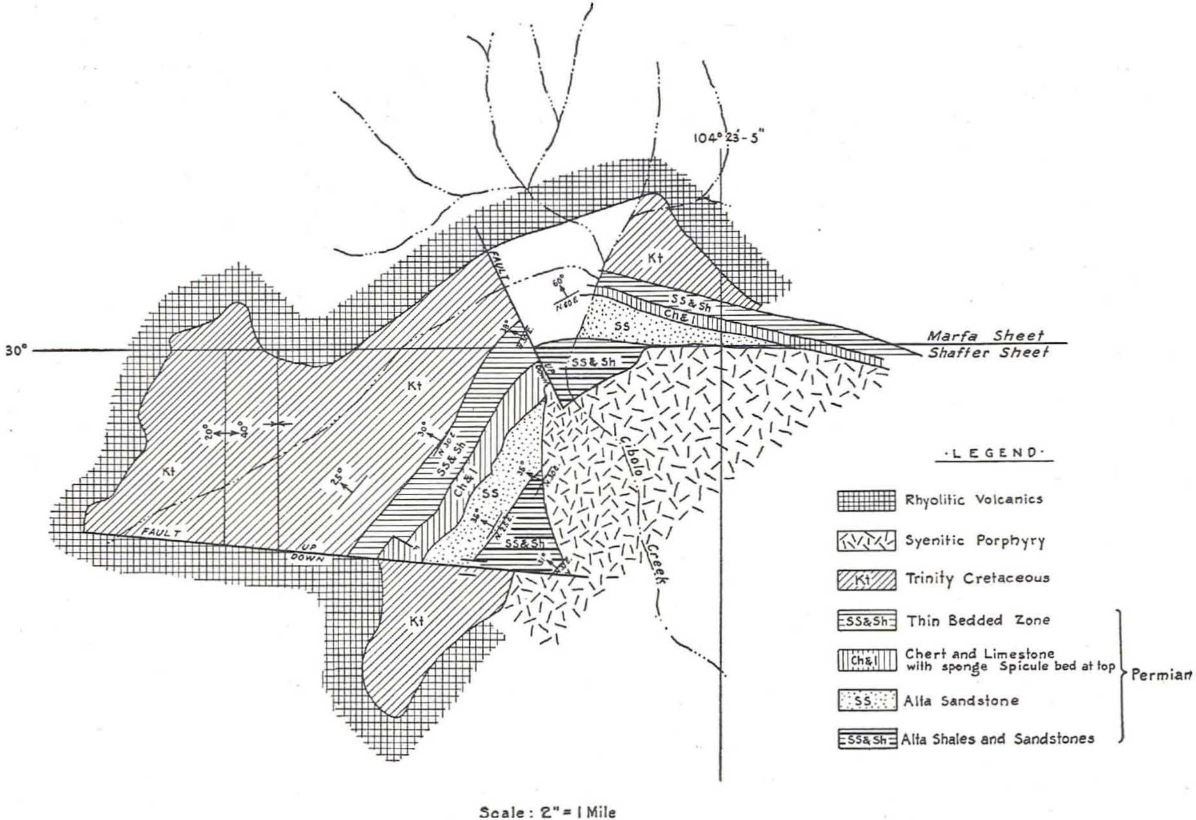

Fig. 1. Geologic map of the Upper Cibolo Basin mapped by plane table with the assistance of Mr. O. M. Longnecker, 1927.

PERMIAN

Udden's original classification of the Chinati series was based on a cross-section made two or three miles north of the Cibolo Ranch and south of the Ojo Bonito intrusion. It is as follows from top downwards:

Section of Chinati Series 2 to 3 Miles North of Cibolo Ranch

		Feet
	Cibolo Beds	
8.	Yellow limestone	650
7.	Thin-bedded zone	470
6.	Zone of sponge spicules	85
5.	Lower brecciated zone	133
4.	Transition beds	100
	Alta Beds	
3.	Yellow sand	1,500
2.	Dark shales	2,000
	Cieneguita Beds	
1.	Basal deposits	1,000
		5,938

This section has been reviewed in the field by the present writer, his opinion being that the entire Chinati series is a single uninterrupted depositional unit grading from partly coarse detrital deposits at the base to pure limestones at the top. In age the series extends from close to the base of the Permian to at least as high as the top of the Word and Delaware Mountain formations of other parts of Trans-Pecos Texas.

The Cieneguita-Alta beds are also known from near Ciudad Victoria, capital of the State of Tamaulipas, Mexico, where the same fossil foraminifera, the same "mortar beds," and same shales are found.

With regard to fossils submitted from the Cieneguita beds Dr. J. W. Beede says: "So nearly as I can determine these fossils belong in the base of the Permian or at least in the transition zone."[2]

[2]Personal communication.

Dr. Udden's classification and description of the type section covers all essentials. However, the lower brecciated zone is probably largely cavern deposits which explains the brecciation. In the vicinity of the 30th parallel of latitude, where the map accompanying this report was made, the members (3) to (7) or from the yellow sand to the thin-bedded zone inclusive are exposed, and all except the yellow sand show marked lithologic differences from those of Udden's type section. The same members are also exposed in Pinto Canyon, although only the lower 400 feet of the yellow sand member (3) is there exposed.

The upper Cibolo basin exposures (in vicinity of 30th parallel) will now be described in some detail.

The lowest member there exposed is the equivalent of Udden's yellow sand. The lower sub-member, which we will call the green sandstone, does not differ essentially from Udden's yellow sand except in its dirty greenish color. It consists of sandy and muscovitic, consolidated, nodular-bedded mudstone and sandstone. This is overlain by platy fine-grained, argillaceous sandstone, succeeded by medium-bedded quartzites which oxidize on the surface to light rusty-brown. The quartzite shows abundant wavy laminae, and its upper part exhibits fucoidal markings and a few narrow beds of fine grit. The color of the quartzite ranges from cream through various shades of brown and gray to greenish. The more indurated layers of the quartzite form hog-back escarpments.

The transition beds of Udden apparently are not present in this section and the succeeding member, the lower brecciated zone, has changed greatly in lithology. Udden's lower brecciated zone consists of a grayish-white, heavy-bedded limestone, but in upper Cibolo basin, the member is mainly chert, blue, black, brown, and gray in color and only a minor amount of limestone in scattered thin beds, nodules or concretions. The limestone is either crystalline or fine-grained, with a network matrix of silica. The limestone is dark gray in color and contains silicified fossils—*Waagenoceras, Fusulina elongata, Lyttonia,* and *Richthofenia*—which indicate it to be of Word Permian age. Other fossils occur among which may be mentioned the following: *Medlicottia, Hustedia, Camarophoria,* many sponges and fenestelloids and rhomboporoid bryozoa, *Productus,* and *Aviculopecten.* Some of the cherts are made up largely of *Fusulina elongata.* The cherts occur in very irregular beds and also as lenses and concretions. The very top of the member has platy dark brown argillaceous beds. Just east of the narrows on Cibolo Creek, this member contains much thin-bedded sandstone with dark blue to black chert.

Udden's zone of sponge spicules, 85 feet thick in his type section, is represented here by a single persistent bed, not over a foot in thickness, of hard dense silicious limestone, composed largely of sponge spicules.

Udden's thin-bedded zone is almost completely destitute of fossils in the upper Cibolo basin. Some calcitized ammonoids were found in a single limestone lens, and one thin limestone full of *Fusulina elongata* was found just above the sponge spicule layer at the western limit of outcrop.

The thin-bedded zone in upper Cibolo basin consists of fine micaceous sandstone in the lower part and sandy shale in the upper part. The sandstone is in thin layers interbedded with shales and weathers a rusty color. The shales are coarse-grained and very coarsely laminated or platy, are dark brown to gray in color, show a small amount of phosphate, and some of them bitumen when treated with ether. They weather light gray or pinkish-lavender. Scattered throughout are large and small fine-grained, dark gray, limestone concretions and small flattened ball-like concretions either of chert or originally of marcasite now altered. The marcasite balls are characteristic of the upper part and the chert balls of the lower part. Most of the detritus making up this member appears to be silt. East of the road to Ojo Bonito, the member is greatly metamorphosed by the porphyry intrusion, the lower sandy part having been changed to blue-gray quartzite and the upper more shaly part to very dark blue-gray hornfels. The member is unconformably overlain by the Etholen conglomerate of the Trinity. Its thickness is approximately 500 feet.

Fossils submitted to Dr. James Perrin Smith from the thin-bedded zone, upper Cibolo basin, one-half mile east of Cibolo Creek, north flank of Ojo Bonito, one mile south of the 30th parallel are identified by him as follows:[3]

Agathiceras girtyi
Adrianites marathonensis
Stacheoceras gilliamense
Perrinites sp. ?

He concluded that they belonged to strata correlative with the Word formation.

CRETACEOUS

Trinity sediments unconformably overlie the Permian. The basal formation is the Etholen conglomerate or Campogrande formation with many pebbles of the underlying Permian. Many pebbles are of a white fine-grained limestone, which overlies the thin-bedded zone three miles north of the Cibolo Ranch. The Trinity, as a whole, is made up of argillaceous gray limestone, cream-colored to rusty sandstones, variegated sandy shales, and conglomerates. The succession is similar to that farther north, where it has been divided into the Etholen and Cox formations and to that in the vicinity of Shafter farther south, where it has been named the Presidio and Shafter beds by Udden. The Trinity is overlain by the volcanic series.

INTRUSIVE SYENITIC PORPHYRY

The intrusive so far as mapped in the upper Cibolo basin is a part of the Ojo Bonito intrusive mass described by Dr. Udden. It is a coarse grained porphyry in the main, rapidly disintegrating in the arid climate and forming rounded boss-like knobs and smaller hills and larger hills covered by much shattered and jointed large rounded boulder-like blocks.

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[3]Letter of December 12, 1928.

It is sufficiently clear that the porphyry is post-Trinity, since the Trinity is tilted, metamorphosed and faulted by its action. On the other hand, the field evidence of its age with respect to the earlier volcanic rocks is not so clear. Both here and in San Antonio Canyon, in the Chinati Mountains, a part at least of the volcanic series is tilted away from the intrusive masses as if these volcanics had been extravasated previous to the time of intrusion. Also, so far as known in Trans-Pecos Texas the rhyolitic volcanics are older than the syenitic rocks and their extrusive equivalents. However, every rock member on the map comes into direct contact with the upper surface of the intrusion. The larger fault, which most likely has been caused by the intrusion, cuts the rhyolitic volcanics as well as the older sedimentaries. The Ojo Bonito intrusive is relatively a large mass. The top of it may have absorbed by stoping most of the overlying rock and thrust the rest aside by its doming action. Such stoping would explain the rhyolitic rocks in places directly overlying the porphyry.

A second alternative would be that the faulting as well as the tilting of the rhyolitic volcanics are later than the syenitic intrusion. A third would be that renewed faulting and tilting occurred after the extrusion of the rhyolitic volcanics and that the intrusion of the porphyry followed by a long epoch of erosion which removed the porphyry cover preceded the outpouring of the lavas and tuffs.

The latter would be proved by finding water-worn detritus of the syenitic porphyry in the basal part of the volcanic series.

A point in favor of the third alternative is that the volcanics are tilted at a lesser angle than the sedimentaries. If indubitable evidence of contact metamorphism should be found at the base of the rhyolitic volcanics where they directly overlie the porphyry the first explanation advanced would be the correct one.

There may really be two epochs of intrusion, since Dr. Udden found granitic dikes cutting the dioritic rock in San Antonio Canyon and reports granite lying at the Cieneguita contact in the Ojo Bonito plutonic mass. Such granite might, however, be Basement Complex. In the Quitman Mountains, syenitic porphyry in the middle and granite at both north and south ends are both clearly intrusive into the Cretaceous and in that general area intense deformation of the Cretaceous followed by great ercsion both took place before rhyolite eruptions began, although in the Big Bend syncline, volcanism began before the close of the Cretaceous.

The Chinati Mountains proper are largely made up of volcanic flows and pyroclastics. These cover the sedimentary rocks with the exception of those domed up by the intrusion and situated at the foot of the southeast flank. The outcrop of the intruded sedimentaries form an irregular ellipse, the south side of the longer axis of which lies west of the town of Shafter, the northern side of the longer axis being crossed by the 30th parallel of latitude, as shown on the accompanying map. The west and southwest margins of the sedimentary ellipse are covered by the volcanics. The areal relationships are suggestive of the San Antonio Canyon and the Ojo Bonito intrusive areas being part of a single mass in which perhaps more or less differentiation of magma may have taken place or intrusions may have had different dates. If there is a single intrusive mass it is the second in size of intrusive masses of later than Pre-Cambrian age in the State, the Quitman intrusive being the largest.

Some of the unsolved problems of this intrusive mass have been mentioned above. If magmatic stoping on the large scale suggested has really taken place an important contribution to igneous geology will be forthcoming. Also, what are the relationships of this intrusive mass to the great Rim Rock fault zone, since the intrusion continues the line of the latter? Can the Rim Rock fault be traced farther south or south-southeast at or near the base of the west foot of the Chinati Mountains? The topography is suggestive of this possibility.

A study of the intrusive history and its contact action may lead to the discovery of remunerative mineral deposits. The contacts of limestone with syenitic or monzonitic intrusions have many profitable ore deposits in the southwest. The purer limestones when intruded, are especially fruitful. The yellow limestone of the Permian and the Finlay, Fredericksburg, and Washita limestones of the Cretaceous are most favorable but there is much lateral variation in the section between the Alta and the yellow limestone and in various mining districts all other rocks besides limestones have profitable ore bodies. This leads us to the subject of contact metamorphism.

CONTACT METAMORPHISM

The Ojo Bonito intrusive has metamorphosed all the varieties of sedimentary rock wherever it is in direct contact with them. In the Cieneguita, about half way between Sierra Alta and the area of the accompanying map, black and white coarsely crystalline marble, hematite deposits, quartzites, and black dense hornfels have been formed, the latter from the shales. Within the area of our map, the Alta beds have been locally changed to quartzites and hornfels. East of the road to Ojo Bonito, near the eastern end of our map, the sandy lower part of the thin-bedded zone has been changed to blue-gray quartzite and the upper, more shaly part of very dark blue gray hornfels. Here also much silica has been added to the lower Trinity rocks, to the basal part much irregular rusty chert or chalcedony and the lower limestones have been changed from gray to white color and are very hard, dense and siliceous. In this particular area, the compass needle is deflected by buried magnetic deposits. Just south of the southern of the two large faults mapped, remnants of marble and quartzite rest on the upper surface of the intrusive porphyry. Quartz veins and small dikes cut all the sedimentary rocks shown on the map.

FAULTING

Faults shown on the map radiate from the periphery of the intrusive. A few faults of small displacement are not shown. The largest fault is the southern one. At its eastern end it has a displacement of 1850′ or more. When the chert and limestone member is brought up into contact with the Trinity an arroyo follows the fault and exposes a vein of hematite-cemented breccia in the fault plane with strata dragged parallel to the fault. Just to the east of this the chert and limestone member is turned and dragged parallel to the fault in a narrow block bounded on the north by the short fault mapped in the Alta beds. North of the larger fault near the upper Alta contact the strata of the chert and limestone member have been squeezed into a small anticline and syncline.

The other large fault mapped separates the eastern area with dips averaging twice those of the western area from the western area of lower dips.

The anticlines and syncline shown at the west are parallel to the Rim Rock fault farther west and belong to the Cordilleran fold axes.

PHYSIOGRAPHIC NOTES

Both the large faults markedly influence the topography and drainage lines. The more resistant lower strata of the Permian form a narrows on Cibolo Creek with an alluviated basin above, which is left blank on the map. One prominent striking hogback of resistant limestone can be traced throughout the Trinity outcrop, forming narrows on the drainage lines. The tributaries of Cibolo Creek within the sedimentary area are parallel with the strike and therefore consequent but the main Cibolo Creek, as Udden said, is probably superimposed.

The basin of Cibolo Creek has a number of broad alluvium-covered terrace flats, also noted by Udden. Local hard layers crossing Cibolo Creek are responsible for the formation of at least part of the terrace flats. A hard porphyritic sill forms a narrow gorge on Cibolo Creek from near the mouth of Oso Creek to north of the Cieneguita ranch house. The narrows produced by the secondary siliceous limestone one-half mile below the Cibolo ranch house on Cibolo Creek has permitted the widening of the drainage courses of both Cibolo and Sierra Alta Creeks above the narrows.

The porphyry outcrops forms a low rolling plain surmounted by numerous exfoliated knobs. Cibolo Creek has cut a trench in this general plain surface. Rejuvenation of drainage is also shown in dissection of debris fans, especially at the northeast base of the volcanic cliffs of the summit area of the Chinati Mountains. The volcanic area to the north and east of the mapped area is very maturely dissected from one or more former local base-levels. Probably some of the higher alluvial slopes and terraces were formed during the Santa Fe lacustrine epoch and have subsequently been dissected upon the disappearance of the lake but the entire Cibolo Basin must be studied before the depositional and erosional surfaces of the lacustrine epoch can be separated from those of later date.

THE TEXAS METEOR OF JUNE 23, 1928

BY

E. H. SELLARDS

The appearance of a large meteor coming to the earth or so near to the earth as to be both seen and heard, although not entirely unusual, is nevertheless of such interest as to justify permanent record. On June 23, 1928, such a meteor appeared in southwest Texas, observations of which are recorded in the following pages. Although falling on a clear, bright afternoon this meteor was of such brilliancy as to attract wide attention and to be seen for two or three hundred miles. It appeared in the sky, according to the most reliable observations, at or near 4:40 in the afternoon and traveling with great swiftness, disappeared without, so far as evidence has been obtained, reaching the earth. In the following pages are assembled the combined observations of a large number of persons who saw and reported on the meteor. For this information the writer is indebted largely to correspondents and to those with whom he has talked. In assembling the considerable amount of data of various observers it becomes apparent that in the few seconds in which the meteor could be observed its characteristics impressed themselves differently on the minds of different persons. It is probable too that some characteristics of the meteor, such as light and color, appeared differently from different viewpoints. In these notes I have sought to assemble the observations in which there is a fair degree of agreement among the various observers. Special acknowledgment is due Mr. Frank M. Getzendaner, Geologist of the Humble Oil Company at Uvalde, who has contributed data essential in determining the position of the meteor.

GENERAL APPEARANCE

The general appearance of the meteor is given by several observers. All agree that it flashed out in the sky to great brightness suddenly, and that its course was traversed in a few seconds. All who were near observers agree that it ceased to be visible before reaching the earth. The meteor is variously described as "a ball of fire shooting across the sky," as having "the appearance of a skyrocket," and as "a dark ball with a fiery tail." Phenomena usual to meteors were observed, including light, sound, and a cloud or train.

As is usual with meteors, some of the phenomena presented were very deceptive. This applies in particular to the apparent distance from the observer, the size of the object, and the distance through which it remains visible. The apparent distance overhead at the time of the explosion is given as only "a few hundred feet." Many persons from fifty to one hundred miles from the meteor either searched for or thought of searching for it on the belief that it had fallen near at hand.

To those who were near at hand the light of the meteor appeared as "brilliant," "incandescent," "similar to the light of the sun," "not blinding but very bright," "as bright as the sun." One observer says that although looking through smoked glasses the light of the meteor was a strain to the eye.* Some describe the light as having a play of colors; others failed to observe any such variation in color. To those at a greater distance the light appeared for the most part a dull red. Obviously the conditions under which the light was observed and the distance from the meteor affected its appearance. To those who were looking towards the sun the meteor appeared with essentially the same distinctness and brilliancy as to those who were looking away from the sun.

THE CLOUD

The cloud which attended the meteor was seen from almost as great distances as was the light itself and was seen in fact by many more people, for while the flash of light marking the path of the meteor lasted no more than a few seconds, the cloud floated in the clear sky and continued visible from some points of observation for more than an

*The smoked glasses were being worn as a protection against the bright sunlight.

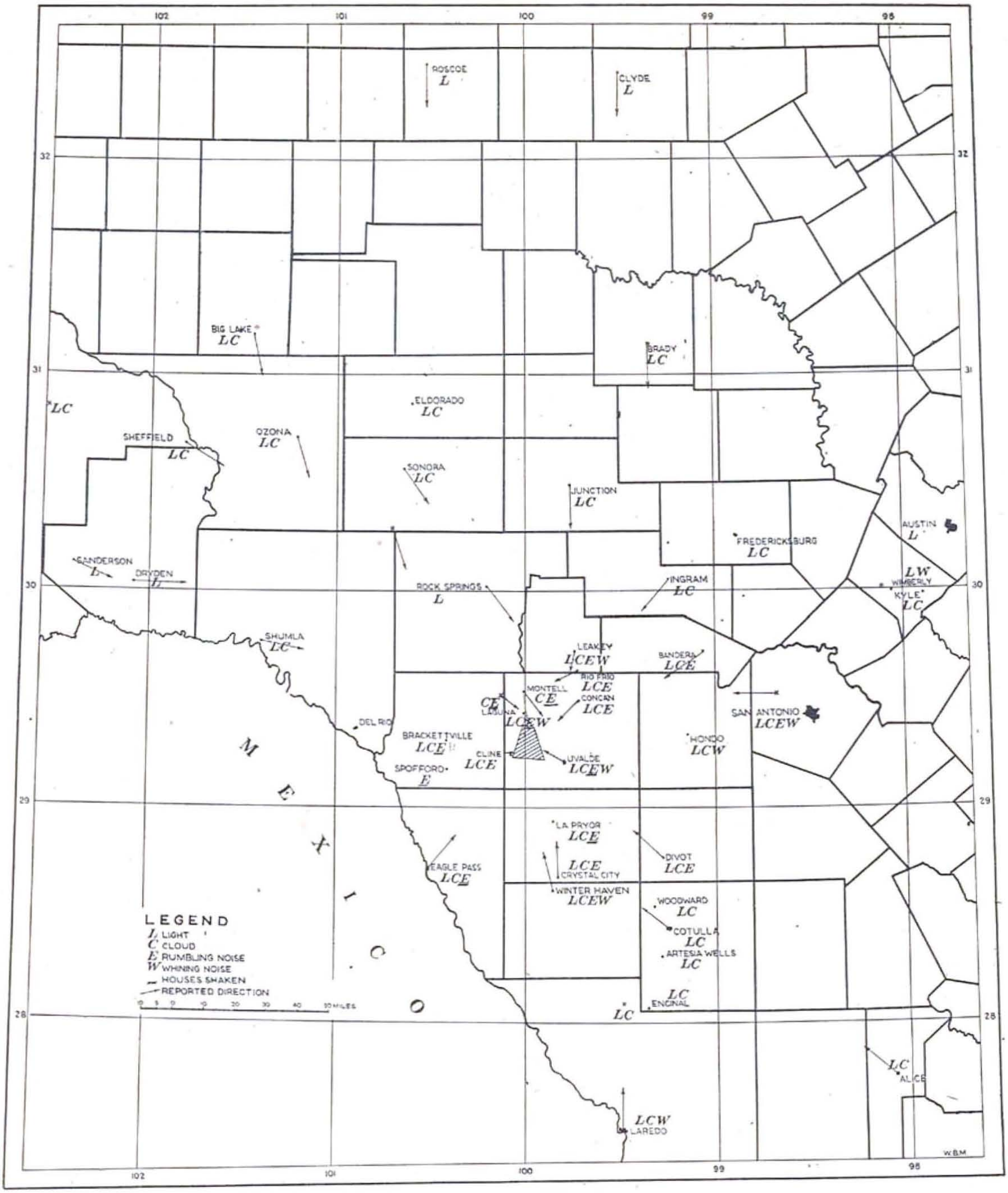

Fig. 2. Map showing localities from which the meteor was seen. The lettering on the map is explained in the legend. In addition to localities shown on this map the meteor was seen from near Corpus Christi and is reported to have been seen also from Brownwood. The shaded area indicates the region where the meteor was apparenty overhead.

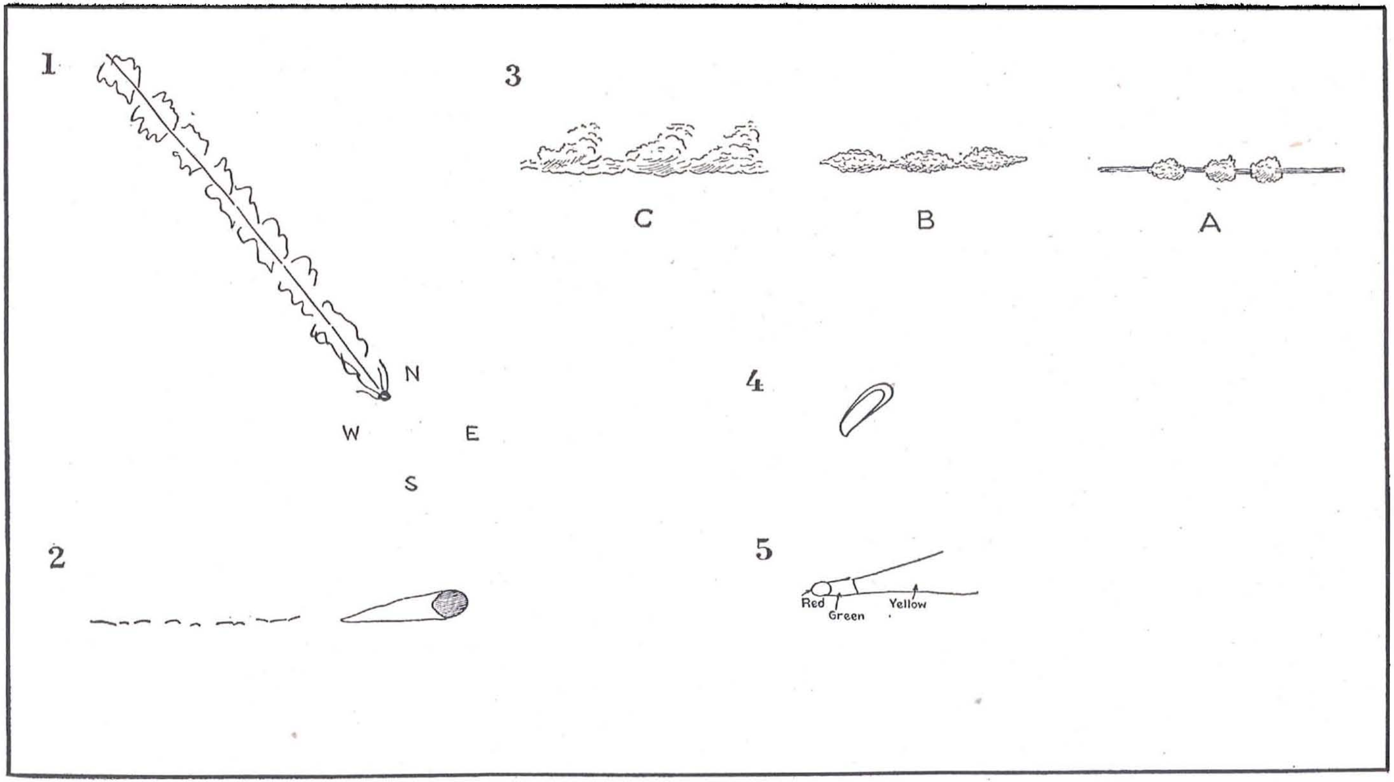

Fig. 3. Sketch showing appearance of the meteor and of the cloud as seen by various observers. No. 1, sketch made by observer at Laredo. No. 2, sketch made by observer at Alice. No. 3, the meteor cloud as seen from Uvalde: (a) soon after explosion; (b) 30 minutes later; (c) about one hour after the explosion. No. 4, sketch made by observer at Hondo. No. 5, sketch made by observer at Ozona.

hour. This cloud doubtless appeared differently from different viewpoints and is variously described. By those who saw it earliest the cloud is described as being at first a wisp or thread of smoke forming in the path of the meteor and gradually spreading into a cloud. It is described by all observers as light in color and cloud-like in appearance.

Observations on the duration of the cloud are as follows: From localities east (looking toward the sun), seven to ten minutes, ten to twenty minutes, thirty minutes, thirty to forty-five minutes, nearly an hour; from localities west (not looking towards the sun), one hour and twenty minutes, and "until sundown"—about three hours.

THE SOUND OF THE METEOR

WHIZZING OR WHINING SOUND

Two distinct sounds accompanied the passage of the meteor. The first of these was coincident with the flash of the meteor and is dscribed as a "whizzing" and "whining" sound. It is also described as like the passage of a skyrocket through the air and as a "shhh" sound. The following detailed observations will show how definitely and unmistakably this noise was observed. An observer states that at the time of the appearance of the meteor he was repairing a wire fence and was stooping over close to the ground fastening the lower wire of the fence. In this position he heard distinctly a whizzing sound which he at first supposed to be made by an aeroplane with the engine shut off preparatory to lighting in an aeroplane field nearby. Upon looking up, however, he saw the flash of the meteor. Other statements are: "I saw it fall, but would not have seen it had I not been attracted by the sound it made. It sounded 'shhh,' and shot across the sky from southeast to northwest." "My husband, daughter and myself were driving from Kerrville to San Antonio that Saturday afternoon. I heard a buzzing noise and looked out of car window, saw a big ball of fire shooting across the sky in a northwest direction. I called my husband's and daughter's attention to it, and before they could get to the west side of car the ball of fire was nearly all gone, but they saw the sparks and smoke that it left behind." "I was sitting with my back to the northwest when I heard a noise—a hiss or a whiz. A dog standing near growled and then barked." A lady at Uvalde relates that she was lying on the bed by her north window when she heard a "whining, whistling noise" which continued for a second or so before she looked up. Just after turning her head to look out of the window there was a long flash of light across the sky, so quick she was not sure at which end it began and at which it finished. She got the impression of two long, slender streaks of flame with a slit between them. Almost immediately after the flash, white smoke began to form along the line of the flash. The whining noise continued for an appreciable interval after the flash. An observer near San Antonio "heard a sizzling noise overhead and looking up saw a very brilliant dazzling object tearing through the air."

This noise as of a skyrocket is of interest since it seems seldom to have been observed in connection with meteors. Such a noise, however, is recorded in at least one previous fall of a meteor, that of October 1, 1917.[1] Since the rate of travel of the meteor is much in excess of the rate of travel of sound, it is impossible that a sound wave propagated in the usual way could have arrived coincident with the light from the meteor. This noise is reported coincident with the flash of light at localities as much as two hundred miles apart. One must either consider some other explanation for the noise or must discard a considerable number of observations made independently at various places and under varying conditions, all of the observations being in essential agreement.*

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[1]Udden, J. A., The Texas Meteor of October 1, 1917, University of Texas Bulletin 1772, page 45; also Science, Dec. 21, 1918, pp. 616–17.

*A brief account of sounds reported accompanying the fall of the meteor was published by the writer in *Science*, March 15, pp. 297–298, 1929. Following the publication of this note the writer received from Mr. Fred W. Kranz of Geneva, Illinois, the following suggestion: "One is forced to the conclusion that this sound was actually produced on or near the ground, and is due to some influence of the meteor, this influence being essentially instantaneous in its action. This practically limits this influence to some type of electro-magnetic phenomenon and it seems that the cause of the sound itself should be looked for in the realm of noises which could possibly be produced by electrical disturbances. The possibility of some sort of electrical brush discharge occurs to me, having in mind the whizzing character of the noise described. It would seem that the meteor could accumulate a considerable static charge. Perhaps this suggestion of an electrical phenomenon could

RUMBLING SOUND

The sound most widely heard and most commonly described is that which is usually observed in connection with the passage of meteors and probably more nearly resembles thunder than any other sound with which it can be compared. At Uvalde and Brackettville several observers described this sound as of sufficient intensity to jar the buildings. A correspondent at Uvalde writes as follows: "I was sitting on the floor in the southeast corner of a room, when I heard a terrific noise. First impression was of an unusual loud clap of thunder which shook the house from top to bottom. I immediately knew that it was not thunder or earthquake. Two more explosions followed. I heard a rumbling sound after the explosions." (Went outside of house.) "Sounded like a multitude of auto trucks in operation and finally decreased blending with the auto traffic of the city." An observer at Brackettville who was also indoors says: "I heard a loud explosion followed by reverberations which lasted about fifteen seconds, the intensity of which shook the cantonment barracks." An observer at Laguna, north of Uvalde, says: "The detonations lasted for several seconds, perhaps half a minute or a minute. Its sound was as of a continuous roll of thunder or heavy artillery a few miles off." An observer at Crystal City describes the noise as resembling distant thunder. These descriptions of the sound are by those who were most nearly under the meteor and by whom the meteor was perhaps best heard.

The following account of the effect of the explosion of the meteor has been obtained by Mr. Frank M. Getzendaner: "W. R. Wilson, Mine Superintendent, was sitting by the side of a building of the mine when the meteor exploded. He

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be checked up by inquiry from radio broadcasting stations and possibly radio listeners as to any electrical disturbances which might have been noticed at the time of the appearance of the meteor." Recently another record of this noise accompanying the fall of a fireball has been reported. C. P. Olivier and O. E. Monnig: "Texas Fireball of August 8, 1928." Pop. Astron. XXXVII, May, 1929. These authors refer to the fact that "a somewhat similar popping accompanies the aurora in northern regions at certain times." Mr. J. H. Wayman, of Pittsburgh, Pennsylvania, claims to have made some years ago a phonograph record of a similar noise accompanying a flash of lightning. (Letter of May 11, 1929.)

was thrown into the air by the percussion as though the explosion had occurred under him. Inside the building was a drum of gasoline from which five gallons had been withdrawn. The drum was standing on end with the plug unscrewed from the end; a tin tube almost the size of the hole was standing in the drum. The percussion caused considerable gasoline to flow through the tube, splashing the walls and floor with gasoline to apparently several gallons, and the drum head was forced outward."

With regard to this report Mr. Getzendaner writes as follows: "The statement of Mr. Wilson as to his experience at the mine in Kinney County was given to me by his employer, Mr. B. Y. Sharp, and I have not been able to see Mr. Wilson in person to question him. . . . This statement leaves room for the interpretation, I believe, that the percussion possibly knocked Mr. Wilson from the box on which he was sitting, but that whatever upward motion there was to his body might have been from his reflexes in trying to recover himself from falling."

Several observers describe the explosive sound, and some insist that more than one explosion occurred. Mr. C. M. Lawrence, a civil engineer, who at the time was six or seven miles northwest of Laguna, gives the following account: "First impression was of a dynamite shot but repeated so rapidly that the sound passed the 'cornpopper' stage to a roll like thunder. The time was 4:40 P.M. and the duration of the sound one and one-fourth minutes." Mr. E. A. Smith, observing the meteor from about 20 miles north of Uvalde, states that it "hesitated as it exploded, then traveled southwest and exploded again and disappeared."

HEIGHT OF THE METEOR

The interval from the flash of the meteor to the arrival of the sound, although not taken by any observer, is obtained approximately at three localities, as follows: At the mine of the Uvalde Rock Asphalt Company near Cline, Mr. Bruce Smith relates that while he did not see the meteor his attention was called immediately afterwards to the cloud of smoke. The sound of the meteor came one and one-half or two minutes later. This interval of time was obtained by re-enacting with Mr. Smith as nearly as possible the events that transpired between the appearance of the smoke and the arrival of the sound. These events were as follows: At the time Mr. Smith's attention was called to the smoke he was talking with his foreman. Learning that some Mexican laborers in the pit had first seen the smoke both men walked to them, a distance of about fifty yards. There they learned that some of the men had seen both the flash of light and the formation of the smoke trail. After talking with these men Mr. Smith and his foreman walked several steps back towards where they were first standing. It was then that the rumbling sound reached them. Going over the same ground with Mr. Smith walking at about the same rate and using as nearly as could be estimated the same amount of time in conversation resulted in an estimate of one and one-half to two minutes from the flash of light to the arrival of the sound. This would indicate that the meteor was not more than 18.5 or 25 miles from this locality,[2] perhaps somewhat less. Observations made at Uvalde by Mr. Frank M. Getzendaner gave similar results indicating two minutes as the time between the flash and the sound. Reverend Thomas W. Griffith, who observed the meteor from near Laguna, estimates that the time from the explosion to the arrival of the sound was 25 seconds. Mr. Griffith states that his estimation was obtained as follows: "About a dozen of our boys (from Camp Mishi-Mokwa) were in swimming when the meteor first made its appearance and they were watching its course when the explosion took place. They then all left the water and rushed to me, where I was standing on the bank, elevated about twenty feet above them and about thirty feet from the part of the pool they

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[2]Mr. Smith did not at first connect the sound with the meteor. On the contrary as blasting is used in the quarries he at first thought that a blast had been discharged prematurely. However, later, seeing no mishap in the mine, he recognized that the sound came from the meteor. Others about the mine and in the surrounding region were similarly mistaken as to the source of the sound, and following the passage of the meteor a number of telephone calls came to the mine asking if the powder magazine had exploded.

were swimming in. They had reached me and were all trying to ask questions when the rumble was heard. Therefore, I think the time stated above (25 seconds) to be fairly in accordance to facts."

These estimates of the distance to the meteor are checked and supplemented by instrumental measurements made by Mr. Getzendaner from Uvalde, and Mr. C. M. Lawrence from a point about seven miles northwest of Laguna. Immediately after the passage of the meteor Mr. Getzendaner using a Brunton pocket transit obtained azimuths of the beginning and the end points of the smoke cloud as follows: beginning point, north 86 west, end point north 42 west; altitude of smoke cloud, beginning point 46°, end point 32½°. Mr. Lawrence made but one measurement, the altitude, which from his point of observation was 37½°.

Using the combined observations of various persons the position of the meteor is placed as overhead somewhat east of Cline and its course slightly east of north. Accepting this position and course of the meteor and applying the readings made by Mr. Getzendaner, the height of the cloud is found to be at the beginning point 17 miles or somewhat less if east of Cline; end point 12 miles; length 15 miles or somewhat less. Mr. Lawrence's measurement is incomplete, but roughly checks those previously obtained, or if differing indicates a slightly lower elevation of the cloud.

It is probably true that the visible course of the meteor coincided with the length of the cloud as this appears to be in accordance with the observations made. If this is true the visible course of the meteor was likewise through a distance of about 15 miles.

VELOCITY OF THE METEOR

The time during which the meteor was visible was brief. However, that it remained visible an appreciable time is indicated by several observations. Those who saw the meteor in some instances called to others who looked in time to see it. Probably two seconds is a fair estimate of the duration of the flight.

If the length of the visible course of the meteor was as much as 15 miles the meteor had on this estimate a velocity of $7\frac{1}{2}$ miles per second. If, however, the visibility extended to three seconds, the meteor's velocity was 5 miles per second. Either of these estimates is within the limits of observed velocities of meteors of this type when low in the earth's atmosphere.

CONCLUSIONS

The observations obtained indicate that the meteor or fireball approached to within possibly five miles of the surface of the earth before its visible course was terminated by an explosion. Its rate of travel in the latter part of its course approximated 5 or $7\frac{1}{2}$ miles per second. While the meteor was not observed to reach the earth it is not impossible that after the final explosion parts of it fell to the ground. The cloud had a length of about fifteen miles and was visible a varying length of time from different stations, the maximum being more than an hour, possibly three hours. In addition to the explosive and rumbling sounds usual to meteors there was heard an earlier noise coincident with the flash of the meteor, which, although well authenticated, remains unexplained. The cloud which formed along the path of the meteor is probably due to meteor dust particles which reflect light and hence are luminous until dissipated.

THE PALEOZOIC OF THE PEDERNALES VALLEY IN GILLESPIE AND BLANCO COUNTIES, TEXAS

BY

RICHARD A. JONES[1]

INTRODUCTION

The most southerly exposures of the Paleozoic rocks which fringe the granites and schists of the Llano Uplift of Texas lie along Pedernales River in Gillespie and Blanco counties. For some fifty miles south from Pedernales River, the Comanche, or Lower Cretaceous, mantles the country as far as, and a little beyond, the Balcones Escarpment. Very little is known of the rocks that may be found by drilling beneath the Cretaceous formations between this escarpment and Pedernales River. A few widely scattered holes have been drilled but not enough to give much idea of what underlies the Comanche sediments.

The author, in the autumn of 1927, made a geologic reconnaissance along Pedernales River from Fredericksburg, Gillespie County, across Blanco County, to Travis County. This reconnaissance was undertaken to determine, if possible, what rocks are buried beneath the Cretaceous.

PREVIOUS WORK

The Llano Uplift, with its varied geology, both stratigraphic and structural, has attracted attention since the beginnings of geologic investigation in Texas. However, the southern border of this region has been largely passed over; for the greater part of geologic work has been done north of Pedernales River in Llano and Burnet counties[2] and along the northern edge of the uplift.

Dr. Ferdinand Roemer, who between 1840 and 1850 visited the Pedernales valley while en route to the Central Mineral Region, says **(8)**:

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[1]San Antonio, Texas.

[2]See especially, Paige, Sidney, **(7)**.

"Surrounded by . . . . Cretaceous deposits, there exists between the Pedernales and San Saba rivers a belt of granite rocks and of Paleozoic strata. The latter are characterized by their fossils as Silurian[3] strata and Carboniferous limestone; both are different in their organic character from the corresponding formations in the Mississippi valley, as might be expected considering the great distance and difference in latitude."

In 1853–54, the United States and Mexican Boundary Survey, under command of Major Emory, examined a portion of the country southward from the Central Mineral Region but the geologists attached to this survey recorded few observations along Pedernales River. Dr. Benjamin F. Shumard, appointed first state geologist of Texas in 1858, made investigations of parts of the Central Mineral uplift, obtaining a good outline knowledge of the geology of the region. Without doubt he must have had some information on the Pedernales valley, but he seems to have been occupied chiefly with the central and northern part of the district. In 1876, Dr. S. B. Buckley (**1**) mentioned the occurrence of granite, with Cretaceous beds lying directly upon it, near Fredericksburg, Gillespie County. Comstock's two detailed reports on the Central Mineral Region (**2** and **3**) contain much information on the rocks of the Pedernales region. Hill in 1901 published a map (**4**) which shows the occurrence of granite in west-central Blanco County, and the existence of a strip of Cambro-Ordovician rocks along the Pedernales River. Previously, 1897, Hill and Vaughan (**5**) made extensive observations on the Lower Cretaceous formations of the Pedernales valley. However, notwithstanding these early publications, the geology of the Pedernales River appears on the State geologic map (**9**) "Paleozoic Undivided."

PEDERNALES RIVER

Pedernales River, heading in western Gillespie County, flows almost due east through this county, runs entirely

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[3]The rocks, which the early investigators of this region termed "Silurian," are now classified as the Ellenburger limestone of Cambro-Ordovician age.

across Blanco County in a direction north of east, touches the extreme northern tip of Hays County, and then continues northeast to the Colorado River in western Travis County. The length of the river is approximately 100 miles. Running water is found at all seasons of the year, for the stream is fed by springs, although in the dry months of the summer there may be only small brooklets a few inches deep, connecting one water hole with another. In eastern Gillespie County the broad plain of the river valley is a rich agricultural district, first settled by Germans in 1846. Farther east in Blanco County the Cretaceous uplands are rugged and the river is entrenched in limestone canyons, with rapids and falls caused by the harder strata.

The Pedernales valley is easily accessible. The main improved highway from Austin to Fredericksburg, Gillespie County, passes through Johnson City, Blanco County. In eastern Gillespie County, this highway runs for miles parallel to Pedernales River, much of the way but a few rods from the stream. Pedernales River is crossed by many fords, either rock bottom or cement-dip crossings. Among these crossings are Hammet's Crossing of the Pedernales in Travis County; the crossing just north of Johnson City, Blanco County, on the road to Marble Falls; McDougall's Crossing, Blanco County, three miles northeast of Hye Postoffice; and Colebreath Ford, a short distance west of Hye Postoffice, and several crossings in eastern Gillespie County.

AREAL GEOLOGY

In the drainage of Pedernales River in eastern Gillespie County and in Blanco County are exposed rocks ranging in age from Lower Cretaceous sediments to Pre-Cambrian or Algonkian granites and including Cambrian, Cambro-Ordovician, and Pennsylvanian. The formations included in this report are as follows:

- Lower Cretaceous (Comanche)
  - Glen Rose limestone
  - Gillespie sand
  - Travis Peak sand

Pennsylvanian
- Smithwick shale
- Marble Falls limestone

Cambro-Ordovician
- Ellenburger limestone

Cambrian (undifferentiated Hickory, Cap Mountain and Wilberns formations)

Paleozoic, undifferentiated

Pre-Cambrian granites

The writer's observations in the Pedernales valley being of a reconnaissance nature, time was not available in which to map the formations closely, nor would such mapping be possible without the aid of detailed topographic maps, which do not exist. The accompanying geologic map, however, shows the general distribution of the geologic formations along Pedernales River, as determined by reconnaissance examination, and is the most complete areal geologic map of the Paleozoics[4] of the region so far made public. Descriptions of the rocks of the various geologic ages follow, in order from youngest to oldest.

LOWER CRETACEOUS (COMANCHE SERIES)

Lower Cretaceous, Comanche series, representing the Aptian and Albian divisions of the European Cretaceous, outcrop over a large portion of the Pedernales drainage in Blanco and Gillespie counties, almost completely surrounding the exposures of Paleozoics and granite along Pedernales River. It is clear that the Cretaceous once entirely covered the area of the present Pedernales drainage, and that the older rocks have been exposed by the erosional activity of Pedernales River and its larger tributaries. These Cretaceous formations, described and mapped by Hill, will be briefly reviewed.

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[4]In the map accompanying the present paper, to avoid confusion, the Lower Cretaceous (Comanche) formations are shown undivided. They are mapped by Hill (4) and by Hill and Vaughan (5).

TRINITY DIVISION

GLEN ROSE FORMATION

The Glen Rose formation is the upper part of the Trinity division. The character of the Glen Rose, as exposed in the Pedernales valley, is similar to that of the formation elsewhere,—a succession of evenly-bedded, argillaceous, arenaceous, or chalky limestones, alternating with strata of marly clay. The beds are of different thicknesses, and the predominant color of exposures is white, yellow, or buff. The Glen Rose is locally overlain by areas of the younger Walnut clay and Comanche Peak and Edwards limestones of the Fredericksburg division, left as erosional remnants on the summits of the highest hills.

The topography of much of the Comanche terrane near Pedernales River is that everywhere so typically formed by the erosion of the Glen Rose limes and marls,—high, flat-topped mesas and conical hills, terraced and benched by outcropping limestones, interbedded with soft marls. The Glen Rose hills are excellently displayed south of Pedernales River, near Johnson City, Blanco County, where, as viewed from the northern side of the river, the perspective is that of an elevated, long, even-crested ridge, notched by V-shaped valleys; in the tall mesas fringing the basin of Pedernales River and Barron's Creek at Fredericksburg; and in the long finger of upland country which projects eastward from Gillespie County into Blanco County, separating the Paleozoic outcrops on Pedernales River from those on Willow Creek to the north.

As the Comanche ocean advanced from the southeast over the ancient land of central Texas, Basement sands and conglomerates were laid down at the edge of the forward moving seas. Off shore where the waters were deeper and less turbid, the deposition of sands was replaced by the deposition of limes and marls. Thus, while basal sands were being deposited along the beaches of the Lower Cretaceous coast-line, limes and marls were simultaneously being deposited seawards. Therefore much of the Glen Rose formation is equivalent in age to various parts of the basal Cretaceous sands. Hill says **(4)**:

"There is no doubt that . . . . the Basement Sands transgress nearly all the entire time interval occupied by the Glen Rose limestone in the sections to the east; . . . . that in ascending the slope of the pre-existing Paleozoic floor to the northward they (the Basement Sands) traversed diagonally a vertical column of the Cretaceous formations, representing a long period of time."

It is obvious from the conditions of deposition that the Glen Rose formation is much thicker in the southern and eastern part of the region of Comanche deposition than to the north and west, nearer the margin of the Lower Cretaceous ocean. The Glen Rose has been found to be very thick in various deep holes drilled for oil, below the Balcones Escarpment and south or east of the region of Comanche outcrop. For example, the Glen Rose of the subsurface of southwestern Bexar County is at least 1,785 feet thick, and possibly 1,994 feet in thickness. (Jones, **6.**)

Hill states (**4**, p. 381):

"West of Round Mountain Postoffice, Blanco County, the entire Trinity division between the Cambrian limestone below and the Fredericksburg above consists of less than two hundred feet of pack sands and sandy clays, of which the upper 50 feet are clays and limestones of the Glen Rose type containing Nerinea, resting upon Basement Sands. Seven miles east at Shovel Mountain, the Glen Rose limestones are 60 feet thick; 9 miles farther east at Round Mountain, Travis County, the Glen Rose beds are 445 feet thick."

GILLESPIE FORMATION

In the western part of the Pedernales drainage a different phase of the Cretaceous sand appears, being especially exemplified in the valleys of Pedernales River and Barron's and Palo Alto creeks, around Fredericksburg. The basal sands there contain many beds of grit and coarse sand, composed almost entirely of granitic debris, as quartz and feldspar fragments. The sands and clays are often bright vermilion in color; and the formation as a whole is characterized by a predominance of red coloration, far exceeding in amount the red coloring of the Basement sands elsewhere on Pedernales River. This facies of the sands has been called by Hill and Vaughan (**5**, p. 121) the "Gillespie formation." The rocks appear to have been derived largely from the detritus of a land mass of granite and Cambrian sandstones, which is, no doubt, the explanation of the dominant red color of the series. Concerning the relative age of the Gillespie formation, Hill and Vaughan state:

"These [the Gillespie beds] might possibly be correlated with the basal sands of the Travis Peak formation, but they are more probably the stratigraphic equivalent of the lower portion of the Glen Rose formation where it rests on the Travis Peak."

TRAVIS PEAK FORMATION

The type locality of the Travis Peak formation is Travis Peak Post Office, in northwestern Travis County. Hill (**4**, pp. 131, 140) describes the formation as follows:

"In the author's opinion, the Travis Peak beds represent the oldest of the Cretaceous formations exposed at the surface in the Texas section . . . . In general, the Travis Peak beds . . . . consist of conglomerate, composed of coarse, rounded pebbles of Silurian (Cambro-Ordovician), and Carboniferous limestones, granite, Llano schists, and quartz, derived from the adjacent Paleozoic rocks; beds of finely cross-bedded pack sand; white, siliceous shell breccia, resembling the Florida "coquina"; and some bands of blue, reddish, and greenish-white clays, having much the characteristic colors of the Potomac beds of the Atlantic coast, and they are sometimes accompanied by lignite and fossil bones."

In Hill's report the Travis Peak is divided into the Sycamore sand, Cow Creek beds and Hensell sands.

As nearly as exact analysis of such an upward transgressing series as the Trinity can be made, the basal Comanche along Pedernales River in eastern Blanco County may be classified as Travis Peak. The confused and intricate heterogeneity of the Trinity sands may be seen from Hill's description quoted above; and the heterogenous nature of the formation may be strikingly observed in eastern Blanco County in the general vicinity of Hammet's Crossing of Pedernales River. The thickness of the Travis Peak has been estimated as from 250 to 300 feet. (Udden, **9.**)

The topographic expression of the Basement sands in the Pedernales valley is often that of gentle slopes beneath the Glen Rose limestones, which cap the higher hills. At Fredericksburg, the Gillespie formation has been eroded into a large, basin-like valley. On the other hand, the Basement sands at some places give rise to rugged topography. In eastern Blanco County, the deep canyon of Pedernales River is incised in the Travis Peak formation.

Profound Unconformity at Base of Cretaceous.—The profound unconformity and the long erosional period between the Paleozoic and Mesozoic eras are perhaps nowhere better exhibited than in the Pedernales valley. The Basement sands lie upon the ancient land surface, overlapping formations from Pre-Cambrian to Pennsylvanian. In places, the sands rest directly upon granite; elsewhere they are found in almost horizontal attitude, lying upon steeply dipping beds of Cambrian limestone and sandstone, upon the Ellenburger limes and dolomites of Cambro-Ordovician age, and upon the Marble Falls limestone of the Pennsylvanian.

PENNSYLVANIAN

MARBLE FALLS LIMESTONE

The Marble Falls limestone of the Bend series of the Pennsylvanian is noted by Udden, Baker, and Böse **(9)** in the Pedernales drainage in northeastern Blanco County. At the Falls of the Pedernales, about 5 miles southeast of Cypress Mill Post Office, the river, at the northern tip of a large bend, cuts across the Marble Falls formation. Here in Pedernales River and in bluffs on each side are many outcrops of blue-black lime, weathering gray to bluish. The rock is usually hard, dense, and fine-grained, but there are some crinoidal beds of crystalline texture. The strata are thin-bedded to massive, and range up to four feet in thickness. They form rapids or low falls in the river; and the outcrops in the river bed are often much pot-holed, where there has been opportunity for the boulders, which litter the stream course, to do corrasive work. The limestone is identical in appearance with Marble Falls limestone from the type locality of the formation on Colorado River at Marble Falls, Burnet County. The dip is to the southeast at a rate of 8 to 10 degrees.

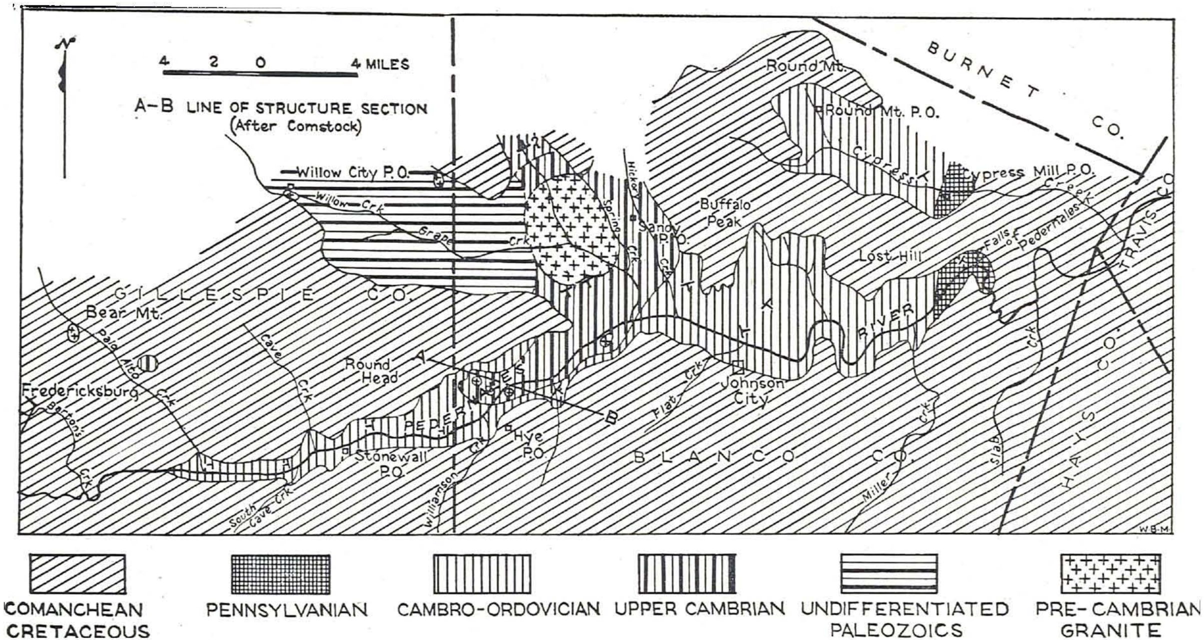

Fig. 4. Geologic map of Pedernales Valley. By Richard A. Jones.

In the immediate vicinity of Cypress Mill Post Office, the Marble Falls limestone again appears, and is separated from the outcrops on Pedernales River by a belt of Cretaceous highland. The Pennsylvanian strata at Cypress Mill Post Office are blue-black limestones, similar in lithology to the rocks at the Falls of the Pedernales. The beds range from massive to thin-bedded and almost shaly.

Time was not available for tracing out the complete areal extent of the Marble Falls outcrop at either Cypress Mill Post Office or the Falls of the Pedernales; and the area of the outcrop, as shown on the accompanying geologic map, is only approximate. The outcrop at Cypress Mill Post Office may perhaps connect with the Marble Falls outcrop in southeastern Burnet County, unless it be interrupted by the Comanche beds of Shovel Mountain and vicinity. The Marble Falls outcrop on Pedernales River may occupy either a larger or a smaller area than that shown on the geologic map, for the writer did not have time to walk the river fully in this part of Blanco County. Nor were measurements made of the thickness of the Marble Falls formation. In regions to the north where the Marble Falls limestone has been closely studied, its thickness is said not to exceed 450 feet. (**9**, p. 45.)

Collections of fossils were made from both the Cypress Mill Post Office and the Falls of the Pedernales localities of Pennsylvanian outcrop. One-half mile west of Cypress Mill Post Office, on the road to Johnson City, fossils were found in a thin, slabby, fine-grained, blue-black limestone, which directly underlies a section of thin-bedded chert, weathering reddish-brown. About 300 yards upstream from the ford at the Falls of the Pedernales, fossils were collected from a bed of Productus limestone, outcropping near the base of the bluffs on the south side of the river. This collection was submitted to Dr. George H. Girty of the United States Geological Survey, who reported as follows:[5]

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[5]Letter of April 9, 1928.

The collections appear to be two in number,—one from Cypress Mill Post Office, the other from the Falls of Pedernales River.

In the collection from Cypress Mill, I recognize the following species:

Orbiculoidea minuta	Pugnax aff. rockymontana
Chonetes sp.	Spirifer aff. opimus
Productus sp.	Ambocoelia planiconvexa
Pustula aff. wallaciana	Spiriferina sp.
Rhynchopora sp.	Hustedia mormoni

In the collection from Pedernales River, I recognize:

Sponge spicules	Productus ovatus
Pustula aff. scabricula	Ambocoelia planiconvexa?

In spite of the fact that these two faunas contain scarcely a species in common and that they afford scant grounds for comparison with the well-known Pennsylvanian faunas to the north and east, I believe that both are of Pennsylvanian (Pottsville) age and that in a general way they confirm your assignment of the beds in which they are found to the Marble Falls limestone. To the statement just made, I attach one condition, namely, that the formation with which you are concerned and which was the source of these collections may contain calcareous beds rightfully belonging in the overlying Smithwick shale. The two faunas (Marble Falls and Smithwick) have not been differentiated by critical study, but your collections suggest to me Smithwick more than Marble Falls.

The fossils from the Falls of the Pedernales come not from a shale section but from a thick limestone section, identical in lithology with samples of Marble Falls limestone from the type locality of the formation on Colorado River to the north. At Cypress Mill Post Office, the Cambro-Ordovician Ellenburger limestone is not far distant from the black lime from which the fossils were collected. For these reasons, the writer believes that the fossils from both Cypress Mill Post Office and the Falls of the Pedernales are from the Marble Falls formation. It is possible that faulting may have disarranged the outcrop of the Marble Falls (the author did not have time to make detailed examinations of structure), and that the collections come from the upper part of the Marble Falls limestone, where the fauna would be gradually grading into that of the Smithwick shale.[6]

CAMBRO-ORDOVICIAN

ELLENBURGER LIMESTONE

The Ellenburger limestone of Cambro-Ordovician age outcrops over an extensive area in the Pedernales valley. In Blanco County, east, north, and northeast of Johnson City, it appears over a wide strip in the drainage north of Pedernales River, and occupies a narrow belt on the south side of the river. Still farther northeast, beyond a ridge of Lower Cretaceous hills, it covers a large territory in the valley of Cypress Creek.

West of Johnson City, the Ellenburger occupies a narrow belt along the immediate incision of Pedernales River. Immediately east of the Blanco-Gillespie County line, north and northeast of Hye Post Office, the regularity of the Ellenburger outcrop is broken by Upper Cambrian beds and by granite; but in Gillespie County the Ellenburger extends continuously in a slender strip along Pedernales River to a point about five miles southeast of Fredericksburg. The most westerly exposures of the Ellenburger limestone are at the junction of Palo Alto Creek, Gillespie County, with Pedernales River, and extend upstream a short distance to the first ford of the river above the mouth of Palo Alto Creek.

Along Pedernales River and its tributaries, the Ellenburger is a thick limestone and dolomite series. Time was not available to determine the total thickness of the forma-

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6The writer did not observe any outcrops of shale that might be classified as Smithwick shale. It is possible that the Smithwick shale along Pedernales River has not yet been exposed by the denudation of the Trinity. On the other hand, outcrops of Pennsylvanian shale may exist in the deep and tortuous canyon of Pedernales River, east of the Falls of the Pedernales, a canyon into which the writer did not penetrate. Comstock, in his report on the Central Mineral region, (3, p. 661) seems to refer to the existence of Pennsylvanian shale in the Pedernales canyon in Blanco County, southeast of Cypress Mill Post Office.

Two wells drilled for oil and gas near Hammet's Crossing of Pedernales River, in Travis County adjacent to the corner of Travis, Hays, and Blanco counties, after passing through the surface Trinity sands, penetrated a thick section of shale, apparently Smithwick. This subsurface condition will be discussed under "Well Data."

tion, but it probably approximates that in the Llano-Burnet region to the north, about 1,000 feet. (7, p. 7.) However, the dip of the formation is from 5 to 10 degrees over a large area in Blanco County, and, drilling might show the complete section of the Ellenburger south of Pedernales River to be in excess of 1,000 feet. The Ellenburger erodes into hilly or rolling areas, many of which are covered with rounded, hummocky limestone outcrops; and it forms steep bluffs, as along Pedernales River. The Cambro-Ordovician area contains much red soil, at places clayey, elsewhere very siliceous and cherty. The Ellenburger limestones are hard, and well-bedded, and in thickness range from thin-bedded, or slabby, to massive. On weathered surface the color is mostly gray, rarely white, brown, or bluish. A rare occurrence of light green-blue rock outcrops as a thin bed about one-third the way from Johnson City to Round Rock. Upon fresh exposure the rock is mostly gray, rarely dove colored, brownish, white, or purplish. The commonest Ellenburger is a dense, finely crystalline rock, locally approaching lithographic stone in texture; less common is a medium coarsely crystalline rock some of which may be classed as marble.

The Ellenburger contains nodular or thinly bedded chert, mostly white or yellowish, rarely red. Locally this chert is so abundant as to mantle the surface, particularly in the eastern part of the area. Fossils are rare in this formation. Raised, twig-like impressions, resembling fucoids, occur in an outcrop in a stream bed immediately south of the highway, 1.6 miles northwest of Cypress Mill Post Office, Blanco County, on the way to Round Mountain Post Office.

An excellent exposure of the Ellenburger may be seen in the bluffs on the north side of Pedernales River, at the point where the road from Johnson City to Marble Falls crosses the river. Over 60 feet of section is here exposed. The limestone weathers dark gray. The interior is light gray, some having purplish blotches. The texture varies from smooth and dense to crystalline. The strata are hard, and are thin-bedded to massive, from one foot to three feet thick. Much chert occurs, disseminated in the rock, and also as irregular, white and yellowish beds up to a foot thick. Some of the chert becomes porous on weathering, displaying linings of quartz crystals on the interior of small cavities.

Various hand samples of limestone from the Pedernales drainage were submitted to Dr. E. H. Sellards, of the Bureau of Economic Geology, Austin, Texas, who had thin sections of the rocks made for study under the microscope. The determinations on these samples follow:

Samples from locality along road about one-third of distance from Johnson City to Round Mountain Post Office, Blanco County: No. 2227,—Ellenburger.

Samples from bluff on north side of Pedernales River, Blanco County, at crossing of Johnson City-Marble Falls road, No. 2226,—Ellenburger.

Samples from road between Round Mountain Post Office and Cypress Mill Post Office, Blanco County, No. 2223,—Ellenburger.

Samples from road between Johnson City and Sandy Post Office, Blanco County, west of Johnson City—Marble Falls road,—Probably Ellenburger.

Samples from between Colebreath Ford of Pedernales River, Blanco County, and point upstream where road from Luckenbach, Gillespie County, crosses river, No. 2225,—Ellenburger.

Samples from Pedernales River, Gillespie County, at point where road from Luckenbach crosses river, No. 2220,—Probably Ellenburger.

Samples from junction of Palo Alto Creek and Pedernales River, Gillespie County, and from ford of Pedernales a short distance upstream (most westerly exposures of Paleozoic limestones), No. 2219,—Ellenburger.

CAMBRIAN

In western Blanco County there is an extensive area of Cambrian along Pedernales River, and north of the river, in the drainage of Grape, Spring, and Hickory Creeks. The outcrops are associated with various small knobs of granite along Pedernales River and with a large mass of granite in the valley of Grape Creek, north of the river.

The Cambrian of the Pedernales country consists of both sandstone and limestone. There is a large amount of red, ferruginous sandstone, iron rock, or impure iron ore. Certain exposures of this ferruginous sandstone have a peculiar, black, burnt appearance. There are also brown and gray, bluish-green, and white sandstones. The sandstones vary in hardness from soft and crumbling to hard and even quartzitic. In texture they range from fine-grained to very coarse. The sands are well stratified and vary from thin and shaly to slabby to massive, some beds being four feet or more in thickness. Large, shallow, widely-spaced ripple marks occur locally. Glauconite is widely distributed through the sandstones, in places as separate grains, elsewhere as large streaks and splotches of a bright green color. An interesting lithologic feature is the considerable number of beds composed of large, clean, well-rounded quartz grains. This rounding and assorting of the quartz is worthy of further study. Such rounding would suggest long transportation and corrasion of the quartz grains, or perhaps even wind and desert weathering, but it appears that the material composing the sands could only have been transported a comparatively short distance, and apparently had its origin in the pre-Cambrian granites and schists of the Llano Uplift.

There is much limestone of a very coarsely crystalline texture, with occasional streaks of calcite; in color, light gray mottled with brown; carrying much glauconite, and sometimes fragments of small shells. This limestone facies appears characteristic of the Cambrian, for nothing similar was observed in the Ellenburger outcrop in this region. Other limestones are fine-grained and harder. On weathered surfaces the limestones are usually dark gray or brown. They range from very thin-bedded, almost shaly, to slabby, paving stone thickness to massive, sometimes attaining a thickness of eight feet. The thin-bedded phase often presents a greenish tinge. The writer observed little or no chert in the Cambrian limestones. As in the Cambrian sands, glauconite is widely disseminated in the limes. Beds of sandy lime or limy sand are numerous in the Cambrian outcrop. Some yellow and brown, ferruginous, sandy shales, and some purple shales were noted. Small, round, ferruginous concretions occur in places. In some localities near the granite basement there is a coarse arkose, composed of angular quartz and feldspar fragments.

At McDougal's Crossing of Pedernales River, three miles northeast of Hye Post Office, Blanco County, on the road to Sandy Post Office, excellent and typical outcrops of the Cambrian strata may be seen in the bluffs and hill slopes on both the north and south sides of the river. In the creeks and on the high hills around Sandy Post Office, Blanco County, there are also many well displayed exposures of the Cambrian rocks. In many cases individual strata may be traced by the eye for long distances around the hill slopes.

In Gillespie County, about five miles east of Fredericksburg, a small area of Cambrian outcrop, surrounded by basal Trinity, appears in the bed and nearby slopes of Palo Alto Creek, or of a large tributary of this creek. The rocks are glauconitic sandy lime, and thin-bedded to massive, glauconitic, brown to red to purplish to tan sandstones, in places carrying shell fragments. This was the only outcrop of Cambrian observed by the writer near Fredericksburg and Pedernales River in Gillespie County; although much Cambrian occurs in Gillespie County farther northeast on the road to Llano.

The Cambrian strata give rise to a more abruptly hilly topography than the adjacent Ellenburger limestones. The weathered rocks, including the limestones, present sharper edges than the rounded Ellenburger outcrops.

The writer did not have time to separate the Pedernales Cambrian into subdivisions, but it undoubtedly can be divided into the Hickory, Cap Mountain, and Wilberns formations, as mapped in Llano and Burnet counties. The lithology is very similar to that of the Cambrian exposed to the north in the Llano-Burnet region. The thickness of the Cambrian of the Pedernales drainage is probably about the same as that in Llano and Burnet counties, where the maximum thickness is said to be between 600 and 700 feet. (**7**, p. 6.) As in the region to the north, the beds all appear to be of Upper Cambrian age.

Fossils are found in various localities throughout the area of Cambrian rocks, although the strata as a whole are poorly fossiliferous. In low, rocky bluffs on the north side of Pedernales River, a short distance upstream from McDougal's Crossing of the river, three miles northeast of Hye Post Office, Blanco County, trilobites occur in a hard, rather thin-bedded, gray, crystalline, crinoidal or cystoidal limestone, carrying grains of glauconite. The fossils are usually fragmental, but a few well preserved small trilobites were collected. One specimen with especially well preserved cephalon and glabella shows the animal rolled and curled into a ball, a habit of trilobites first acquired in the Upper Cambrian time.

In the vicinity of Sandy Post Office, Blanco County, there are many outcrops of a ferruginous, red sandstone, composed either of small, perfectly rounded quartz grains or of oolites. Small, well-preserved shells are numerous, especially when the rock is split along the bedding-planes. Good collections of fossils can be made along the road on the hill slopes east of Sandy Post Office, immediately across Hickory Creek.

Fossils from these two localities were examined by Dr. Charles E. Resser, Associate Curator of Stratigraphic Paleontology, United States National Museum, who reported as follows:[7]

> Both lots of fossils submitted are Upper Cambrian in age. The limestone belongs to the Wilberns formation which is exposed to the north in the Llano-Burnet region. The ferruginous sandstone, if it underlies the limestone, would probably represent either the Cap Mountain or the Hickory formation. The species are practically all undescribed and hence cannot be listed.

Cambrian-Ellenburger Contact.—It was found very difficult to differentiate uppermost Cambrian from lowermost Ellenburger. Along Pedernales River in the vicinity of the mouth of Grape Creek, and also elsewhere in western Blanco County, there are outcrops of massive, gray limestone, sometimes carrying grains of glauconite, but apparently no chert, which may be either Cambrian or Ellenburger in age. Therefore, the boundary between the Cambrian and Ellen-

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[7]Letter of March 16, 1928.

burger, as shown on the accompanying geologic map, is but approximate.

Lead Mining Prospects.—An interesting fact in connection with the Cambrian rocks of the Pedernales valley is that efforts were formerly made to mine lead in an area on Pedernales River, in western Blanco County, north of Hye Post Office, and near the old Westbrook Post Office, a settlement abandoned some forty years ago. Comstock **(3,** p. 587) states:

The workings in this field have not been extensive, but there are two or three localities, not widely separated, from each of which a small amount of galena has been taken. These spots are marked upon the plan by asterisks.[8] Mr. McMillan has dug some shallow shafts at the contact of the granite with the Cambro-Silurian limestones, and a very similar set of conditions is evident in the tract further south at the Pedernales River, and on the land of Mr. Holden, nearly east from McMillan's at old Westbrook Post Office.

The writer did not have time to search out the abandoned lead diggings, but they can no doubt be found by close examination. Comstock **(3,** p. 588) says of the lead ore found in various parts of the Central Mineral Region as well as in the Pedernales valley:

The lead ore is almost wholly galena, in cubical crystals of small size. In some cases a meagre incrustation of lead carbonate of oxide is apparent in the limestones, but no important deposits of this nature have been discovered. There are usually no other minerals associated with the galena, which is scattered through the containing rocks without regularity and commonly not in any considerable abundance . . . . There is no need of examining any locality which is not more or less covered by Cambrian and Silurian [Ordovician] strata, i.e., by sandstones and limestones. The occurrence in such areas of a greensand or a brown weathering limestone, or of both, along a line of faulting, especially near where a dense but somewhat coarse-grained granite outcrops is the best situation for exploring. . . The galena will be found in the brown limestone or greensand, or occasionally in dikes or in zones of distribution in other layers.

The galena ore along Pedernales River has not yet been developed on a commercial scale. Probably the deposits are not of commercial value, for had the ore been rich enough to make mining profitable, mines would doubtless long since have been developed.

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[8]See small map accompanying geologic structure section, this paper.

UNDIFFERENTIATED PALEOZOICS

In the valley of Willow Creek or North Grape Creek, in Gillespie and Blanco counties, there is an extensive area of Paleozoics, which was not examined by the writer. The road from Willow City Post Office, Gillespie County, to Sandy Post Office, Blanco County, passes along the northern edge of the valley of Willow Creek. Numerous outcrops of Paleo-

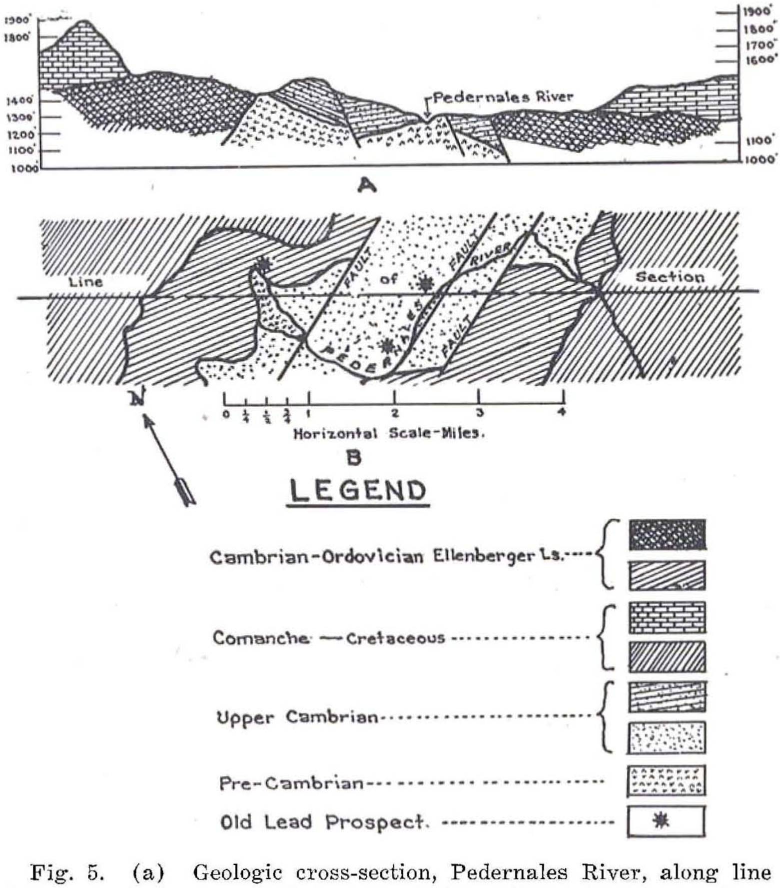

Fig. 5. (a) Geologic cross-section, Pedernales River, along line A-B on geologic map of Pedernales Valley; (b) geologic map along line of section. Asterisks denote old prospect holes for lead ore (galena). Adapted from Comstock (3), page 586. The nomenclature on Comstock's maps has been altered to present usage.

zoic rocks,—limestones and red sandstones,—were observed along this road. The area along Willow Creek, shown as Paleozoic Undivided, on the accompanying map, contains, no doubt, Cambrian and Cambro-Ordovician (Ellenburger) rocks, of the same character as those which are exposed along Pedernales River to the south. Granite appears in the bed of Willow Creek at the crossing of the road from Fredericksburg to Willow City Post Office; and again appears some miles to the east of Willow City Post Office on the north side of the valley of Willow Creek. Other granite outcrops may possibly exist in the interior of the valley.

PRE-CAMBRIAN

GRANITE

There are various outcrops of granite in the Pedernales valley in western Blanco County. Granite also outcrops in the drainage of Pedernales River in eastern Gillespie County.

Blanco County Granites.—In the immediate incision of Pedernales River in Blanco County, just east of the Gillespie County line, several granite knobs exist. From east to west, these occurrences of granite are as follows:

1. About 8 miles northwest of Johnson City and a few hundred yards upstream from the Willow City crossing of Pedernales River, large outcrops of granite appear in the bed of the river, and a small hill of granite (part of the same knob) lies immediately south of the river.
2. A short distance upstream from McDougal's Crossing of Pedernales River, three miles northeast of Hye Post Office, granite crops out in the stream bed. As at the Willow City Crossing, the main body of granite is a rounded hill, south of the river and continuous with the granite in the river.
3. Granite again appears in Pedernales River a short distance west of the above outcrop, the main granite mass being here north of the river.

Comstock notes the occurrence of granite on a tributary of Pedernales River, about one and a half or two miles northwest of the granite in the river bed above McDougal's Crossing. The writer did not have opportunity to make a trip to this locality. (See Fig. 1.)

The three outcrops of granite visited by the author on Pedernales River in western Blanco County are all small in area. The first knob above McDougal's Crossing of the Pedernales occupies a small area almost circular in outline. The rock has the usual rounded surface of granitic weathering, and is a medium to coarse-grained, pink or red granite, composed principally of quartz and orthoclase feldspar, with some specks of biotite mica.

North of Pedernales River, reconnaissance examination points to the existence of a large, roughly circular area of granite along Grape Creek and its tributaries. About two miles west of the crossing of Grape Creek by the road from Hye Post Office to Sandy Post Office, several granite knobs of considerable height, sufficient to be topographic landmarks, appear. The rock is typical red granite. Elsewhere in this general area, both east and west of Grape Creek, ranchers report the existence of rounded hills and slopes of bare rock, which would seem from the description to be granite. Along Spring Creek, an eastern tributary of Grape Creek, the road from Sandy Post Office to Tosca Post Office and Willow City Post Office passes over granite continuously for about one and a half miles.

Gillespie County Granites.—In the valley of Palo Alto Creek, four miles east of north of Fredericksburg, the county seat of Gillespie County, is a large hill of granite, known as Bear Mountain. This hill is of very considerable height; is about three-fourths of a mile long, trending north and south; and is said to cover an area of some 82 acres. On the summit of Bear Mountain is a remarkable example of erratic weathering. An immense, rounded boulder, that must weigh many tons, is weathered completely free, except for two or three tiny supports, which connect it with the main body of granite. The boulder appears balanced on these insignificant pedestals, and is hence known as Balanced Rock. The heavy mass seems likely any day to become loosened and fall; but it has been balanced as it now is as long as the locality has been known to the oldest settlers of Fredericksburg.

The granite of Bear Mountain is a medium-grained, pink or red hornblende-granite, of high grade commercial quality. In addition to being valuable as structural material, it takes an excellent polish and is suitable for ornamental and monumental purposes. The rock was first quarried in 1888, when the granite was used in the construction of the old City Hall at San Antonio. Quarries in this granite have been continuously operated since 1904.

As previously mentioned, outcrops of granite appear in the drainage of Willow Creek, from ten to fifteen miles northeast of Bear Mountain. There are, also, numerous granite hills in northeastern Gillespie County. This area, however, is beyond the limits of the present report, being chiefly in the drainage of Colorado River.

Age of Granite and Relation to Paleozoics.—It is held that the granites of the Llano-Burnet region to the north of Pedernales River are all of Pre-Cambrian age **(7)**, intrusive into the Algonkian (?) rocks, the Valley Springs gneiss and the Packsaddle schist, but not intrusive into any of the Paleozoic formations. It is believed by the writer that the granites of the Pedernales valley are likewise Pre-Cambrian in age, and not intrusive into the Paleozoics. The earliest theories, however, maintained that the granite knobs on Pedernales River were of later geologic age. Comstock **(3,** p. 586) thought that some granitic intrusions had forced their way through the Cambrian into the Silurian [Ordovician]. It is not surprising that the idea of Paleozoic granites occurred to the early geologic investigators of the Pedernales valley. In the river bed the Cambrian limestones form perfect, curving lines of outcrop around the granite. The rocks dip away from the granite from 5 to 15 degrees. The situation is exactly what one would expect to find if intrusive granite had gently pushed its way upward into sedimentary rocks, arching the strata above it. Moreover, the granite does not everywhere underlie the same kind of sediments. In Pedernales River, as mentioned above, Cambrian limestone lies directly on the granite; but a few miles farther north, in the area of granite knobs about two miles west of Grape Creek, the granite seems directly to underlie Cambrian sandstones. Such a feature as this is suggestive that the granite might be intrusive, having penetrated into different parts of the Cambrian rock section. However, examination of the contact of the granite with the Paleozoic sediments, does not reveal evidence of intrusion, such as contact metamorphism. On the contrary, the evidence points to deposition of the Paleozoics on a pre-existent granite surface.

At an excellent exposure of the granite-Cambrian contact at the first granite knob west of McDougal's Crossing of Pedernales River, Blanco County, a massive bed of limestone, about 8 feet thick, gray on the interior, but weathering brown, rests directly on granite. The base of the limestone in some places is rather thin-bedded for a few inches. The contact line of limestone and granite is wavy and irregular and the upper 2 feet of the granite is soft and crumbling, suggesting that it represents an ancient surface, weathered before the superjacent limestone was deposited upon it. Also, fragments of Cambrian rock, apparently containing inclusions of debris from the granite knob, were collected.

No contact metamorphism was observed at this locality, nor was any observed downstream at the granite outcrop above Willow City Crossing of the Pedernales. In the region to the north, where, as mentioned above, Cambrian sandstones seem to rest directly on the granite, phenomena were observed which might suggest contact metamorphism. Some of the sandstone beds in close proximity to the granite are very hard and quartzitic. One piece of reddish and purplish quartzite contained a large area of pure, white quartz. However, some of the sandstones are slicken-sided. It is believed that any metamorphism of the Cambrian sandstones in this locality is due to the heat and pressure of faulting, rather than to igneous intrusion, especially since faulting along the granite contact is very pronounced to the east along Spring Creek (see under "Structure").

It appears that the Cambrian rocks were laid down on an irregular basement of eroded granite, perhaps having considerable relief, so that islands of granite may have emerged from the ocean during part of Cambrian times. Such a topographic base for sedimentation would explain the fact that the granite is not everywhere in contact with the same portion of the Cambrian section. For example, a part of the granite basement of relatively low relief might have been buried under sandstones, as the shallow waters of the Cambrian sea first encroached upon the land; and, as the waters grew deeper and more calm, and limestones were deposited, higher points of the granite floor might have had limestones laid down directly against, and over, the granite. Subsequent diastrophic movements from the beginning of post-Cambrian to the present may have so warped the earth's crust that the relative level of various granite hills, as exposed today by denudation, may not be the same as during the period of Cambrian deposition; but this does not invalidate the theory of Cambrian sedimentation above discussed.

The steep dips of the Cambrian strata off the granite knobs, in places 15 degrees or more, need not necessarily imply arching of the rocks by the upthrust of an igneous intrusion. Regular and orderly dips could be formed by the laying down of sediments on a granite base, as long as the slope of the base did not exceed the critical angle of deposition. The writer does not know the maximum angle at which sediments will cohere as a slope stratum at the side of a steep incline; but it is reasonable that strata should be able to copy and reflect a depositional slope of quite pronounced inclination. Once persistent depositional dips were established in the sediments abutting the irregularities of relief of the granite basement, later compacting and slumping of beds around the granite cores could easily increase the dips to the amount observed around these granite knobs. Anticlinal and dome structure, due to settling, have been proven to exist over various Buried Hills, whether of granite or of other resistant rock.

Granite Island in Comanchean Ocean.—Proof of the ideas above expressed of the relation of the granite of Pedernales River to the Paleozoic rocks may be seen in the relation of the granite of Bear Mountain, Gillespie County, to the Cretaceous rocks, which surround it. Palo Alto Creek cuts into the base of the north slope of Bear Mountain, affording in the stream bed excellent exposures of the contact of the granite with the Basement sands of the Comanche. At this contact red and white, principally red, sands and grits, composed of feldspar and quartz fragments, lie directly on the granite along an irregular, wavy line of unconformable contact. It is obvious that the basalmost Trinity has been derived from debris eroded from the granite. The upper surface of the granite is soft and crumbling, as if it had been a weathered surface for long ages before Trinity deposition began, just as to the southeast on Pedernales River, the character of the granite beneath the Cambrian also suggests a pre-depositional weathered surface.

The Trinity sands dip northward off the slope of the granite mass. It is evident that their dip is mainly depositional, and that in geologic times not long past individual strata of the Comanche sands extended farther up the granite slope than they now extend. The dips in the Trinity are not so steep as the dips of the Cambrian off the granite knobs of Pedernales River, but an immensely shorter time for the accentuation of dips by settling and compacting around the granite core has existed in comparison with the long period of time since Cambrian days.

The north base of Bear Mountain, so well exposed by present erosion, is, as mentioned above, in contact with the basal sands of the Trinity. The valley of Palo Alto Creek east of the mountain is also entirely composed of the red-colored lowermost Trinity sediments. However, on the west side of Bear Mountain, immediately across a narrow road high on the slope of the elevation, is a tall hill composed of white and yellowish marly and limy beds, presumably belonging to the Glen Rose formation. The writer did not see the exact contact of these beds with the granite, but they appear to be in direct contact with the higher part of Bear Mountain.

This field evidence indicates that Bear Mountain was once an island in the Lower Cretaceous ocean; that, as the Trinity sea transgressed over central Texas, the forwardmoving, shallow edge of the ocean deposited the basal Comanche sands on, and against, the lower gentle slopes of Bear Mountain, with marked depositional dip; and that, as the front of the encroaching sea moved inland and the tumultuous waters of the beach zone were replaced by deeper, clearer waters, the marls and limes of the Glen Rose overlapped the Basement sands and were laid down against the higher levels, and over the peak of Bear Mountain, with less and less depositional dip, as the slopes of Bear Mountain grew more abrupt.

SCHIST

The writer did not observe any outcrops of schist in the Pedernales valley. However, in northeastern Gillespie County the road from Fredericksburg to Llano passes through an extensive area of rugged granite hills rising out of narrow valleys, in which schist outcrops. Schist likewise appears in the adjoining area to the east in northwestern Blanco County; and it is possible that schist may also occur along Grape Creek, a few miles north of Pedernales River, in association with the large granite outcrop there, as the writer did not have time in which to penetrate into the interior of this granitic district.

STRUCTURE

Only the more evident structural features of the Paleozoic rocks along Pedernales River could be noted in reconnaissance examination. Detailed mapping of structure would require a large amount of time with the aid of precise instrumental surveys.

Regional structure anticlinal or domal.—In addition to the self-evident fact that the pre-Cretaceous structure of Gillespie and Blanco counties is, in the widest structural meaning, part of the southern slope of the Llano Uplift, the regional structure of the Paleozoics exposed in the Pedernales valley in eastern Gillespie County and in Blanco County appears to be anticlinal or domal.

The outcropping of several granite knobs in the immediate incision of Pedernales River, and of a larger granite area a few miles to the north in the drainage of Grape Creek, has been mentioned. In western Blanco County, Cambrian strata are in contact with the granite. East of this area of granite and Cambrian, the Ellenburger limestone outcrops for many miles in Blanco County down the valley of Pedernales River; and the Marble Falls limestone appears in eastern Blanco County. West of the Cambrian and granite area on Pedernales River, the Ellenburger limestone outcrops along the stream in eastern Gillespie County.

A traverse down the immediate course of Pedernales River from the last exposure of Ellenburger, slightly above the mouth of Palo Alto Creek, eastern Gillespie County, to the Falls of the Pedernales, eastern Blanco County, reveals the following cross-section: Cambro-Ordovician (Ellenburger limestone), Cambrian, granite, Cambrian, granite, Cambrian, granite, Cambro-Ordovician (Ellenburger limestone), Pennsylvanian (Marble Falls limestone). Such an areal arrangement denotes anticlinal structure. Moreover, the dip of the Paleozoics also indicates major anticlinal structure: they trend roughly north and south, and are crossed from east to west by Pedernales River in eastern Gillespie County and in Blanco County. East of the area of granite and Cambrian in western Blanco County, the predominant dip in the Ellenburger and Marble Falls limestones is easterly,—east, northeast, southeast,—with an average of 5 to 10 degrees. In eastern Gillespie County on Pedernales River, the predominant dip in the Ellenburger limestone appears to be westerly,—west or southwest,—but at a lesser angle than in Blanco County, for the average dip is from 2 to 5 degrees.

Whether the anticlinal structure seemingly thus displayed in eastern Gillespie County and in Blanco County is structure caused by actual folding, or is structure in which the rocks owe their inclination to deposition on, and later compacting against, a large granite mass, is unknown. Probably the structure is due to original deposition on the slopes of a granite mass, and to compacting of beds against the granite, with consequent increase of dip, in later geologic times, with accentuation of structure by warping, uplift, and fracture during Mesozoic and Cenozoic times.

It is possible that the regional structure is domal instead of anticlinal. This depends largely upon the underground trend and extent of the granite to the south of Pedernales River. If there is a buried granite mass, of large linear extent in a direction approximately north and south, the structure would be anticlinal. On the other hand, if the subterranean granite extends only a short distance south of Pedernales River at a shallow depth, the structure of the Paleozoics along Pedernales River in Blanco County and in eastern Gillespie County is domal or quaquaversal.

Possible buried granite ridge.—The various outcrops of granite in the Pedernales valley appear to be parts of an extensive granite basement, which denudation has exposed. In corroboration of the above hypothesis, drilling in Gillespie County has encountered granite at shallow depths. A well drilled on the Morris Ranch, on Pedernales River, about 11 miles southwest of Fredericksburg, found granite at a depth of 180 or 200 feet, and drilled in the igneous rock to a total depth of 1,100 feet. Another well, about 11 miles east of Fredericksburg, went into granite at approximately 300 feet and continued in granite until the hole was abandoned at 660 feet. Detailed information on the two above mentioned wells will be given under Well Data.

It is possible that a large, buried granite ridge may extend in a southerly or southwesterly direction from the region of granite outcrop in the Pedernales valley in eastern Gillespie County and western Blanco County. The writer does not wish to be quoted as stating that such a buried granite ridge does exist; but only calls attention to the fact that a continuous, shallow mass of granite may extend for some distance south or southwest from Gillespie and Blanco counties. In this connection Hill (**4**, p. 87) states:

> Southward (from the Llano Uplift), in Gillespie County the granites are overlain by the Cretaceous rocks of the Edwards Plateau, and are re-exposed in small areas by the incisions of the Pedernales drainage. They are also penetrated by well-drills beneath the surface of the Cretaceous at Kerrville, and 12 miles northward, showing that the granites are buried for a considerable distance to the south of their present outcrop. No hypothesis can be formed concerning their extent to the north, west, and east.

In one of the Charles Schreiner wells, drilled for water, at Kerrville, granite is said to have been found at 1,250 feet, and drilled into for 75 feet, to a total well-depth of 1,325 feet. (**5**, p. 271.)

Slope of Paleozoic basement.—An idea of the degree of eastward or southeastward slope of the eroded Paleozoic floor, upon which the Comanche beds were deposited, may be gained from the areal geology of the Pedernales valley. In Gillespie County, about 5 miles southeast of Fredericksburg, the most westerly exposure on Pedernales River of the Paleozoics,—the Ellenburger limestone, directly overlain by the Trinity sands,—has an elevation of about 1,500 feet. Forty miles north of east downstream, at Hammet's Crossing of Pedernales River, in Western Travis County and immediately east of the eastern line of Blanco County, basalmost Trinity is exposed in the bluffs and in the river bed, at an elevation above sea level of about 750 feet. This gives a fall in elevation of the top of the Paleozoic basement of approximately 750 feet in 40 miles, or between 18 and 19 feet to the mile.

Minor structure.—Much minor structure exists in the Paleozoic rocks along Pedernales River, both folding and faulting. Possibly the faulting should not be considered a minor structural feature, but should be regarded as of major importance; for faulting is of major structural significance in the Llano-Burnet region to the north. In the present paper faulting is classified as minor structure only relatively, in comparison with the more evident regional structure off the granites of the Pedernales drainage in western Blanco County.

Along Spring Creek, western Blanco County, on the road from Sandy Post Office northwestward, there are excellent exposures of faulting, in which granite has been forced into fault-contact with the red and brown Cambrian sandstones. On Pedernales River, north and east of Hye Post Office, Blanco County, faulting also occurs. Granite is faulted against Paleozoic limestone on the north side of the valley of Willow Creek, some miles east of Willow City Post Office, Gillespie County. Without doubt many faults may be mapped in the Pedernales drainage, affecting various members of the Paleozoic section. There is also no doubt that local folds may be mapped in the Paleozoic rocks. In Pedernales River, upstream or westward from the mouth of Grape Creek, Blanco County, the limestone bluffs expose their strata as undulating in anticlines and synclines, with opposing dips of from 2 to 5 degrees. Elsewhere in the area, dips may be found that indicate minor folding.

About 7 miles southwest of Hye Post Office, on the north bank of Pedernales River and in Gillespie County, an interesting detail of folding is shown in an exposure of Ellenburger limestone. The general dip at this outcrop is 5 degrees, south 45 west; but certain thin strata exhibit much crumpling and bending into small waves that the massive strata in immediate contact do not display. The thin beds are evidently less competent than the heavy limestones and have been distorted by stresses transmitted through the massive beds, which have not affected the latter.

Comanche structure.—The Lower Cretaceous beds rest in an almost horizontal attitude upon various parts of the Paleozoic section. In places they show gentle folding, which may possibly sometimes reflect Paleozoic structure; but in general they have a practically undisturbed, slight southeast dip.

WELL DATA

Shallow water wells are numerous in Gillespie and Blanco counties, but few deep holes have been drilled, either for water, or for oil and gas. Gillespie County, however, has some wells that give subsurface information of value to the geologist, and important data on eastern Blanco County are furnished by two wells drilled in extreme western Travis County, immediately east of the Blanco County line.

H. Reimers 1, Summerow

Located on the J. C. Little Survey near Hamilton Pool, Travis County. Well completed in 1926. T. D. 1,275 feet. Log supplied by E. D. Summerow.

Driller's Log

	Depth in feet
Vegetable mold	2
Sandy limestone	40
Shell breccia	41
Blue, clayey shale	55
Blue limestone	59
Blue, clayey shale	84
Brown shale	87
Blue lime	94
Brown shale	102
Red, clayey shale	109
Hard sandstone, color dark	113
Brown sandstone	127
Brown sandstone, very hard	138
White limestone	149
Brown lime	165
Red clay	175
Red sand and gravel	183
Lime and shell	187
Red sandstone	196
White lime and shells	200
Red clay and gravel	245
White limestone and shell	250
Red clay and gravel	265
White sandstone	266
Blue shale	268
Breaks yellow and blue clay	278
Breaks yellow and green clay	290
Olive-green gumbo	293
Gray, clayey shale	305
Black, sandy shale	320
Gray, clayey shale	365
Hard, black shale	405
Blue shale	410
Black slate	414
Black shale	445
Blue shale	476
Breaks of shale and slate	492
Blue shale	497
Black slate	549
Black shale	550
Black slate	630
Black shale, flags of gray lime	656
Gray lime	657
Black shale	658
Gray lime	660
Black slate	695
Black slate and lime flags	730
Black slate, sand, and lime	745

	Depth in feet		Depth in feet
Black shale, oil scum	754	Gray lime	872
Slate and shale, oil scum	813	Black shale	984
Limestone	816	Gray lime	986
Shale and lime	822	Black shale	1,030
Shale	824	Black shale, flint noted	1,060
Gray limestone	866	Black shale	1,134
Black shale	871		

Description of samples by E. H. Sellards and O. M. Richey; submitted by E. D. Summerow, 1926.

	Depth in feet
Cuttings of dark gray non-calcareous shale with a very little clear quartz	400
Dark gray, non-calcareous shale	650
Dark gray, non-calcareous shale. Carbonaceous shale. Sub-angular to rounded grains of clear quartz noted in washed material	1,050
Cuttings of blackish-gray shale. Pebbles of dark, blackish-gray, black and green flint were observed. The samples and washed material appear to be Smithwick shale	1,138
Dark gray, non-calcareous shale. Apparently Smithwick shale	1,190

This well starts in the Comanche series, and passes the base of the Cretaceous at 266 feet. From this depth to 1,275 feet the section is logged as predominantly black shale.

Romberg 1, Cypress Creek Drilling Association

Located in Travis County near Cypress Creek about 2 miles northwest of Hamilton Pool and near the Travis-Blanco county line, 1½ miles north of Austin-Cypress Mill road. T. D. 1,560 feet.

The writer was unable to obtain a log of this well, but Mr. G. C. Jones, of Marble Falls, Burnet County, one of the promoters of the test, gives the following information:

Letter of November 1, 1927:

> I have not a prepared log of this well at hand, but will say that we drilled 1,560 feet, and found shale clear down to the bottom of the hole. Of course, this shale had sandstone flags from a few inches to as much as 20 feet thick, seeming to conform to the sandstone flags seen in the exposed Smithwick shale in this country. The shale gradually increased in hardness as the hole went down, at times being almost hard

> enough to be taken for Marble Falls. The color ran from a light, creamy-slate to a black, always seeming to have some calcareous, sandy flecks through it. We had a few rainbows all the way down, usually in, or just as we passed through the sandstone flags; and, two or three times, enough gas to flash on top of the slush where we dumped in a barrel. We lost the hole at 1,560 feet by caving.

The records of these two wells show a remarkable thickness of shale, apparently in the stratigraphic position of the Smithwick shale. The Summerow well shows 1,009 feet of shale, between the base of the Trinity at 266 feet and the total well-depth of 1,275 feet; and stopped in shale. The Cypress Creek Drilling Association number 1 also started in the Trinity; and drilled through a greater thickness of shale beneath the Trinity than did the Summerow test. Assuming the thickness of the Trinity in the two wells to be approximately the same almost 1,300 feet of material, predominantly shale, were penetrated in the second well; and the well was abandoned in shale. This great thickness of shale is difficult to understand in view of the fact that the Smithwick shale elsewhere has a thickness of but little over 400 feet.

Morris Ranch Well, Gillespie County

Located on the Morris Ranch 11 miles southwest of Fredericksburg and 9½ miles northeast of Kerrville. T. D. 1,100 feet.

No log of this well is available. However, Mr. Charles Morris says:

> The well was drilled at the foot of a limestone mountain of about 250 feet height, and about ¼ mile from the Pedernales River. We struck water at about 50 feet, and at 200 feet we struck the granite. We cased off the water to the granite and drilled on 600 feet more, and struck more water and it rose to the level of the first water; and then we went on 300 feet more, all in the same granite, and no more water.

Samples of the granite from this well were examined by Hill and Vaughan (**5**, p. 273).

SCHEBLER WELL

Located 11 miles east of Fredericksburg
Log made by Marvin Lee from samples

	Depth in Ft.		Depth in Ft.
White lime	217	Lime and granite	240
Lime, some granite	221	Lime, gray	243
Sand, hard, gray	226	Shale, gray, limy	249
Sand, fine, gray	235	Lime and granite	254

	Depth in Ft.		Depth in Ft.
Lime and quartz	259	Granite	319
Lime ?	270	Granite, red	327
Granite, gray	274	Granite, brown	383
Lime and granite	278	Granite, red	542
Quartz and dark shale	281	White quartz powder	558
Dark shale	296	Granite, red	650
Quartz and shale	300	Granite and black shale ?	652
No sample	304	Granite, red	660

Total depth, as far as is known, 660 feet.

A. & B. KOTHMAN WELL

Located on J. T. Stell Survey, No. 44, 450 varas northeast from the junction of Live Oak Creek with Pedernales River; 5 miles southwest of Fredericksburg. T. D. 580 feet.

Description of samples by J. A. Udden; submitted by H. H. Sagebiel.

Brownish, light gray dolomite, with a few fragments of gray limestone. In thin section the dolomite is seen to be coarsely crystalline	200
Gray, impure, dolomitic limestone. In thin section this material is seen to consist of many single crystals of varying sizes in a granular, shaly-appearing matrix. In thin sections many minute, black particles are seen, around which a brown stain is formed. These are apparently oxidized pyrite particles	450
Very light gray, almost white limestone, of compact and crystalline texture. Some irregular patches are very finely crystalline, appearing almost granular under low magnification. Some greenish, cavern(?) clay present. Aspect that of the Ellenburger	550
Dark, cream-colored, and white dolomitic limestone. In thin section two fragments are seen to be mostly crystalline with patches of granular texture. Coarse crystallization is seen in some parts of the material. Some fragments of the limestone have a greenish color. Aspect of the Ellenburger	580

CONCLUSION

It is evident, from the description in the preceding pages of the geology of the formations exposed along Pedernales River in Gillespie and Blanco counties, and from the information furnished by the few deep holes so far drilled in these counties, that rocks ranging in age from Pre-Cambrian granite to Pennsylvanian sediments may be expected to be encountered by the drill in the region south of Pedernales River, covered on the surface by the Comanche strata.

Accurate prophecy of what rocks lie beneath the Lower Cretaceous at any particular locality is well-nigh impossible. The drill may find granite, Upper Cambrian sands and limes, Ellenburger limestone of Cambro-Ordovician age, or Marble Falls limestone, or younger formations of Pennsylvanian age. Schist may perhaps be found in some places.

The writer feels that the possible oil resources of this region south of Pedernales River, on the upper or inner side of the Balcones fault, in southern Gillespie and Blanco counties, and in Kendall and Kerr and adjacent counties, are worthy of consideration. It is possible that the Marble Falls limestone exposed at the surface on Pedernales River in eastern Blanco County may in the subsurface describe an extensive arc of a circle to the south and southwest in the general region south of the Central Mineral province. Should the Marble Falls limestone, or younger Pennsylvanian formations of petroleum-bearing character, be present in any extent, then there exists an oil horizon, which has yielded large production in the Ranger district of north-central Texas, north of the Central Mineral uplift.

However, wildcatting for new fields in the Comanche-mantled country south of Pedernales River is, in the light of the present imperfect geologic knowledge of the district, a most uncertain undertaking. The Lower Cretaceous beds conceal the subsurface conditions, both the character and structural conditions of the Paleozoic rocks. However, surface Comanche structures should be considered as possible reflections of buried Paleozoic structures. Geophysical examinations would appear advisable, with the thought of locating possible granite or limestone "highs," or "buried hills." The subsurface data furnished by wells may give clues to favorable structure. All information, given by surface geology, by geophysical findings, and by well drillings, should be carefully compared with possible speculations, and deductions, that the geologist may develop.

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PRATT WELL IN WEBB COUNTY

BY

RICHARD A. JONES[1]

The well described in this paper is located on the Pratt Ranch in north-central Webb County, about 5 miles southwest of Encinal. The record of this well affords an aid in deciphering the subsurface Tertiary section of the Rio Grande Embayment.

BASIS OF STUDY

The writer had access to a series of laboratory analyses of rotary cuttings and cores from this well taken at depths ranging from 395 to 5,033 feet. These laboratory analyses were from the following sources: Miss Alva Ellisor, paleontologist, Humble Oil and Refining Company, Houston, Texas; Mrs. Paul Applin, paleontologist, Rio Bravo Oil Company, Houston, Texas; E. H. Sellards and others, Bureau of Economic Geology, University of Texas; and determination of Midway foraminifera by Mrs. Helen Jeanne Plummer, Austin, Texas. The writer gratefully acknowledges indebtedness to these sources of information. Reports on samples from 132 different depths were available; and for some samples there were two or three analyses from the sources mentioned above. These analyses of well samples were, in conjunction with the data furnished by the driller's log, the basis of the study.

The well begins in the upper part of the Cook Mountain formation and extends into the Midway. Thus, the formations in which drilling began and ended are known. The problem then is to subdivide the Eocene sediments penetrated into the proper formation units and to determine the lithologic character of these formations.

A tabulation was prepared showing, opposite the depths of the well sample analyses, the following data: (1) General lithology; (2) color; (3) lime content; (4) character

[1]San Antonio, Texas.

of quartz grains; (5) presence or lack of bituminous content; (6) minerals occurring, including all minerals noted in the analyses: (a) siderite, (b) calcareous nodules, (c) pyrite, (d) glauconite, (e) mica, (f) chert, (g) marcasite, (h) aragonite, (i) calcite, (j) gypsum, (k) lignite and coal, (l) phosphate, (m) bentonite, (n) rhyolite sand; (7) igneous rock; (8) oil and gas showings; (9) fossils.

The detailed analysis was successful in exhibiting definite faunal, mineralogic, and lithologic zones, which, although overlapping somewhat, set forth very clearly the various formations. A chart showing how the analysis differentiated between the Eocene formations accompanies this paper.

EOCENE SECTION

The writer's interpretation and description of the Eocene rocks penetrated in this well in descending order from youngest to oldest, follows:

CLAIBORNE GROUP

COOK MOUNTAIN-MOUNT SELMAN FORMATIONS

The combined thickness of the Cook Mountain-Mount Selman formations is 2,330 feet.

To 2,330 feet a marine fauna occurs, consisting principally of Turritellas and shark teeth and of various species of foraminifera. Glauconite is abundant to 2,200 feet, below which depth for a considerable interval there is no glauconite. It was found impossible to differentiate the Cook Mountain from the Mount Selman. The sediments of these two formations include sand, sandstone, sandy shale, and shale that is partly calcareous and partly non-calcareous. The dominant color of the samples is gray, a contrast to the often reddish tone of surface exposures of the formations. This gray subsurface tone is, no doubt, due to lack of oxidation of the iron content of the strata. Lignite is scattered throughout almost the entire section but is most abundant about the middle of the series. A large amount of pyrite is present. Other mineralogic characteristics are: very little bituminous content, practically no siderite, considerable amount of small calcareous nodules, scattered flakes of mica, many chert grains, no calcite, no phosphate, some volcanic ash. The quartz grains of the sands and sandy shales are medium to fine, angular to subangular, and predominantly transparent or translucent, with a small percentage of rose, smoky, orange, and green quartz. A peculiar feature is the lack of gypsum in well samples, in contrast to the large quantity of this mineral in the surface Mount Selman. Possibly the gypsum in the Mount Selman outcrop is secondary, due to chemical reactions from weathering.

WILCOX GROUP

BIGFORD FORMATION

Thickness, 720 feet, from 2,330 feet to 3,050 feet.

The zone correlated as Bigford by the writer is distinguished from the Cook Mountain-Mount Selman zone in that it carries almost no glauconite and has practically no fossils. A very few ostracods were all the fossils found in the well samples. The general lithology and mineral characteristics are much the same as those of the Cook Mountain-Mount Selman zone. Some lignite occurs.

CARRIZO SANDSTONE

Thickness, 310 feet, from 3,050 feet to 3,360 feet.

The driller's log shows considerable black shale in this zone, but well samples display little general lithologic difference in the Carrizo, Bigford, Mount Selman, and Cook Mountain formations. However, this zone carries a large amount of glauconite. At 3,360 feet, this second glauconite zone stops, corresponding roughly with a great change in lithology at 3,300 feet, as shown by analyses of well samples, at which latter depth the gray sands, sandy shales, and shales disappear, giving place to a thick section, extending to the bottom of the hole, of brown and black, bituminous shale carrying sandstones.

The formation, as exhibited by well samples, is non-calcareous; a large amount of siderite is present; there are few calcareous nodules; numerous pyrite crystals occur; there is much mica, but little chert; there is no calcite; neither lignite nor phosphate occurs; and the series is non-fossiliferous, save for some leaf impressions. The driller's log records a water-sand in this zone from 3,100 to 3,108 feet.

INDIO FORMATION

Thickness, 740 feet, from 3,360 feet to 4,100 feet.

The rock section is brown and black, fissile shale, with which are interbedded two types of sandstone: (1) A fine-textured sandstone, and (2) a friable sandstone. The shale is bituminous, with a greasy luster. The driller's log also records a large occurrence of black shale below 3,300 feet, checking with the analyses of well samples. The sediments of this part of the section differ greatly from those at higher level. The rock is almost entirely non-calcareous; has a large amount of siderite; carries some few calcareous nodules; has little pyrite; the lower part displays glauconite, the upper part does not; there is much mica, but no chert; no lignite occurs; and there are no fossils save a few scattered ostracods.

Igneous rock found in samples from 4,004 feet to 4,012 feet is described by the Bureau of Economic Geology as follows: "In washed material—a few, small, more or less roundish grains of greenstone, which is composed almost entirely of dark-green chlorite, are found. These fragments are evidently from an igneous rock, probably from a pebble of this material, although they may have been from a thin flow or sill of altered basaltic rock."

Undetermined, Indio or Midway Formation

Thickness, 355 feet, from 4,100 feet to 4,455 feet.

At 4,100 feet a marine fossil zone appears, the first since 2,330 feet. This zone is characterized by a foraminiferal fauna. A few ostracods are also present; and there are numerous fragments of gastropods, and some small, pyritized

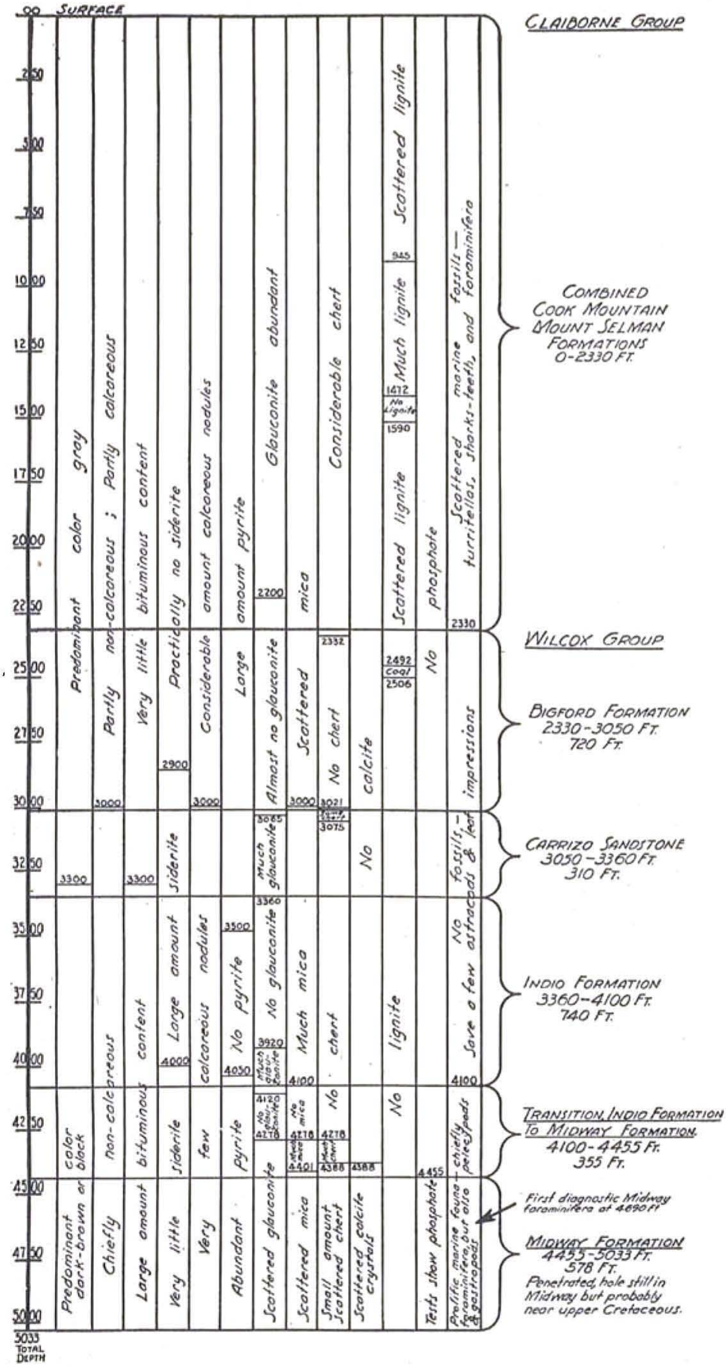

CHART SHOWING MANNER IN WHICH EOCENE FORMATIONS IN A-D-J OIL COMPANY NO. 2-B PRATT RANCH SURVEY 1127 NORTH-CENTRAL WEBB COUNTY, SOUTHWEST TEXAS, MAY BE DISTINGUISHED BY FAUNAL AND MINERALOGICAL ZONES, CHARTED THROUGH ANALYSES OF CORES AND CUTTINGS.

Fig. 6. Chart of sample analyses.

pelecypod shells. The same lithology prevails as in the preceding zone—brown and black, bituminous shale, with the same two types of sandstone, a fine-textured sandstone and a friable sandstone. The beds are chiefly non-calcareous; contain little siderite; have few calcareous nodules; carry abundant pyrite; display little glauconite; have no mica save toward the base of the section; and carry little calcite. The age of this part of the section is undetermined.

MIDWAY GROUP

MIDWAY FORMATION

Thickness, at least 578 feet (drilling stopped in Midway), from 4,455 feet to 5,033 feet.

The section is of the same brown and black, bituminous, fissile shale, as in the preceding zone, carrying the same kind of interbedded sands. The strata in this interval have a prolific marine fauna. The first diagnostic Midway fauna occurs according to Miss Ellisor at 4,690 feet. Concerning the section below 4,690 feet, Miss Ellisor states:

> "These cuttings from 4690 feet to 5033 feet are the same, and contain an assemblage of foraminifera that are Midway in age. These fossils are the same as those found in a well in southwest Dimmit County, from 1700 feet to 1800 feet. As these foraminifera have not yet been found farther up the hole in A-D-J Oil Company number 2B-Pratt, they are evidently in place. A specimen of *Pulvinulina rosetta* found at 4408 feet must be a reworked Cretaceous species in the Midway, as there are no other Cretaceous fossils found in the well."

In samples submitted to the Bureau of Economic Geology at depth 4,330–4,334 feet, Mrs. Plummer identified the following foraminifera: *Anomalina ammonoides* var. *acuta,* and *Triloculina alleni;* in samples from 4,727 to 5,033 feet Mrs. Plummer found the following: *Vaginulina robusta, Cristellaria midwayensis, Nodosaria affinis, Pulvinulina exigua, Globigerina pseudo-bulloides, G. triloculinoides;* and undetermined ostracods and gastropods.

The lithology and probably the fauna in this interval is similar to that in the section from 4,100 to 4,455 feet. The reasons for regarding the higher interval as undetermined in age are: (1) The first diagnostic Midway foraminifera are found at 4,690 feet; (2) this depth corresponds roughly with the appearance of phosphate in the well samples at 4,455 feet. The Midway of Texas is characterized in many places by the presence of numerous, small phosphate nodules. However, it is possible that the entire fossiliferous section from 4,100 to 5,033 feet is of Midway age, thus making the Midway in this well at least 933 feet thick.

Some mineral characteristics of the Midway zone are: Principally non-calcareous; very little siderite; few calcareous nodules; abundant pyrite; some mica; small amount of chert; scattered crystals of calcite; some glauconite.

THICKNESS OF EOCENE

This record indicates over 5,000 feet of sediments in the Eocene section of north-central Webb County. It is possible that the well is not vertical, as it is known that such deep holes are often drilled with considerable departure from "plumb." Should the hole be crooked, the true thickness of the rocks penetrated by the test would be somewhat less than that indicated by the drilling measurements. However, no information exists concerning any deviation from the vertical, and, in the absence of such data, the thickness of 5,033 feet recorded by the drilling measurements is assumed to be correct.

Such a thickness of sediments in the formations involved is far above the estimates of thickness which have been made from the study of Eocene outcrops in the Rio Grande Embayment. Deussen considers that the maximum thickness of the Eocene section, from Cook Mountain to Midway, inclusive, in the coastal plain of Texas west of Brazos River is 3,891 feet.[2] Trowbridge estimates that the maximum thickness of the Eocene, from Cook Mountain to Midway, inclusive, along the Rio Grande is 3,131 feet.[3] The section indicated by this well is thus from 1,100 to 1,900 feet

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[2]Deussen, Alexander, Geology of the Coastal Plain of Texas west of Brazos River. U. S. Geol. Surv., Prof. Paper 126, pp. 21, 22, 1924.

[3]Trowbridge, A. C., A Geologic Reconnaissance in the Gulf Coastal Plain of Texas, near the Rio Grande. U. S. Geol. Surv., Prof. Paper 131-D, pp. 88–94, 1923.

thicker than previous estimates for these formations. However, such a thickness is not improbable. The outcropping belt of Eocene to and including Cook Mountain in this part of the state is 50 miles wide. A thickness of 5,000 feet therefore implies a regional dip of 100 feet per mile, which to the writer seems probable for the average rate of dip of the Eocene beds in the northwestern part of the Rio Grande Embayment.

POSSIBILITIES OF DEEP PRODUCTION IN LOWER EOCENE

One of the most interesting features revealed by the study of this well is the character of the rocks below 3,300 feet, which for over 1,700 feet, are predominantly brown and black bituminous shales, carrying interbedded sands. This section represents the Indio and Midway formations.

The Indio (Wilcox group) and Midway formations, as judged by surface lithology, do not appear especially favorable as oil and gas reservoirs. However, this well shows that these formations, in subsurface extension Gulfward beneath the Coastal plain, have changed greatly. If the lithology of the Indio and Midway formations, as exhibited in this well, be not merely a local facies, and if this thick, dark, bituminous shale series, with numerous intercalated sands, occupy a wide area in the subsurface of the Rio Grande Embayment, the possibilities of deep oil and gas production from the lower Eocene strata of the region are worthy of consideration.

PENNSYLVANIAN OSTRACODA FROM MENARD COUNTY, TEXAS

BY

BRUCE H. HARLTON

INTRODUCTION

The ostracoda described[1] in the following pages were collected from Pennsylvanian limestones exposed in the San Saba River valley, near Hext in eastern Menard County, Texas. This locality is about 21 miles west of the western side of the Llano-Burnet uplift of pre-Cambrian rocks.

The outcrop consists of about 230 feet of limestone interstratified with thin shales and marls. Part of the limestone is massive and part thin bedded. The megafauna consists of long-range Pennsylvanian forms, brachiopods predominating. The microfauna is abundant and of the several classes present the ostracoda are here described. Conclusive evidence of the age of the formation which has heretofore been in doubt is found in the foraminifera which are diagnostic of the Canyon series and of the Graham formation in the Bend Arch area.[2] The strata overlie the Marble Falls limestone of Lower Pennsylvanian age, exposures of which are found in the river valley, and underlie the Trinity conglomerate of Lower Cretaceous age. A columnar section and an areal map showing the fossil localities are reproduced in figures 7 and 8.

The fossil localities enumerated below are those referred to in this paper.

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[1]The opportunity of studying the fossils described in this paper and of offering the paper *for publication* has *been afforded the* writer *by* the Amerada Petroleum Corporation, Tulsa, Oklahoma.

[2]In the Bend Arch area the writer finds no break in the microfauna between the uppermost formations of the Canyon series and the Graham formation heretofore placed in the Cisco series. For this reason the writer is of the opinion that the Graham formation should be grouped with the several formations now placed in the Canyon series.

Locality 1. On William Horton Survey No. 137, Horizon A on columnar section. A bed of limestone carrying large corals. This bed is overlain by Trinity conglomerate.

Locality 2. Near northeast corner of C. F. W. Nickel Survey No. 135, Horizon B on columnar section. Marly shale and limestone, highly fossiliferous. This horizon is especially rich in micro-fossils, with foraminifera and ostracoda predominating. Most of the forms from this locality are in a beautiful state of preservation.

Locality 3. On Ludwig J. Sahm Survey No. 164, Horizon H on columnar section.

Locality 4. Near northwest corner of Heinrich Voges Survey No. 76. Collection from yellow shales of Horizon I, just above the unconformity with the Marble Falls limestone.

In the primitive types of the ostacoda, such as the genus *Bairdia*, great variations within the species have been noticed. One may have great difficulty in grouping the various forms and variations into species. A continuous variation which exists within a species is found to be of no stratigraphic value; whereas if a variation exists between two known species, and its relation is established, it is found to be of stratigraphic importance. The variations shown by the forms described appeared to the author as entirely fortuitous and without significance.

Some carapaces which are referred to the genus *Amphissites* undoubtedly constitute a new genus, but additional forms are necessary for its description. The same is true of a form assigned to the genus *Bythocypris*. The new genus *Bairdianella* is represented by two new species and is united with *Bairdia* in the family *Bairdiidae*.

The writer wishes to express his gratitude for helpful suggestions to Drs. R. S. Bassler and E. O. Ulrich of the U. S. National Museum, Mr. J. Brookes Knight, and Miss Betty Kellett, and especially to L. B. Snider who collected the material.

DESCRIPTION OF SPECIES

Family BEYRICHIIDAE Jones

Genus HOLLINA Ulrich and Bassler

HOLLINA RADLERAE Harlton

Pl. 1, figs. 2 a–c

Hollina radlerae Harlton, 1928, Journ. Pal., vol. 2, p. 133, pl. 21, figs. 2 a, b.

Shell large and stout, semi-ovate, slightly convex, with long, straight hinge line and wide, concave, strong marginal frill. Including the frill the shape of the valves is typically semi-circular. Surface exhibits three rounded tubercles, one near the posterior cardinal angle, a second small one beneath, and a third very pronounced one near the center of the dorsal margin. A distinct swelling of the surface lies along the ventral margin of the valves. A strong depression of the surface occurs between, and extends some distance beneath, the largest and smallest of the tubercles. Surface distinctly granulose. The anterior extremity of both valves is protected by a row of spines and slightly posteriorly by a row of small beads; on some specimens the minute beads are in a scattered arrangement.

Length, 1.2 mm.; height, 0.64 mm.

Locality 3. Plesiotype, U. S. National Museum, No. 80555.

HOLLINA ULRICHI Knight

Pl. 1, fig. 3

Hollina ulrichi Knight, 1928, Journ. Pal., vol. 2, p. 237, pl. 31, figs. 4a, b.

Carapace large and stout, semi-ovate, oblique in outline; hinge line straight; anterior end rounded and denticulate; posterior obliquely rounded. Surface of valves with two rounded tubercles situated at the dorsal half, one on each side of a deep central depression, the anterior tubercle very pronounced. A strong, large marginal frill with radiate undulations rises abruptly at the antero-ventral border and gradually dies somewhat below the postero-dorsal angle.

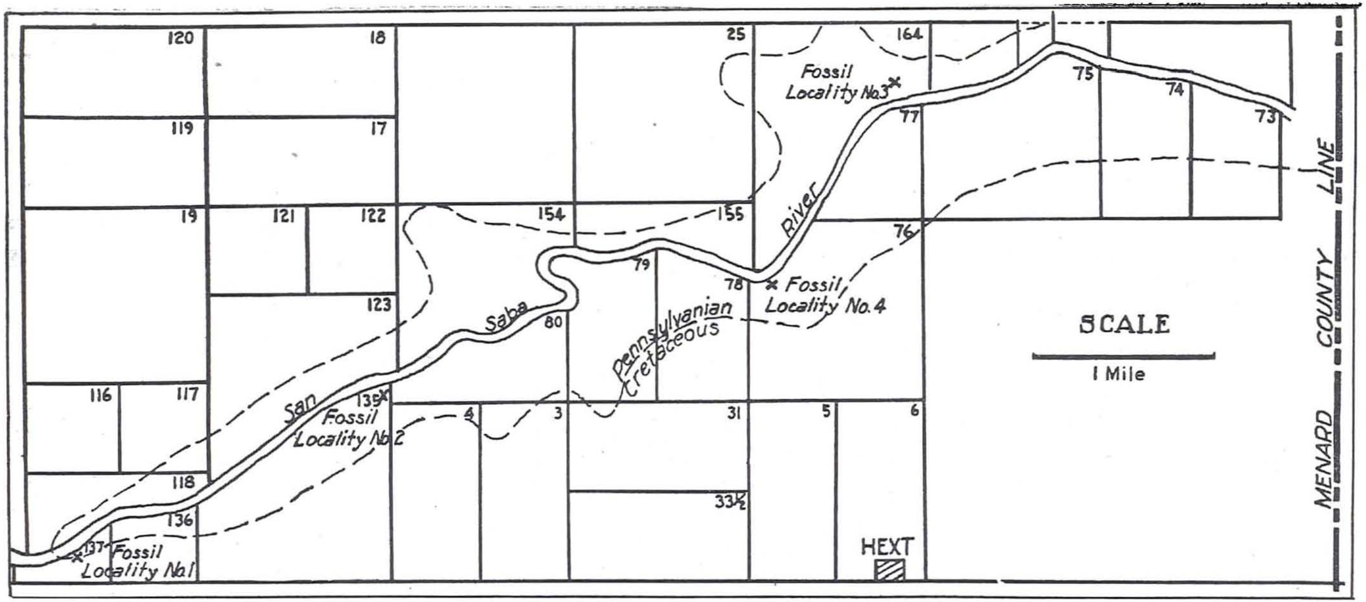

Fig. 7. Map of part of eastern Menard County showing fossil localities and giving the numbers of the land surveys. Pennsylvanian rocks outcrop in the San Saba river valley, and the contact between them and the Cretaceous is shown by the broken line.

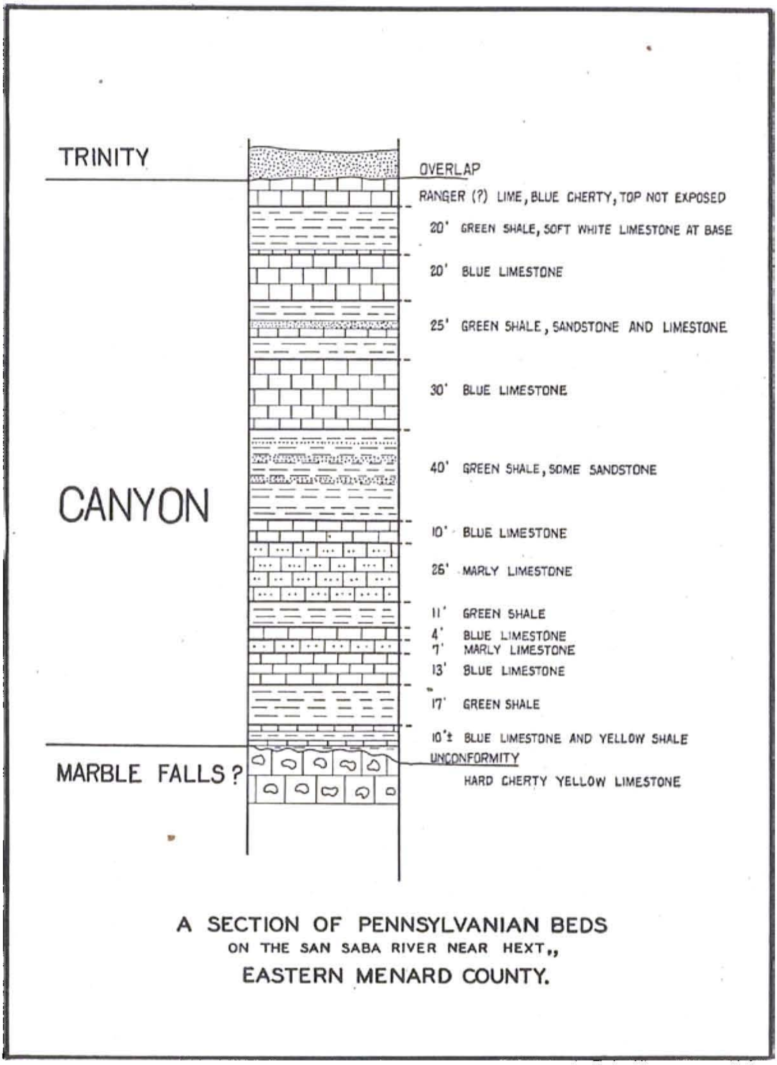

Fig. 8. Columnar section.

Anterior extremity of left valve protected by a row of spines, the spine at the antero-dorsal angle especially pronounced; immediately back, a row of minute beads is situated. Surface coarsely papillose.

Length, 1.10 mm.; height, 0.70 mm.

Locality 3. Plesiotype, U. S. National Museum, No. 80556.

HOLLINA BUEHLERI Knight

Pl. 1, fig. 4

Hollina buehleri Knight, 1928, Journ. Pal., vol. 2, p. 237, pl. 31, fig. 1; pl. 34, fig. 8.

Carapace semi-ovate, oblique, about twice as long as high; hinge line straight; anterior end rounded, posterior end obliquely rounded. Equivalved, but outer edge of margin of left valve appears slightly beveled to fit under edge of right valve; anterior extremity of both valves protected by a row of minute beads. A prominent dorsal sulcus slightly posterior to the middle extends down the valve about midway; upper end of the sulcus restricted in width by the bordering nodes. Surface of the valve posterior to the sulcus curved smoothly and rather flatly with a small node bordering and protruding into the upper two-thirds of the sulcus and barely extending above the curvature of the surface. Anterior to the sulcus a prominent circular to reniform node protruding into and constricting the sulcus opposite the posterior node. Lower surface of the valve in the form of a low broad poorly defined ridge connecting anterior and posterior surfaces and blending into them smoothly. A rather narrow, ridge-like frill rises abruptly from a point on the anterior extremity near the margin and about two-thirds of the way down the antero-dorsal angle, and extends around the valve above the margin, dying away close to the postero-dorsal angle. The anterior margin of the valve as far down the point at which the frill arises carries a few short irregular spines. The surface is minutely granular.

Length, 1.10 mm.; height, 0.70 mm.

Locality 3. Plesiotype, U. S. National Museum, No. 80557.

HOLLINA FORTSCOTTENSIS Knight

Pl. 1, fig. 5

Hollina fortscottensis Knight, 1928, Journ. Pal., vol. 2, p. 237, pl. 31, fig. 2.

Very similar to *H. buehleri* Knight and differs in the wider frill and distinctly radiating lines. Anterior extremity of left valve protected by a row of minute beads and in front by a row of distinct spines.

Length, 1.00 mm.; height, 0.56 mm.

Locality 2. Plesiotype, U. S. National Museum, No. 80558.

Genus HOLLINELLA Coryell

HOLLINELLA MENARDENSIS n. sp.

Pl. 1, figs. 6 a, b

Carapace small, semi-ovate in outline; hinge line straight. It has a distinct subcentral sulcus and a prominent anterior node; posterior node less pronounced. A marginal frill consisting of a row of papillae or short narrow spines occupies the true position of the frill. A row of minute spines extends around the ventral and end margins and almost reaches the hinge line at both ends. At the anterior extremity a row of minute beads is situated.

Length, 1.04 mm.; height, 0.60 mm.

Locality 2. Cotype, U. S. National Museum, No. 80559.

The most diagnostic feature about *H. menardensis* is the very distinct and characteristic thickness lengthwise through the center of the valve. Due to this thickness the spines are not well developed.

HOLLINELLA GRAHAMENSIS (Harlton)

Pl. 1, fig. 7

Hollina grahamensis Harlton, 1927, Journ. Pal., vol. 1, p. 203, pl. 32, figs. 2 a, b.

This species can easily be distinguished from the rest of the group. The spines of the marginal frill are of very even character and are very pronounced. The surface is minutely granireticulated.

Locality 3.

HOLLINELLA OKLAHOMAENSIS (Harlton)

Pl. 1, figs. 8 a, b

Jonesina oklahomaensis Harlton, 1928, Journ. Pal., vol. 2, p. 133, pls. 21, figs. 2 a, b.

Carapace small, semi-ovate, hinge line straight. It has a distinct subcentral sulcus and a prominent anterior node; posterior node small, sometimes rather inconspicuous. The test in the dorsal view is ovate in outline and rounded at the ends. Surface distinctly granulose.

Length, 1.11 mm.; height, 0.58 mm.

Locality 2. Plesiotype, U. S. National Museum, No. 80561.

This simple type of organism does not have the marginal spines and the entire surface is coarsely papillose.

Family KLOEDENELLIDAE Ulrich and Bassler

Genus JONESINA Ulrich and Bassler

JONESINA TEXANA n. sp.

Pl. 1, figs. 14 a, b

Carapace small, subovate in outline, the left valve overlapping the right; dorsal border straight; posterior end well rounded, anterior abruptly curved into the ventral edge. A deep sulcus marks the posterior half of the valves and in front of it, close to the dorso-posterior angle is a very distinct impression with a pronounced rounded boss between. The pronounced anterior swelling extends somewhat above the hinge line. The posterior extremities of both valves are protected by a small carina extending along the inner edge of the ventral margin to the anterior extremity. The holotype, a well preserved specimen, shows only remnants of this carina at the ventral margin and anterior extremity. Some specimens give the appearance of the presence of very minute beads. Viewed from above the test is typically wedge-shaped, posterior end thin and sharp, anterior swollen, with a sharp dorso-posterior slope.

Length, 0.74 mm.; height, 0.46 mm.; thickness, 0.4 mm.

Locality 4. Holotype, U. S. National Museum, No. 80562.

Genus KIRKBYINA, Ulrich and Bassler

KIRKBYINA INFLATA n. sp.

Pl. 1, figs. 15 a–e

Carapace small, subovate in outline, right valve large, overlapping the left. Dorsal border straight or very slightly curved; extremities rounded, the anterior more pronounced. The shell has a rather distinct subcentral sulcus with a very inconspicuous anterior node. At the dorso-posterior angle of the right valve a spine is developed. At the hinge line a distinct groove occurs from the spine to the middle. Viewed from above the anterior end is thin and rounded, the posterior bluntly rounded and inflated.

Average dimensions: length, 0.6 to 0.7 mm.; height, 0.4 to 0.5 mm.; greatest thickness, 0.4 to 0.5 mm.

Locality 2. Cotypes, U. S. National Museum, No. 80563.

Family GLYPTOPLEURIDAE Girty

Genus GLYPTOPLEURINA Coryell

GLYPTOPLEURINA POWERSI n. sp.

Pl. 1, fig. 16

Shell unequivalved, subquadrate in outline; dorsal margin straight, with contact depressed slightly; the left valve overlaps the right at the cardinal extremities and on the free margin. The distinct dorso-medial sinus is bordered by a large posterior node and from it an inosculating costa extends to the anterior node, downward, forward and backward, curving dorsally beneath the medial sinus. Ventral to this costa is another that approximately parallels the free edge and lies in the crest of the steep ventral slope.

The marginal flange is narrow, corrugated, incomplete, and most conspicuous along the anterior and posterior extremities.

Length, 1 mm.; height, 0.5 mm.; thickness, 0.5 mm.

Locality 2. Holotype, U. S. National Museum, No. 80564.

Genus GLYPTOPLEURA Girty

GLYPTOPLEURA TEXANA n. sp.

Pl. 1, figs. 17 a, b

Carapace subquadrate in outline, thick shelled, and strongly ribbed with subconcentric ridges. Dorsal margin straight; anterior extremity gently rounded, posterior more or less rounded. A subcentral pit is situated just above the central rib; above this is a long rib and another short anterior one. The ribs above and below the central rib are more or less connecting at the posterior end. Below the central rib three parallel ribs are situated. In addition there occurs a somewhat indistinct marginal rib which diminishes at the posterior extremity. Surface smooth.

Length, 1 mm.; height, 0.56 mm.; thickness, 0.5 mm.

Locality 3. Holotype, U. S. National Museum, No. 80565.

GLYPTOPLEURA SPINOSA n. sp.

Pl. 1, fig. 18

Carapace subquadrate in outline, thick shelled, and strongly ribbed with concentric ridges. Dorsal margin straight; extremities rounded. A subcentral pit is situated just above the central rib and from this pit two short ribs extend to the extremities. Above them a strong curved rib is developed with another short one on the anterior portion. Below the central rib three parallel ribs are situated. The marginal rib is rather indistinct, and the ribs at the posterior extremity grade into spines. Surface smooth.

Length, 1 mm.; height, 0.56 mm.; thickness, 0.5 mm.

Locality 3. Holotype, U. S. National Museum, No. 80566.

GLYPTOPLEURA MENARDENSIS n. sp.

Pl. 2, figs. 1 a–c

Carapace subquadrate in outline, thick shelled, and strongly ribbed with concentric ridges. Dorsal margin straight; extremities rounded. A subcentral pit is situated immediately above the medial rib; above and below the central rib occur two strong parallel ribs which connect at the posterior extremity. A divided rib is situated above and two straight ones below. A marginal rib, which diminishes at the posterior extremity, is developed. Surface smooth.

Length, 1 mm.; height, 0.56 mm.; thickness, 0.48 mm.

Locality 1. Cotypes, U. S. National Museum, No. 80567.

Family KIRKBYIDAE Jones

Genus AMPHISSITES Girty (emend Knight)

AMPHISSITES DATTONENSIS Harlton

Pl. 1, figs. 9 a, b

Amphissites dattonensis Harlton, 1927, Journ. Pal., vol. 1, p. 206, pl. 32, figs. 9 a, b.

Shell small, oblong subquadrate, with thick flattened edges, straight back; cardinal angles moderately sharp, anterior less sharp of the two; valves with a very small crescentiform ridge situated near the middle of the test. On the dorso-anterior portion is a very pronounced, almost straight vertical ridge. The marginal ridge, which likewise is well developed, runs parallel with the free edges, starts more or less directly below the vertical ridge, and gradually diminishes along the dorso-posterior portion. Surface finely reticulated. Small narrow pits near the middle of the ventro-anterior and posterior portions; likewise another small pit at the anterior side at the crescentiform ridge.

Length, 0.5 to 0.8 mm.; height, 0.3 to 0.45 mm.

Locality 2. Plesiotype, U. S. National Museum, No. 80568.

AMPHISSITES CISCOENSIS Harlton

Pl. 1, fig. 10

Amphissites ciscoensis Harlton, 1928, Journ. Pal., vol. 2, p. 134, pl. 21, figs. 5 a, b.

Shell small, oblong subquadrate in outline, with flattened edges; straight back; cardinal angles sharp. Valves with a prominent, large, rounded or subrounded node situated near the middle of the shell. On the dorso-anterior portion is a very pronounced, curved, stout ridge, extending into the marginal ridge and gradually diminishing along the dorso-posterior portion. Surface reticulated. Small narrow pits along the edges of the ridge; also, a very pronounced pit on the posterior side at the central node.

Length, 0.7 mm.; height, 0.4 mm.

Locality 2.

AMPHISSITES (?) TEXANUS (Harlton)

Pl. 1, fig. 11

Kirkbya texana Harlton, 1928, Journ. Pal., vol. 2, p. 136, pl. 21, figs. 6 a, b.

Amphissites allerismoides Knight, 1928, Journ. Pal., vol. 2, p. 265, pl. 32, figs. 10 a-c, pl. 34, fig. 4.

Shell small, oblate in shape; hinge line straight, cardinal angles obtuse; ends rounded, the posterior higher. A narrow unreticulated margin extends from angle to angle. Just outside the margin and separated from it by a narrow groove is a low but distinct carinate outer flange, passing from angle to angle. Within and above this is another low but distinct flange, the inner flange, which also passes from angle to angle. The two flanges are separated by rows, usually three in number, of reticulation pits. At the dorso-anterior portion of each valve is a pronounced ridge which extends almost over the entire dorsal half of the test and gradually diminishes along the dorso-posterior portion. Surface coarsely reticulate. No Kirkbyan pit or muscle spot was observed on the holotype.

Length, 0.5 to 0.82 mm.; height, 0.25 to 0.41 mm.

Locality 2. Plesiotype, U. S. National Museum, No. 80570.

AMPHISSITES (?) MENARDENSIS n. sp.

Pl. 1, fig. 12

This species has the same general characters as *A. texanus* (Harlton) and differs in the relatively larger size, more pronounced anterior node and shoulders, and furthermore in the presence of a third rudimentary innermost carina separated from the second by two rows of reticulation pits. The Kirkbyan pit or muscle spot is very distinct. Surface very distinctly reticulate.

Length, 0.72 mm.; height, 0.4 mm.

Locality 2. Holotype, U. S. National Museum, No. 80571.

AMPHISSITES (?) SIMPLICISSIMUS Knight

Pl. 1, figs. 13 a–c

Amphissites simplicissimus Knight, 1928, Journ. Pal., vol. 2, p. 266, pl. 32, figs. 11 a-d, pl. 34, fig. 6.

Carapace small, suboblong in outline. Dorsal margin straight, cardinal angles moderately angulated; ventral margin straight, but curving gradually into the well rounded ends. Dorsal view narrowly suboblong with parallel sides. Valves inequal, left valve slightly overlapping the right. The entire margins of both valves are protected by a row of small spines. No sulci, nodes or flanges are developed, except that the postero-dorsal region is very slightly wider. Surface distinctly reticulate, with spines scattered irregularly over it. A distinct Kirkbyan pit is developed near the middle of the shell.

Length, 0.65 mm.; height, 0.36 mm.

Locality 2. Plesiotypes (two beautiful specimens), U. S. National Museum, No. 80572.

The reference of these questioned forms to *Amphissites* is doubtful, and they appear to be representatives of a group different from typical *Amphissites*. However, additional new species are necessary in order to describe a new genus.

AMPHISSITES (?) HEXTENSIS n. sp.

Pl. 2, figs. 6 a–d

Carapace suboblong in shape; hinge line straight; cardinal angles angulated; outer obscurely carinated frill running with the free edges. Viewed ventrally the flange is rather wide and is not separated by reticulation pits. At the dorso-anterior is an abruptly elevated ridge extending over the entire surface of the shell and gradually thinning toward the posterior. The inflated anterior ridge usually extends above the hinge line. A central muscle spot is developed. Surface distinctly reticulate.

Average dimensions: length, 0.9 mm.; height, 0.46 mm.; thickness, 0.46 mm.

Locality 2. Cotypes, U. S. National Museum, No. 80573.

Genus KIRKBYA Jones (emend Knight)

KIRKBYA KELLETTAE n. sp.

Pl. 2, figs. 2 a–c

Carapace suboblong in outline; hinge line straight; ends squarely rounded; cardinal angles sharp; outer and inner marginal carina running from angle to angle and separated by usually five or six rows of reticulation pits. The surface exhibits a very pronounced elevated ridge rising at the dorso-anterior end and extending into the dorso-posterior portion, in which direction it becomes thinner. Just below the ridge a central Kirkbyan pit is situated. Surface distinctly reticulated.

Length, 1.66 mm.; height, 0.76 mm.; thickness, 0.80 mm.

Locality 2. Cotypes, U. S. National Museum, No. 80574.

KIRKBYA CLAROCARINATA Knight

Pl. 2, figs. 3 a, b

Kirkbya clarocarinata Knight, 1928, Journ. Pal., vol. 2, p. 258, pl. 32, fig. 2, pl. 33, fig. 2.

Carapace inflated, in side view canoe-shaped, with long straight hinge line. Ends more or less obtusely rounded; ventral margin flatly curved or straight. Edges bordered by a narrow margin; inner flange short and frilled somewhat. The area between the flanges is most steeply inclined to the plane of juncture of the valves and is some distance up on the sides, leaving the low but distinct outer flange in sight when the shell is viewed from the side. Two obscure nodes bordering the dorsal region may be observed, the anterior more pronounced. Surface finely reticulate. At the middle of the shell a distinct Kirkbyan pit is situated.

Length, 0.86 to 1.05 mm.; height, 0.43 to 0.50 mm.

Locality 2. Plesiotype, U. S. National Museum, No. 80575.

KIRKBYA KNIGHTI n. sp.

Pl. 2, figs. 4 a, b

Carapace suboblong in shape; hinge line straight; cardinal angles moderately sharp; marginal frill with radiating lines. Viewed from the ventral side the inner and outer carina are widest near the middle, where they are separated by five or more rows of reticulation pits; at the ventro-anterior and posterior portions the pattern between the carina is made up of three rows of reticulation pits, and one or two at the cardinal angles. At the dorso-anterior a pronounced elevated node is developed. There is a long, rather sharp central ridge, and just below this ridge a Kirkbyan pit is developed.

Length, 0.92 mm.; height, 0.46 mm.; thickness, 0.46 mm.

Locality 2. Holotype, U. S. National Museum, No. 80576.

KIRKBYA CANYONENSIS n. sp.

Pl. 2, figs. 5 a, b

This species has the same general characteristics as *K. knighti* and differs in the presence of the ventro-anterior node, which is not developed in *K. knighti*.

Length, 0.76 mm.; height, 0.4 mm.; thickness, 0.36 mm.

Locality 2. Holotype, U. S. National Museum, No. 80577.

Family BAIRDIIDAE Ulrich and Bassler

Genus BAIRDIA McCoy

BAIRDIA POMPILIOIDES Harlton

Pl. 2, fig. 7; Pl. 3, fig. 8

Bairdia pompilioides Harlton, 1928, Journ. Pal., vol. 2, p. 140, pl. 21, fig. 13.
Bairdia subcitriformis Knight, 1928, Journ. Pal., vol. 2, p. 322, pl. 43, figs. 5 a, b.

Shell large, elongately subdeltoid in outline, length about twice the height. Overlapping dorsal border of left valve thick, the ventral overlap moderately strong near the middle. Dorsal border elevated, straight or slightly curved near the middle; dorso-anterior slope slightly concave, dorso-posterior slope with a pronounced conspicuous curve to the sharply pointed beak. Ventral border straight or slightly incurved; anterior extremity rounded, most prominent above; posterior extremity acuminate. Valves inequal, hingement formed by the overlap of the left valve over the right.

Length, 1.4 to 1.96 mm.; height, 0.7 to 1.0 mm.

Locality 2. Plesiotype, U. S. National Museum, No. 80578.

BAIRDIA HOXBARENSIS Harlton

Pl. 3, figs. 1 a–d

Bairdia hoxbarensis Harlton, 1927, Journ. Pal., vol. 1, p. 211, pl. 33, fig. 12.
B. altifrons Knight, 1928, Journ. Pal., vol. 2, p. 324, pl. 43, figs. 6 a, b.

Shell elongate, length about two and one-half times the height; dorsal border straight or very slightly curved; dorso-posterior angle rather sharp with straight slope, posterior beak moderately pointed. The ventral border is straight or gently curved near the middle; antero-ventral extremity well rounded. Dorsal overlap slight; ventral overlap confined near the medial area. Inflation of shell very pronounced throughout. Surface smooth, evenly convex.

Length, 1.2 mm.; height, 0.6 mm.

Locality 1. Plesiotype, U. S. National Museum, No. 80579.

BAIRDIA HISPIDA Harlton

Pl. 3, figs. 2 a, b

Bairdia hispida Harlton, 1928, Journ. Pal., vol. 2, p. 140, pl. 21, fig. 14.

Shell thick, subrhomboidal in outline, the point of greatest thickness near the middle; length about one and one-half times the height. Overlapping dorsal and ventral borders of left valve thick. Dorsal border arched, dorso-anterior gradually curving into a straight slope, dorso-posterior rather abruptly bent into a straight slope to the extremity. Postérior extremity acuminate, arching broadly into the ventral margin; anterior extremity less acuminate than the posterior. Greatest convexity near middle of shell. Valves inequal, hingement formed by the overlap of the left valve over the right. Surface evenly convex, smooth.

Length, 1.26 mm.; height, 0.77 mm.

Locality 1. Plesiotype, U. S. National Museum, No. 80580.

BAIRDIA NITIDA Harlton

Pl. 3, figs. 3 a, b

Bairdia nitida Harlton, 1928, Journ. Pal., vol. 2, p. 39, pl. 21, fig. 12.

Test small, strongly inflated, subrhomboidal in outline, the greatest thickness being near the middle; overlapping dorsal and ventral edges of left valve thick. Dorsal border elevated and straight or very slightly curved near the middle; dorso-anterior and posterior slopes more or less straight; posterior extremity bluntly acuminate. Ventral border curved to the anterior extremity. Valves inequal, hingement formed by the overlap of the left valve over the right. Surface evenly convex, smooth.

Length, 1.2 mm.; height, 0.8 mm.

Locality 2. Plesiotype, U. S. National Museum, No. 80581.

BAIRDIA GRAHAMENSIS Harlton

Pl. 3, fig. 4

Bairdia grahamensis Harlton, 1928, Journ. Pal., vol. 2, p. 139, pl. 21, fig. 11.

Shell small, subdeltoid in outline, length usually a little less than twice the height. Overlapping dorsal border of left valve thick, ventral overlap moderately thick near the center. Dorsal border arched, dorso-anterior slope straight, dorso-posterior slope slightly concave, with an inconspicuous curve at the extremity; ventral border straight or very slightly curved. Anterior and posterior extremities acuminate. Valves inequal, hingement formed by overlap of the left valve over the right. Surface evenly convex, smooth.

Length, 0.8 mm.; height, 0.5 mm.

BAIRDIA OKLAHOMAENSIS Harlton

Pl. 3, figs. 5 a, b

Bairdia oklahomaensis Harlton, 1927, Journ. Pal., vol. 1, p. 209, pl. 33, fig. 7.

B. auricula Knight, 1928, Journ. Pal., vol. 2, p. 319, pl. 43, figs. 3 a, b.

Shell large and thick, subrhomboidal in outline, the point of greatest thickness being at the posterior upper half, near the middle of the shell; overlapping dorso-anterior edge of left valve moderately thick, the ventral overlap strongest near the middle. Dorsal border arched, with the dorso-anterior slope more or less straight, dorso-posterior slope with small conspicuous curve near the middle. Ventral border straight or slightly curved near the middle; anterior extremity rounded, most prominent above; posterior extremity acuminate. Valves inequal, hingement formed by overlap of the left valve over the right. Surface evenly convex, smooth.

Length, 1.2 mm.; height, 0.7 mm.

Locality 2. Plesiotype, U. S. National Museum, No. 80583.

BAIRDIA SUBELONGATA Jones and Kirkby

Pl. 3, figs. 6 a–d

Bairdia subelongata Jones and Kirkby, 1879, Jour. Geol. Soc. London, pp. 573–74, pl. 30, figs. 1–11, 16.

B. subelongata Harlton, 1927, Journ. Pal., vol. 1, pp. 210–11, pl. 33, fig. 11.

B. subelongata Knight, 1928, Journ. Pal., vol. 2, p. 326, pl. 43, fig. 9.

Length, 0.7 to 1.4 mm.; height, 0.4 to 0.6 mm.

Locality 2. Plesiotype, U. S. National Museum, No. 80584.

BAIRDIA MACDONELLI n. sp.

Pl. 3, figs. 7 a, b

Shell elongately subdeltoid in outline, length about twice the height. Overlapping dorsal edge moderate; ventral overlap confined only near medial area. Dorsal border moderately elevated, straight or somewhat curved near the middle; dorso-anterior slope straight, posterior slope with a pronounced curve to the sharply pointed beak. Ventral border straight, extremities rounded. A very conspicuous short beak is developed at the antero-dorsal angle. Valves inequal, hingement formed by the overlap of the left valve over the right.

Length, 1.5 mm.; height, 0.66 mm.

Locality 2. Cotypes, U. S. National Museum, No. 80585.

BAIRDIA HEXTENSIS n. sp.

Pl. 3, fig. 9

Shell elongate, length about two and one-half times the height. Dorsal overlap moderate, thin ventral overlap only near the middle of the shell. Dorsal border elevated, straight near the middle; dorsal anterior and posterior slopes straight. Ventral border straight, with well rounded ends; extremities acuminate. Surface evenly convex, smooth.

Length, 1.6 mm.; height, 0.66 mm.

Locality 2. Holotype, U. S. National Museum, No. 80586.

The upward pointing acuminate anterior and posterior beaks characterize this species.

BAIRDIA MENARDENSIS n. sp.

Pl. 4, figs. 1 a–d

Carapace strongly inflated, subrhomboidal in outline, with very pronounced convexity near middle. Overlapping dorsal and ventral edges of left valve distinct. Dorsal border a broadly rounded arch, with the dorso-posterior slope straight to the distinctly angulated, bluntly acuminate beak, the dorso-anterior slope concave. Ventral border more or less straight near the middle, curving gently toward the extremities. Surface evenly convex, smooth.

Average dimensions: length, 1.3 mm.; height, 0.8 mm.

Locality 2. Cotypes, U. S. National Museum, No. 80587.

BAIRDIA MARGINATA n. sp.

Pl. 4, fig. 2

This species has the same general characteristics as *B. menardensis* and differs in the broadly elevated, angulated dorsal border, which is more or less straight near the middle. The pronounced convexity is more posterior and its rapid thinning toward the anterior portion is conspicuous.

Length, 1.26 mm.; height, 0.7 mm.

Locality 2. Holotype, U. S. National Museum, No. 80588.

BAIRDIA CRASSA n. sp.

Pl. 4, figs. 3 a–c

Carapace small, inflated, subrhomboidal in outline. Greatest convexity near dorso-posterior third. Overlapping dorsal and ventral edges of left valve distinct. Dorsal border arched, more or less rounded. Dorso-posterior slope straight to the sharply backward pointing, acuminate beak. Ventral border straight near the middle, curving gently toward the extremities. Surface smooth, evenly convex.

Average dimensions: length, 1.08 mm.; height, 0.64 mm.

Locality 2. Cotypes, U. S. National Museum, No. 80589.

This species differs from *B. menardensis* in the pronounced inflation at the dorso-posterior third, which in most cases extends above the hinge line, also in the rather sharply pointed posterior beak and in the smaller size of the shell.

BAIRDIA RECTA n. sp.

Pl. 4, figs. 4 a–e

Carapace small, elongate, overlapping dorsal and ventral edges of left valve thick. Greatest convexity near middle of shell. Dorsal border roundly curved; posterior beak bluntly pointed. Ventral border more or less straight, curving gently toward the extremities. Surface evenly convex and ornamented with irregular scattered reticulation pits.

Average dimensions: length, 1 mm.; height, 0.5 mm.

Locality 3. Cotypes, U. S. National Museum, No. 80590.

This species shows many variations, especially along the dorsal border, and the author considers it superfluous to describe these inconsistencies (see illustrations). Photographs of this species all showed different variations. These variations must have taken place shortly after the death of the organism, and the position in which the animal was laid down undoubtedly played an important part. The reticulation pits are very peculiar indeed, and there is some doubt in the author's mind whether they existed at all before the animal's death. All the variations are found at the same horizon, have the same stratigraphic range, and furthermore are found in the same localities, showing that the organisms occupied the same habitat.

Genus BAIRDIANELLA n. gen.

Genotype: Bairdianella elegans n. sp.

This genus has the same general characteristics as *Bairdia* but has no dorsal overlap and a thin, somewhat indistinct ventral overlap, usually only near the middle of the shell.

BAIRDIANELLA ELEGANS n. sp.

Pl. 4, fig. 5

Carapace small, suboval in shape, greatest convexity near the middle. Dorsal border uniformly curved; ventral border straight and extending more or less towards the conspicuous, sharply pointed posterior beak, which is most prominent above; anterior ventral portion gradually curved. The left valve overlaps the right very slightly near the middle of the ventral border; no dorsal overlap. At the dorsal border the edge of the right valve is very indistinctly elevated. Surface evenly convex, smooth.

Length, 0.76 mm.; height, 0.34 mm.

Locality 2. Holotype, U. S. National Museum, No. 80591.

BAIRDIANELLA OBLONGATA n. sp.

Pl. 4, fig. 6

Carapace elongate in shape, length a little over twice the height. Dorsal border gently curved, posterior beak bluntly rounded; ventral border straight, curving gradually at the extremities. The left valve overlaps the right slightly near the middle of the ventral border; no dorsal overlap was observed. Near the middle of the dorsal border the edge of the right valve has the appearance of being somewhat elevated.

Length, 1.24 mm.; height, 0.5 mm.

Locality 2. Holotype, U. S. National Museum, No. 80592.

Genus BYTHOCYPRIS Brady

BYTHOCYPRIS (?) TEXANA n. sp.

Pl. 1, fig. 1

Carapace subtriangular to subrounded in shape; ventral margin short and nearly straight. Greatest convexity near dorsum; greatest height near the middle of shell. Anterior and posterior ends equally rounded and rounding sharply but smoothly into the venter. Surface smooth, evenly convex. Right valve slightly larger, giving the appearance of overlapping the left on all sides.

Length, 1 mm.; height, 0.8 mm.

Locality 2. Holotype, U. S. National Museum, No. 80593.

No evidence of a subcentral pit has been observed in this species. The reference of this form to *Bythocypris* is doubtful, as its outline and other characteristics are different from typical *Bythocypris*. Additional new species may perhaps assign this form to a new genus.

Genus MACROCYPRIS Brady

MACROCYPRIS MENARDENSIS n. sp.

Pl. 4, figs. 7 a, b

Carapace elongate, length nearly three times the height. Dorsal border elevated and curved toward the extremities; ventral border more or less straight. Posterior extremity sharply pointed. Right valve larger, overlapping the left slightly on all sides.

Length, 1.14 mm.; height, 0.4 mm.

Locality 2. Holotype, U. S. National Museum, No. 80594.

Genus CYTHERELLA

CYTHERELLA OVOIDIFORMIS Harlton

Pl. 4, figs. 8 a–c

Cytherella ovoidiformis Harlton, 1927, Journ. Pal., vol. 1, p. 141, pl. 21, figs. 15 a, b.

Locality 2. Plesiotype, U. S. National Museum, No. 80569.

CYTHERELLA CALCAR Harlton

Pl. 4, fig. 9

Cytherella calcar Harlton, 1927, Journ. Pal., vol. 1, p. 141, pl. 21, figs. 16 a, b.

Locality 2. Plesiotype, U. S. National Museum, No. 80582.

A YEGUA-EOCENE DELTA IN BRAZOS COUNTY, TEXAS

BY

LYMAN C. REED AND OSCAR M. LONGNECKER, JR.[1]

INTRODUCTION

During the summer of 1927 the writers had the opportunity to study in detail a portion of Brazos County. First the surface geology was worked out and then the area was core drilled. The surface work brought out evidence of a deltaic condition within the Yegua formation which will be described in detail, and coring suggested that the greater part of the Yegua may be of deltaic origin. Further, a sharp lithologic break is indicated between the Yegua and beds which are possibly transitional from the Cook Mountain.

The area discussed in this paper lies in the central western portion of Brazos County, which is in the east-central part of the State of Texas. Geologically the county is in the Tertiary formations of the Coastal Plain. The area extends from the town of Bryan in a southwestward direction for about five miles and in a northwest-southeast direction for about three miles. The northern part of the county is occupied by the Cook Mountain formation which on the southeast is overlain by the Yegua formation. The area described is within the boundaries of the Yegua outcrop.

The Yegua formation is made up of unconsolidated beds of carbonaceous clays, gypseous clays, sands, and poor grade lignites, all of which are irregularly bedded. Occasionally there is a brackish water or marine fauna. The environments favorable for such deposits are shallow waters such as lakes, swamps, lagoons, coastal bays, stream valleys, and deltas where a relatively abundant and rapid supply of material is received. There is little or no regularity in the deposition of any of the materials composing the formation.

[1]The opportunity of working out the geology of this area and offering the results for publication has been afforded the authors by the Rio Bravo Oil Company.

The basal Yegua in some localities appears to be transitional from the underlying Cook Mountain (Claiborne), as maintained by Dumble[2] and corroborated by a recent investigation[3] at the type locality on Yegua and Elm Creeks, Lee County, Texas. At the latter locality there is a sparse fauna identical with that of the Cook Mountain and presumably preserved in bays and estuaries. In Brazos County, which is some thirty miles northeast of the type locality, the surface beds of the Cook Mountain and the Yegua are also suggestive of a gradual transition from marine to fresh water deposits. In the area which will presently be discussed drill cores show that from the typical Cook Mountain upward there are from fifty to one hundred feet of beds comparable to the Elm Creek section of Dr. Gardner[3]. Above this is a sharp lithologic break into the typical Yegua beds of carbonaceous clayey sand interbedded with sand, clay, lignite, and a little volcanic ash.

SURFACE GEOLOGY

Following a detailed description of an unusual deltaic condition of the surface beds of the Yegua formation a discussion of the underlying material down to the Cook Mountain will be taken up.

Within the outcrop of the Yegua in Brazos County there is a belt about two miles wide which is of unmistakable delta origin. A great deal regarding this deltaic condition is not known, but the investigation revealed some interesting features. Steeply inclined beds, conglomerates, homogeneous sandy clays, and sharp contacts are typical of this belt. The accompanying map and cross-sections are taken from original detailed work and depict the features discussed in this paper.

As may be seen from the map the area has a peculiar arrangement of inclined beds. In the central portion the beds are relatively flat, thinly bedded, and on the whole composed of material different from the adjoining beds.

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[2]Dumble, E. T., *Geology of East Texas*, Univ. Texas Bull. 1869, 1919, p. 81.
[3]Gardner, Julia, *Journal of Paleontology*, Vol. 1, 1927, p. 245.

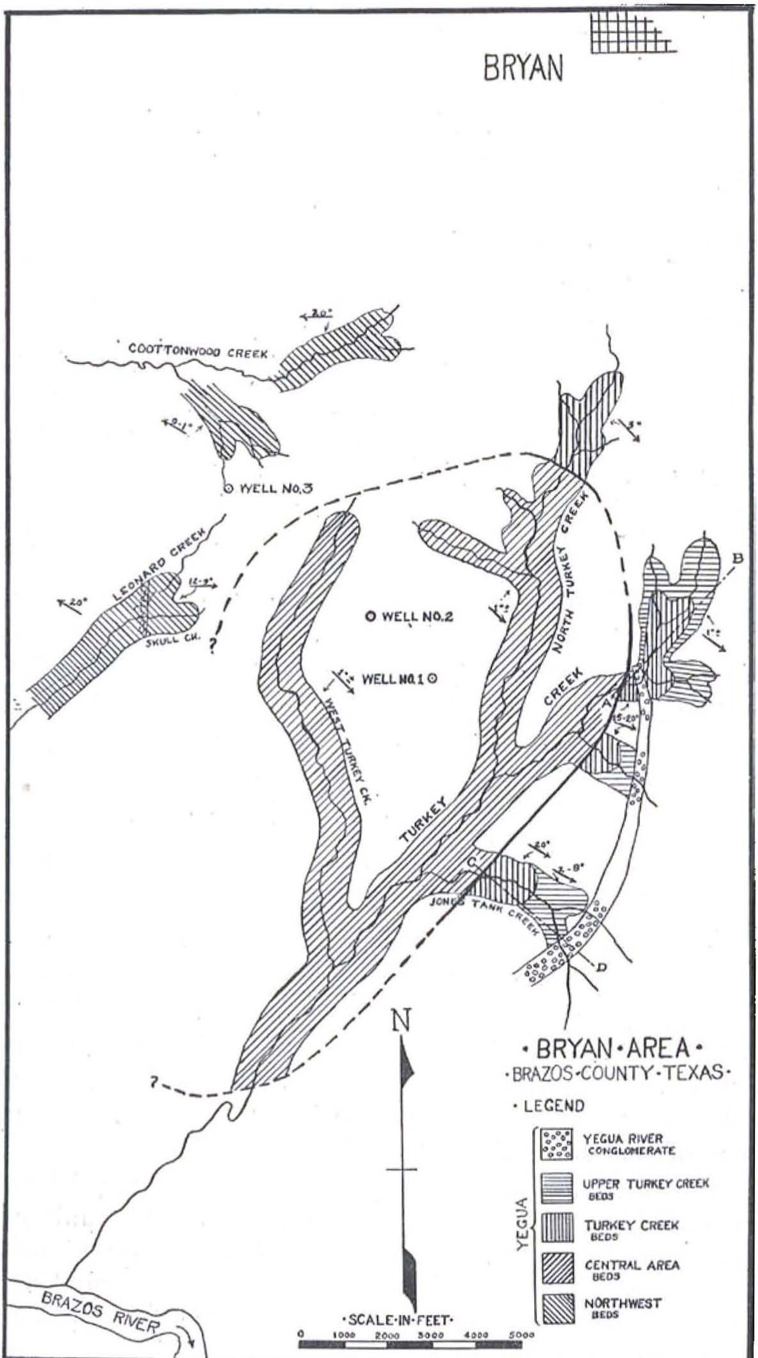

Fig. 9. Sketch map of Bryan area.

Bordering the relatively flat-lying beds in a circular fashion are beds that slope away at high angles as would be the case on the flanks of a salt dome. Where the steeply inclined beds come against the flat beds there is a contact which may easily be mistaken for a peripheral fault. The inclined beds are more or less homogeneous in texture. The following is a description of the area as divided into the several mappable divisions. The Central Area beds, Northwest beds, Turkey Creek beds, and Upper Turkey Creek beds are lithologic divisions which represent exposures in the various portions of the area. These terms are used as a convenience in describing the deposits, and not as formation or member names.

Central Area Beds.—This unit is believed to represent top set beds, the general inclination of which is to the southeast at an angle of about 1 degree (fig. 9). Unlike those to be described under the other divisions, the topset beds are made up of definite, well stratified materials. The following is a section made from surface exposures:

		Feet
1.	Light gray massive sand	5.0
2.	Gray sandy clay, poorly stratified	4.0
3.	Unstratified gray sand	3.5
4.	Similar to above	12.5
5.	Carbonaceous clay to lignite	1.0
6.	Carbonaceous clay	2.5
7.	Gray cross-bedded sand with fucoidal markings	2.5
8.	Same as above but not cross-bedded	3.5
9.	Alum-bearing, brown clay and yellow sand	About 20.0

The next in series may really belong stratigraphically below the Central Area beds, and there is evidence both for and against this interpretation; however, for the purpose of this paper they are better placed above.

Northwest Beds—Leonard Creek.—The material on Leonard Creek is foreset toward the northwest at a uniform rate of 20 degrees. For a considerable distance the material is the same, comprising interbedded white sand and light gray bentonitic clay, as well as volcanic ash. Opalized plant remains are present. The sand lenses in the upper part have in places been indurated to quartzite. As the cross-section shows (fig. 10) there is a change in lithology down the creek to younger beds of interlaminated white sand and chocolate-colored clay with an inclination of only about 5 degrees. Near the head of Leonard Creek, and also in Skull Creek at the place marked "contact," and extending up the creeks for a short distance is homogeneous dark gray clay mottled with white sand containing carbonaceous particles throughout. In lithology this is somewhat similar to the Turkey Creek beds (fig. 10).

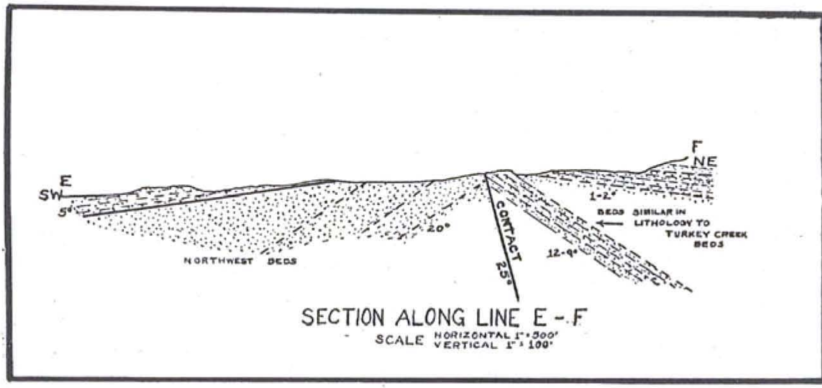

Fig. 10. Section on Leonard and Skull Creeks drawn to scale. Note change in lithology down the creek and similarity to the Turkey Creek beds on the northeast side of the contact line.

Cottonwood Creek.—In the upper part of Cottonwood Creek there is exposed a mass of clay conglomerate and material foreset 20 degrees toward the west which, with the exception of the conglomerates, resembles the Leonard Creek beds downstream from the "contact."

In the branch which enters Cottonwood Creek from the southeast the northwest inclination of the beds decreases from 9 degrees to 1 degree near the confluence with the main creek. The total exposure is virtually the same sand interbedded with carbonaceous clay and mottled with sand and clay. This is foreset upon a thin horizontal lignite bed.

It is nearly impossible to correlate the various exposures on the northwest side and for the present purposes it does not matter. The main point is that they are cross-bedded, channeled, and lensed beyond comparison. The futility of attempting a correlation may be realized when it is said that there was great difficulty in correlating even continuous cores less than two thousand feet apart in this deltaic complex.

In the upper part of Turkey Creek and in Jones' Tank Creek there are several lithologic units that will be taken up separately and in their proper stratigraphic sequence. On this side of the map the various beds may be stratigraphically correlated and they even preserve their characteristics from one locality to another.

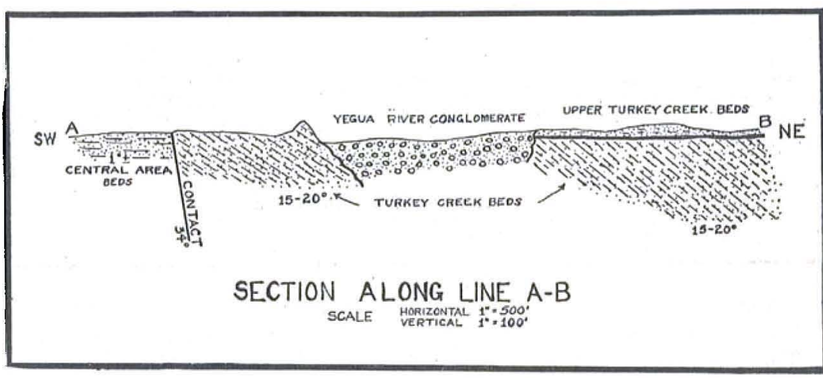

Fig. 11. Section on Turkey Creek drawn to scale to show fore-set Central Area Beds. Note the uniform dip and lithology of Turkey Creek beds; the River Channel, and the lignite at base of North Turkey Creek Beds.

Turkey Creek Beds. (See figures 10 and 11.) Both the 15–20 degree southeast persistent inclination and the homogeneous lithology of this bed are surprising. Wherever seen it is of precisely the same character, composed of gritty clay mottled and lensed with sand which gives it the appearance of having been deposited too quickly for sorting. Volcanic ash also makes up part of the constituents. When moist this bed is dark gray, but is nearly white when dry.

Many jet black leaves entirely preserved without having their tissues replaced are found in the bed. The total thickness cannot be measured accurately, but some bluffs show it to be at least 25 feet.

A characteristic feature of the foreset beds in this area, especially in the Turkey Creek beds, is the development of fairly definite bedding planes giving the aspect of true dip at intervals of about four feet. Between these inclined planes, particularly if at a steep angle, the sediments tend to be horizontal, with the resultant appearance of shearing. Why the above mentioned interval should occur at all in beds of this character may have its explanation in seasonal or periodically burdened rivers; at any rate, the deposition was rapid.

Upper Turkey Creek Beds.—Immediately above the bevelling off the Turkey Creek bed are the Upper Turkey Creek beds which lie in a horizontal position. At the very base is a thin poor grade lignite containing an abundance of fossilized nuts, opalized plant remains, and silicified tree trunks with their roots extending into the underlying bed. Above the lignite are beds which vary from a slightly carbonaceous laminated light gray ashy clay to a finely laminated volcanic ash partially decomposed to bentonite and containing specks of carbonaceous matter. About ten feet above the base is another thin lignite bed. The material overlying the second lignite is somewhat similar to the lower part of the member. Silicified wood is common. The thickness of this bed is at least 20 feet.

This bed does not appear to have been of deltaic origin (i. e., includes no highly foreset beds) and it may be that the latter condition terminated with the Turkey Creek beds.

Yegua River Conglomerate. (See figures 10 and 11.)—As may be seen from the map and sections this conglomerate has the shape and trend of a river channel. It gouges both the Turkey and Upper Turkey Creek beds, and its contact with the former is quite clear at one outcrop. The bed is composed of clay balls, some angular, up to a foot or so in diameter which have been derived from material similar to that in the Turkey Creek bed. Considerable sand, both in lenses and as massive beds, is present with the conglomerate. No flint pebbles or petrified wood fragments were observed. As may be noted on the cross-sections, this conglomerate appears to be of considerable thickness, for it was found nearby 40 feet above its position in the main creek. In the upper part of Jones' Tank Creek, the last of the exposures, a few feet of stratified sandy clays intergrade with the conglomerate, but they may be merely another lens within the conglomerate. The extent of the river channel, beyond what is shown on the map, cannot be determined, and its relation to its surroundings is not clear. It may be of a much later age than the adjacent beds and represent a lagoonal invasion during an overlap of another formation.

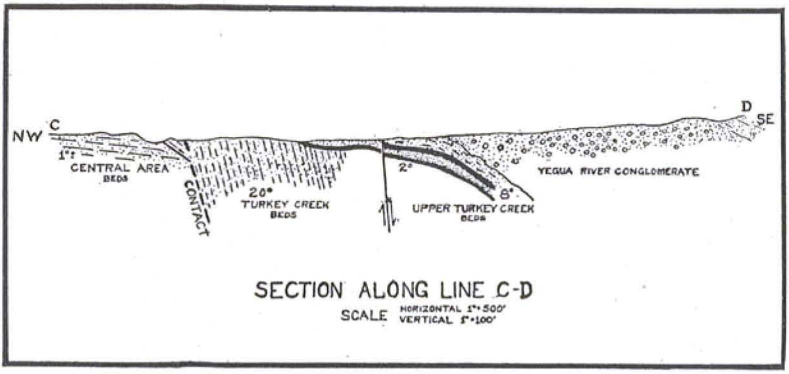

Fig. 12. Section on Jones' Tank Creek drawn to scale. Note how beds lay on 5° contact but soon steepen to 20°. At this locality, the Yegua River Conglomerate contains considerable sand.

No beds stratigraphically higher than these are exposed in the immediate area, but it is known that the Yegua formation has an areal extent of at least five miles farther to the southeast.

Angular Contacts.—There are several well defined contacts associated with the highly foreset beds which indicate, at least, their relative sequence of deposition. The first is on Leonard and Skull Creeks in the west part of the area mapped. It has a north 20 degrees west strike and a dip of 25 degrees toward the northeast (see fig. 10). From this point the beds on the west side are inclined at an angle of 20 degrees away from the contact and those on the east come in on top and are therefore younger. They dip in an easterly direction at an angle of about 15 degrees.

On the east side of the area a contact is seen at three different localities which join to form a boundary for the relatively horizontal beds of the Central Area. In the upper part of the main Turkey Creek bed the first contact (see cross-sections) has a strike of north 20 degrees east and a dip of about 35 degrees toward the east. The Turkey Creek foreset beds come in over the flat lying ones with a dip approaching that of the contact. The contact is slickensided, which is attributed to subsequent differential settling and not to faulting.

The second contact is in a tributary a short distance southwest of this. In all relations it is of the same nature except that the foreset beds are lying untidily upon the contact.

The last contact has changed in strike to north 30 degrees east and the dip of the plane is only 5 degrees. The foreset beds appear on the plane at this angle but steepen to their usual inclination of 20 degree within a few feet. Quite a distance farther to the southwest this same contact is inferred by the presence of the conglomerate and by the proximity of the Central Area beds to one another.

A great deal of time was spent studying the beds described in the preceding paragraphs and the only explanation that the writers have to offer for the origin of their mode of deposition is by deltaic agency. The details of such a delta would be difficult of explanation, but in a broad sense it occupied about three or four miles in width, judging from the erratic dips. A study of the cross-sections attached to this paper will add considerably to an understanding of these beds. A valuable criterion for the determination of foreset beds was found to be horizontally-bedded lignite truncated by steeply inclined beds. All of the materials which compose the beds in the area were deposited in shallow waters and the depositing stream carried a great quantity of sediments. Lignites and topset beds were deposited in portions of the area while the land was undergoing a gentle subsidence and through changes in the course of the depositing stream rather than by oscillation.

Despite the realization of the origin of the steeply inclined beds, three core tests were put down to correlatable horizons within the Cook Mountain in order to be sure that the presence of the virtually horizontal beds surrounded by foreset material with a definite contact did not have some reflected structural significance. These cores show the subsurface portion of the Yegua, the possible transitional beds, and the upper portion of the Cook Mountain.

SUBSURFACE GEOLOGY

The positions of the three core tests of the Rio Bravo Oil Company are shown on the map (fig. 9). Number 1 is Mary Lanza No. 2; Number 2 is Mary Lanza No. 1; and Number 3 is Bankers and Mortgage No. 1. These wells were all drilled to the Cook Mountain for correlative purposes and there found satisfactory markers (fig. 13). The material in the Yegua formation was found to be somewhat similar in wells numbers 1 and 2, while that in well number 3 was different beyond correlation. The section in wells numbers 1 and 2 may be summarized as follows:

Depth in feet	
25–60	Bentonite, sand, and clay.
60–61	Lignite.
61–105	Unstratified gray sandy clay.
105–160	Sand series. Medium grained sand bearing water.
160–170	Two thin beds of lignite separated by sandy clay.
170–260	Gray clays and sands, partially stratified.
260–385	Thick sand series. Medium grained sand. Bears water. This rests directly upon the clays of the Cook Mountain, although in well number 2 there was a thin lignite bed at the base of the thick sand series.

In well number 3 (4,730 feet northwest of well number 2) the material, although of the same general character, cannot be correlated with that of the other wells. In well number 3 there are more lignites, more clays, and the thick sand series is absent. Even in the 1850 feet between wells numbers 1 and 2 there is a noticeable change in lithology. For instance, both of the thick water sands, which in well number 1 are nearly a pure sand, become laminated with both clay and carbonaceous matter in well number 2. The clay and sand interval just above the first water sand increases from 25 in well number 1 to 45 feet in well number 2. Likewise, the clay and sand interval between the two water sands increases from 65 to 100 feet in thickness.

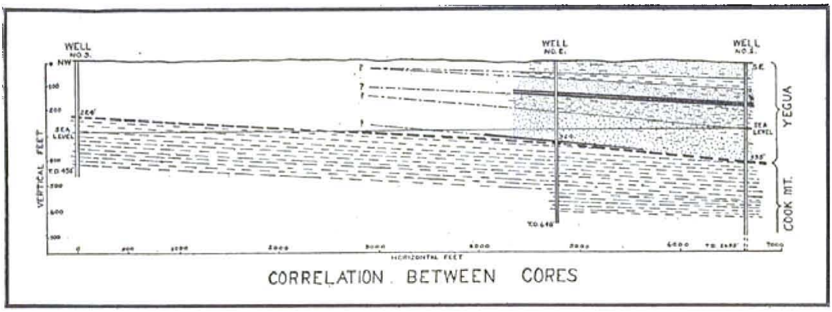

Fig. 13. Between Wells 2 and 3, Cook Mt.—Yegua Contact is uniform, but in Well No. 1, 40 feet has been eroded away. In all cases, there is a sudden break between non-marine and marine sediments. The Yegua dips at a steeper angle than the Cook Mt., and the former thickens to the southeast with a change in lithology.

As may be seen from the correlation chart (fig. 13), the dip of the Yegua is nearly twice as great as that of the Cook Mountain, giving the appearance of a succession of wedges thickening down the dip. If these were extended on the chart, some would disappear before even reaching well number 3. Judging from the character of these beds it appears that they are in part of deltaic origin just as are the surface beds.

At the base of this non-marine Yegua series there is a sharp lithologic change into marine beds. In wells number 1 and 2 this marine bed is 90 feet thick, and in well number 3 it is fifty feet thick. Although the bed is not distinctly like the true Cook Mountain in that it lacks glauconite and abundant fossils, it is wholly different from the overlying non-marine Yegua. It has been thought that this bed may be comparable to the Elm Creek type section as recently described by Julia Gardner. Even if this is true there is an unconformity accompanied by change in lithology from marine to fresh water deposits and also accompanied by an increase in dip. It is therefore apparent that the information which the core tests yielded does not in this place agree with the generally accepted idea that there is a gradual lithologic and faunal transition from the marine Cook Mountain to the non-marine Yegua.

SUMMARY

This paper deals with a small area just southwest of Bryan, Brazos County, Texas, that was studied in detail and subsequently core drilled. The surface formation is Yegua in age, composed of foreset and topset deltaic beds with numerous irregular contacts. The cores show the Yegua to be composed of nearly four hundred feet of non-marine beds separated from the Cook Mountain (Claiborne) by an abrupt lithologic break. The upper fifty to ninety feet of the Cook Mountain may be compared to the type locality of the Yegua on Elm Creek, Lee County, where the beds are thought to be transitional from the Cook Mountain to the Yegua.

THE UNIVERSITY DEEP WELL IN REAGAN COUNTY, TEXAS

BY

E. H. SELLARDS AND WALDO WILLIAMS

INTRODUCTION

The well, record of which is here given, is located on land of the University of Texas in the southwestern part of Reagan County. It was drilled by the Group No. 1 Oil Corporation, a subsidiary of the Texon Oil and Land Company and is known as 1–B.[1] The well is remarkable in several respects. At the present time it is by several hundred feet the world's deepest well;* being a producer it is the deepest oil producing well; temperature measurements having been made to a depth of 8,300 feet, this well affords the deepest recorded earth temperature. Initial production in the well was small but has increased and the subsequent history has been unusual in that although the well is now in its sixth month since initial production the quantity production is still increasing. The gravity record has likewise shown a gradual increase. The curve of production and the probable causes of increase in gravity are subsequently discussed. The well produced oil from four horizons as follows: 2460; 3022; 6277; and 8523 feet. It produced gas from three horizons as follows: 2461; 2900; and 8482 feet. The oil from the well is now gravity 59.5 B and is approximately 70 per cent gasoline, and can in fact be used in cars

[1]The original holding company was the Texon Oil and Land Company of Delaware under which as subsidiaries were organized Group No. 1 Oil Corporation, Group No. 2 Oil Corporation, and Texon Oil and Land Company of Texas. Fifty per cent or more of the stock of each of these companies is held by the Texon Oil and Land Company of Delaware. Group No. 1 Oil Corporation held the producing lease in Reagan County. Its wells were designated as follows: To the 2,400 foot pay, 1–A, 2–A, 3–A, etc.; to the 3,000 foot pay, 1, 2, 3, etc.; and one deep well, the one here described, numbered 1–B. A controlling interest in these companies has recently been acquired by the Marland Production Company which has now merged with the Continental Oil Company and taken the latter name.

*The Shell Oil Company No. 11 Nesa Well which is now being drilled at Long Beach, California, is reported to have reached a depth of 9280 feet and hence exceeds the University well in depth.

unrefined. The gas, on the other hand, is relatively lean yielding but about .65 of a gallon of gasoline per 1,000 cubic feet of gas, although a recent charcoal test shows a possible recovery of 1.17 gallons per 1,000 cubic feet.

The well was begun on February 8, 1926, and on the following April 18 was completed as an oil and gas producer at depth 2,469 feet. The initial daily production at this depth was 370 barrels of oil, gravity 38 B, and 100,000 cubic feet of gas. At 2461 feet the well made a show of oil and produced 400,000 cubic feet of gas per day. The well was allowed to produce from 2469 feet from April 18 to August 15, 1926, the total production being 32,152 barrels of oil. The amount of gas produced at this depth was not separately recorded.

In August, 1926, work on the well was begun preparatory to deepening and on September 27 underreaming was begun by which to enlarge the hole and lower the 10-inch casing. At 2900 feet gas was obtained, and at 2910 an oil show, and on November 23 at 3010 feet the oil producing horizon, the Texon pay, of the Big Lake oil field was reached. Production at this horizon which began on January 5, 1927, was small and on February 8, 1927, notice was given of intention to deepen beyond the Texon pay, the well having produced from the Texon pay in 34 days only 1,065 barrels of oil, gravity 38 B.

On July 11, 1927 after passing several oil shows in dark shale the well discovered the third oil producing horizon at 6277 feet. Drilling was continued and the well produced by occasional heads from this horizon, the total production being 1235 barrels of oil, gravity 41 B.

Drilling difficulties increase as a rule with depth. The well was drilled with cable tools, and in the lower drilling the 10,000 foot wire line cable had to be replaced at two month intervals. This well was twice burned while drilling, first on May 26, 1927 at depth 5315 feet; and again on April 29, 1928 at depth 8230 feet. In each case the fire was caused by sparks from the brake band of sand reel igniting gas. The derrick in use is a tubular steel derrick and in each case the damage caused by the fire required

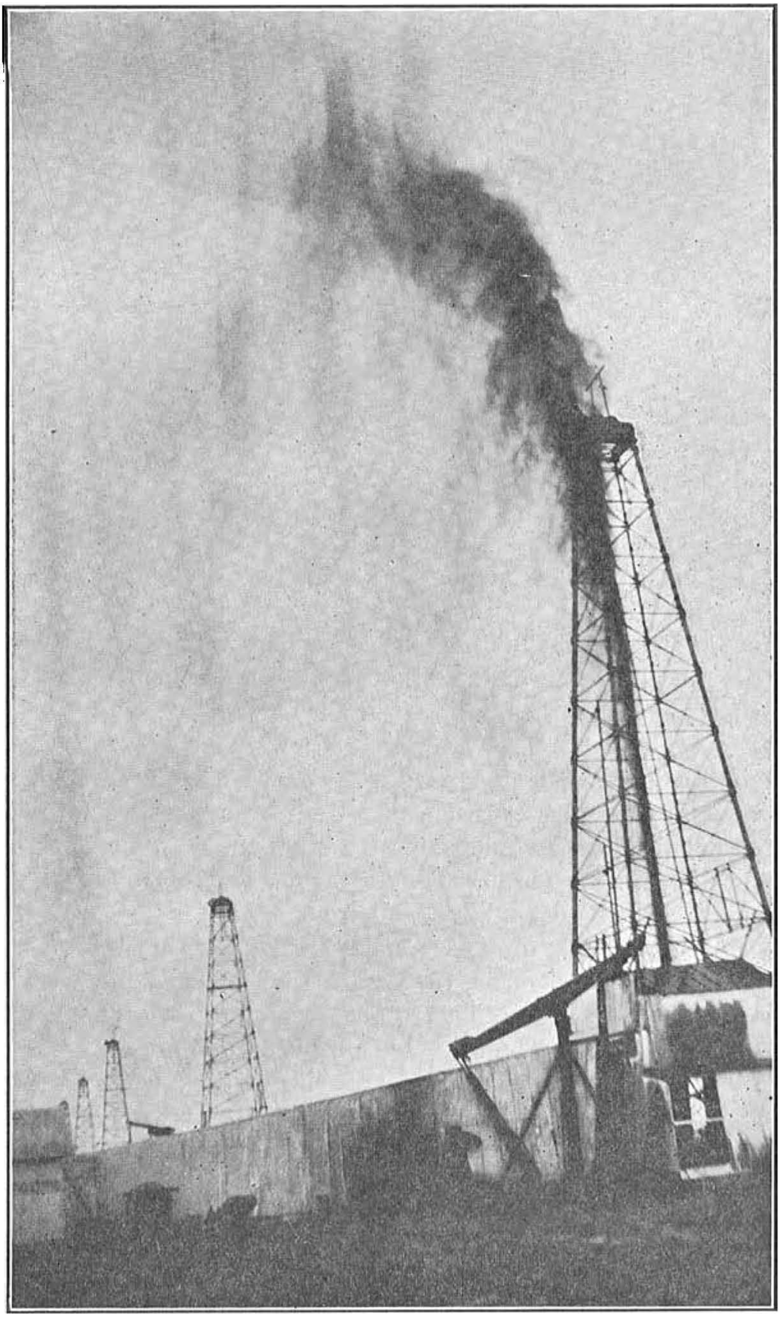

Fig. 14. View of University Deep Well, Reagan County, Texas. Oil production from depth 8525.

only the replacing of certain of the members nearest the fire.

Steam power was used in drilling to a depth of 2469 feet. From 2469 to 2570 power was obtained by the use of a gas engine. In deepening the well from 2570 to 2855 feet steam power was used, then gas from 2855 to 3020 feet, then steam from 3020 to 4740, then Clark gas engine from 4740 to 5345 feet, then steam to 6555 feet. At 6555 feet electric motors were installed and the drilling was by electric power from 6555 feet to the bottom of the well.

The oil producing horizon reached at 6277 feet consisted of three feet of oil sand which flowed by heads during a shut-down period of one month following its discovery making a total of 250 barrels oil of 41 gravity. Five and three-sixteenths inch casing was set at 6176 feet. This horizon continued producing oil as the well was being deepened and the oil swabbed at four or five day intervals amounted to about 15 barrels for each swabbing. If the well was allowed to stand for as long as a month it would make one or two heads of 40 or 50 barrels when opened. By December 1, 1928 total production from this horizon amounted to 1235 barrels, gravity 41.7.[2] At 8482 feet a gas producing horizon was reached. There was no oil with this gas except that which accumulated from the 6277-foot horizon which was brought out by the gas. At 8523 feet the well reached the deep oil pay horizon.

On the morning of December 1, 1928, at the depth of 8523 feet the drill broke through a shell of hard limerock. The gage on that day indicated 500,000 cubic feet of gas and 40 barrels of oil. The oil being produced at that time was gravity 44.7. Obviously, however, this oil was appreciably affected by oil from the 6277 foot horizon. Owing to the gas pressure it was not possible to lower the tools to the

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[2]This production was probably not all from 6277 feet but probably came in part from 6830 feet. In Big Lake Oil Company well No. 131, located 2240 feet from the south and 920 feet from the east corner of Section 1, Block 2, a five foot sand with show of oil and gas was recognized at 6,830 feet. On drilling deeper, oil stood in the hole 700 feet.

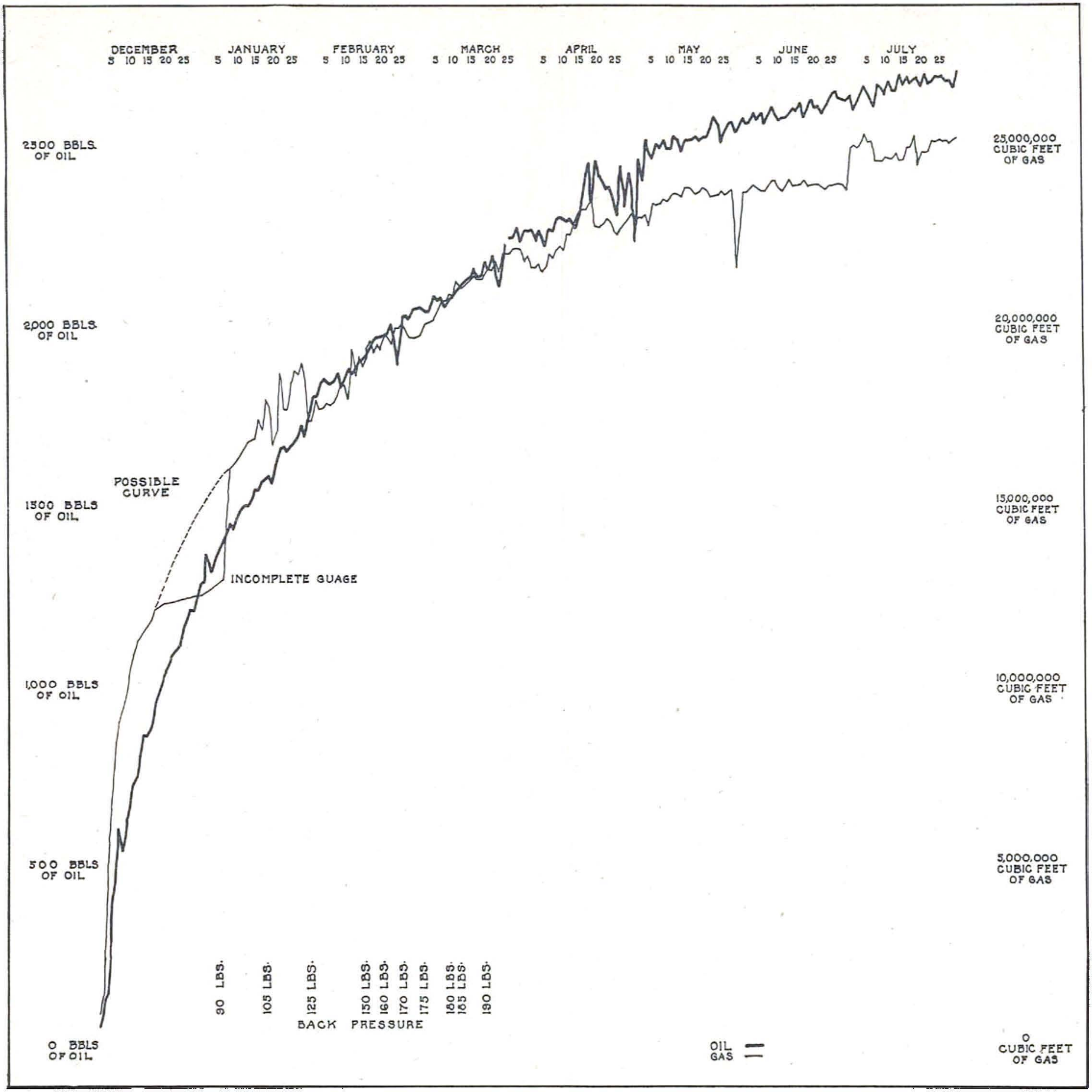

Fig. 15. Production curve of University Deep Well, Texon Oil and Land Company No. 1–B, Reagan County, Texas, from December 1, 1928, to July 31, 1929.

bottom of the hole to continue drilling. Subsequent measurements, however, indicated that the well by its flow had deepened itself at least two feet to 8525. The half million cubic feet of gas production and the 40 barrels of oil of December 1, 1928 has increased continuously to the present time. Production on July 31, 1929, was oil 2714.28 barrels and gas 25,298,000 cubic feet. The detailed history of the well is given on pages 191–201. The curve of production is given in figure 15.

GEOLOGIC SECTION

This well is located in the southern part of the great salt basin of west Texas and adjoining states. The Pennsylvanian and Permian sediments of this basin are overlain by Triassic and Cretaceous formations. The deep well starting in the Cretaceous terminates probably in Pennsylvanian. The geologic section in the Big Lake oil field in which this well is located has been given by Sellards and Patton[3] (figure 1).

CRETACEOUS

The Cretaceous at this locality is chiefly that of the Fredericksburg series, including the Edwards, Comanche Peak, and Walnut formations consisting of limestones and marls. The Georgetown formation of the Washita series is probably not present in the section in this field although it may be present in the escarpment south of the field. The Fredericksburg series contains a marine fauna. Underneath the Fredericksburg are the basement sands of the Cretaceous which from lack of fossils are undetermined as to age but may represent a part of the Glen Rose. These sands are usually water bearing. In the deep well the base of the Cretaceous is probably near depth 510 feet.

TRIASSIC

The Triassic section at this locality although variable in thickness approximates 300 feet. Farther to the north the

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[3]Sellards, E. H., and Patton, L. T., The Subsurface Geology of the Big Lake Oil Field. Bull. Am. Assoc. Petr. Geol., pp. 365–381, 1926.

Triassic becomes thicker and in Midland County has a thickness of about 1000 feet.[4] The Triassic includes non-fossiliferous red shales and sands, gray and white sandy shales, calcareous sandstones, and conglomerates. These deposits are characterized by the presence of mica in greater abundance than in either Permian or Cretaceous formations and by the presence of phosphate in widely disseminated but small quantities. The sands of the Triassic often contain water. In the deep well the Triassic probably extends from 510 to 840 feet, having thus a thickness of 330 feet. Within this interval three water sands are reported as follows: at 548 to 565, at 720 to 765, and at 825 to 840 feet.

PERMIAN

The Permian at this locality is of great thickness and includes a wide variety of sediments. It may be divided into the red bed series consisting of red and gray sands and clays, salt and anhydrite 2000 feet more or less, the dolomite series 800 feet, and underneath this a series of black shales and shaly limestones of undetermined thickness.

THE RED BED SERIES

The uppermost part of the red beds immediately under the Triassic include red sands and clays, underneath which are the salt and anhydrite beds which alternate with chiefly red sands, the whole series resting upon the dolomitic limestones. Usually three salt horizons are present which may be designated as upper, middle, and lower salt beds, the intervening strata being anyhdrite, sands, and clays.

The top surface of the Permian is irregular owing to Pre-Triassic erosion. The interval from the top of the Permian to the first salt bed is variable but approximates 350 feet. The strata of this interval include brick-red shales and red more or less shaly sandstones with some thin beds of anhydrite. The color of the Permian clays and

[4]Sellards, E. H., and Schoch, E. P., Core Drill Tests for Potash in Midland County, Texas. Univ. Texas Bull. 2801, p. 164.

sands is dull red as compared to that of the more richly colored Triassic. The sands are fine as well as dull in color. Other differences are the comparative absence of phosphate and mica in the Permian in contrast to their prevalence in the Triassic. In the deep well the Permian above the salt apparently has a thickness of 270 feet, the first salt having been entered at 1110 feet.

The First or Upper Salt Beds.—Of the three salt beds the first or uppermost is the thickest and most persistent. Its average thickness approximates 500 feet although within the salt beds are some thin layers of anhydrite. With the salt there is found more or less of the potash mineral polyhalite. The polyhalite is widely scattered through the salt and a diamond drill core recently reported on by the United States Geological Survey indicates that it occurs in some approximately pure beds. Thus at 1310 feet this report indicates a polyhalite stratum 1.5 feet thick, containing 10.65 per cent potassium oxide, or including leaner beds, 2.25 feet, containing 7.62 per cent potassium oxide. At 1526 feet, within 129 feet of the base of the salt, is reported a polyhalite stratum 2 feet thick containing 10.85 per cent potassium oxide, or including adjoining leaner layers 35 inches of polyhalite averaging 8.27 per cent potassium oxide.[5] The bottom of the first salt in the deep well is placed in the log at 1655 feet, giving this salt member in this well a thickness of 545 feet.

Interval Between the First and Second Salt Beds.—Underneath this great body of salt there is found usually heavy anhydrite deposits more or less interspersed with sands and clays and some salt. In this particular well a salt stratum 14 feet thick is logged at 1728 to 1740 feet. The anhydrite beds of this interval are usually from 200 to 250 feet thick.

The Second Salt Beds.—The second or middle salt beds of this series are often poorly defined and less well developed than either the first or the third salt beds. In some

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[5] U. S. Geol. Surv., Memorandum for the Press, March 25, 1929.

cases the middle salt consists of a single bed but more often of a number of beds separated by anhydrite, red sandstone, and shale. The whole interval of the middle salt series approximates 100 feet. In the deep well this salt series is found at 2080 to 2190 feet and may extend somewhat below 2190 feet.

Interval Between the Second and Third Salt Beds.—The principal anhydrite beds of the red beds series lie underneath the second salt series. The interval includes usually two fairly well defined anhydrite zones. The uppermost of these immediately under the second salt series in some wells is found to include 150 or 200 feet of anhydrite. Below this are red sands and clays followed by another anhydrite bed which may also reach a thickness of 200 feet. The anhydrite is throughout more or less interspersed with red sands and clays. The log of this particular well indicates an unusual amount of sands and clays within this interval to the exclusion of anhydrite. The interval between the second and the third salt beds on the average approximates 550 feet.

Oil and gas are obtained in a number of wells in the field from within this interval at depth of between 2400 and 2500 feet. In the deep well there was a show of oil filling the hole at 2461 to 2466 feet accompanied by 400,000 cubic feet of gas per day. When drilling was continued to 2469 feet an initial production of oil of 370 barrels was obtained. From this horizon as already stated the well produced 32,152 barrels of oil. Upon deepening the well below this pay horizon a heaving sand was encountered which came into the well as rapidly as removed.[6] This sand horizon which has been recognized at this horizon in several other wells in the field is a loosely cemented sandstone or more

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[6]In well No. 2-C of the Big Lake Oil Company located 1,625 feet from the north and 250 feet from the east corner of Section 1, Block 2, in this field, the succession in this interval was found from cores to include sandstone, and a thin bed of salt underneath which was loose, uncemented, or heaving sand. The salt stratum, probably about two feet thick, was of a pinkish color. The occurrence of this salt illustrates the fact that there are thin salt strata occurring at intervals through the red bed series.

probably an uncemented sand which moves under pressure into the hole. Gas coming through the sand probably aids its flow into the well.

Third or Lower Salt Beds.—A third salt is recorded for most of the wells of this field. As in the case of the middle salt beds this deeper salt is variable in amount and in the number of beds recorded. Frequently only one salt stratum is reported although in some of the wells several strata are indicated, separated by anhydrite or red sands and shales. In the deep well there is no record in the driller's log of the deep salt horizon. It is evident that there is considerable variation in the section as between wells even within this particular oil field and some of the records indicate occasional thin salt beds in addition to the three principal salt series here described.

The character of the rocks in the Permian red bed series is further shown in the following description of samples taken from one of the wells in this field.

TEXON OIL AND LAND COMPANY GROUP 1, NUMBER 2

Located near center of Section 36, Block 9. Elevation 2,754.6 feet. Description of samples by L. T. Patton, 1925.

	Depth in feet
Brick red shale, gypsum, anhydrite and a few pieces of salt.	1125–1175
Red sand and silt, a few pieces of white anhydrite and some salt. Few pieces of gypsum also noted. Sand grains from 80 to 90 microms in diameter.	1205–1215
Clear crystalline salt, some of which has a slightly reddish tinge. A few pieces of red mineral which optic test shows to be only anhydrite and not polyhalite.	1215–1230
Salt with a few pieces of red shale and some red anhydrite. No material giving test for polyhalite noted. Clear salt gives fair test for potassium with flame test and salts of phosphorous copper oxide bead shows presence of sylvite.	1225–1235
Crystalline salt with a slight reddish tinge, some silty material and some red anhydrite. None of the reddish mineral tested shows tests for polyhalite, but only anhydrite. Clear salt gives strong flame test for potassium and test for sylvite with salts of phosphorous and copper oxide bead.	1235–1245

Crystalline salt of slightly reddish color, red silt and some anhydrite. One small piece of reddish mineral was shown by its optic properties (anisotropic, biaxial negative, refractive index between 1.540 and 1.550) to be polyhalite. Clear salt gives fair flame test for potassium and with salts of phosphorous and copper oxide bead gives test for sylvite. 1247–1255

Crystalline salt with slightly reddish tinge and pieces of reddish mineral resembling red anhydrite. Representative pieces of the latter were dissolved in boiling HCl. Solution gave slight flame test for potassium. Small portion tested with barium chloride and ammonium oxalate solution respectively showed the presence of sulphate radical and calcium; another small portion was treated with a drop of nitric acid excess of ammonium chloride, neutralized with ammonia, drop filtered, placed on a glass slide beside a drop of sodium ammonium phosphate solution and slide warmed and two drops allowed to coalesce; on cooling skeletal x-shaped crystals and flat tubular crystals with pyramidal truncation were found proving the presence of magnesium. One piece of reddish mineral was also heated in closed tube and gave abundance of water; mineral therefore a hydrated potassium magnesium calcium sulphate or polyhalite. Clear salt gave good test for potassium and with salts of phosphorous and copper oxide bead colors flame azure blue, showing the presence of sylvite. 1265

Salt with some few pieces of white gypsum. Salt gives tests for sylvite, described in 1265. 1275–1285

Red clay. Washed sample shows a large number of pieces of red mineral. Some pieces of the latter show fusibility indicating polyhalite and also give water in closed tube. Pieces of these subjected to mineralogical tests described under the depth of 1265 feet give good tests for polyhalite. Both red anhydrite and polyhalite evidently present. 1295–1305

Salt and pieces of reddish mineral which makes up about one-third of the sample. Fusibility tests indicate that a number of these pieces are polyhalite and mineralogical test described at the depth of 1265 feet show that polyhalite is present. Clear salt gives very strong test for potassium and strong test for sylvite. 1295

Salt and some pieces of a reddish mineral. Salt tested with microcosmic salt and copper oxide bead colors flame azure blue, showing the presence of anhydrite. Pieces of reddish mineral treated in closed tube gives moisture. Thin splinters fuse in luminous flame indicating mineral not anhydrite. Powdered mineral dissolved in boiling HCl solution gives slight flame test for potassium being somewhat obscured by the calcium flame. A portion of the solution treated with ammonium oxalate gives a white precipitate indicating calcium. Another portion was treated with ammonium chloride and a drop placed on a warm slide and treated with a drop of ammonium phosphate gives skeletal x-shaped crystals of magnesium ammonium phosphate. The mineral therefore, contains potassium, calcium magnesium, sulphate and water of crystallization which is the composition of polyhalite. 1325–1335

Clear crystals of salt with some pieces of reddish mineral. Selected pieces of the latter do not give tests for polyhalite given above, except for calcium sulphate showing them to be anhydrite. Clear salt crystals show presence of sylvite with copper oxide sodium ammonium phosphate. 1345–1355

Salt which has a slight reddish tinge and some pieces of reddish mineral. Some pieces of the latter show fusibility tests for polyhalite and others for anhydrite. Pieces of former subjected to mineralogical test for polyhalite described under the depth of 1265 feet give good tests for polyhalite. Both red anhydrite and polyhalite evidently present. Clear salt gives strong flame test for potassium and with salts of phosphorus and copper oxide bead gives test for sylvite. ? 1353

Crystalline salt. Some of the salt slightly reddish but all such pieces tested readily soluble, not polyhalite. Crystalline salt gives strong flame test for potassium and salts of phosphorous and copper oxide bead test shows the presence of potassium and give strong flame test for potassium. 1355–1365

Clear crystalline salt with a slightly reddish tinge. Salt gives slight test for potassium and slight test for sylvite. No tests for polyhalite obtained, the few pieces of reddish material so far as examined being red anhydrite. 1365–1375

Crystalline salt and pieces of red mineral, none of the latter which were tested gave the mineralogical or optic tests for polyhalite, but only for anhydrite.

Crystalline salt gives strong flame test for potassium and test for sylvite.	1385–1392
Crystalline salt. Salt gives strong flame test for potassium and with salts of phosphorous and copper oxide bead colors flame azure blue, showing the presence of sylvite. Red minerals which make up a small portion of the sample so far as tested, gave tests only for anhydrite and not for polyhalite.	1395–1400
Crystals of clear salt together with some reddish material. Selected pieces of the latter when dissolved in boiling HCl, yield test for potassium calcium, sulphate and slight test for magnesium with sodium ammonium phosphate. Some polyhalite present together with anhydrite.	1395–1400
Crystalline salt. No reddish mineral giving test for polyhalite found. Clear salt gives good flame test for potassium and with salts of phosphorus and copper oxide bead presence of sylvite is shown.	1405–1415
Clear crystalline salt with very few pieces of reddish mineral part of which test shows to be anhydrite and a few pieces of polyhalite, as shown by tests described under the depth of 1265 feet. Clear salt gives strong flame test for potassium and good test for sylvite.	1415–1425
Clear salt and approximately about 5 per cent of reddish mineral. About 20 pieces of the latter were selected and subjected to fusibility tests for anhydrite and polyhalite. About 5 proved to be anhydrite. The other pieces were subjected to the tests for polyhalite described under the depth of 1265 feet. Tests showed material to be polyhalite. Clear salt yields good flame test for potassium and with salts of phosphorus and copper oxide bead gives test for sylvite.	1425–1435
Clear salt with some pieces of light reddish mineral. Selected pieces of the latter in the majority of cases show fusibility tests indicating polyhalite. Latter pieces tested according to tests described for 1265 feet show presence of polyhalite. Clear salt gives strong flame test for potassium and good test for sylvite with salts of phosphorous and copper oxide bead.	1455–1465
Clear crystalline salt with slight reddish tinge. No test for polyhalite obtained. Gives fair flame test for potassium and only slight test for sylvite.	1465–1475
Similar to that from the depth of 1465–1475 feet. No polyhalite detected.	1475–1485
Similar to the sample from 1475–1485 feet, except that a few pieces of reddish mineral yielding test for poly-	

halite described under the depth of 1265 feet were found.	1485–1495
Light red sand and silt and few small pieces of anhydrite. Sand grains vary from 60 to 100 microms in diameter.	2175–2195
Light red sand and silt and few small pieces of anhydrite. Figure 3 is camera lucida drawing showing size and shape of the sand grains.	2175–2195
Light red sand pieces of gray and white anhydrite. More or less perfect crystals of quartz among the sand grains.	2805–2815
White and dark gray anhydrite and pieces of light brown sandstone. Number of well developed crystals of quartz noted.	2815–2825
Similar to that from the depth of 2805–2815 feet. Some pieces of sandstone cemented with limonite and some pieces of sandy red shale noted.	2825–2835
Similar to the preceding (2825–2835 feet). A number of crystalline pieces of quartz seen.	2835–2845
Light gray and white anhydrite. A few pieces of crystallized quartz noted.	2845–2855
Gray and white dolomite, some gypsum and light red colorless sand.	2855–2865
White and gray anhydrite. A number of fairly perfect and relatively large quartz crystals observed.	2865–2875
Light gray friable material, which is evidently a mechanical mixture of finely ground rock. The washed sample consists of pieces of sandy dolomite.	2875–2880
White and gray anhydrite and some gray dolomite. The dolomite after being digested with acid leaves a residue of sand grains. Some anhydrite seen in thin section.	2880–2890
Gray and white anhydrite and gray sandy dolomite. The thin section of the dolomite shows a large proportion of sand grains.	2890–2900
Gray to brown dolomite and some brown shale and a few pieces of anhydrite. In thin section the dolomite is seen to contain numerous small rounded bodies, resembling oolites. Not the representative oolitic dolomite found in the wells in this field, however. Also several elongated bodies, the latter being composed of small grains.	2900–2910
Finely ground fragments of dark gray dolomites. Thin section shows dolomite to be very fine grained and somewhat sandy.	2910–2915

Similar to that from the depth of 2910–2915 feet.	2915–2925
Light gray dolomite which silver chromate test shows to contain about 10 per cent of calcite. In this section optic test shows some anhydrite replacing the dolomite. Several indeterminate oval-shaped bodies seen in thin section.	2925–2935
Light gray very oolitic limestone. The oolites are very numerous and make up a large proportion of the limestone. Silver chromate test shows that less than 10 per cent of the grains of the rock consist of dolomite. This appears to be the typical dolomite horizon found in this field.	2935

TRANSITION INTERVAL

Underneath the lower salt series are strata of red clays and sands, anhydrite, calcareous sandstones, and sandy dolomites constituting a transitional zone grading into the dolomite series below. Within this transitional zone at depth 2682 to 2690 feet in the deep well a cavey red sand is reported.

THE DOLOMITE SERIES

From the sandy dolomites of this transitional interval some oil production has been obtained in this field. The principal production, however, is from an oolitic horizon averaging about 20 feet in thickness occurring within but near the top of the dolomite series. This oolite horizon is described by Sellards and Patton as follows:[7]

> The oolites in this horizon are very numerous and in some cases make up nearly the entire rock. They vary in size from 0.2 mm. to 0.5 mm., the greater number being near the latter size. They are concentric in structure and usually show a central body or nucleus, often consisting of a sand grain. Figure 5 shows a photomicrograph of a portion of a well sample indicating the proportion of oolites to other material. In many cases, the oolites break out from the matrix when the rock is broken up by the drill and are found in the samples as separate particles (Fig. 6). On the other hand the oolites are in some cases firmly imbedded in the matrix, but the rock is nevertheless quite porous. In cases where oolites break out easily from the matrix they might be mistaken for coarse sand by

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[7]Sellards, E. H., and Patton, L. T., Subsurface Geology of the Big Lake Oil Field. Bull. Am. Assoc. Petr. Geol., X, pp. 375–376, 1926.

a casual observer, and in one case at least they were so recorded by the driller. This may partly account for the persistence with which the drillers insist that the production comes from a sand. Microchemical tests show that, aside from the occasional sand grain nucleus in the oolites, the rocks vary from relatively pure limestone to pure dolomite. This oolitic zone is not only a distinctive but a very constant zone and there is practically no instance of a well within the field, of which a complete and carefully kept set of samples is available, in which this zone is not easily and definitely identified.

The oolitic stratum which is the principal oil producing horizon of this field was reached in the deep well at 2910 feet. Owing to interference by surrounding wells the production from this horizon was small. Samples were not received from the dolomite series in the deep well. However, from wells previously drilled in this county it is known that the sediments for as much as 300 feet below the main producing horizon consist of dolomites, sandy dolomites and sandstones. Owing to the lack of samples the thickness of the dolomite series of this well is not accurately known but is probably 800 or 900 feet.

PERMIAN AND PENNSYLVANIAN

THE SHALE SERIES

Underneath the dolomites deep drilling has revealed approximately 5,000 feet of dark colored calcareous and sandy shales, limestones, dolomites, and sandstones. Throughout much of this section shales predominate. They are, however, calcareous and being well indurated grade into limestones and dolomites. In parts of the section the strata are so sandy as to be classed as sandstones and sand is found very generally in the shale. Throughout this great interval the sand included in the shale is exceedingly fine and the individual sand grains are scarcely to be seen except by the aid of thin sections. It is only near the base of the section, as shown by this deep well, that coarse or medium coarse, well rounded sand grains are found. Fossils in this shale section are few and it is not possible at present to divide the series into formation units. It is Permian in part and in part Pennsylvanian.

From samples in the Bureau of Economic Geology, Mr. Bruce Harlton recognized fossils as follows:

Depth in feet	
7000–7020	*Cornuspira* sp., and crinoid stems.
7520–7550	*Ammovertella* sp., and *Endothyra* cf. *ameradaensis* Harlton.
7640–7670	*Globivalvulina rotundata* Galloway and Harlton, *Orobias* sp., *Ammovertella* sp., *Rhombopora lepidodendroidea* Meek, *Endothyra ameradaensis* Harlton, *Bairdia* sp. (anterior portion broken), *Fusulina* sp., and crinoid stems.
7800–7840	*Fusulina* sp., fragment of *Climacammina*, *Globivalvulina* cf. *raduidata* Galloway and Harlton (broken), and crinoid stems.
8250–8305	*Endothyra bowmani* Phillips, *Tuberitina* cf. *bullacea* Galloway and Harlton, crinoids and bryozoans.
8447–8476	Many ostracod fragments and crinoid stems.

Among these fossils many are long range and hence are not of service in separating Permian and Pennsylvanian. However, fossils occurring at 7640 to 7670 feet including *Globivalvulina rotundata*, *Orobias* sp., *Endothyra ameradaensis* are regarded by Harlton as indicating Pennsylvanian sediments. From this horizon is identified also *Rhombopora lepidodendroidea*. On the evidence of these fossils the Pennsylvanian-Permian contact must be placed at some place above 7640 feet, probably above 7520–7550 feet.

A more exact correlation can be made only by the aid of cores or other new information. A rotary well is now being drilled in the field by the Big Lake Oil Company from which cores will be taken below 3700 feet. These cores will be reported upon subsequently.

DRILLER'S LOG

Following is the driller's log on the deep well.

Located 250 feet from west line and 2,728 feet from the north line of Section 36, Block 9, University Survey. Elevation 2,734 feet.

	Depth in feet to:	Notes	Date 1926	Driller's remarks
Shale, yellow, surface material	10	Cretaceous to 510 feet	Feb. 8	Rigging up
Shells	60		8	Rigging up
Gumbo, blue	100		9	Waiting on conductor and cement to set.
Lime, blue, hard	150		10	Building rig
Lime, white, soft	210		10	Building rig
Lime, soft white	300		11	
Sand, water	350	First water sand	11	
			12	Fishing
Sand	375		13	Hitching on and bldg. rig
Sand and R. R., broken	465		13	
Sand and R. R., broken	510	Triassic 510 to 840 feet	14	
R. R. caving	545		15	
R. R. caving	548		16	Running 15″ csg., cable measurement 548′
Sand, water	565	Second water sand	17	Shoe joint over all 21.4
Sand and lime	650	Lime conglomerate	17	15″ settled 16′ total 564′
Red rock	664		18, 19, 20	Underreaming 15″ csg., fishing and underreaming
Red rock	700		21	Underreaming finished; hole dry 15″ total 662′
Shale, sandy	720		22	
Sand, water	765	Third water sand	22	4 BPH wtr. U/R 15″ to 765′
			23	Underreaming 15″ csg.
Red rock	825	Total 15″½″ csg. 769′	24	Underreaming 15″ csg. 6 hrs. Pipe on bottom 769.1′
Sand, water	840	Fourth water sand	24	4 BPH wtr.
Red rock	960	Top of Permian	25	
Red rock	1050	Anhydrite	26	
Lime	1070	Red beds	26	
Red rock	1080	Top 1st salt-1110′	26	Broke jars—fishing
RR and shells	1110		27	
Salt	1165		27	Fishing
Salt	1655	Bottom 1st salt-1655′	28, Mar. 1, 2, 3, 4, 5, 6, 7, 8, 9	Fishing; ran 12½″ second time over tools; pulling pipe cleaning out; bailing water; running 12½″ 65 joints=1330.9″

	Depth in feet to:	Notes	Date 1926	Driller's remarks
Red rock, caving	1720		9	
Lime	1728	Anhydrite	9	
Salt	1740	Top 2nd salt—1728′	9	
Red rock and shells	1745	Bottom 2nd salt—1740′	10	
			11 to 18	Underreaming 12″ csg.; fishing underreaming slips; fished out 1 lug 12:08 P.M.; Fishing for lugs; cleaning out—got lugs out 5 P.M.
Red rock	1845		19	Cleaned out 200′ and bailing water.
			20, 21	Bad hole
Red rock and shells	1950		22	
Red rock and shells	2080	Top 3rd salt—2080′	23	
Red rock and salt	2190	Bottom 3rd salt—2190′	24	
Red rock and salt	2290		25	
Sand red and lime	2360	Hole caving	26	
Lime	2385		27	
Sand and red rock	2425	Anhydrite	27	Bad hole at 2415′
			28	Fishing for bailer.
Red rock	2440		29	SD for casing.
		Red beds	30	SD to run 10″ running 10″ loading hold.
Red sand	2450	Heaving sand	31	10″ csg. 2443′10″
			April 1	Running 8¼″ 2450′
Sand, hard	2454	Drlg. reports missing 4–2–26 to 10–10–26. Sandstone.	2	Ran cag. on time 2454–8¼″ 2454′
Lime	2461	Inf. from slip dated 4–6–26	3 to	
Sand, red	2466	Top pay 2466′ Shallow	6 to	Show oil, filling up hole 400,000 gas; no wtr.
Sand	2469		11	Drilled to 2469′ and ran 45′ 5 3/16″ liner wilth 5 3/16″—6 ⅝″ swedge nipple and 6⅝″ shoe on top-bottom joints with perforated bull plug in bottom.
		Permian red beds Drilled with steam to 2469′	14–15	Swab-water and mud.
		Drilled with gas from 2469–2570′. The heaving sand below the shallow pay is probably a loosely cemented sandstone which slacks on being exposed and possibly under compression is forced or runs into the open hole causing much trouble. The gas in this zone has been identified in several other west Texas wells.	16–18 & Aug. 11 to Sept., 28	Swab oil and red sand—200 bbls. Shallow pay produced 32,152 bbls. up to 10–15–26 date of notice of intention to deepen. Completed to RR Com. 4–18–26 IP 370 bbls 100.000 cu. ft. gas. est. TD 2466′. Deepening—Red sand coming in as fast as can be cleaned out. Rigging up; pulling casing; fishing for rods jacking on pipe; started underreaming.

	Depth in feet to:	Notes	Date 1926	Driller's remarks
Sand, heaving	2550		29 to Oct. 2	Underreaming to 2470' and underdrilling and lowering 10" csg.
			3	Red sand coming in bad; tools in and fished out stringing up drlg. tools.
Lime	2555		4	Red sand coming in bad.
Lime	2561	Dolomite sandy. Used gas engine to 2570'.	5	Under-drilling 10" csg.
Red rock	2570	Used steam engine from 2570–2855'. Shale red.	6	Under-drilling and lowering 10" csg.
		Anhydrite	7–9	Rigging up boiler and engine. Trouble with wtr. pump. Cleaning out trouble with pump.
Red rock	2575		10 to 20	Red sand coming in bad. Cleaning out red sand; drilling out iron and red sand.
Sand	2580		21	Wire line broke; fished out tools; splicing line; broke again; ready to splice.
Shale	2583		22	Puttin~ two splices in wire line SD 8 hrs.-wtg. on gas.
Shale	2590		23	Stringing up tools to underream; sand came in up to csg.; cleaning out.
		Total 10" csg. 2590' Anhydrite	24 to 26	Cleanin~ out and underreamin~ and lowering 10" csg.; cleaning out gas weak for steam.
Sand and lime	2600			
			28	Gas too weak to drill with; running wtr. in well.
Shells, sandy	2630		29	
Sand, red	2650		30	Splicing wire line.
Red rock	2665		30	
Lime	2670	Dolomite and anhydrite	31	Splicing wire line; trying to lift csg. to underream and cleaning out.
Lime, gritty	2682	Dolomite sandy	Nov. 1	Slush pit full of red sand coming back under derrick and running into cellar.
Lime, gritty	2690		2	Red sand running in bad: get ready to change drlg. line; fighting cave due to SD
Lime	2700		3	Changin~ drlg. line; cleaning out red sand; running in bad.
Shale, sandy	2720		4	Gas low
Shale	2726		5	
Lime	2740	Dolomite and anhydrite	5	
Shale	2760		6	
Lime	2765		6	

	Depth in feet to:	Notes	Date 1926	Driller's remarks
Shale	2770		7	
Lime	2780	Top of lime 2780'. Dolomite hard.	7	Shut down for gas
Lime, hard	2800		7	
Lime, hard	2820		8	Shut down for gas
			9	Running 8¼" csg.
Lime	2825	Total 8¼" csg.–2825' Dolomite	10 to	Shut down waiting clamping up nipple; stringing up tools.
Lime	2840		16	Shut down for gas
Lime	2855	Gas Engine (Tyco)	17	No gas; taking out steam engine; connecting up gas engine
Lime	2900	Gas at 2900'	17–19	Broken clutch on Tyco engine; put new clutch on engine and spliced sand line
Sand and lime	2920	Oil Show 2910'. Top Texon pay. Oolitic dolomite.	19	
Sand and lime	2940		20	Gas engine down
Shale and lime shells	2950		20	Gas engine down
Lime, broken	2980		21	Gas engine down; clutch needs oiling.
Sand, shell, shale	3010		22	
Lime, sandy	3020	Dolomite, sandy	23	Nine hrs. shut down; broke drlg. line; fishing.
		Shut down; changing gas eng. 11–28–26. ⅞ by 5000' Black wire and Steel Company drilling line. Changing to steam 1-14–27. Notification to RR Co. of intention to deepen 2–8–27. Total production Texon Pay 1065 bbls.	24 to 1927 March 3	Fishing for tools, jarring on tools. Drilling by tools; running hollow reamer; Milling bole off tools in hole; swabbed 84 hours; changing engines and rigging up steam; drilling by tools; spudding by tools and fishing; running hollow reamer; drilling out rock.
Shale, sandy	3050	Fifth water, sulphur	4	
Shale, dark	3080	6⅝" csg._3080'	5–6	Putting in new brake wheel; putting in 6⅝" csg.
Lime	3095	Dolomite	7–8	Bailing hole; drilling and bailing water; not shut off; repairing boilers.
Lime shells, broken	3148		9–10	Putting on cable and splicing drlg. line.
Lime gray, hard	3290		11–15	
Lime	3306		16	
Slate	3316		16	Changing tools to case; stringing tools to drill deeper.
Lime shells, broken	3360		17–18	Repairing boiler
Sand	3370		18	

	Depth in feet to:	Notes	Date 1927	Driller's remarks
Lime	3375		18	
Shale	3390		18	
Lime, sandy	3410	oolitic dolomite	19–20	Running 5 3/16″ csg.—3400′. clamping csg.; waiting on clamping nipple.
Sand, black	3417		21	Stringing up tools; bailing wtr.
Lime	3420		21	Bailing water
Sand	3470	6th water sand; R–3426′ find quartz sand and iron stained limestone.	22–25	Bailing water; changing sand lines.
Sand, close, hard	3480	Sandstone	26	
Sand, hard	3482		27	Repair boiler; pulling 5 3/16″ csg.
			28–29 to	Pulling 5 3/16″ csg.; stringing up tools straightening; straight reaming; shut down.
Lime	3513		April 3–5	Started up at noon after waiting 5 3/16″ packer; changing drilling cable and sand line.
Shale	3545		5–6	
Lime shells	3560		6	
Shale	3610		7	
Lime	3654		8–9	
Shale	3690	P–3705′ dk gr dol shale & gray sandstone	9–10	
Sand	3710		10	
Lime	3718	P–3730′ ditto dolomite	11	
Shale	3730	P–3756′ dolomite and shale	11	
Lime, sandy	3766		11–12	
Shale, sandy	3778	P–3770′ limestone and dol. shale	12	
Lime, sandy	3834	P–3800′ ditto; some sandstone	12–14	Boiler trouble
Shale, sandy	3910	P–3850′ fine clear quartz and sd-gr; P–3882′ limestone and shale. Quartz sand	15–16	
Sand	3918			
Shale, sandy	4216	P–3950′ shale; some sand. P–3985′ sandy calcareous shale. P–4065′ gray calcareous shale. P–4120′ black calc. shale; gray calc. shale. P–4200′ black mic. calc. shale; some sandstone and quartz, and shaley lime; some pryritic shale.	18–29	Knocked off bit; fished out bit.
Sand	4218		29	Running 6⅝″ reamer preparing to run 5 3/16″ csg.

	Depth in feet to:	Notes	Date 1927	Driller's remarks
Sand, missing	4228		30	Running 5 3/16" csg.
			May 1	Running 5 3/16" csg.; waiting on clamping nipple.
Sand	4230		2	String up tools C O Bailing water 5 3/16" at 4228'.
Shale	4515	P–4365' Gray calc. sandstone. Black calc. shale; black cald. shale; black calc. mic. shale; hd. black calc. sandstone; hd. black limy sh; some quartz; fine gr. calc. sandstone; hd. black mic. pyritic shale.	3–10	
Shale	4545		10–11	
Sand	4554		11	
Shale, sandy	4595			
Sand-OIL showing	4621	Fine gr. calc. shaley mic. sandstone. Oil showing 4600'	12	
Shale, sandy	4761	Shale and sandstone; some impure dolomite; shale and sandstone; putting in Clark engine.	12–17	Stranded drilling line; putting on more cable
Sand, showing OIL	4766	Oil showing 4761–66'. Shale and some quartz.	18	
Shale, sandy	4985	Shale and sandstone; gr. calc. shale. Clark drilling engine used from 5–17–27 to 5–26–27, 4740–5345'	18	Shut down at 5:00 A.M.—no gas.
Lime	4993		22	
Shale	5315	Samples burned from 4828–5345'. Rig burned 4:00 p. m., 5–26–27. (Sparks from brake band of sand reel.) Permian possibly Word formation from Radiolaria.	22–26	
Lime, black	5480	Hd. blk. calc. mic. shale; bituminous not non-calc. shale; hd. blk. calc. mic. sh-pyritic and little impure quartz. Steam 6–15–27 to 7–29–27—5445 to 6555'.	26 to June 18	Records burned in fire supplied by subsequent measurement. Rigging up etc. Bit stuck in tight hole; splicing drlg. line; sand reel won't pull bailer.
Lime, gray hard	5620	Shale and some lime; grey siliceous lime; shale.	19–21	Working on clutch on sand reel.
Lime, black	5660	Sandstone	22	
Lime, gray hard	5725	Shale and lime and sandstone	23–24	Fishing sand line out; sand out calf-wheel brake-chain and clutch.
Lime, black	5820	Shale, sandstone, crinoid stem; gr. lime and sh.	25–26	
Lime, hard	5860	Gray lime	27	
Lime, gray hard	5900	Calcareous shale	28	
Lime	5940	Sandstone, shaley	29	

	Depth in feet to:	Notes	Date 1927	Driller's remarks
Lime, gray soft	6000	Shale, calc.	30	Splicing line.
Lime	6040	Shale, calc.	July 1	
Lime, gray	6075	Shale, calc.	2	
Shale, black	6135	Shale, sandstone.	3–5	Cannot make band wheel clutch lift; bailer needs new lining.
Lime, sandy gray	6155	P–gray lime; sand and shale	6	Working on clutch on band wheel.
Shale, sandy	6200	Hard black shale	7	
Shale, black	6235	Correcting drilling log; black shale, shaly sandstone	8	
Lime, gray hard	6249	Black shale, shaly sandstone	9	
Lime, gray	6266	Gray sandstone	10	Cannot pull bailer; clutch broken.
Sand, OIL showing and gas	6277	Show oil and gas; gray sandstone	10	
Sand, OIL PAY	6280	Top 3rd–6277′	11	
Shell, broken, shale, black	6320	Sandstone and shale	11	
Shale	6331	Sandstone and shale	12	
Lime, black	6342	P–Shale and sandstone	12	Running steel line to 6338′
Shale	6353	Shale and sandstone	12	
Shale and lime shells	6368	Shale, sandstone	13	Changing and splicing sand line and making clutch arm
Lime, gray hard; sandy hard	6507	Black shale; some sandstone; and lime; some dolomite lime; sandy shale; shale dolomitic sandstone; shale and lime.	14–24	Splicing drilling line and working on sand reel clutch; changing sand reel; tools hung up 1500′ off bottom (Comb wrench); fishing for bailer and chaning sand line.
Lime, shale	6537	Lime, shale, sand, gr. sandstone, sandy shale, brown sandstone.	25–27	Changing ends with drilling line.
Lime	6555		28–29	Changing and splicing sand line; 3 hrs. bailing; hole cleaned of B.S.; put in new wheels
		Group No. 1 Oil Corp. took over drlg. Electrical equipment 6555′ to bottom. Thru this period the 5 3/16″ was pulled from 4228′ the 6⅝″ was ripped and cemented to shut off water and oil from 2970 to 3050′ and then cemented. It had to be cemented three times before it held. Underreaming 5 3/16″ in hard formation; most of it had to be reamed twice. 2 new ⅞ x 4500 Hazard drlg. lines; total 5 3/16″ csg. 6176′.	to Dec. 11	SD to equip the well with electric motors 2–25–85 slip ring oil field motors (3 phase) Westinghouse with controls and Medart Countershaft. Rigging up; cementing at 2950′. Drilling cement out and bailing water; drilling cement 3280′ very hard; go through cement 3486′ P. M. 27th; reaming at from 4320 to 6065′ cleaning out 6120 to 6175′. Reaming again at 6060′; cleaning out 6178′; clamping up; bailing anc celaning out; cut and clamp up 5 3/16″ csg. Drilling out cement 5 3/16″ csg. at 5060′; fishing for bailer; cleaning out, washing down and bailing.

	Depth in feet to:	Notes	Date 1927	Driller's remarks
Lime, black hard	6570	Amerada Determination: Upper Wolfcamp. Pure—6555′ shale.	12	Drilling new hole; meter measurement.
Lime, sandy black hard	6585	Sandstone and limestone. 6576′ black shale with dol. partings.	13	
Lime, black hard	6715	6615′—shale and dolomite; shale, limestone and flint. *Hyperammina* sp; 6630′ concretions, black shale fine ground; 6645′ dolomite with dol. partings; crinoids.	14–19	
Lime shell, hard	6730		19	
			20	No hole made splice cable, babbit beam saddle, tug wheel, parts put on sand wheel brake.
Lime, shell, black hard	6760	6745′ shale, dol. lime, sandstone	21–22	
Lime, black hard	6770	Shale, dol. limestone.	23	
Shale, black	6785	Shale, dol. limestone, sandstone.	24	
Lime, black	6800	Shale, dol. limestone, sandstone; dolomite	to 26	
Shale, black	6815	Shale, dol. limestone, sandstone	27	
Lime, black hard	6820	Shale, dol. limestone, sandstone	27	
Lime shell, hard	6825	Shale, dol. limestone, sandstone	28	
Shale, black	6840	Shale, dol. limestone, sandstone; 6840′ buff sandy dolomite very fine texture.	28	
Lime, shell, black hard	6845	Shale, dol. limestone, sandstone. 6850′ argil. dolomite	28	
Lime, sandy grey medium	6860	Shale, dol. limestone, sandstone	29	Swab and bail.
Lime, black	6885	6880′ dark impure	30	
Lime, black hard	6895	6890′ buff imp. dol. dk shale with dolomite partings.	31	
Lime, black hard	6910		1928 Jan. 1	Shale still rvnning in gets awful thick
Lime, black hard; medium; harder; hard; medium	7210	6950′ dark fine grained impure shale; 7000′ dolomite; 7010′ brownish dk. impure shale. Shale, dol. limestone, sandstone; shaley limestone and shale; hd. gr. shale and dk. limestone.	2–17	Harder than usual; sand reel about gone; replace brass bushing and clutch brake on sand reel; swabbed; about 2500′ oil in hole; swab 2 ft. in gun barrel tank.
Shale, black soft	7220		18	
Lime, black hard	7230		18	

	Depth in feet to:	Notes	Date 1927	Driller's remarks
Slate, black medium	7250	7240' dark fine grained shale	19	Swab 5–10½'–6–6"; cut off and spliced cable.
Lime, black hard	7275		20	
Lime, shell black hard	7290	7290' dolomite with dol. partings.	21	
Lime, black hard; very hard 7545'; extra hard 7580'	7646	7320' dk. fine grained shale; tray of ostracods; 7390' lower Wolfcamp?; dark gray shale; shale, gray brown limestone. University determination: dk. gray calc. shale and brownish gray lime. 7450' dark gray shale and little lime; 7480' dark gray shale; oil stained. 7520' dk. gray calc. shale and brown limestone. 7620' dk. gr. calc. shale; 7640' dk. grk. shale and med. brown sh. Pure: shale-gr-brown limestone; flint and quartz; sh. limestone and brown flint.	22 to	Ran sand line off; repair sand reel. SD 18 hrs. No hole made repairing sand reel; installing extra brake wheel and putting in new tug wheel parts; no drilling done since 27th. Repairing tug wheel; sand reel; start up at noon; Swab. Ran on another cable cut off about 1200' of the Hazard line run since 11–8–27; Swab—11'2" now in tank will need new tug wheel to swab again (Need ⅞ x 4500 Hazard Drlg. Line). Swab and splice line; lost and fished out bailer. Swab—spliced sand line; swab; SD 8 hrs. electricity off; SD 8½ hrs. electricity off.
Lime, gray hard	7660		23	
Lime, sandy black hard	7670		24	Swab.
Lime, black hard; sandy at 7820'; hardest yet at 8062'; very hard 8067–8082'	8160	Univ; Gray limestone; 7680' gr. shale, calcite, calc. shale; 7710' few quartz grains; 7740' OIL stained shale, calc; 7750' gr. calc. shale and few clear quartz grains; 7760' dk. gr. shale med. gray limestone and quartz grains; 7780' gr. shale dk. A little calcite; 7810' gr. sh. limestone and little calcite. Possibly Pennsylvanian: 7880' dk. gr. sh.; little calcite; 7920' gr. sh. med. limestone and some calcite; 7940' gr. sh. brownish gr. limestone. 7980' dk. gray shale; 7990' same and med. gr. limestone; 8030' dk. gr. sh.; 8050' same and med. gr. limestone. 8080' dk. gr. shale; 8090' dk. gr. sh. a little limestone and some pyrite; 8100' dk. gr. non-calc. sh. many radiolaria and sponge spicules. New ⅞ x 4500 Pure Hazard Drlg. line; shale limestone and flint; quartz fragments sh. limestone, flint and quartz; went in with fishing string and lost it; fished from 3–22 to 3–28 got both strings. Ran new ¾ x 10 000' Black Drlg. Line ½"x10,000' Black sand line. Shale and limestone; shale; limestone and brown flint.	25 to April 24	Cut and splice cable; spooled top cable ran on another cable. Shut down 18 hrs. waiting on and changing sand sleeve pulley; bailing out and sand reel clutch on band wheel broke; put sand reel sprocket on band wheel shaft. Swab and get ready to work on tug wheel. SD 18 hrs. rebolling brake wheel. Splice cable and put on brake band; put up crown and sand pulleys; run in two splices on cable; swab 6" twice; cable broke fishing. Fishing; got up in casing still sticking; fishing string fast in casing; jerking 30 hrs.; got fishing tools out working on turn jars; fishing for tools with 700' of cable in them; got cable and tools by 10 A.M. 3–26–28; changing lines; swabbing; cleaning out; breaking in new cable; lost bottom section of bailer in hole; fishing for bailer—2 hrs.; SD at 2:30 A.M. 4–7–28 electricity went off till 8 A.M. Hardest lime that has been found at 8062; motor burned out; changing motors, breaking new joints, swab. Very hard from 8060 to 8075'; put compound on cable; change electric control.

	Depth in feet to:	Notes	Date 1927	Driller's remarks
Lime, black	8180		April 25–26	
Slate	8225	Univ: 8200′ black non-calc. sh.; some fine sand	27–29	
Lime	8230	While rebuilding this rig the electrical equipment was used to drill Texon—Univ. No. 1 South of Best, Texas. Bailer went to bottom when rig burned;	29 to Aug. 15	Rig burned 1 A.M. again sparks from brake band of sand reel; upper part of derrick uninjured; cleaning and rebuilding rig after fire; concrete foundations for everything; put on new ¾x10,000 R. L. Plow steel Black wire and Steel Co. drilling line and new ½x3500 plow Steel Black—sand line; drilling line used to fish bailer; got them; waiting for motors; rigging up; well flowed 117½ bbls. installing motors and control; 8-3-28 well flowed 92½ bbls.; rigging up.
Lime, black	8245		16–18	Start drilling.
		Later found part of a combination wrench had caused the trouble. It had probably been in the hole for some time but was back in some pocket and came out in time to catch the bailer about 1200′ off the bottom.	19 to Sept. 12	Lost bailer; fishing; waiting on Dickson gray; run hollow reamer; swabbing and running impression block; cut off swivel, change tools; driving bailer splice cable; drive bailer to bottom; fish with grab; fished bailer out with friction socket; splice cable and swab; string up and start to drill again; drilling iron or awfully hard shell; still very hard.
Correction	8245–8250		13	Drilling hard measured with moseir meter corrected to 8250′. Spliced line; swab; caving; bad hole; lose bailer fishing; fished bailer out and spool lines to go to No. 7; waiting on drilling line; run on new cable; run and splice sand line, flowing well bail and stretch cable; change sand reel brake drum; work on sand reel; taking temperature test; 5720′ equals 122 degrees F. 6500′ equals 135 degrees F. 7000′ equals 143 degrees F. 7500′ equals 152 degrees F. 8000′ equals 161 degrees F. 8300′ equals 170 degrees F. Bailing mud; mud running in again; do lots of bailing; hole awfully muddy; change sand reel back brake. No hole made swab and bail mud; working very light—1 driller off; swab.
Lime, black; gr. at 8281 and 8340; hard at 8332, 8399, 8461′.	8480	Univ: 8336′ dark non-calc. sh fine grained mic. Some calcite; 8367′ sh limestone and calcite; green and black shale; blk. shale with sand; blk. shale with little calcite; dk. gr. to blk. shale; 8407′ dk. gr., blk. shale; little calcite; 8411′ dk. gr. to black shale small amount of calcite; 8437′ dk. gr. blk. some calcite; 8439′ grains sand; 8439′ dk. green and blk. non-calc. shale and calcite; and small amount pyrite; no fossils. 8447′ some shale little calcite; few grains sand; 8454′ fine grained blk. shale more calcite; 8467′ fine grained shale; little calcite; no fossils; ⅞ x 11,000′ Black drlg. line.	14 to Nov. 18	
Lime, black sandy	8482	Top of Gas Sand-hard rounded.	19	
Sand (quartz)	8484	Quartz sand 8482′; abundance well rounded quartz shale; calcite 8486′ well rounded quartz sand.	19	

	Depth in feet to:	Notes	Date 1927	Driller's remarks
Lime, sandy dark	8490	8490′ dk. gr. and blk. sh. with little sand and little calcite; no fossils.	20	
		Lost and fished out swab.	21–22	Swabbed and broke cable; fishing for tools; got tools out start drilling.
Sand, dark; hd. at 8502	8506	8500′ some shale; lots calcite not much sand; 8506–10′ same with quartz sand.	23–26	Corrected by meter; gas increasing.
Lime, sandy gr hard	8514	8510′ gr. to blk. shale with 8514′ light colored calc. some calcite and sand.	27	
Shell, sandy gr	8515		28	
Lime, sandy gr.	8516		28	Swab; flow more gas.
Lime, black hd.	8518		29	Flowed one head.
Lime shell, blk.	8520		30	
			Dec. 1–2	No hole made, gas increasing; drillings gum up bailer; clean hole; oil flow 40 bbls. no hole.
Lime shell	8523	Top of 4th pay	3	Gas pressure too great to bail; gas increase.
Sand-(inc sample)	8525		4	Can't get tools in hole.

SOME UPPER CRETACEOUS TAYLOR AMMONITES FROM TEXAS

BY

W. S. ADKINS

Early in 1924, Mr. E. L. Porch discovered a level of phosphatized ammonites in the upper Taylor formation at localities about 5 miles west of Emhouse, Navarro County, Texas, and these ammonites and other associated fossils he kindly gave to the writer for description. At a later date there was discovered in Travis County a Taylor locality with about the same fauna similarly preserved. Material from the San Carlos and Terlingua districts, which is discussed in this paper, was collected in 1928 by Mr. M. B. Arick and the writer. For convenience of future reference there is also described in this paper a small Taylor brachiopod which occurs near Terlingua in association with a fauna of micromorphic ammonites, gastropods and other limonitized fossils.

Figured material and types of new species are in the collections of the Bureau of Economic Geology at Austin.

The Taylor formation is mainly of Santonian age, and the portion of the Taylor from which the Austin and Emhouse fossils here discussed come is upper Santonian, of Stantonoceratan age in Spath's 1926 zonation. Further, the level of the San Carlos fossils here discussed is probably of basal Stantonoceratan age, zone of *Placenticeras guadalupae* (Stantonoceras).

The following ammonites have been reported from the Taylor and its equivalents in central Texas:

Baculites asper Morton
Baculites taylorensis n. sp
Baculites sp. Stephenson
Scaphites hippocrepis Morton
Scaphites porchi n. sp.
Scaphites aricki n. sp.
Scaphites spp. Stephenson
Turrilites spp. Stephenson
Parapachydiscus streckeri Adkins
Parapachydiscus travisi n. sp.
Hamites (?) clinensis n. sp.
Hamites (?) taylorensis n. sp.
Ancyloceras cfr. tricostatus (Whitfield) Stephenson

The following ammonites are recorded from the San Carlos beds, supposed to be Taylor equivalents, in western Presidio and Jeff Davis counties:

- Placenticeras (several species)
- Baculites asper Morton
- Baculites ovatus Say
- Baculites spp.
- Pseudoschloenbachia chispaensis n. sp.
- Mortoniceras cfr. shoshonense Meek
- Hamites (?) cfr. taylorensis n. sp.
- Placenticeras guadalupae (Roemer) *(Stantonceras)*
- Mortoniceras delawarense (Morton)
- Hamites spp. Vaughan
- Scaphites sp. aff. S. nodosus Owen
- Schloenbachia (?) n. sp. Stanton
- Heteroceras sp. indet. Stanton
- Hamites spp. Stanton

Baculites taylorensis n. sp. .... **Plate V, figures 9–11**

Straight limb fragments, gently tapering. Cross-section ovate, not broadly so, somewhat as in American baculites figured as *B. asper* (e.g., Meek 1876, Inv. Pal. Mo., p. 406, fig. 60), broadly rounded on dorsal (antisiphonal) side, more sharply rounded on siphonal side. The shell and cast bear on the central and dorsolateral portions of the flank a few, distant, heavy, arcuate nodes, placed almost transverse to the long axis of the shell, somewhat coarser at dorsal end, more finely prolonged at ventral end, slope on side toward aperture more gentle, toward initial end of shell more abrupt. In addition, between these crescents, there are a few faint striæ or raised ridges which arch sharply forwards to cross the dorsal and ventral midlines. This species is large for the genus.

Suture with usual elements, lobes and saddles somewhat dissected. Siphonal lobe broad, with a small lobule in the mid-line as recorded by Reeside for *Baculites codyensis* Reeside;[1] first saddle tall, narrow bifid; first lateral lobe taller than siphonal lobe, bifid; second saddle and second lobe nearly quadrate, bifid; third saddle smaller, quadrate, bifid. Antisiphonal lobe bifid.

The coarse, distant nodes and their position distinguish this species from the common American species already described. There are large individuals from formations equivalent to part of the Taylor near San Carlos, Texas, somewhat similar in shape, size and taper, but they have the more broadly oval cross-section and the distant, rounded nodes of *B. asper*. The new species has no marked resemblance to *B. anceps* or to *B. aspero-anceps* Lasswitz, or to *B. codyensis* Reeside.

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[1]Reeside, J. B., Jr., 1928. Cephalopods from the lower part of the Cody shale of Oregon Basin, Wyoming. U. S. Geol. Surv., Prof. Paper 150–A, 4, pl. 2, figs. 6–19 (esp. figs. 12, 16, 19).

Taylor: Travis County, Manor-Austin road, 7.5 miles northeast of Austin (holotype and paratypes). At this locality the sandy, glauconitic clay in a restricted zone of about 2 feet thickness contains innumerable phosphatized individuals, both shells and casts, of this baculite.

Scaphites porchi n. sp.............................. ....**Plate V, figures 1–3**

Material at hand consists of two individua's having coiled portion not preserved but having straight limb and part of the hook, the non-septate living chamber with only one suture at proximal end; and one individual showing part of living chamber. These are phosphatized casts in a sandy, glauconitic matrix.

Form obese but slightly less so than *Scaphites aricki;* it consists of coiled portion and short, thick extended limb. No distinct ribs visible. Ornamentation consists of four rows of thick, pointed tubercles on each flank. In a given length of coil there are about 5 coarse tubercles in the dorsalmost row, 7 in the second row, 8 in the third row, and 9 in the fourth row. The venter is a smooth, concave band. Spacing of the tubercles is somewhat more open on the upper part of the hook.

The suture is typically scaphitic. The external (siphonal) lobe is nearly quadrate and somewhat inflected on the sides; first saddle asymmetrically divided by two lobules, as is true also in some of the more mature sutures on the septate portion of the straight limb in *S. aricki;* first lateral lobe not much broader than siphonal lobe, bifid; second saddle slightly broader than second lobe; third lobe small, situated on umbilical wall.

This species and the next have no close resemblance to other described American species so far as is known to the writer. Schlüter has figured[2] some Upper Cretaceous species with 5 rows of nodes on each side. Of these *Acanthoscaphites pulcherrimus* (A. Römer)[3] is a compressed species with an entirely different form and ornamentation from the two Texan species here described.

Another species, *Acanthoscaphites spiniger* (Schlüter)[4] has 4 rows of tubercles on each side, but differs from the species here described in its much more compressed form, and in its numerous, prominent ribs. These species occur in the Upper Campanian Mukrontenkreide. Such resemblances are only superficial, and in fact, these two Texan species do not have the features of *Acanthoscaphites* (genotype:

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[2]Schlüter, Clemens, 1871. Cephalopoden der oberen deutschen Kreide, pl. 26, figs. 1–5.

[3]Reeside, . B., Jr., 1928. Te schaphites, an Upper Cretaceous ammonite group. U. S. Geol. Surv., Prof. Paper 150–B, p. 33.

[4]Schlüter, Clemens, 1871. Ceph. ob. deutsch. Kr., pl. 26, figs. 1–5.

S. tridens Kner[5]), but seem closer to the Coniacian *Scaphites ventricosus* Meek and Hayden,, the genotype of *Anascaphites* according to Hyatt, a species of *Scaphites* according to Reeside.[6] Another American species, *Scaphites iris* Conrad[7] from Owl Creek, Ripley, Mississippi, seems to have 4 rows of nodes on each side, but is more compressed than the present species. *Scaphites nodosus* Owen and its varieties are likewise more compressed.

Taylor (about 150 feet above base): Travis County, Texas, Austin-Manor road, 7.5 miles northeast of Austin, in cut through Taylor upland on east side of Big Walnut Creek valley and just east of Missouri, Kansas and Texas Railway (holotype and two paratypes in Bureau of Economic Geology).

Scaphites aricki n. sp...**Plate V, figures 7–8**

This and the preceding species do not greatly resemble the species published in the American literature available to the writer; they both have four rows of tubercles or spinose processes on each side of the ventral mid-line, and in general form and appearance more resemble certain European scaphite species. They differ in the coarseness of the processes: in *Scaphites porchi* n. sp. they are very heavy and prominent, but in *Scaphites aricki* n. sp. they are small.

Form of holotype and paratype obese, ventricose casts, with the usual coiled portion, and a short, thick extended limb. Holotype has preserved only the coiled portion and the beginning of the straight limb; paratype has most of the straight limb and the beginning of the hook. Coiled portion with about 12 primary, dorsolateral ribs extending across umbilical wall to the dorsalmost row of tubercles. The tubercles of the second row lie either on these primary ribs, or at the dorsal end of weak intercalated ribs. Ventrally from the second row, weak bifid or trifid riblets proceed and mostly pass between tubercles of the third row, but at places two of these enclose tubercles of the third row, producing a "loop-and-button" arrangement. Paired riblets of similar arrangement with intercalated single ones cross the venter between the two rows of fourth tubercles, which bound the width of the siphonal lobe. A tubercle of one row thus generally lies opposite a space between two tubercles of an adjacent row, and the riblets originating at the tubercle pass through this space. A half-volution on the coil has about 18 tubercles of the

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[5]Nowak, Jan, 1911. Untersuchungen über die Cephalopoden der oberen Kreide in Polen. II Teil: Die Skaphiten. Bull. Acad. Sci. Cracovie, Cl. sci. math. et nat., Série B, Sci. nat., 547–589, pls. XXXII–XXXIII (esp. pp. 565, 570–579, pl. XXXII, figs. 1–7; pl. XXXIII,figs. 26–29).

[6]Reeside, J. B., Jr., 1928. U. S. Geol. Surv., Prof. Paper 150–B, p. 26.

[7]Conrad, T. A., 1858. Jour. Acad. Nat. Sci., Phila. (II), 3, 335, pl. 35, fig. 23. Whitfield, R. P., 1892. Gast. Ceph. Raritan clays and greensand marls, New Jersey, 265, pl. XLIV, figs. 4–7.

ventralmost row and about 36 riblets crossing the venter, corresponding to about 6 primaries of the dorsalmost row. Ribbing and tuberculation on the straight limb are similar but more open.

The sutures on this species are typically scaphitic, with saddles bifid, and lobes trifid in their less advanced stages, later becoming bifid: in this species, even on the coil, the visible first lateral lobes are bifid, but unsymmetrically so; many of the second laterals are trifid.

External (siphonal) lobe tall, considerably inflected; first saddle tall, not very broad, nearly symmetrically divided by a prominent, trifid lobule; first lateral lobe broad, shorter than external lobe, broader than first saddle, asymmetrically bifid; second saddle narrow, bifid by small, pointed lobule; third lobe short, trifid, situated on umbilical wall. Internal suture not seen.

Taylor: Travis County, Austin-Manor road, 7.5 miles northeast of Austin in road cut just east of Missouri, Kansas and Texas Railway (holotype and paratype). Also at locality 5 miles west of Emhouse, Navarro County.

Horizon: About 150 feet above base of Taylor formation. This locality exposes a zone of *Baculites taylorensis* n. sp., *Baculites anceps*, the two *Scaphites* here described, *Parapachydiscus travisi* n. sp., and numerous pelecypods and gastropods. The fossils are phosphatic casts in a sandy, glauconitic clay.

Another individual from about 5 miles west of Emhouse resembles this species in most features, but differs in being much more compressed laterally. Its whorl thickness is only 59 per cent of its diameter, and in *Scaphites aricki* it is 76 per cent.

Parapachydiscus travisi n. sp. .... **Plate VI, figures 7–9**

Five individuals from the locality west of Emhouse have the following proportions:

	I		II		III		IV		V	
	mm.	%	mm.	%	mm.	%	mm.	%	mm.	
Diameter	54	1.0	50	1.0	50	1.0	43	1.0	41	1.0
Height of last whorl	26	.48	27	.54	24	.48	22	.51	21	.51
Thickness of last whorl	22	.41	21	.42	20	.40	17	.40	15.5	.38
Umbilicus	16	.30	15	.30	14	.28	13	.30	11	.27

Casts: form discoidal, compressed, subangustumbilicate, involute (about ⅝ overlap onto next inner whorl). Elevated oval cross section, thickest at umbilical boundary of flank. Venter rounded, no keel, crossed by low ribs, position of siphuncle marked by faint elevation bounded by two faint depressions. Ribs numerous, low, subequal, marked by prominent umbilical tubercles (about 13–14 on last volution), faint over middle of flank, prominently bent forwards towards aperture on crossing venter, where there are at least twice as many ribs as at the umbilicus.

The species in form and suture greatly resembles *Parapachydiscus neubergicus* F. v. Hauer and the genotype *P. gollevillensis* d'Orbigny. The lobes and saddles are markedly tall and straight, as figured in the suture of *P. gollevillensis*[8] and *P. neubergicus*.[9] The siphonal lobe is tall and considerably dissected; first saddle narrow, bifid; first lateral lobe taller than siphonal lobe, trifid, elaborately and symmetrically inflected; second lateral lobe slightly shorter than siphonal lobe, trifid; third lateral lobe located on steep umbil'cal wall; saddles bifid. The internal suture consists of a tall, slender, trifid internal (antisiphonal) lobe, and two other lobes, which are tall, trifid, and of decreasing size away from the dorsal mid-line.

This species differs from *P. neubergicus* in having the dorsal portions of the primary ribs, and the umbilical tubercles, much less prominent, and the lobes more distinctly trifid. It is similar in many features of form to *P. gollevillensis*,[10] but differs in having the ventral portions of the ribs more oblique, more inconspicuous, and less numerous. The suture is rather similar. These related species are both Maestrichtian, later than Taylor.[11]

Taylor: Five miles west of Emhouse (holotype); 7.5 miles northeast of Austin, on Manor road (paratypes).

Hamites (?) clinensis n. sp.......... .. ..**Plate VI, figures 10–11**

This species is not referable to *Hamites* as properly understood, but until better and more extensive material of the species is available and until the Upper Cretaceous genera are more adequately treated in the literature, it will be practicable to defer the accurate generic assignment of this species.

It has hamitoid coiling, long straight limb and hook in one plane, and in form somewhat resembles *Hamites elegans* D'Orbigny.[12] Holotype consists of a cast with one limb and the beginning portion of the hook; cross-section short oval. Ribs subequal, slightly inclined. Two rows of tubercles, one row on each side of the ventral

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[8]D'Orbigny, A., 1840. Paléontologie française, terrains crétacés, Céphalopodes, pl. 101.

[9]Grossouvre, A. de, 1894. Recherches sur la craie supérieure. II partie: Paléontologie—Les ammonites de la craie supérieure, 207–213, fig. 80 (on page 209).

[10]Grossouvre, 1894, Amm. craie sup., pl. XXIX, fig. 5; and esp. XXXI, figs. 9 a–b. Seunes, Jean, 1892. Contributions à l'étude des céphalopodes du crétacé supérieur de France. Soc. géol. France Mém. 2, 10–13, pl. V (XIV), figs. 1, 2, 3 a–c.

[11]Seunes 1892, Contr., p. 12. Spath, L. F., 1926. On new ammonites from the English chalk. Geol. Mag., LXIII, pp. 77–83 (esp. table, opp. p. 80).

[12]D'Orbigny, A., 1840. Pal. franç., terr. crét., Céph., pl. 133, figs. 1–5.

midline. Each tubercle is elongated along the limb, and covers two ribs. These alternate with one non-tuberculate rib; all ribs cross the venter, and on crossing the dorsum are reduced but distinct. Also, there is on the midline a faint, rounded swelling opposite the tubercles.

Suture of I. U. L. E. type, with two bifid lateral lobes on each side. All saddles and lobes except the internal (antisiphonal) lobe are symmetrically bifid. External (siphonal) lobe tall, with trifid, slender points; it is located asymmetrically in respect to the lines of tubercles. First saddle nearly symmetrically bifid by a small trifid lobule. First lobe longer than siphonal, bifid. Second lobe of same length as siphonal, bifid. Internal (antisiphonal) lobe short, trifid, the middle lobule least conspicuous.

The two rows of tubercles of this species suggest its relation to the family Nostoceratidae and its similarity to *Oxybeloceras*[13] such as the species figured by Spath[14] from the Upper Senonian (Campanian–Maestrichtian) of Pondoland.

Taylor (Anacacho reef facies): Texas Asphalt pit near Cline, Uvalde County, Texas (holotype in Bureau of Economic Geology).

Hamites (?) taylorensis n. sp. .... **Plate VI, figures 12–13**

This species will eventually be referred to another genus, when the Santonian hamitids and other uncoiled forms are better worked out. Hamite-like limb fragments, some nearly straight, most of them slightly curved in one plane.

The cross-section is a short oval, with a ventral facet bounded by the two rows of ventro-lateral tubercles. There is no visible swelling or tubercle on the ventral mid-line. The ribs are slightly oblique, and subequal on flanks and venter, except that every third or fourth rib is slightly thicker over the ventral portion, or else two thin ribs are bundled together; on these primaries are the two rows of tubercles.

Suture of I. U. L. E. type, somewhat dissected. The external lobe is tall and symmetrical; the siphuncle is visible as a narrow rounded ridge. The internal lobe is tall, narrow and bifid, somewhat unsymmetrically. The other two lobes are large and symmetrically quadrifid. The saddles are bifid. This suture is suggestive of *Diplomoceras cylindraceus* (D' Orbigny), a Maestrichtian "hamite."[15]

Taylor: Holotype a cast from locality 5 miles west of Emhouse; paratype from Austin-Manor road, 7.5 miles northeast of Austin.

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[13]Genotype: *Ptychoceras crassum* Whitfield, 1877, U. S. Geogr. Geol. Surv. Rocky Mtn. region, Prel. Rept. Pal. Black Hills, pp. 45–46.

[14]Spath, L. F., 1921. Ann. Durban Mus., III, pt. 2, 50–51, pl. VII, figs. 2 a–b.

[15]D'Orbigny, A., 1840. Pal. franç., terr. crét., Céph., pl. 136.

Also: western Presidio County, Chispa-San Carlos road, about 14 miles south of Chispa Summit, near abandoned oil test and just east of prominent fault line.

Pseudoschloenbachia chispaensis n. sp.................**Plate V, figures 5–6**

The proportions of two individuals are:

	I		II	
	mm.	%	mm.	%
Diameter	87	1.0	58	1.0
Height of last whorl	44	0.5	31	0.53
Thickness of last whorl	20	0.23	15	0.26
Umbilicus	19	0.22	12	0.21

Individual I, the holotype is somewhat corroded and crushed laterally, and individual II gives truer proportions.

Form lenticular, thin, subangustumbilicate, rather involute (overlaps ⅔ of next inner whorl). Tall cuneate cross section, thins abruptly on either side of keel, thickest slightly ventral of middle of flank. Keel entire, low, sharply rounded. Ribs numerous (about 25 in last half-volution), low, rounded, subequal, many dichotomous, or branched and unbranched alternating. Those which reach umbilicus have distinct umbilical tubercle. At the mid-flank the ribs are reduced in height.

Suture very similar to that of *P. papillata* (Crick) Spath.[16] Siphonal (external) lobe tall narrow; external saddle bifid; first lateral lobe as tall as siphonal lobe, as wide as external saddle, trifid; second, third and fourth lobes located on flank, trifid; saddles bifid; fifth lobe on steep umbilical wall.

The genus *Pseudoschloenbachia* Spath,[17] with genotype *A. umbulazi* Baily, is recorded from Umkwelane Hill, Umfolozi, Zululand, and from Pondoland.

Taylor (San Carlos beds): Western Presidio County, Chispa-San Carlos road, about 14 miles south of Chispa Summit (holotype and paratypes, all casts).

Mortoniceras sp. aff. shoshonense Meek....................**Plate V, figure 4**

Small calcitic ammonites similar to this species[18] occur in the San Carlos district, associated with *Placenticeras sancarlosense* Hyatt, *Pseudoschloenbachia chispaensis* Adkins n. sp., and a considerable

[16]Spath, L. F., 1922. On the Senonian ammonite fauna of Pondoland. Trans. Roy. Soc. S. Afr., X, pt. III, 113–147 (esp. p. 141, pl. IX, fig. 1a).

[17]Spath, L. F., 1921. On Cretaceous cephalopoda from Zululand. Ann. S. Afr. Mus., XII, pt. VII, 236–242, pl. XX, figs. 2–3, text fig. B 1–6.

[18]Reeside, J. B., Jr., 1928. U. S. Geol. Surv., Prof. Paper 150–A, 9, pl. 7, figs. 1–11; pl. 8, figs. 1–4.

fauna of gastropods, pelecypods, corals, reptilia and other fossils, in beds of approximate Taylor age.[19] The species has some resemblances to *Mortoniceras bourgeoisi* de Grossouvre[20] from the French Santonian. *M. shoshonense* is recorded from the Cody shale (Coniacian) of Wyoming, by Reeside.

Taylor (San Carlos beds): Presidio County, Chispa-San Carlos road, about 14 miles south of Chispa Summit (rare).

Terebratulina brewsterensis n. sp. .... **Plate VI, figures 1–6**

Shell small; larger (ventral) valve rounded anteriorly, projecting in the beak region. At the beak the posterior margins meet at about a right angle; the contour of the shell anteriorly is nearly square, with rounded corners. The smaller valve is rectangular in contour, somewhat wider than tall, and with rounded corners. Most individuals are thin; there is a rarer ventricose form. Larger valve somewhat convex, beak prominent, cardinal area large in proportion; hinge line nearly straight. Pedicel opening (delthyrium) large, not closed by deltidial plates; the delthyrium has a circular outline, but is open anteriorly on the hinge line. Larger valve has low, broad median sinus, and is ornamented with 50–60 low rounded, subequal radial ribs at the margin. From the beak region, there proceed a few stronger radial ribs. At a later stage a few others of equal strength are inserted between the first. At a still later stage many of these bifurcate into fine ribs. The ribbing of the smaller valve is essentially similar. Small valve, length 7 mm., width 8 mm.; large valve, length 8.5 mm., width 8 mm.

The brachial appartus is not visible in the specimens at hand.

This species is comparable to, and probably congeneric with, *Terebratula guadalupae* F. Roemer,[21] described from the Austin chalk at the ford of Guadalupe River, New Braunfels, Texas. It differs from Roemer's species in contour, in convexity of valves, in details of the beak region, and in horizon; it is somewhat similar in ribbing. The smaller valve is more quadrate, both valves are much less convex, the ribs are more distinctly granulated, and the pedicel opening is larger, than in *T. guadalupae*. The ribs on some individuals are coarser than in that species; one individual (Pl. VI, fig. 1) is unusually inflated, and may belong to another species.

Taylor: Alpine-Terlingua road, at steep clay hill east of Hen Egg Mountain, about 14 miles north of Terlingua (holotype and five paratypes in Bureau of Economic Geology).

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[19] Vaughan, T. W., 1900. U. S. Geol. Surv., Bull. 164, pp. 76–82.

[20] Grossouvre, A. de, 1894. Amm. craie. sup., pl. XIV, figs. 3–5.

[21] Roemer, Ferdinand, 1852. Die Kreidebildungen von Texas und ihre organischen Einschlüsse, 82, pl. VI, figs. 3 a–d.

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(All figures x 25)

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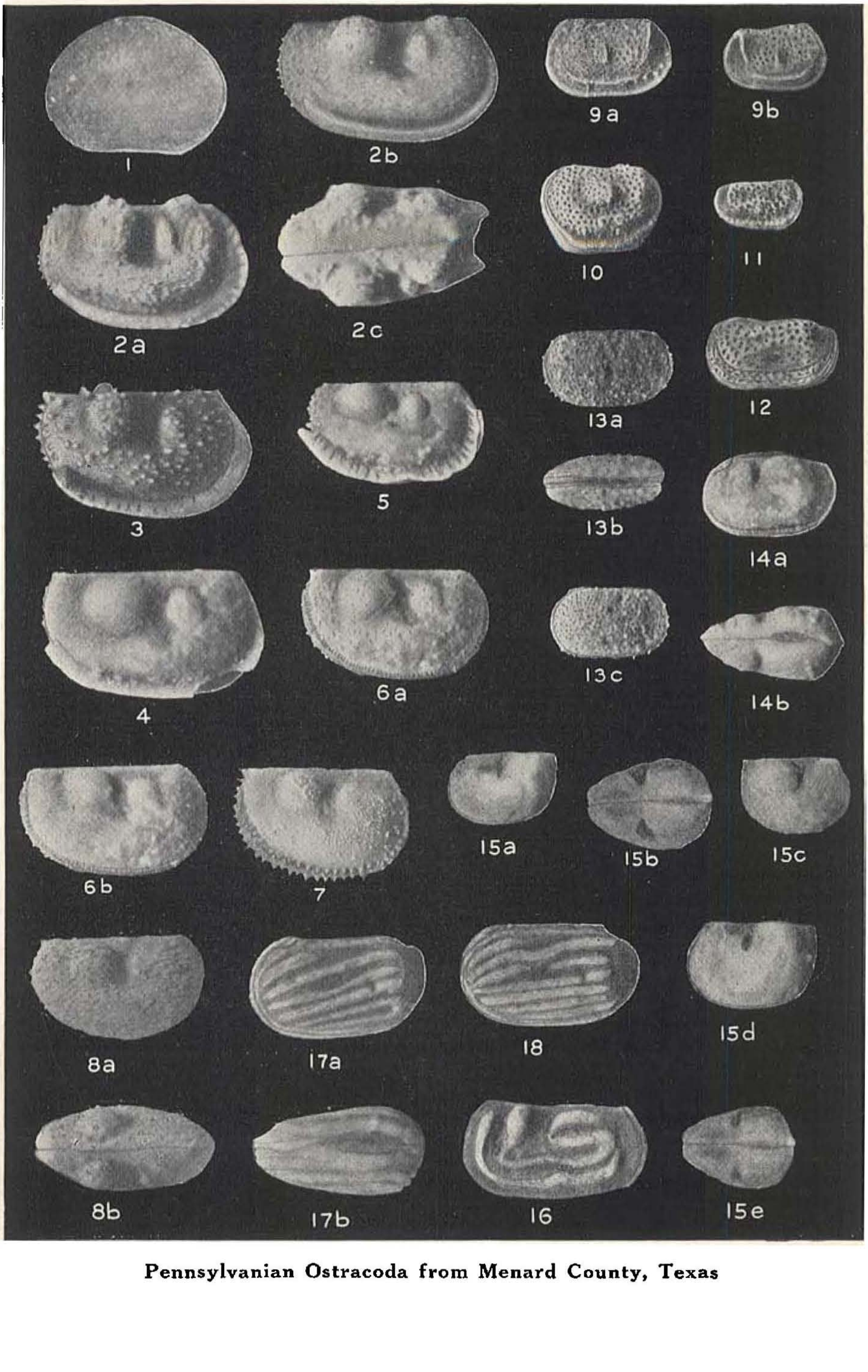

Pennsylvanian Ostracoda from Menard County, Texas

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(All figures x 25)

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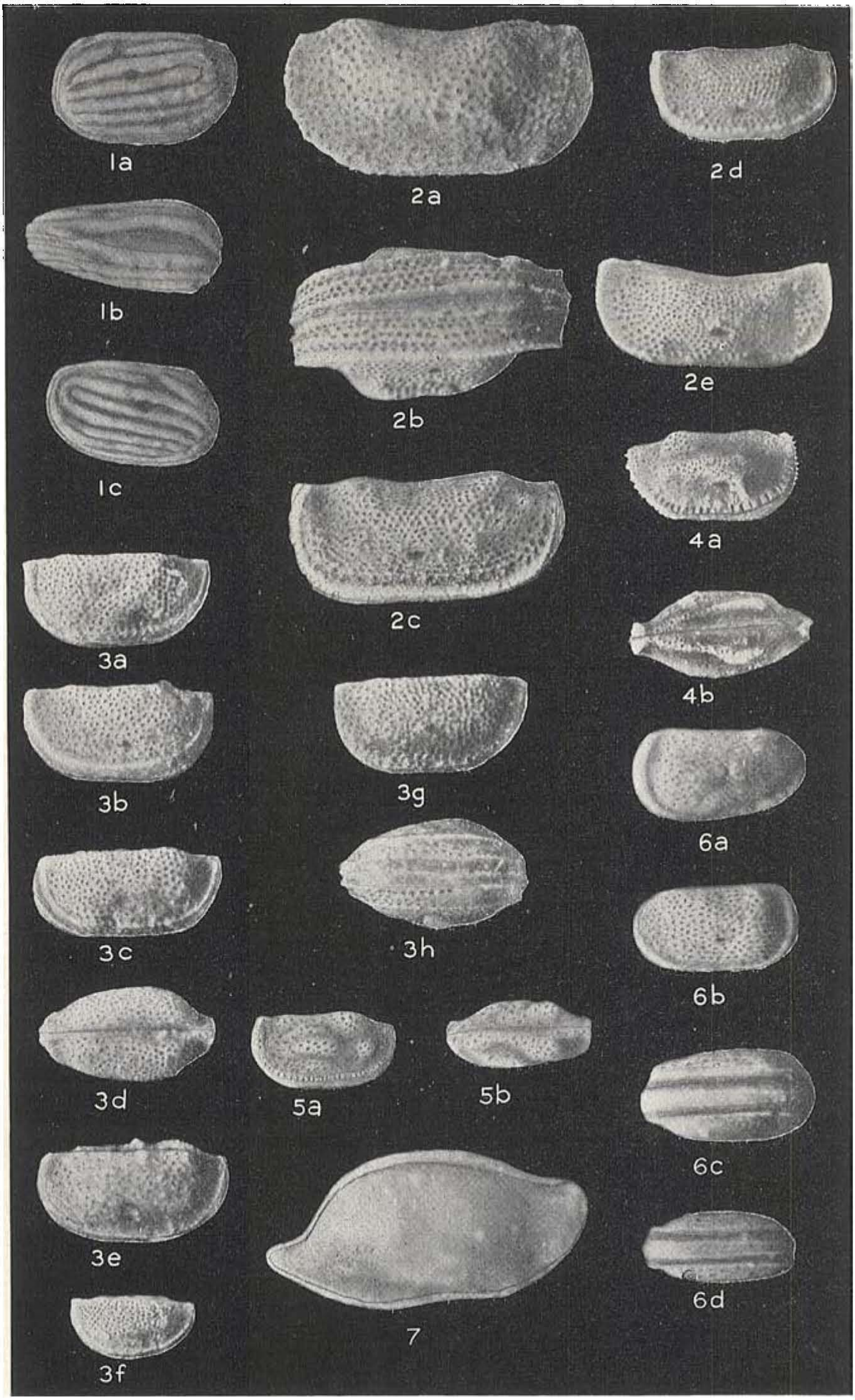

Pennsylvanian Ostracoda from Menard County, Texas

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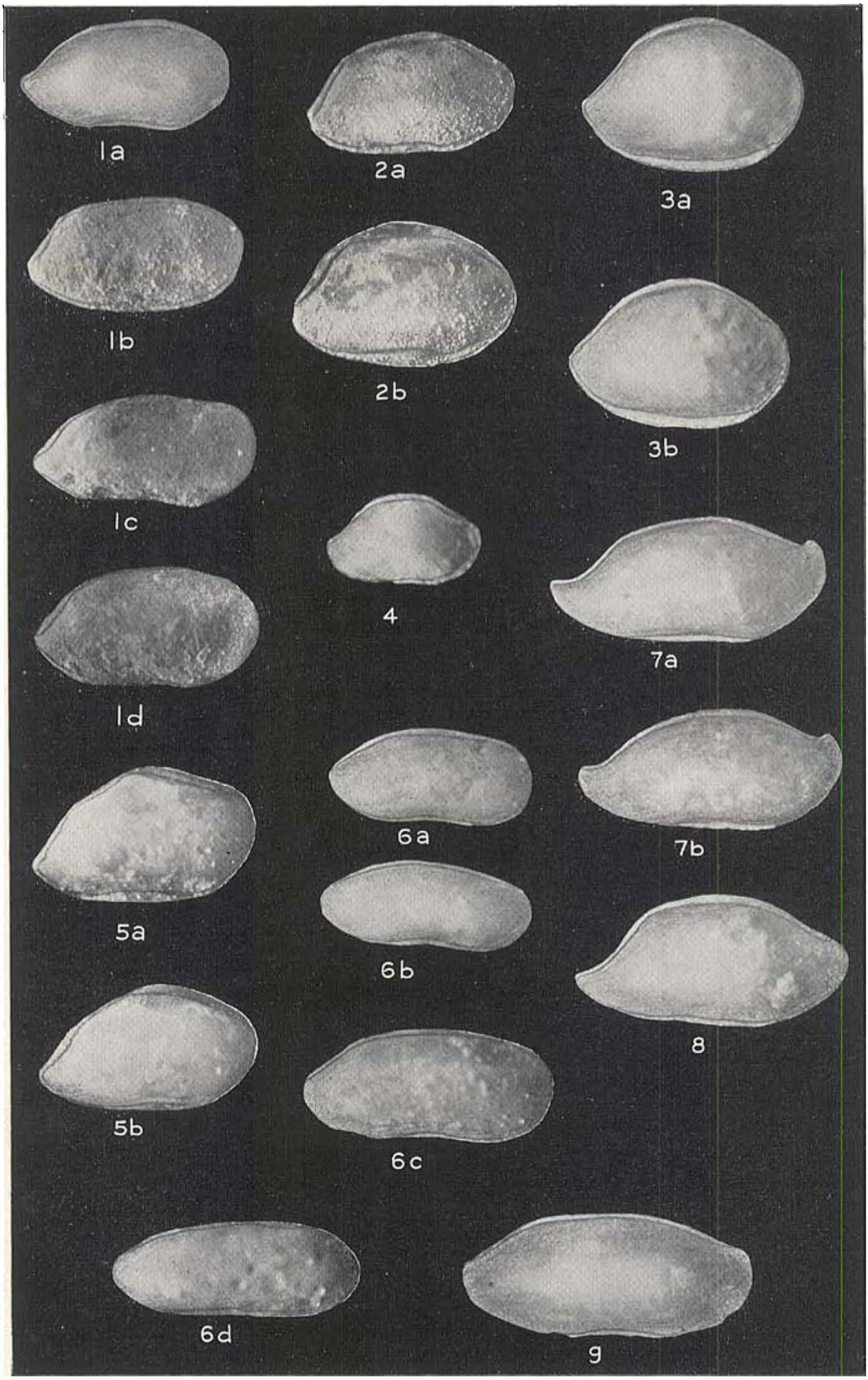

Pennsylvanian Ostracoda from Menard County, Texas

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(All figures x 25)

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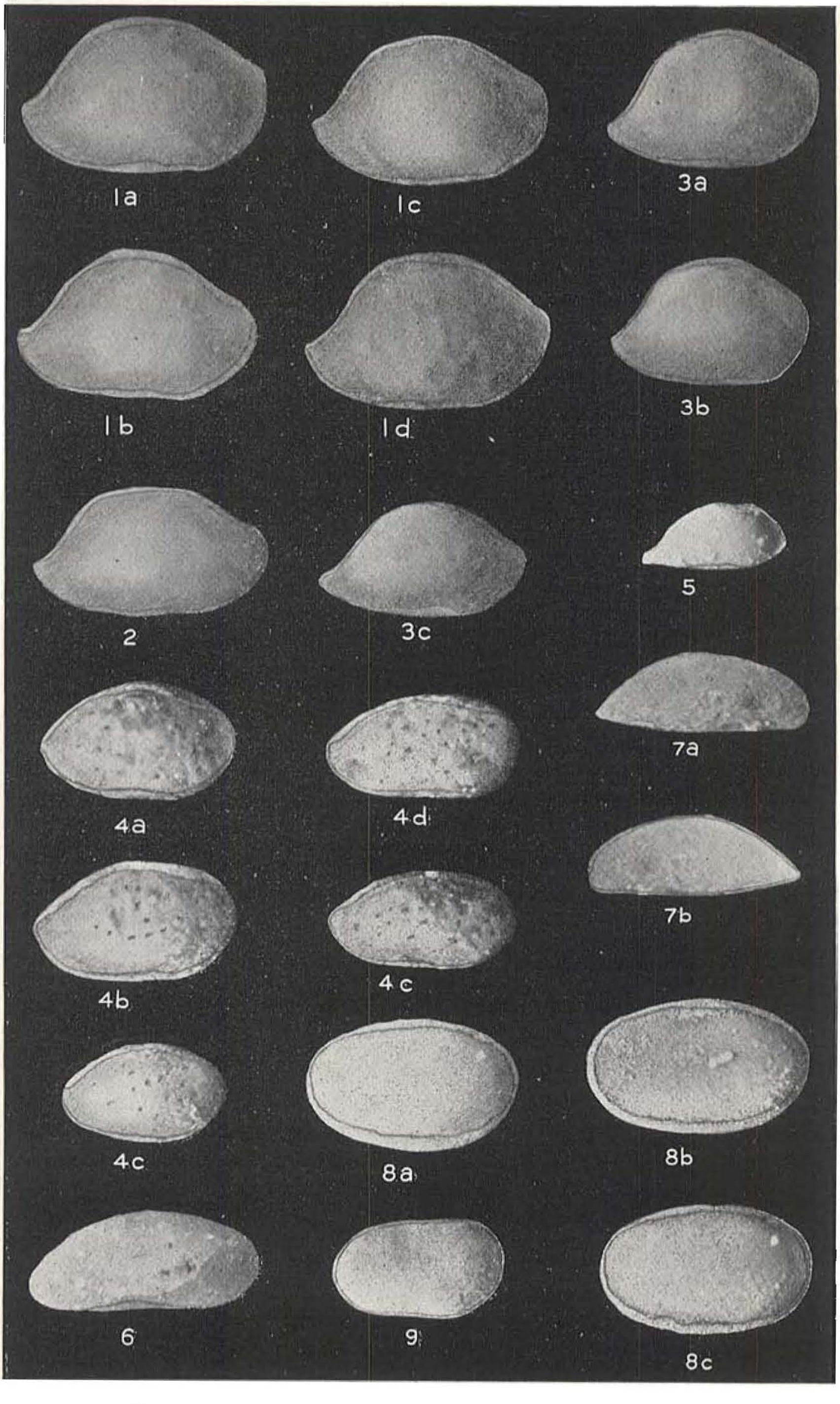

Pennsylvanian Ostracoda from Menard County, Texas

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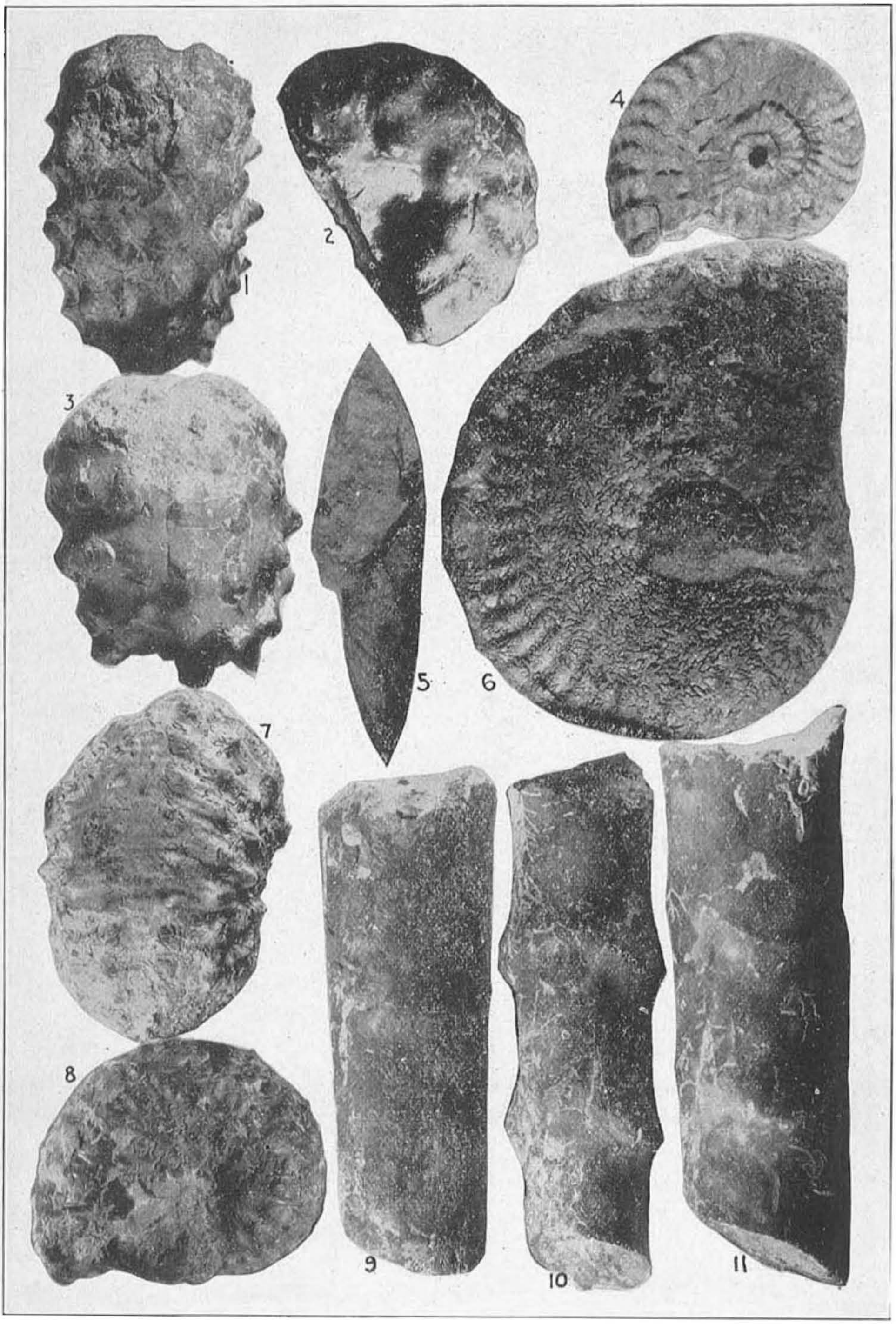

Upper Cretaceous (Taylor) Ammonites from Texas

PLATE VI

Figs. Page

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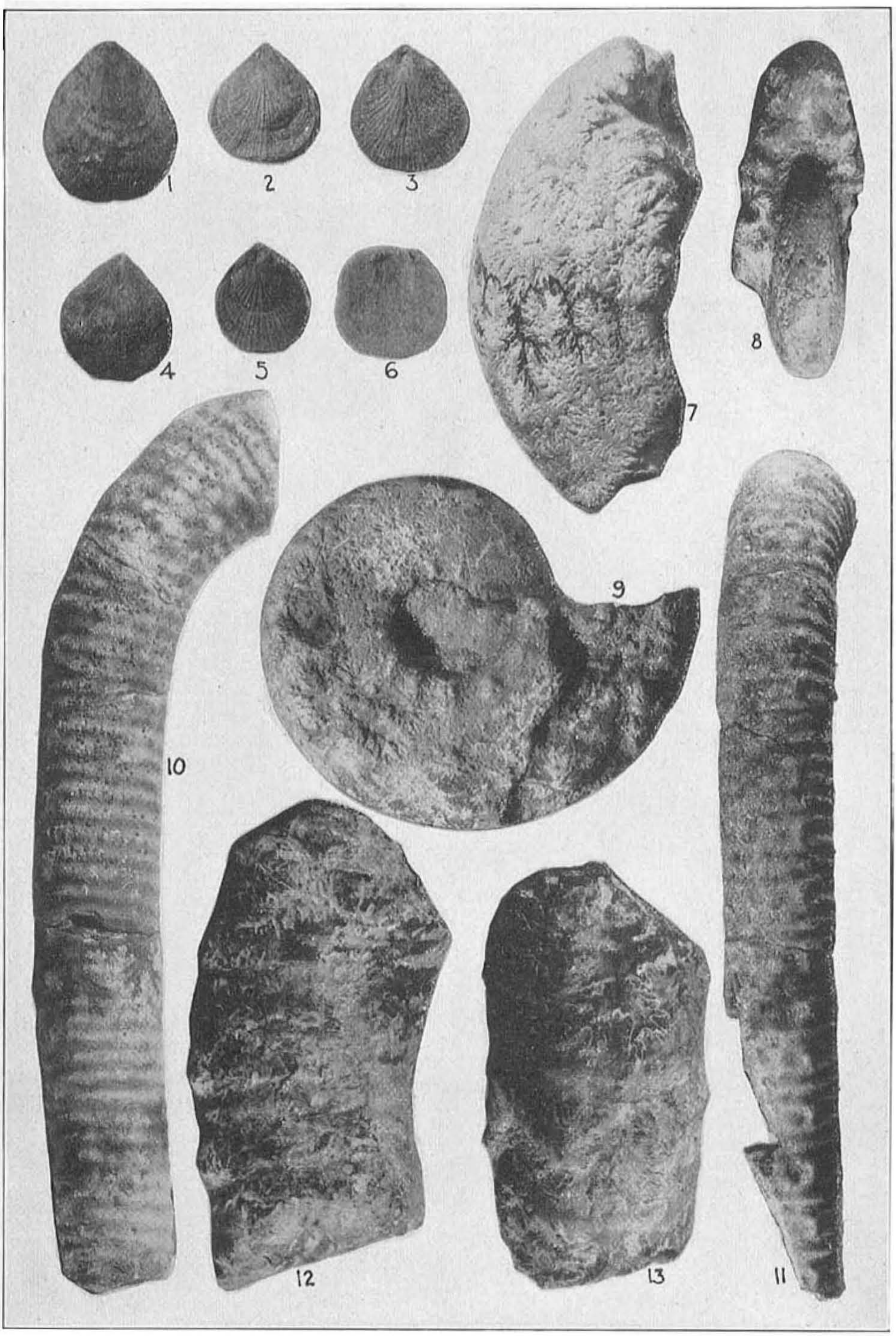

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