University of Texas Bulletin

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W. M. WINTON

BUREAU OF ECONOMIC GEOLOGY

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

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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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INTRODUCTION

Denton County is in the second tier of counties in the north-central part of the State. It is almost square, with sides nearly thirty miles each, and a total area of 941 square miles. The county was organized in 1846, being separated from Fannin County and was named for John B. Denton, one of the pioneer settlers. The position of this area is shown in Figure 1.

The population of the county, according to the estimate of the Denton Chamber of Commerce was 40,000 in 1925, of which the City of Denton and its environs includes 10,500.

Figure 1. Map of Texas showing locations of Denton County (in black). "L.C." indicates Lower Cretaceous and "U.C." Upper Cretaceous outcrops.

Denton, the county seat, includes two of the most important state schools, the College of Industrial Arts, also known as the State College for Women; and the North Texas Teachers' College. The combined annual enrollment of the two schools is about 6,000. The presence of these two great schools, and the use which may be made by the students of this bulletin, is partly responsible for the inclusion of much of the scientific and paleontologic data presented here.

Other towns of some importance are Justin, Ponder, Krum and Sanger, on the Santa Fe Railroad in the western part of the county; Roanoke, Aubrey and Pilot Point, on the Texas and Pacific Railroad; and Lewisville and Garza, on the Missouri, Kansas and Texas Railroad in the eastern part.

The region is one of considerable economic possibilities, some of which will be indicated in this paper. Unfortunately, most residents of Texas think of the geologic possibilities as limited to oil and gas only. The likelihood of any development of sources of petroleum in Denton County is very remote, although this point is discussed in more detail later. However, the possibilities for Portland cement plants, large irrigation and flood control districts, crushed rock, gravel, lime and other industries are great. Some of these possibilities will be discussed. The permanent value to the community of such a plant as that of the Acme Brick Company at Denton is far greater, though less spectacular and exciting than an oil well.

Presented with this bulletin is the first detailed geologic map of the county, although some geological study has been made previously. R. T. Hill in 1900 in Part 7 of the Twenty-first Annual Report of the United States Geological Survey published a map and a study of the geology of all of the North Texas counties included in the Black and Grand Prairies. Unfortunately this splendid monograph is not readily available to the occasional student. Copies are rare and valued highly. The supply of the Government Printing Office was exhausted long ago, and the only source now is the second-hand book dealers. Persons desirous of making a more detailed study of the Texas Cretaceous rocks than is included here should, if possible, provide themselves with this work. The general stratigraphy and paleontology of the Lower Cretaceous of this part of the State is discussed in considerable detail in two publications of the State Bureau of Economic Geology: *The Geology of Tarrant County* (the next adjoining county to the south) and *Paleontological Correlation in North Texas.* Both of these are to be had for a small sum from the Bureau. The county is included in the *Review of Texas Geology*, another publication of the Bureau which discusses the geology of the State as a whole and presents a large geologic map of the entire State on a scale which makes the sheet about a yard square. This also may be obtained from the Bureau.

The customary bibliography will be omitted from this paper as the writer (with W. S. Adkins) has recently presented a fairly complete bibliography on the geology and paleontology of the lower Cretaceous.[1]

No topographic map of this area has been published, although a part of the lower margin is included as the north part of the Fort Worth sheet, published by the United States Geological Survey and later revised by the Corps of Engineers, United States Army. This sheet may be obtained from the United States Geological Survey.

Precise levels in the county are limited mainly to the profiles of the railroads, to city works in Denton, and to the area at and above the Garza dam. A list of elevations will be given in another chapter.

A detailed soils map of the county, by W. T. Carter and M. W. Beck, was published in 1922 by the Bureau of Soils of the United States Department of Agriculture. Copies of this map and the accompanying bulletin may be obtained from the Department of Agriculture or through one's Congressman. The base map of the soils survey, revised by N. N. Harris, county engineer for Denton County, was the

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[1]Paleontological Correlation in North Texas. University of Texas Bulletin 1945.

principal areal base used in mapping the geology, and shows not only all details of roads, villages and other landmarks, but also the trace of all streams and the branches, a feature very helpful in mapping the geology. Considerable assistance was obtained from the original soils map in the determination of the outlines of the alluvial valleys, although in some places flood plain deposits which are mapped together by the geologist have been subdivided by the experts of the Bureau of Soils. A remarkable coincidence between the soils map and the geological map is seen in the area of the one marking off the Houston Clay, shallow phase, and in the other, the Austin Chalk outcrop.

Temperature and rainfall records for any considerable time are lacking, but the nearness of most of the county to either Fort Worth or Dallas should enable those interested to transfer data from these cities to different parts of Denton County.

The county is traversed by the main lines of the Gulf, Colorado and Santa Fe and the Texas and Pacific and by a Dallas to Denton branch of the Missouri, Kansas and Texas railroads. This last line has been electrified and a regular schedule of interurban cars is maintained between Dallas and Denton. The Saint Louis and San Francisco Railroad passes through the southeastern corner.

The public roads have been considerably improved in recent years, and besides a number of improved county roads the area is traversed by State Highways Numbers 10, 39 and 40, which through most of the county are asphalt roads of the finest type.

ACKNOWLEDGMENTS

First on the list should come Mr. N. N. Harris, County Engineer of Denton County, who furnished an accurate base map drawn on the original soils map and showing all new roads, public improvements and drainage features. Major John B. Hawley, by way of a "vacation" from a busy engineering practice accompanied the writer for a month during the geologic mapping. Mrs. W. M. Winton

drew the geologic map from the field data, and also constructed most of the figures. Misses Sadie Mahon and Margaret Carpenter and Messrs. C. I. Alexander and W. L. Moreman, members of the writer's staff, gave much aid in the photography and the miscellaneous work, and wrote entire sections in the chapter on Micrology.

GEOLOGY

The geology of this county is more varied than most of the other North Texas counties with the single exception of Grayson County.

The following geological column is exhibited in Denton County (see Figure 2):

UPPER CRETACEOUS OR GULF SERIES:

Austin Chalk.
Eagleford.
Woodbine.

LOWER CRETACEOUS OF COMANCHEAN SERIES:

Grayson (the upper portion equivalent to the Buda, the lower portion equivalent to the Del Rio.)
Main Street (equivalent to the Bennington of Southern Oklahoma and equivalent to the upper portion of the Georgetown limestone of Central Texas.)
Pawpaw (included in the Georgetown limestone.)
Weno (the upper portion equivalent to the quarry limestone of the Red River section, and in the northern part of Denton County still preserves the quarry characteristics. This is also included in the Georgetown limestone in Central Texas.)
Denton (in the Georgetown limestone.)
Fort Worth (in the Georgetown limestone.)
Duck Creek (forming the lower part of the Georgetown limestone in Central Texas.)
Kiamitia.
Goodland (Edwards and Comanche peak to the south.)
Walnut.
Trinity-Paluxy.

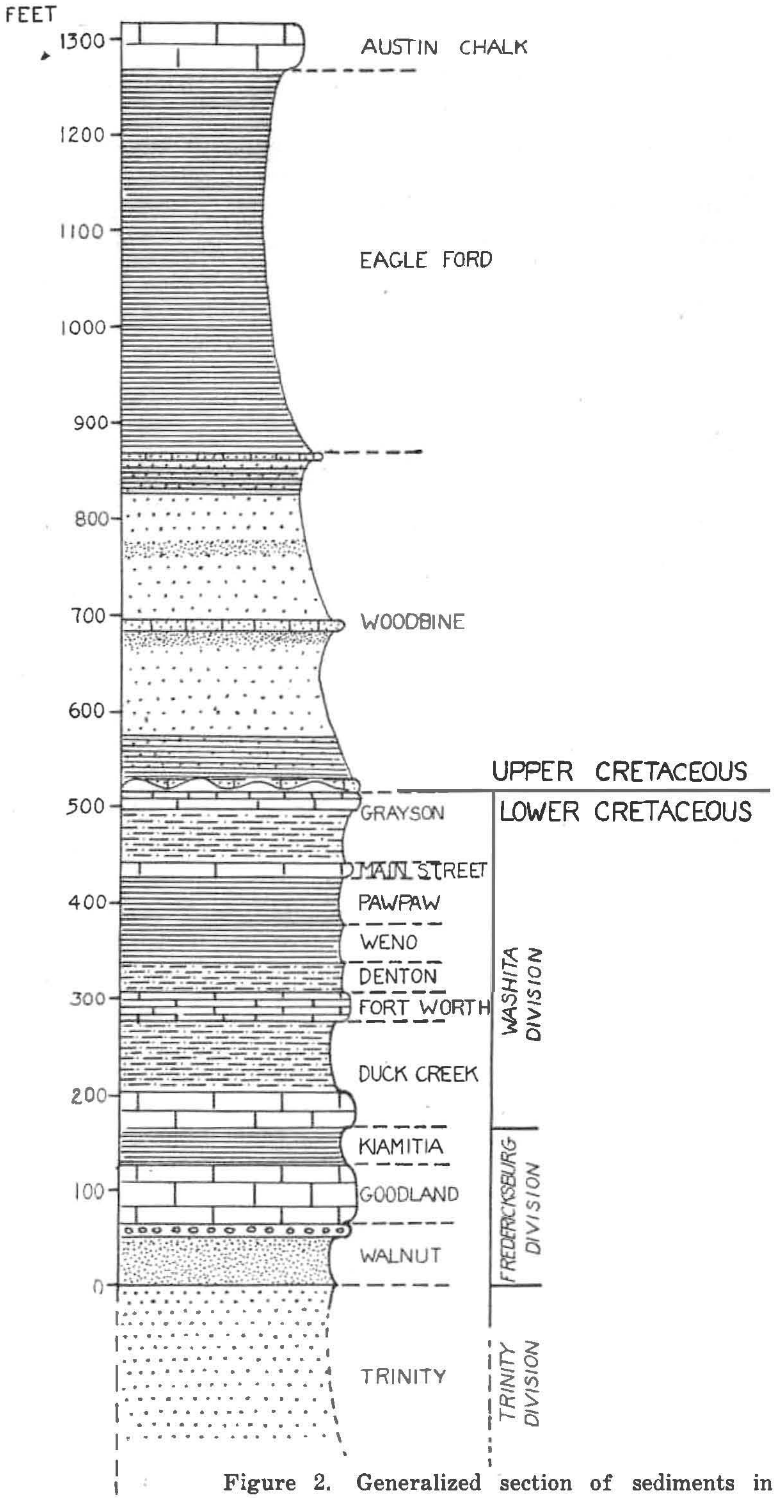

Figure 2. Generalized section of sediments in Denton County.

It is customary to consider the formations of the lower Cretaceous in three large divisions as follows: *Trinity*, including the Trinity, Glenrose, and Paluxy; *Fredericksburg*, including Walnut and Goodland; *Washita*, including all formations from the Kiamitia upward. In spite of the traditions attached to this grouping it is far from satisfactory. In the original Denison section the partings are readily made on a purely lithological basis but if the divisions as represented at Denison by the fossil sequence are applied in other parts of the State, difficulties arise. Serious difficulties involve the proper placing of the Kiamitia and of the lower portions of the Walnut.

In Denton County except for thickness changes which will be noted later and for a definite unconformity at the base of the Woodbine the rocks are practically parallel and conformable with each other and without structures in the current use of the term. The attitude of the rocks is simply ordinary dip slightly south of east at a rate of forty-seven feet to the mile forming a so-called homocline. There are no indications at the surface of any important folds or faults. In fact the region is remarkably structureless for such a large area.

The correlation of the different formations within the State of Texas appears to be fairly well agreed upon now. The last points to be cleared up have been concerning the equivalence of the Grayson in North Texas with the Buda and the Del Rio in central and southern Texas. The correlation of the various parts of the Cretaceous column in Texas is somewhat under dispute. Older writers have thought that the Cenomanian of the Paris basin is represented by that part of the Texas column included between the base of the Fort Worth and the top of the Woodbine which would make the Duck Creek equivalent to Vraconian. Dr. Gayle Scott, a member of the writer's staff at Texas Christian University, will present soon a correlation paper based on six years of field experience in the Texas Cretaceous and a year of study in the museum and laboratories of the University of Grenoble in France. This paper will present evidence that the Texas Comanchean exhibits an unprecedented and hitherto unsuspected development of the Vraconian, extending from the bottom of the Duck Creek to the top of the Grayson. This evidence has been submitted to and approved by a number of competent European experts, notably Dr. W. Kilian.

Description of the Column

Trinity-Paluxy Sands. The outcrop of these sands in Denton County is limited to a negligible area in the extreme northwestern portion (see geologic map). These sands, however, underlie all parts of the county and for this reason a rather full discussion will be given.

These sands, which are known as the Antlers sands in southern Oklahoma and in many parts of North Texas, exhibit an interesting phenomenon which was first described some twenty-five years ago by Dr. R. T. Hill.[2] At Decatur in Wise County at a point of about the latitude of the City of Denton a wedge of limestone appears, called the Glenrose limestone. This limestone increases rapidly in thickness to the south and to the east at a rate originally estimated by Dr. Hill of fifty feet to the mile, but now known to be considerably less than this. This separates the Antlers sands into the two formations known to the south as Paluxy and Trinity. The upper of these, the Paluxy, is fairly important nearly to the Red River and is a water bearing sand which in some places is a valuable source of water.

The lower sand or the Trinity extends in all directions under the Glenrose limestone and is the principal source of underground water over vast areas. An overwhelming majority of the artesian waters in the central, northern and even western portions of the State have their origin in the Trinity sand.

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[2]Hill, R. T., Geology of the Black and Grand Prairies, U. S. G. S. 21st Annual Report, Part 7.

Just how far west the Trinity sand is a reliable source of water is not known. In Howard County, the City of Big Spring, at about the 101st meridian, gets all of its water from wells sunk to the Trinity sand. The supply is adequate for a city of about 6,000, a 50-ton raw-water ice plant and extensive railroad shops. The famous "Big Spring" itself, now unfortunately exhausted, was due to a fissure in a natural basin extending down to the Trinity.

The flow of water in North Texas obtainable from the Trinity is sometimes very great. One of the city wells in Denton delivers at times as much as 800,000 gallons per day.

The Paluxy and Trinity sands in north Texas have been thoroughly explored by a large number of water wells drilled over a period of sixty years, also by some carefully logged oil wells, and recently by core drills in the northern part of Tarrant County.

Certain outstanding features are notable in connection with these sands. One of these is the physical composition, the rounded nature of the grains, and the clean white nature of most of the sand (see Plate 22). Another distinctive feature is the remarkable uniformity of the composition of the mineral part of the water from any given level. This subject will not be discussed here but one point important enough to mention is the constant presence of considerable bicarbonate.[3] The water is never hard and the total solids is always low. Just how much the cities of Central and North Texas owe to the waters of the Trinity sand is an interesting subject for conjecture.

Another phenomenon peculiar to these sands is the replacement to the south of the lower portion by a porous

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[3]F. W. Hogan, Professor of Chemistry in Texas Christian University, in carrying out some analyses on Trinity waters has discovered that the bicarbonates as usually given are too high. The water if taken promptly from the well and analyzed at once will show a much higher proportion of carbonates to bicarbonates than is usually recorded. If the water is allowed to stand from twelve to twenty-four hours the carbonates sometimes may be all converted to bicarbonates.

limestone known as the Travis Peak. This limestone does not appear in exposures north of the Brazos. It now appears that the encroachment of the Travis Peak is not only in the southward direction but also eastward, somewhat like the Glenrose limestone, although on a more gradual scale. In recent diamond drill holes in the northern part of Tarrant County, spongy fossiliferous limestone was encountered in the Trinity sands well below the Glenrose. Not enough is known concerning the micrology of the Travis Peak to say definitely that these limestones belong to this formation. However, in preparing stratigraphic columns from these drill cores we have tentatively called these limestones Travis Peak (see Figure 4).

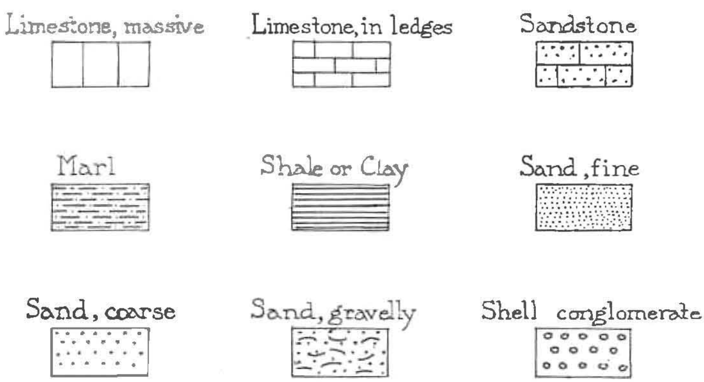

Figure 3. Explanation of symbols used in figures in this paper.

The Trinity-Paluxy sands contain occasional thin seams of lignite and near the base at least one seam of petroleum bearing material. In Comanche County in exposures this appears as an asphaltic sand about two feet thick. In Madill, Oklahoma, this material is about fifteen feet thick and delivers some oil, being the source of the shallow wells in the Madill field. This has been interpreted, at least at Madill, as representing seepage from the underlying Pennsylvanian shales. In view of the wide extent of this petroleum member, this explanation hardly fits. As the writer has pointed out in previous papers the presence of this seam

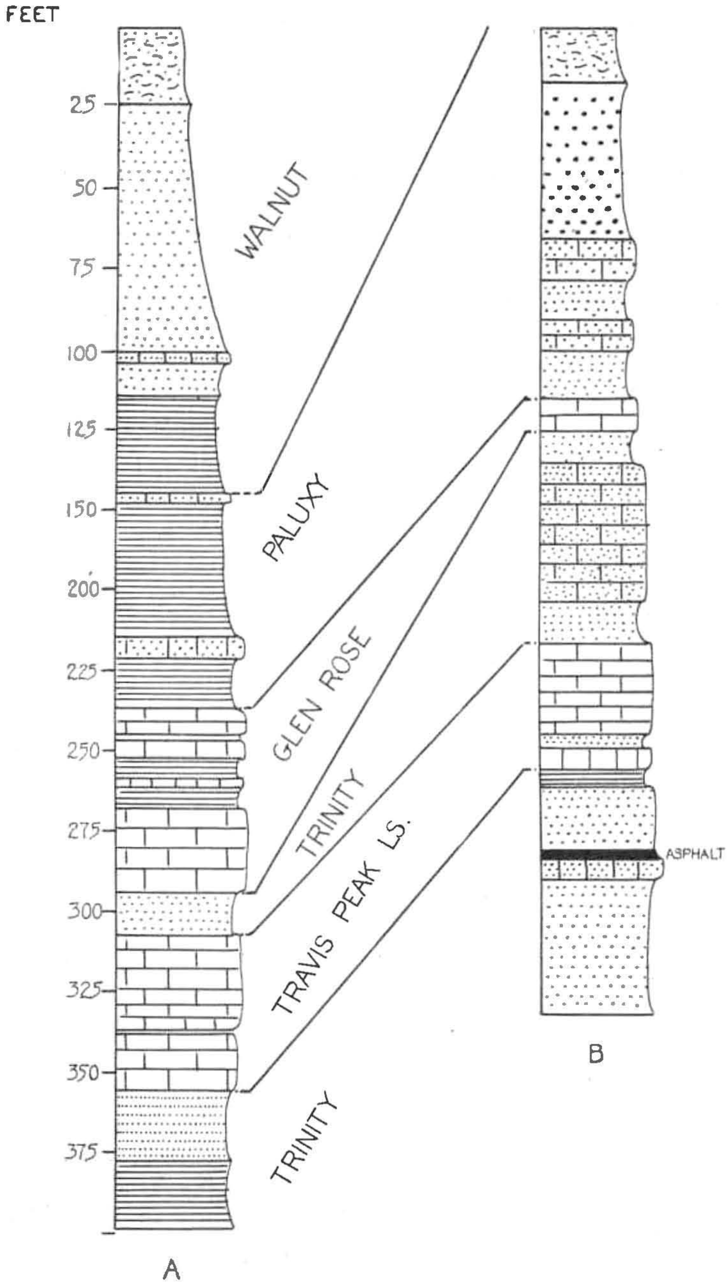

Figure 4. Graphic record of diamond drill cores in northwestern part of Tarrant County, showing the limestones in the Trinity division. Column B is near the Denton-Tarrant boundary; Column A is four miles southeast of B.

gives slight showings of oil over most of North Texas in all wells which penetrate this deep. Many an oil boom decidedly expensive to the community has been carried on in hopeless territory on the basis of the "slight showing" which nearly always appears in the well at this depth. The presence of this seam has been known for over thirty years and in certain parts of Tarrant and Parker counties water wells during the past thirty years have suffered a slight contamination from this oil, in some cases enough is present to make the water objectionable to cattle.

Walnut. This formation in North Texas is marked by a thick conglomerate of shells of the fossil oyster *Gryphea marcoui* forming a conspicuous cap varying in thickness from sixteen to eighteen feet. Under this are a series of sands, a few sandstone ledges and a few clay seams. These sands, forming the lower part of the Walnut, do not contain fossils and the parting between the bottom of the Walnut and the top of the underlying Paluxy is poorly defined and not well agreed upon. In Central Texas the Walnut lies directly upon the Glenrose limestone and the parting is easily mapped. In North Texas the writer and his associates have always considered the top of the Paluxy as being marked by the coarse red sandstone which can be sharply distinguished from the overlying lighter colored and finer grained sands of the Walnut. As a matter of fact the Paluxy formation as such is not as good as the other Comanchean formations which were defined by R. T. Hill. The shell conglomerate cap is itself an admirable and easily mapped formation. The top of the formation is very cleanly marked as the sudden changing of the depth of the seas between Walnut and Goodland time caused such a great reduction in the number of the oysters as to amount to almost extinction of the race. The top of the Walnut conglomerate is a veritable stratigraphic benchmark and has been observed and used by the writer and his associates over a large area in North Texas and West Texas and has been observed and used as a marker in well cores and other subsurface work. The appearance of the conglomerate is unmistakable even in the well cores.

The formation of shell conglomerates in the Comanchean of North Texas is a very interesting phase of which random observations have been made and recorded but no detailed discussion has yet been presented. In the ascending column or actual historical time four conspicuous conglomerates are formed, each by a separate species of fossil oyster, although only in the case of the Walnut conglomerate is the areal extent of any importance.

The four conglomerates in succession are as follows: first, the Walnut formed, as noted above, by *Gryphea marcoui;* second, at the top of the Kiamitia formed by *Gryphea navia*, being local in extent and conspicuous only in northern Grayson County, in Texas, and in southern Oklahoma; third, conglomerates in the Denton formed locally at several points by the shells of *Gryphea washitensis;* fourth, and least important of all, occasional very local conglomerates formed in the Grayson formation by the shells of *Gryphea mucronata.* In the field it is entirely possible for a careless worker to mistake one of the three upper conglomerates for that of the Walnut. Without going into a discussion of the differences of the four species of *Gryphea* it is enough to state that one certain point of distinction is the matter of thickness. The Walnut conglomerate even when considerably eroded will be a dozen or so feet thick and the local conglomerates in a higher formation are usually about one or two feet thick, in rare cases that of the Denton may extend through as many as three ledges, each about one foot thick.

Other fossils are encountered in the shell conglomerate. The most conspicuous is the flat oyster *Exogyra texana* (see Plate 11). This oyster may be said to serve as a broad horizon marker for the Walnut, Goodland, and Kiamitia as it occurs in all three of these formations and in no others of the series. Its zone of abundance is in the upper Walnut and the lower Goodland. Other fossils found in the Walnut are of less importance and are listed and described in the chapter on Paleontology.

The soft Walnut sand and the overlying hard conglomerate cap make a combination very favorable for abrupt escarpments which are especially conspicuous along the headwaters of Clear Creek in the northwestern part of the county. In many parts of North Texas these abrupt escarpments are known locally as "mountains." A variation of this form of weathering is seen in the occasional mesa-like outliers of the Walnut still preserved in areas of the underlying Paluxy sands.

Goodland. This limestone formation named after the village of Goodland in southern Oklahoma, starting with a thickness of about twenty feet, at the Red River, increases rapidly in thickness to the southwest; at the same time the upper portion becomes hard and indurated, the lower soft and marly and south of the Brazos is considered as two formations. The upper or hard portion, south of the Brazos, is called Edwards; the lower softer portion is called Comanche Peak. The Goodland formation is highly fossiliferous and in certain parts of the western part of Tarrant County is a mecca for fossil collectors. In Denton County most of the exposures of the Goodland are in rather inaccessable parts of the western and northwestern part of the county, although well worth visiting by any one in search of fossils. Characteristic and horizon marking fossils are numerous in this formation and are described and figured in the chapter on paleontology.

The thickness of the Goodland in Denton County ranges from a measured 42 feet in the northwestern part of the county to an estimated 75 feet in the southwestern part. In the western part of Tarrant County, near Lake Worth, the thickness is 116 feet. The limestone of the Goodland occurs in thick massive ledges separated by seams of marl. This limestone is unusually white and chalky in appearance. Chemical analyses made for cement projects in Tarrant County have shown that most of this material is composed of over 98 per cent pure crystalline calcium carbonate. This limestone with the combination of the overlying Kiamitia clay makes a perfect Portland cement mixture, although in

Denton County this combination does not offer possibilities at present because of the inaccessability of all good exposures which contain both Goodland and Kiamitia.[4]

Kiamitia. This formation, which represents the close of the time period represented by the life forms in the Goodland, from the standpoint of historical geology may be considered as simply the final phase of the Goodland. The fossils with but a few exceptions are those of the Goodland and very few of the species seen in the Kiamitia persist into the overlying Duck Creek.

The Kiamitia is composed mainly of clays containing some calcareous material with occasional thin ledges of sandy limestone. The upper portion contains less clay and is distinctly calcareous. It contains large numbers of a peculiar and characteristics oyster, *Gryphea navia,* which, as previously noted, at Denison and other points along the Red River sometimes forms a shell conglomerate. The clays of the Kiamitia are black and waxy, contain much organic matter, and in some seams a considerable proportion of pyrite of iron. Presence of this pyrite, which weathers into limonite or hydrated iron oxide, gives a peculiar yellow-brown appearance to all weathered exposures of the Kiamitia. After torrential rains when the weathered material has been removed the black waxy shales become visible and these shales are always conspicuous in well borings.

The thickness changes in the Kiamitia are the reverse of those in the Goodland as this formation thins rapidly to the south and to the southwest. This formation is 42 feet thick in western Denton County, thins rapidly to the south and disappears entirely at the Brazos. Doubtless this thinning is due to the replacement of the lower portions of the Kiamitia away from the shore line by the limestones of the Goodland. The upper or *Gryphea navia* member persists and is recognizable beyond the Brazos. In the

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[4]Portland cement possibilities in Denton County are discussed in the chapter on Economic Geology, and favorable sites for plants are suggested.

Austin region this member becomes a part of the basal portion of the Georgetown limestone. This has caused some confusion in the correlation and although the Kiamitia through most of its extent is distinctly a part of the Fredericksburg group (which contains Walnut, Goodland, and Kiamitia), many writers have classified the Kiamitia with the Washita group (containing the formations from the top of the Kiamitia to the top of the Main Street).

Following is a section in the northwestern part of the county along the north side of Clear Creek northwest of Bolivar:

Section No. 1 (Figure 5). Clear Creek Section in Descending Series

	Feet
Duck Creek:	
13. Massive gray limestone containing *Hamites fremonti*, *Hamites comanchensis*, fragments of *Desmoceras brazoensis*	4.0
Kiamitia:	
12. Marls and clays containing many specimens of *Gryphea navia*	2.0
11. Black shales weathering to yellowish brown, containing a few *Gryphea navia*	20.0
10. Sandy ledge containing *Schloenbachia belknapii*	1.0
9. Black shale weathering to yellowish brown, containing *Exogyra texana*, *Gryphea marcoui*, and *Schloenbachia belknapii*	5.0
8. Sandstone ledge	1.0
7. Black shales containing a few *Gryphea marcoui*	13.0
Goodland:	
6. White massive limestone	5.0
5. Marl seam	.5
4. White massive limestone containing *Schloenbachia trinitensis*	4.0
3. Thin seams of limestone alternating with marl containing *Schloenbachia acutocarinata*, etc.	35.0
Walnut:	
2. Shell conglomerate containing vast numbers of *Gryphea marcoui*, also many *Exogyra texana*	16.0
1. White sands, very fine with rounded oval grains, no fossils	?.

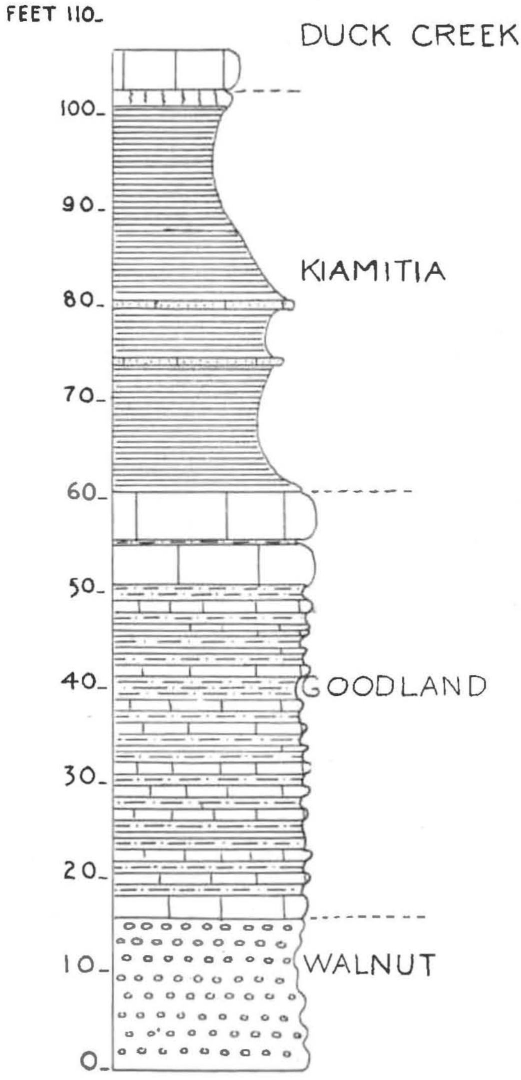

Figure 5. Section on Clear Creek in the northwestern part of Denton County.

Duck Creek. This formation in most parts of North Texas is marked off into two lithologic divisions, the upper a marly number containing a few thin but indurated limestone ledges, the lower composed mostly of massive gray to yellowish limestones. In Denton County this demarkation is less pronounced and the entire formation is more marly than usual, with the exception of the single massive ledge at the base known over most of North Texas as the *Hamites* ledge and an important stratigraphic landmark in geological field work in this region.

The Duck Creek like other formations of the lower Cretaceous changes rapidly in thickness to the south. In this case the change is a thinning apparently of the entire formation as the different fossil zones preserve their relative positions within the formation. The Duck Creek is 193 feet thick at Denison near the Red River and 62 feet in western Tarrant County. No satisfactory exposures continuous enough for thickness measurement have been found in Denton County, but careful observations based on the width of the exposure and the rate of dip indicate a thickness for the Duck Creek in Denton County of about 110 feet.

The Duck Creek is another highly fossiliferous formation and is marked by several zones of conspicuous and characteristic fossils. Perhaps the most interesting from the standpoint of the layman is the great ammonite *Desmoceras brazoense* which marks the lower third of the formation (see plate 4). Other fossils of importance occur in this formation but will not be referred to in this chapter as further details will be given later.

The Duck Creek is marked throughout by the presence of pyrite in nodules which are usually about one-half inch to one inch in diameter and more or less spherical. These nodules weather out, are converted into limonite and make brownish to yellowish streaks on the face of the rock. In many places where the nodules have weathered out completely the limestones have a characteristic pitted appearance. At about the junction of the middle and upper third of the formation is a marly to clay member which contains large numbers of dwarfed fossil species preserved in pyrite. Often the preservation is very fine and the fossils show microscopic details of structure. These small fossils include a number of species of small uncoiled ammonites which have been made the subject of a special publication[5] by one of the writer's associates.

The limestones in the basal portion of the Duck Creek are unusually pure and closely approach those of the Goodland in quality. In the Trinity Portland Cement plant northwest of Fort Worth the mixture is made of Duck Creek limestone and Kiamitia clay. However, this possibility is not encouraging for Denton County, due again to the inaccessibility of good exposures.

The upper portion of the Duck Creek formation is often difficult to distinguish from the Fort Worth formation as many of the upper limestone ledges of the Duck Creek greatly resemble those of the lower Fort Worth. In Denton County there is no lithologic distinction possible although the original formation as established in the Denison section exhibit a clean-cut demarkation. The formation names should be preserved in Denton County as separation is readily possible on the basis of the fossils. Fortunately the change from the fossil life of the Duck Creek time to that of Fort Worth time is also marked by characteristic differences in the microscopic structure in the limestone as will be described in the chapter on micrology.

Fort Worth. This formation, which gets its name from the fact that most of the City of Fort Worth is built upon it, is one of the most remarkably constant of all of the lower Cretaceous formations. This formation extending over many thousands of square miles is fairly uniform in thickness ranging between twenty-five and thirty-five feet. Figures given by some of the earlier writers of thicknesses of fifty to one hundred feet are erroneous due to the inclusion with the Fort Worth of the upper portion of the Duck Creek and with no regard for the fossils, the distinctions

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[5]Scott, Gayle, Gerontic Ammonites of the Duck Creek Formation, *Texas Christian University Quarterly*, Vol. 1, No. 1.

being purely lithologic. South of the Brazos the Fort Worth preserves many of the fossil zones which characterize it in North Texas, although in Central and West Texas it is included in the Georgetown limestone of which formation the Fort Worth forms the middle member.

The lithology of the Fort Worth proper is fairly characteristic, the general appearance in cliff faces and stream cuts being always about the same. The formation is made up of a number of limestone ledges six inches to one foot in thickness, alternating regularly with marl seams of about the same thickness. The ledges and seams are not continuous however, but are thinly lenticular. The fossil zones in some cases overlap but the value of the sequence is unimpaired for stratigraphic work because the zones of abundance in all cases have the same sequence. This is particularly true of some of the ammonites and a few of the echinoids. The formation as a whole is marked by the presence of certain forms which are especially abundant in North Texas. Without going into a discussion of the paleontology at this point it is enough to say that the presence in the limestone of the ammonite *Schloenbachia leonensis* and the large echinoid *Hemiaster elegans* (see plate 4 and plate 13) occurring together is final and decisive evidence that the exposure is that of the Fort Worth formation.

The Fort Worth formation is of negligible importance from the economic standpoint. The lime ledges are unfavorable for building stone because of imperfect cleavage, too much marl is present for the formation to be used as crushed rock, and the calcium content is too low to furnish good lime or cement. Unfortunately the soil also formed from the decay of the Fort Worth is rather poor. This soil classified by the soil experts with that from the upper Duck Creek and known as the Denton Clay is of value mainly for grazing purposes. This soil has been made the subject of special investigation and study by the Fort Worth Chamber of Commerce with the hope that it can be made more productive.

A charcteristic rolling topography marks most of the exposure of this formation. The soil is usually treeless and the surface forms broad and gently sloping dip plains, a type of country which extends in the broad strip from the Red River to the Brazos and is known as the Grand Prairie. This distinguishes it from the so-called Black Prairie, another treeless strip which parallels it to the east and is formed by the soils of the Eagleford and the Austin Chalk. The two strips are separated by the heavily wooded exposures of the Woodbine formation known as the "cross timbers" or sometimes "eastern cross timbers" to distinguish it from the less defined but also wooded exposures to the westward of the Walnut, Trinity and Paluxy sands which are sometimes referred to as the "western cross timbers."

Denton. This formation is of varied lithology, ranges in thickness from twenty-five to thirty-five feet, and is marked by limestone ledges very rich in fossils and especially *Gryphea washitensis.* Between the fossiliferous limestones are found soft marls and clays and in the upper third there occurs a clay member containing dwarf pyritized fossils, the species of which exhibit a striking parallelism with those of the Duck Creek pyrite fauna. The ledges locally are sometimes so rich in fossil *Grypheas* as to form conglomerates as previously noted. The clays forming the upper part of the Denton in this region are not to be distinguished from the overlying Weno except by detailed examinations of the fossils. The Weno in turn is difficult to separate from the overlying Pawpaw. For this reason the geologic map with this paper shows Denton, Weno and Pawpaw mapped as a continuous strip. The defining limits for this strip being the top of the Fort Worth limestone and the bottom of the Main Street limestone.

Besides the *Gryphea washitensis* the Denton formation is marked by the first or lowest occurrence of a conspicuous and peculiar oyster, a species destined to become more conspicuous in the overlying Weno and known as *Ostrea carinata* (see plate 8, figure 3).

A field worker in this region, and also further to the north, must guard against the superficial resemblances of parts of the Denton to other formations. First, the resemblance of some of the localized shell conglomerates to those of the Walnut; second, the slight resemblance of some of the ledges of the Denton, rich in *Gryphea washitensis* and *Ostrea carinata* to the thicker and more indurated "quarry ledge" a conspicuous landmark near the top of the Weno.

Weno. This formation, as noted above, is sometimes difficult to distinguish from the underlying Denton formation and is even more difficult to separate at times, from the overlying Pawpaw. The extremely rich fauna of the Weno and the Pawpaw has been made the subject of a special paper in quarto form and profusely illustrated.[6]

The Weno formation besides containing a varied fauna in the northern part of Denton County and thence northward to the Red River, contains in certain members nacreous fossils preserved in the original shell, often exhibiting true mother-of-pearl luster. These fossils are found in certain clays which weather down quickly on exposure and the fossils are destroyed. For this reason collecting is limited mainly to abrupt cliff faces where overlying hard rocks protect the softer clays. One famous spot of the sort is the so-called "Blue Cut" on the Frisco Railroad northeast of Denison. Another locality not quite so favorable is the road cut on the Sherman highway above Clear Creek, five miles northeast of Denton.

The lithology of this formation is varied and exhibits important changes. In the northern portion nearly all the formation is made up of blue-gray shales and clay with occasional seams of red iron oxides resulting in the oxidation of iron carbonates. The whole formation is capped by a series of very hard calcareous ledges marked by large numbers of *Gryphea washitensis,* and *Ostrea carinata.* This group forms the so-called "quarry" limestone which

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[6]Adkins, W. S., Weno and Pawpaw Formations of the Texas Comanchean, University of Texas Bulletin 1856.

extends into the northern part of Denton County but disappears before the southern boundary of the county is reached. The "quarry" limestone in certain ledges is very hard and of uniform thickness, cleaves well and has been used extensively in North Texas for building purposes. The courthouse at Denton is built of "quarry" limestone, even the outdoor steps. All of the facades of this building exhibit well defined fossils of the two species mentioned above. The quality of this material for a building stone is very high and doubtless is a natural resource which is yet to be developed and exploited on an extensive scale. The Denton County courthouse, erected over thirty-five years ago, exhibits very little pitting and weathering and the fossils do not weather out from the surrounding matrix as is sometimes the case in fossiliferous building stone. The color effect is a light tan and is very pleasing. The material for the courthouse was taken from ledges in the north-central part of the county although no quarry is being operated at this time.

Toward the south the quarry limestone merges with a hard gray, to white, massive limestone which thickens rapidly at the expense of the underlying clays. In the southern part of the county the upper or limestone member of the Weno is about sixteen feet thick.

The lithologic changes of the Weno are accompanied by a rapid thinning toward the south. The entire formation has a thickness of about 105 feet in the northern part of the county near Sanger and a thickness of sixty-six feet in the southern part west of Roanoke.

Pawpaw. Even greater lithologic changes are exhibited in the Pawpaw. In the northern portion the Pawpaw throughout its extent is made up of reddish clays interbedded with red sandstone ledges. The effect locally is often much like that of the Woodbine and a careless observer might easily confuse this with the Woodbine. Besides the similarity in the lithology the Pawpaw in the northern section is usually wooded with a growth of Blackjack and scrub Oaks like the Woodbine. Toward the south the Pawpaw becomes more clayey, the sandstone ledges are fewer, thinner, and much lighter colored due to the presence of more calcareous material.

The Pawpaw is another formation which contains dwarfed pyrite fauna. In this case the fauna is the richest of the sort found in the entire series and contains dwarfed ammonites, clams, oysters, and even corals (plate 3).

The Pawpaw like the Weno thins to the south and is fifty feet thick in the northern part of the county and thirty in the southern. The lithologic changes noted above occur within the boundaries of Denton County as the Pawpaw in the northern part of the county is like that along the Red River and the same formation in the southern part of the county is like that in Tarrant and Johnson counties.

Both the Weno and Pawpaw clays have been used successfully for brick making although as yet this resource has not been developed in Denton County.

Main Street. This is typically a limestone formation throughout its extent from southern Oklahoma where it is known as the Bennington limestone to central and southern Texas where it forms the upper member of the Georgetown limestone.

The lithologic changes are less pronounced than in some other formations but nevertheless occur. The Bennington or northern phase is marked by very massive ledges often two or three feet thick, very heavily iron stained and distinctly yellow-brown in color. The southern or Texas phase is considerably thicker as a whole but the ledges are individually much thinner, are white and are interbedded with light colored marl seams giving an alternating effect much like that of the Fort Worth limestone. The exposures of the Main Street along Buffalo Creek at Cleburne in Johnson County, so strongly resemble exposures of the Fort Worth that only a close examination of the fossils reveals their true character.

The Bennington phase of the Main Street, which occurs in the northern part of Denton County, is marked by large numbers of a small lampshell or brachiopod, *Kingena waco-*

ensis. The southern portion of this formation is characterized by an unmistakable fossil marker, a spirally coiled ammonite, *Turrilites brazoensis.* . This characteristic fossil increases in abundance to the south although it occurs occasionally northward into southern Bryan County, Oklahoma.

As in the case of the Weno and Pawpaw the lithologic changes in the Main Street occur within the boundaries of Denton County. The thickness changes are less pronounced although important. The thickness of the Main Street in the northern part of the county is fourteen to fifteen feet, in the southern part about twenty feet. Excellent exposures of the northern phase are to be seen along the road from Pilot Point to Sanger. Exposures of the southern phase are well exhibited in the escarpment about two miles northwest of Roanoke.

Grayson. For many years observers noted the presence of light colored marls and occasional thin ledges of limestone between the well defined Main Street limestone and the red sands and sandstones of the Woodbine. In most places exposures of this light colored formation were badly overwashed by the Woodbine. For this reason the actual thickness of the Grayson formation was much underestimated. Even so experienced an observer as R. T. Hill estimated the thickness at twenty to twenty-five feet. More detailed work of the last few years has led to the discovery of better exposures and disclosed the fact that the Grayson is at least three times as thick as the older workers supposed. In southern Denton County, near Denton Creek, a series of fine exposures exhibit the Grayson throughout its extent.

The following section, published by the writer and W. S. Adkins several years ago in the bulletin on Tarrant County, is reprinted here.

Section No. 2 (Plate 1). Denton Creek Section, Northeast of Roanoke

Woodbine:	
Red ledge, forming crown of hill.	
Grayson:	Feet
Soft gray marl containing eleven limestone ledges, each 3 to 12 inches thick, the uppermost lying in contact and conformable with the base of the Woodbine. *Lima* sp., *Protocardia* sp. (same as the Weno sp.), *Cidarid* spines (very large), zone of *Hemiaster calvini* and *Enallaster bravoensis* (10 feet below top), *Schloenbachia* sp., *Cyprimeria* sp., *Gryphea mucronata* (scarce), *Pecten texanus* (aboundant), *Plicatula* (abundant), *Scaphites* sp.	37.8
Yellowish limonite stained marl. Rich in *Gryphea mucronata*. Turrilites (small sp.), no other ammonites seen; no echinoids seen. *Pecten texanus*, less abundant than above	15.2
Soft gray marl. Fossils scarce, mostly *Engonoceras* sp., *Gryphea mucronata* and flattened *Exogyra arientina*. A number of red ironstone seams weathering out black	22.2
Main Street limestone:	
Top: *Kingena* sp., very abundant.	

This locality is noticeably more calcareous than those farther west.

In Central and South Texas the Grayson formation becomes two formations; the upper portion becomes increasingly calcareous and in the region of Austin is a well defined unit called the Buda limestone. The lower portion toward the south loses its calcareous character and is mainly clay and is called the Del Rio formation.

In Denton County the part of the upper Grayson which represents Buda in time is not fully agreed upon. R. T. Hill[7] has described the uppermost ledge of the Grayson as Buda, but the writer has always felt that at least the upper twelve feet of the Grayson in Denton County, perhaps more, represent Buda. The tentative correlation of the Woodbine of North Texas with the Buda in Central

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[7]Hill, R. T. Further contributions to the knowledge of the Cretaceous of Texas and Northern Mexico. Bulletin Geological Society of America, 34, No. 1.

Texas, which was made by some earlier writers, is erroneous.

The Grayson formation is highly fossiliferous being marked in certain members by large numbers of *Gryphea mucronata*. As previously noted this fossil may locally form a thin shell conglomerate.

At least one zone of pyrite dwarfed fossils occurs in the Grayson and a similar zone occurs in the Del Rio in McLennan County and has been described by W. S. Adkins. (Geology of McLennan County, Univ. of Texas Bull. 1856.)

Section No. 3 (Figure 6). Clear Creek Station

South side of Clear Creek on Denton-Sherman road, five miles northeast of Denton.

	Feet
Grayson:	
Main Street:	
Gray marls with *Exogyra arietina* and other Grayson fossils	5.0
Brownish, massive, limonite stained, Lms. containing *Kingena wacoensis*, *Turrilites brazoensis*, etc.	5.0
Marl seams, fossiliferous	2.0
Massive white Lms. with lenticular marl seams, typical Main Street fossils	5.0
Pawpaw:	
Sandstone seams with red iron stone	3.5
Shales, with reddish seams	10.7
Gray-blue shales with jasper pebbles, thin seams, and a little ironstone	10.2
Gray to yellowish sandstone ledge, continuous and not lenticular	.5
Gray shales	2.0
Gray sandstone ledge, continuous	.5
Blue-gray shales	17.5
Weno:	
Firm sandstone ledge, gray to yellowish	1.0
Blue-gray shales	3.0
Blue-gray shales with small streaks of limonite-stained material	5.2
Floor level of bridge, below mainly alluvial material.	

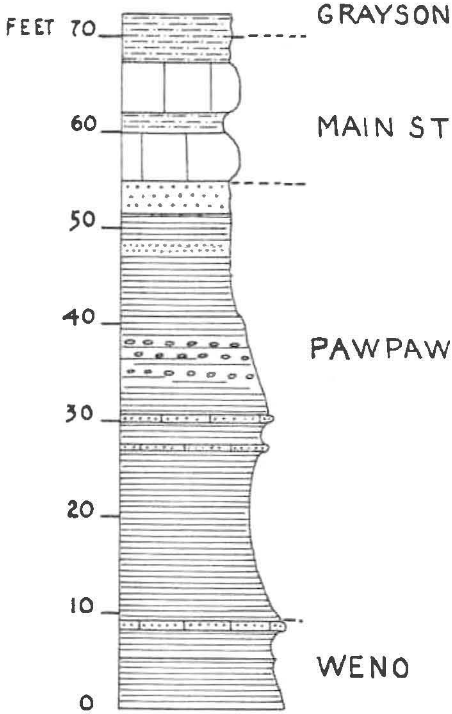

Figure 6. Section on Clear Creek at crossing of Denton-Sherman road, five miles northeast of Denton.

Section No. 4 (Figure 7). Denton Creek Section, East of Justin
By J. A. Taff, U. S. G. S. Annual Report, p. 270

Main Street Limestone:	Feet
8. Terebratula wacoensis zone. In the banks and bluffs of Marshall Branch, from one to two miles northeast of Roanoke, Denton County. The rock is made up of thin bands of hard limestone, and thick (2 to 3 feet) beds of soft, argillaceous lime, which contain great numbers of *Terebratula wacoensis*, many *Turrilites brazoensis*, *Pecten texanus*, and a few *Ostrea subovata*. *Terebratula wacoensis* and *Exogyra arietina* are commingled in the upper layers	15.0

On the south side of Denton Creek, one and one-half miles west of the Missouri, Kansas and Texas Railway, the basal five feet of the Terebratula zone are exposed in the top of creek bluff.

Pawpaw Beds:

7. Friable arenaceous clay, containing many thin, fissile, flaggy sandstone bands interstratified with clay 40.0

Quarry Bed:

6. Light yellow, crumbling limestone, containg *Ostrea quadriplicata, O. subovata, O. carinata,* and *Pecten.* Clay continues to the edge of the creek basin (quarry limestone) 5.0

The marls continue from the top of the bluff downward. Direct stratigraphic connection was not made with the preceding locality. The strata of this locality are below that of the former.

5. Weno (and Denton) formation. East side of Denton Creek, east of Justin. Friable bluish clay containing *O. quadriplicata* with thin fissile, flaggy sand interstratified from the top of the bluff downward 37.0

Ostrea Carinata Beds:

4. Gryphea washitensis zone, with *O. quadriplicata* in the upper two feet of the bed and *O. carinata* in the lower layer, the *Gryphea* fossils forming the mass of the rock 6.0
3. Clay marl, dull blue, friable, and laminated, with a few bands of flaggy, fissile, calcareous sands and arenaceous shell limestone. These layers of marl range from fine shale to bands from 3 to 5 inches thick. The shale bands contain great numbers of small *Gryphea washitensis* and *Pecten.* On disintegrating the marl changes through purplish-blue hues to yellow 27.0

Gervilliopsis Beds:

2. Soft limestone. This rock is exceedingly fossiliferous. It contains innumerable *Plicatula dentonensis Cragin,* also *Ostrea perversa, Exogyra americana, Pecten texanus, Cyprimeria* sp.? 5.0

Fort Worth Formation:

1. Limestone and marl in alternating layers, exposed. The limestone bands vary in thickness from 2 inches to 1 foot, while the marly layers are 1 inch to 6 inches thick.. 23.0

Duck Creek Marl:

The lower 50 feet of the Fort Worth limestone crops out out in bluffs of Oliver Creek, on the Justin and Drop road 50.0

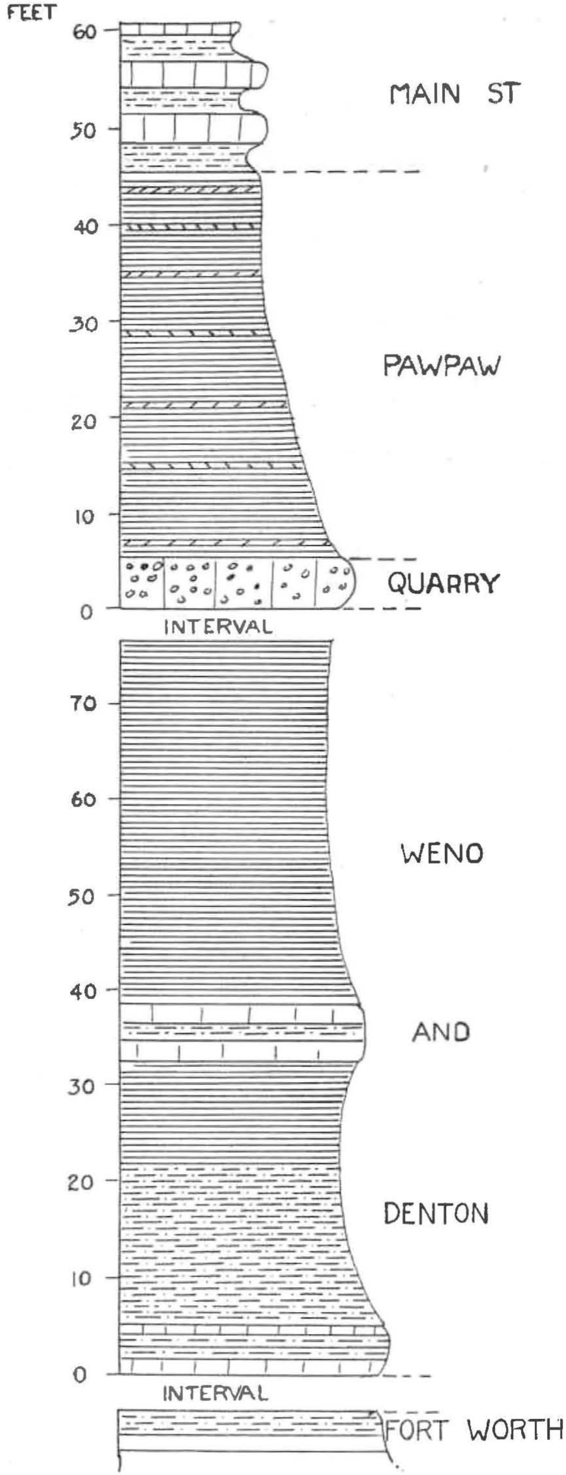

Figure 7. Section on Denton Creek, east of Justin.

Section No. 5. Clear Creek Section

By R. T. Hill, U. S. G. S., 21st Annual Report, p. 275
On Clear Creek, north of Denton, on Gribble Springs Road

	Feet
Pawpaw:	
Arenaceous clay marl, estimated	35.0
Thin band of fossiliferous clay ironstone, not exceeding	.5
Weno:	
Fissile, arenaceous clay marl, with thin laminated sandstone flags at intervals	60.0
White, arenaceous shell limestone	4.0
Marly clay with thin ferruginous sandy flags	15.0
Friable, blue, argillaceous-arenaceous lime, containing very many foraminifers, *Nodosaria texana*, etc.	2.0

UPPER CRETACEOUS

Woodbine. This thick group of sands and sandstones is conspicuous in southern Oklahoma where it is called the Silo formation and is exposed over a wide strip extending from the Red River to the Brazos. To the east and south where the Woodbine plunges under the other formations of the upper Cretaceous it is the source of the oil in several important pools, notably that of Mexia.

The thickness change is very rapid, dwindling from a total of about 900 feet at the Red River to about three feet at the Brazos. South of the Brazos at the base of the so-called Eagle Ford is a member rich in pavement or pharyngeal teeth of certain fishes, also fish scales, as well as ordinary shark teeth. The general appearance of this member and the contained fossils is strikingly like that of the top of the Woodbine in North Texas and may or may not represent the Woodbine. Mr. E. B. Stiles, an experienced micrologist and subsurface worker, agrees with the writer that the basal Eagle Ford in Central Texas represents Woodbine (personal communication). At the present time proof of this correlation is not satisfactory.

A pronounced unconformity exists between the base of the Woodbine and the top of the Grayson. This was first observed by Mr. R. T. Hill and has since been confirmed by the writer, W. S. Adkins, Gayle Scott and other observers.

The Woodbine is marked by three conspicuous indurated sandstone ledges each from two to twenty feet thick, marking the base, the top and the middle of the formation. Between the ledges are softer sandstones, clay and a few seams of lose sand. Near the base are some shales very rich in delicate fossils. These shales are uniformly overwashed by sands in exposures and the fossils destroyed. Not until 1925 was the presence of these shales suspected when they were encountered in diamond core drills sunk by the Tarrant County Water Improvement District.

R. T. Hill in his report on the Black and Grand Prairies, to which reference has already been made, subdivided the Woodbine formation as follows (page 297):

> The general sequence of the beds, so far as they can be established from the study of the outcrops between the Trinity and Red River, will now be stated. This sequence may prove variable after further study:
>
> 1. The lowest beds are usually of impure clay, which is often sandy and lignitic.
>
> 2. An extensive formation of yellow ferruginous sandstone and brown siliceous ironstone, in which impressions of dicotyledonous leaves are sometimes found. These are the Dexter sands of Taff.
>
> 3. Lignitic sandy clays and sands, frequently accompanied by sulphate of iron, magnesian salts, etc. The sands also oxidize into heavy, siliceous, dark-brown iron ore in places. The subdivision is characterized by an extensive molluscan fauna, which is elsewhere alluded to and which may be characterized as the *Aguileria cumminsi* zone. These are the Lewisville beds.
>
> 4. Less ferruginous sands and clays, and in places more calcareous and fossiliferous, gradually passing into the bituminous shale of the Eagleford formation. The upper limit of these beds ends with the zone of *Ostrea columbella* Meek.

The above subdivision is generalized for the Woodbine as a whole and does not take into consideration the three sandstone ledges which mark the southern phase and which persist northward into Denton County. In fact the lowest ledge which is often heavily mineralized, resists weathering and due to the softer underlying Grayson forms conspicuous knobs and hills. Pilot Knob, a famous landmark near the village of Argyle, was formed in this way and is one of many Woodbine outliers still surviving in areas of lower rocks long after the rest of the Woodbine has been removed by the action of water erosion through many centuries. A less pronounced case is the low knob upon which the City of Denton is built.

The Woodbine is marked by great variability, the sands and clays exhibit many colors, are much cross-bedded, and contain occasional lenticular seams of low grade lignite. East of the City of Denton in the middle one of the three sandstone ledges fragments of fossil leaf impressions are found (see plate 2). Doubtless this is part of the flora described by Berry[8], although the specimens found by the writer in Denton County were all fragmentary and in badly weathered sandstone. The writer hopes that some other collector will search this locality more carefully for better specimens.

Only partial sections of the Woodbine are available due to the great thickness of the formation and the irregular weathering. The following sections are the only ones in or near Denton County and are reprinted here from the Tarrant County bulletin:

Section in the Pit of the Acme Brick Yards, Denton, Texas

	Feet
5. Lenticular mass, four members, overlain by a red sandy clay	15.0
4. Light colored limonitic argillaceous member	7.0
3. Red sandstone	5.0
2. Light colored limonitic argillaceous member	1.0
1. Grayish sandy argillaceous member containing several bands of almost black sandstone	14.0
	42.0

A 25-foot boring at this point penetrated the Grayson marl.

[8]Berry, E. W., Flora of the Woodbine Sand at Arthurs Bluff, Texas, U. S. G. S. Professional Paper 129-G.

Section of Woodbine East of Tarrant Station

(The following section is seen south of the railroad below the first bridge west of the county line):

27.	Sandstone ledge, locally a shell conglomerate, containing *Barbatia micronema*, *Ostrea soleniscus*, *Ostrea carica*, *Ostrea* sp., *Exogyra* sp., and other Lewisville fossils. The upper portion is indurated, laminated and especially fossiliferous. Exposed in three cuts nearest the Tarrant-Dallas county line. This is the top of the Woodbine and is overlain by Eagleford shale. Between the two localities it has locally a dip of 2½′ east, but this reduces at most places to about ½′ east	7.0
26.	Light yellowish sand with limonitic stain, usually unconsolidated and containing *Ostrea* sp. (with large attachment scar)	5.0
25.	Arenaceous yellow-brown shales containing *Ostrea* sp.	8.0
24.	Three ironstone bands interbedded with bluish sandy shale	2.0
23.	Thin bedded closely laminated shale with dimension layers of iron-stained red shale, and containing gypsum, limonite, and oyster shells *(O. carica)*. The lower 10 feet is especially fossiliferous	22.0
22.	Bluish red shale with limonite stain and abundant gypsum. *Ostrea carica* is rare in the top	20.0
21.	Loosely laminated thin bedded brown shale, weathering to a rough-faced cliff	5.0
20.	Compact laminated brown shale forming a smooth cliff face	2.0
19.	Three thin red ironstone layers with interbedded compact blue clay	4.0
18.	Bluish limonitic shale	12.0
	(There is a break in the section at this point. A cut of the Rock Island Railway one-half mile east of Tarrant exposes the following section.)	
16.	Thin bedded red sandstone, no fossils seen. Minor faulting present. Gypsum present. Dip is 2 degrees east in the west end of the cut, and straightens out to 1 degree in the east end	10.0
15.	Blue shales containing gypsum and lignite seams. No fossils	12.0

Eagle Ford. This formation is composed of a series of black oily shales with occasional thin sandstone ledges. The total thickness in Denton County is unknown but is approximately 500 feet. The exposures of these shales cover a large part of the eastern half of the county. These shales break down into fine soils which are highly productive.

The Eagle Ford is not marked off into recognizable members. The sandstone ledges are lenticular and are always local and occur at a number of levels. A few fossils occur but are not abundant enough to serve as markers. The micro-fauna of Eagle Ford is rich and varied and a discussion is given in the chapter on micrology.

Austin Chalk. The lower portion of this formation is exposed in the southeastern corner of Denton County and with the underlying Eagle Ford shale forms a conspicuous escarpment which is one of the grand landmarks of Texas and extends almost without a break from near Sherman, in Grayson County, to a point south of Waco, in McLennan County. This escarpment is known by various local names such as "Chalk Hill," "White Rock Mountain," etc.

The lithology of the Austin Chalk is remarkably uniform as the formation throughout is made up of massive fine grained white limestone with occasional thin seams of marl. A common phenomenon is a large number of small faults limited to single ledges, due to slight settling of heavy ledges from the dissolving away of the supporting marl seams. These faults are always local and are varied in their direction. The total slip is usually a matter of inches.

PLEISTOCENE AND RECENT

Alluvial flood plains are quite extensive in Denton County and the width of the stream valley usually indicates that in late Pleistocene the stream was much larger than at present.

The alluvial deposits of the Elm Fork and of Denton Creek contain many vertebrate fossils. No extensive collections of these have been made in this county but further downstream many specimens have been discovered. A list of these fossils may be obtained from the report on Dallas County.[9]

It is likely that these vertebrate fossils, especially the mammoth, mastodon, and other more common ones occur in the gravel deposits of Denton County.

PHYSIOGRAPHY

The physiography of Denton County is fairly simple and the main divisions are purely geologic. These divisions are three: the *Black Prairie,* which is the area of exposures of the Austin Chalk and the Eagle Ford; the *Eastern Cross Timbers,* or the exposure of the Woodbine; the *Grand Prairie* or the exposures of the lower limestones of the Comanchean. Reference to the geologic map accompanying this paper will show the outlines of these three main divisions. All three belong to the East-Central province of the State of Texas as a whole, according to R. T. Hill's classification which is the one in most general use although not entirely agreed upon.

The land surface in the county exhibits a general slope from the northwest to the southeast, following the general drainage lines. The relief is always low in spite of much dissection by streams and their branches. The topographic map has not been made for the county and only general terms can be used for the relief. The highest point in the county is somewhere on the uplands overlooking the headwaters of Clear Creek; the lowest point is where the Elm Fork crosses the county boundary in the southeast. The highest point has an elevation of about 1000 feet above sea level and the lowest about 450 feet. Such elevations as are known are given on figure 8, p. 83.

The drainage of the area is entirely into the Trinity River, although the northern boundary of the county closely approaches the divide between the drainage of the Trinity and the Red rivers. A conspicuous feature of the drainage

[9]Shuler, E. W., Geology of Dallas County, University of Texas Bulletin 1818.

system is the large number of alluvial flood plains, many of which are important enough to be shown on the geologic map. These flood plains are highly productive but in some cases are not protected against floods. The possibilities for dams, for irrigation and flood control are as yet undeveloped. The single large dam within the county is that which impounds Lake Dallas and this water is to be used exclusively for the city water supply of Dallas.

ECONOMIC GEOLOGY

In Denton County, as in other North Texas counties, many important natural resources are as yet untouched. The industries associated with these resources are in no case spectacular and for this reason are often overlooked by the non-technical person in considering the application of geology to industry.

Brief consideration will be given to the oil possibilities. In any region consideration of the petroleum possibilities involves first, the determination of the presence or absence of petroleum bearing formations; second, the uncovering of favorable or unfavorable structural conditions for the concentration of the petroleum. During the past six years a number of reasonably deep wells have been sunk in various parts of the county and adjoining territory and information on subsurface conditions has passed the conjectural stage for most aspects of the problem.

The petroleum possibilities are limited to three: the sands of the Woodbine, the sands of the Trinity, and certain shales and sands in the deeper Pennsylvanian rocks. The Woodbine is an important producer in several fields, for example at Mexia, and is the first possibility considered by the wildcatter. The principal obstacle in Denton County is the total absence of any structure in this formation favorable to the accumulation of petroleum. The Trinity has produced a little oil in "pumping" wells in Southern Oklahoma; but the petroliferous part of this formation must be very thin in Denton County, as only light showings are encountered at this level.

The Pennsylvanian possibilities are perhaps not so definitely closed as are those of the Woodbine and the Trinity. There is evidence of a structural high in the northern part of the county. Sellards[10] has shown that in southern Cooke County, the Cambro-Ordovician limestones come surprisingly close to the surface, about 1800 feet. This, after allowing for the usual Comanchean column, would leave the Pennsylvanian unusually thin. A further difficulty is that drilling for Pennsylvanian oil on the basis of structure in the Comanchean rocks has not proven successful in North Texas. The many wells along the Preston anticline in Grayson and Cooke counties give abundant proof of the inadvisability of drilling on the basis of structure in the overlying Comanchean. The possibility that the Montague County uplift might extend into the northwestern part of Denton County has been considered, but data on this is entirely lacking. The writer's own view is that prospecting in this part of the county would not be justified, even if the Comanchean rocks at the surface should exhibit favorable structure. (There is no evidence that they do.) If oil should be encountered under these conditions, it would be the first time after some three hundred failures, that concentrations in underlying Pennsylvanian rocks had been found in North Texas on the basis of Comanchean structures.

The brick and pottery resources of Denton County are almost inexhaustable and as yet have been used in only one place on anything like a large scale. The Acme Brick Works at Denton uses clays and shales from the lower part of the Woodbine formation. The excavations made by the Acme workers are especially interesting as the pit exhibits the highly varied character of the Woodbine formation. A single face exhibits several different color phases, also the peculiar cross-bedding which is present in the harder

[10]Sellards, E. H., the Underground Position of the Ellenburger in North-Central Texas, University of Texas Bulletin 1849.

ledges and which is sometimes mistaken by inexperienced persons for folding of the strata. A regrettable fact is that in various parts of the Woodbine in North Texas so-called "domes" have been located and actually drilled in the search for oil, despite the fact that the underlying rocks are normal and without folds. Besides the clays of the Woodbine the Weno clays in the northern part of the county offer interesting possibilities for pottery and brickmaking. These clays are used on a large scale by the brick kilns just south of the City of Gainesville.

Cement possibilities are especially good within Denton County. The first and most obvious combination is that of the Austin Chalk and the Eagle Ford shales, a combination which is utilized by the large plants near Dallas. A cement plant using this combination could be established almost anywhere along the Frisco Railroad in the southeastern part of the county. Other combinations, which analyses have shown to be favorable, are the Main Street limestone with the underlying Pawpaw clay. Such a plant could be established, for example, just west of Roanoke. Still another possibility is the combination of the basal Duck Creek limestones with the underlying Kiamitia clay. This combination is now being used by the Trinity plant just northwest of the City of Fort Worth. In Denton County the Duck Creek-Kiamitia combination is available near the City of Justin.

Cement possibilities in the City of Denton or its environs would be limited to the Main Street-Pawpaw combination which can be found in the southwest along the Texas and Pacific Railway and to the northeast near Clear Creek.

Building stones are available in various parts of the county but the best of these is the quarry limestone found in many parts of the northern portion of the county. In actual use this has proved to be a very high grade, handsome-appearing and weather-resisting stone. As previously mentioned the county courthouse at Denton is built of quarry limestone. Considering railroad facilities and general accessability the best site for a large scale exploitation of this stone would be along Clear Creek just south of Sanger. Other limestones within the county are less favorable both in quantity and quality but some of these are of possible value as a source of crushed rock. It is interesting to note that practically all the crushed rock used for concrete within the county is shipped from elsewhere.

Gravel and sand possibilities are very extensive. Almost any of the alluvial flood plains are worth exploring for gravel. A considerable quantity of high grade gravel has been taken out in the past few years from a site near the crossing of the Texas and Pacific Railway and Denton Creek just northeast of Roanoke. Smaller plants of intermittent life have been operated at various other points in the county. A detailed discussion of the requirements for good workable gravel and sand have been given by E. W. Shuler in the Dallas County bulletin previously referred to. The remarks made, while applying to Dallas County primarily, refer to gravels closely similar to those occurring in most parts of Denton County.

Underground water in Denton County is of high grade and is present in several layers, one or more of which are readily reached by the drill in any part of the county. The best of the underground water is that of the Trinity sand, which is reached at the City of Denton at a depth of approximately 1048 feet. The flow from this sand is very great and is probably enough in quantity to supply the city through an indefinite period of growth. Just above the Trinity flow a smaller flow is encountered from sands corresponding to the Paluxy. This water is of a poorer grade than that of the Trinity although a large quantity flows in any carefully drilled well. In the eastern part of the county the underground waters most readily available are those from the Woodbine sand. The position of these is known by local drillers in nearly all parts of the eastern half of the county. It is also well known that some of these members contain water which is strongly contaminated with gypsum and in some cases is sulphurous from having passed over beds of pyrite. In many cases it is necessary to case off these waters to secure lower waters in uncontaminated form. At best the waters of the Woodbine are only passable. In the central and western parts of the county some of the ranch and farm wells, which are shallow, get fair water from the Paluxy, in shallower wells from the sands of the Walnut, and in some cases in very shallow wells some water is obtained even from the Duck Creek formation, although the static level in these shallow wells fluctuates alarmingly with weather changes. As a matter of fact even the static level in wells from the Trinity fluctuates somewhat. The manager of the Denton City Waterworks has informed the writer that this fluctuation is observable but has not been actually measured.

Surface water from the impounding of streams is available in vast quantities within Denton County. The large lake in the eastern part of the county established by the City of Dallas is but one of many possibilities. It would seem highly desirable for public spirited citizens in Denton County to follow the example of Tarrant County and organize a water improvement district to make detailed studies of individual sites for dams, for irrigation, flood control, and other purposes.

Other economic possibilities based on mineral contents of the rocks are negligible. Much pyrite occurs in certain ledges but not in sufficient quantities to be worth exploiting on a commercial scale. Lignite occurs within the county in several thin seams in the Woodbine. A number of these have been examined by the writer and all are very poor quality and are in thin seams and not to be considered as an economic asset.

PALEONTOLOGY

A more full discussion of the paleontology will be included in this paper than is customary in a county report. This is partly because of the two great schools in Denton, partly because many accessible exposures of fossil bearing rocks are present in Denton County which are fairly representative, at least for the lower Cretaceous, of the North Texas region as a whole.

Of course it will be out of the question to give details of the paleontology of each formation but it is hoped that this paper will furnish a brief illustrated manual for the more common or conspicuous species. For detailed fossil lists the reader is referred to the bulletin on the Geology of Tarrant County and for figures and descriptions of horizon marking forms, without regard to their relative abundance, the reader is referred to the bulletin on Paleontological Correlation in North Texas. Both of these papers have been referred to previously.

The preservation of the fossils in the rocks of Denton County is fairly varied, although the overwhelming majority are preserved as simple mud casts. That is, the lime mud of the sea-bottom entered the shell of the animal after the soft parts had become decomposed and became cemented into a cast of the interior of the shell. In most cases the shell itself has been destroyed with the passage of time. This similarity of many of the mud casts, especially of the marine Gastropoda, is a source of considerable confusion, especially as authorities on these forms have always described a species from characteristics of the shell. Within recent years some effort has been made to classify these common internal casts of marine snails in the Texas lower Cretaceous. One of the writer's associates has resorted to the ingenious device of establishing a classification scheme based on casts of modern marine snails belonging to the same genera, but of course different species, as those in the lower Cretaceous rocks. He has prepared artificial mud casts, or veritable *artificial fossils,* by pouring plaster of Paris into modern marine snails, then dissolving away the shell itself and making a study of the cast.[11] Some of the artificial casts prepared in this manner are very interesting and instructive and this work has already thrown considerable light on the classification of the fossil marine snails (see plate 20). Ammonites, echinoids, corals, and bivalves preserved in the form of mud casts can usually be classified with some accuracy.

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[11]Hill, Ben H., New System of Classification of Marine Gastropoda (unpublished).

Another mode of preservation of which mention has been made is seen in the case of many of the dwarfed forms in certain clay layers. Here the shell has been replaced throughout by pyrite or more often marcasite. In the ordinary weathered exposures, the iron sulphide has actually been replaced by iron oxides although it is customary to refer to these minute fossils as pyrite. Another form of preservation is in the form of impressions in the lime or sand. Sometimes details of structure are preserved with great delicacy.

The rarest mode of fossil preservation in these rocks, although occurring in various members, notably certain clays of the Weno, is the actual preservation of the original nacreous shell material itself. In this case, of course, even microscopic details persist.

In various sandstone members some silicified wood is present. This material sometimes is sufficiently well preserved to exhibit microscopic detail (see plate 22).

The paleontology will be discussed briefly by formations and where a species extends through several formations as is often the case. the species will be described in connection with the formation in which it first occurs.

TRINITY-PALUXY

These sands and sandstones in Denton County contain no fossils that have been observed except fragments of silicified wood. Further to the south fossil fish have been found and in Central and South Texas where the Trinity becomes the Travis Peak, fossils are fairly common.

WALNUT

Mention has been made of the common fossil oyster, *Gryphea marcoui.* which makes up the bulk of the shell conglomerate of this formation.

Exogyra texana occurs in this formation for the first time. This species (see plate 11) is a flattened bivalve belonging to the large group of *Exogyras* which are so-called because of the characteristic twisting of the beak.

This species varies considerably in size and in body form but the example figured is representative and its size and proportions can be determined from the plate.

Pecten irregularis (plate 10) is a small scallop shell found not only in the Walnut but also in the overlying Goodland in which its zone of abundance occurs. This species is readily distinguished from the other members of this group by the presence of the very fine "tertiary" ribs in addition to the primary and secondary ribs so common in scallops in the lower Cretaceous.

Holectypus planatus (plate 13) is another characteristic Goodland species sometimes found in the Walnut. This small echinoid is usually well preserved, but the different species of which others besides *planatus* occur, are distinguished by details of the mouth which is on the underside and usually obscured by cemented limestone.

Schloenbachia acutocarinata (plate 5) is a medium-sized ammonite found in considerable abundance in certain horizons of the Goodland and occasionally occurring as low as the Walnut. This ammonite is characterized by extreme flatness and thinness which is the actual shape of the original animal and not due to compression as is thought by some. The size varies somewhat but a fair average is slightly less than one foot in diameter.

GOODLAND

This formation is marked by the presence of a great number of species together with vast numbers of individuals. As most parts of the Goodland in Denton County are in rather inaccessible places only a brief description will be given to the more representative species. The fossil species in many cases occur in the Goodland in definite zones of abundance which are striking and readily recognized when encountered.

Schloenbachia trinitensis (plate 5). This is the largest ammonite of the Goodland limestone although usually found in fragmentary condition it is readily distinguished from *S. acutocarinata* with which it is often found by its greater thickness, its larger size and the greater angularity of its ribs. A more difficult distinction to make is separation of *S. trinitensis* from *S. belknapi* which occurs usually in the Kiamitia. Careful study of the plates should enable the ordinary observer to distinguish between these two species. *S. trinitensis* occurs in greatest abundance in the upper part of the Goodland.

Engonoceras pedernale (plate 4). This small ammonite occurs in some abundance near the middle of the Goodland and is readily recognized by its extremely simple suture pattern and absence of keel.

Protocardia texana (plate 8). This heavy bodied clam can be recognized even in poorly preserved specimens from its general contours. When markings are preserved the lines are in two directions; first radial lines near the anterior end, second concentric growth lines from within outward. Dimensions and proportions can be determined from the plate.

Cyprimeria texana (plate 9). This thin bodied clam known only from its mud casts is poorly preserved in all cases although readily recognized. As in the case of other clams of the Comanchean it is possible that the generic assignment may not be correct. This clam sometimes occurs in great abundance near the top of the Goodland.

Lima wacoensis (plate 9). This small clam, averaging slightly more than an inch and a quarter in length, occurs in some abundance in the Goodland and occurs in various levels in higher formations. The markings are usually well preserved and the radial ribs give a characteristic appearance which makes the local name "Pigeon Wing Clam" highly appropriate.

Ostrea johannae (plate 8) occurs in the Goodland, in Denton County, about the middle and is associated with other species of large and irregular oysters which are much less common. This species is fairly characteristic although like all oysters it was very sensitive to slight changes in environment. All such changes are reflected in the shell (see discussion on *Plicatula dentonensis*).

Homomya sp. (plate 11). This thick-bodied clam occurs about the middle of the Goodland and is often fairly abundant. This species has not been studied in any detail and is figured here merely because of its abundance and with reservations as to the correctness of the generic assignment.

Pecten subalpina (plate 10). This large scallop which occurs occasionally in the Goodland became much more abundant in the later geological times. This species is clearly the ancestral type of *Pexten texanus* which is found in the extreme upper portion of the lower Cretaceous in North Texas. The distinction between the two species is rather slight in intergrade examples but it is customary to limit *Pecten texanus* to those last appearing forms which are marked by a definite flat rib. This leaves the whole evolutionary sequence of the earlier and middle forms with arched ribs in the *subalpina* species.

Hemiaster whitei (plate 12). This very common species of Echinoid was rather loosely described by the paleontologist who first studied it and the description fits several closely allied species common in the upper third of the Goodland. All are small and the distinction is purely scientific as all occur in about the same horizon and their stratigraphic value is not impaired by this scientific laxness. This possibly explains why the species has not been redescribed and the allied species carefully distinguished.

Enallaster texanus (plate 13). This echinoid is readily distinguished from *Hemiaster whitei* with which it occurs by the presence in *Enallaster* of a long and deep anterior sulcus. The distinction of this species from others in the same genus which occur in higher formations is much more difficult to make and is considered out of place in a paper of this kind.

Salenia mexicana (plate 12). This small sea urchin is not common but when encountered is striking enough to attract attention and for this reason is figured here. This species is an excellent horizon marker for the upper third of the Goodland.

Cyphosoma texana (plate 12). This sea urchin is larger than the above and more common although because of the fraility of the test or shell is usually found in fragmentary form. It has very little value as a horizon marker.

Parasmilia austinensis (plate 12). This is a coral belonging to the group popularly known as cup corals. Often specimens are found which are well preserved and exhibit considerable structure on sectioning. This is the largest of the corals occurring in the rocks in Denton County and is a reliable marker for the upper portion of the Goodland.

Cerithium bosquense (plate 20). This is one of many fossil marine snails occurring in the Goodland and is the only one which preserves enough of the external character to be recognized readily by an untrained observer.

Mud casts of Gastropoda (plate 20). These occur in considerable numbers in the Goodland but unfortunately names cannot be assigned to them in the present state of our knowledge concerning them.

Serpula sp. (plate 20). Annelid worm tubes occur in this and all other formations.

KIAMITIA

Fossils in this formation are less common than in the Goodland but when they do occur are mainly those of the Goodland. Two striking exceptions occur of fossils which are definitely diagnostic of the Kiamitia.

Gryphea navia (plate 7). This fossil oyster, as previously noted, occurs abundantly near the top of the formation and sometimes forms local shell conglomerates. This is the most readily recognized of any of the species of *Gryphea* by its characteristic size, its strongly rotated beak, and its thick massive shell.

Schloenbachia belknapi (plate 5). This large ammonite is strongly compressed or flattened and specimens found in Denton County are nearly always fragmentary and strongly stained with yellow-brown iron salts. Entire individuals like that figured in the plate are extremely rare

DUCK CREEK

Desmoceras brazoense (plate 4). This large ammonite is one of the most valuable horizon markers in the entire lower Cretaceous of Texas. The species was one with a short life and its maximum vertical extent of occurrence is never more than ten or twelve feet. In the zone of abundance the number of individuals is often very great although, as is often the case, perfect specimens are not common. In Forest Park, near Fort Worth, Texas, several years ago in grading a road the excavation turned up five hundred different individuals. The better specimens were used in a very clever manner in the construction of ornamental gate posts and as borders for terraces. These ammonites are especially common and conspicuous in the western part of Denton County in the region near the village of Stony. The limits of size are variable. A fair average is a diameter of about twenty inches although the writer has measured a few specimens considerably larger than this, one reaching a diameter of twenty-seven inches. The zone of this ammonite is the lower Duck Creek but does not extend downward into the basal ledge.

Schloenbachia trinodosa (plate 4). Another large ammonite readily distinguished from the above and marking the middle or a little below the middle of the Duck Creek. Careful distinction must be made between this species and *S. leonensis* which is found in the Fort Worth formation. Without going into technical paleontology it is sufficient to say that the ribbing is different between the two species, the arrangement of the tubercles on the rib also different and the general contour is enough different to allow distinction even of poor specimens. A study of the plates will develop enough differences to be usable by the ordinary observer.

Schloenbachia sp. A number of small ammonites occur in the lower part of the Duck Creek formation with a definite sequence which is of profound significance to paleontologists as it furnishes a definite time link between these rocks and corresponding ones in Europe and in Africa.

These small ammonites range from four to eight inches in diameter and species will not be listed here.

Hamites comanchensis (plate 6). This slightly coiled, almost straight ammonite, occurs in the zone of abundance at the base of the Duck Creek and the occurrence is over a wide area in southern Oklahoma, north, central and western Texas.

Hamites varians (plate 6). This minute form averaging rather less than an inch in length is a dwarfed species which is representative of the dwarf fauna occurring in the Duck Creek marl and in certain localities, is very abundant. The preservation is always either in pyrite, marcasite, or limonite.

Gryphea washitensis (plate 7). This oyster occurs occasionally in the Duck Creek, especially in its upper member and is listed here for that reason as this is the first occurrence. However, its zone of abundance is much higher up and in the Denton formation. The species name is appropriately taken from the Washita as it occurs with some abundance throughout the Washita part of the column.

Inoceramus comancheanus (plate 9). This peculiar clam is the only species of the genus occurring in the lower Cretaceous. Later in the upper Cretaceous, especially during Eagle Ford time, the genus developed a great number of species, each with vast numbers of individuals and the characteristic prismatic fragments of the shell occur in almost every cubic inch of the Eagle Ford shales. This species occurs in the lower third of the Duck Creek and is a reliable horizon marker, although individuals are not abundant enough to be used by the casual observer.

Pecten wrightii (plate 10). This angular scallop occurs in the very highest part of the Duck Creek and ranges into the lower Fort Worth. Specimens are not common but are valuable when encountered as definite markers in the column.

Kingena wacoensis (plate 12). This is the only lampshell or brachiopod which occurs in the lower Cretaceous of Texas and the species is the last survivor of a once great race which occurred in many species and many genera in the older seas of Pennsylvanian time. This species has a peculiar occurrence and the record tells the story of migrations away from and back toward the shoreline. The first occurrence is in the Duck Creek in the upper portion. This was limited to a small area near where Fort Worth now is and extending into the southern part of Denton County, as a few individuals can be observed just below the Fort Worth limestone northeast of Justin. The next occurrence was in the Denton formation in an area which is now southern Johnson County and adjoining parts of Hill County. The last occurrence during which a large number of individuals was developed was at the end of Main Street time in the central and northern parts of Denton County. The individuals are preserved in the top of the Main Street limestone in enormous numbers. Two favorable localities for the observation of this are the roadcut above Clear Creek on the Denton-Sherman road and the small creek just east of the Denton Country Club, south of Denton.

Holaster simplex (plate 13). This characteristic biscuit urchin marks the top of the Duck Creek marl and occurs through a vertical extent of twenty-five or thirty feet and occasional specimens are not rare in the lower Fort Worth. The example figured in the plate is the common or "low" phase and it is well to mention that another variety or perhaps species often referred to as the "tall" phase, which is very rare, occurs high in the Fort Worth and is a valuable horizon marker but not often observed except after careful search.

Mud casts of marine snails occur in some abundance in the upper or marly part of the Duck Creek. Our knowledge concerning these forms is not sufficiently advanced at this time to permit the assignment of specific and generic names except in the most haphazard manner.

FORT WORTH

Nautilus texanus (plate 5). This species occurs occasionally in the upper parts of the Fort Worth although its zone, of abundance is properly in the Weno and its vertical extent is very great, as specimens are not rare even in the highest portions of the Grayson. This is a characteristic and readily recognized species and its strong external resemblance to the modern chambered nautilus makes this an interesting museum piece. although it is rather poor as a stratigraphic marker in the field. In this connection, about all that may be said of it is that this nautilus marks the upper portions of the Washita division.

Schloenbachia leonensis (plate 4). This conspicuous ammonite, exceeded in size only by the *Desmoceras*, marks the Fort Worth formation and so far as the writer knows no observed occurrence is known later or earlier than the Fort Worth.

Schloenbachia aff. inflata (plate 6). This small ammonite is fairly common near the middle of the Fort Worth and becase of this is figured and listed here. As yet this species has not been described by American paleontoligists, although it has several times been referred to in various publications, the reference being by a letter or a number.

Hemiaster elegans (plate 13). This is the largest of the biscuit urchins occurring in these rocks. In certain localities, for example the Denton Creek bluffs east of Justin, individuals are very common. This fossil has a number of interesting local names. The most common perhaps being "Texas Star" although "Texas Heart" is also common.

Pecten bellula (plate 10). This small scallop is marked by a large number of very fine ribs which makes it characteristic even in fragments. It is found near the middle of the Fort Worth formation.

Exogyra americana (plate 11). This species has one of the shortest lives of any species known in the Comanchean. The occurrence is through a vertical extent of only a few inches and individuals are not common but are worth searching for in doubtful cases as a specimen in place definitely marks the top of the Fort Worth formation.

Fucoid plant masses (plate 2). These large irregular masses are fairly common in the Fort Worth and occur more rarely in higher formations. No structural details are exhibited and Texas geologists have provisionally considered that these masses are the remains of giant seaweeds. Fragments may be broken off which take peculiar and interesting shapes which are often mistaken by untrained persons for new and rare fossils.

DENTON

Plicatula dentonensis (plate 21). This small clam, commonly called "Catspaw Clam" by the writer's students, occurs in all of the formations of the Comanchean but is distinctly more abundant in the upper ones. It is first notably abundant in the Denton formation and reaches no definite zone of abundance as do many of the other fossil species in these rocks; but, in general, specimens are more common in certain members of the Pawpaw and in the Grayson. This clam is closely related to a number of small modern marine clams of the genus *Anomia.* This genus gets its name from a Greek word meaning "unlike" because of the strong dissimilarity or lack of uniformity between different individuals of the species. All bivalve clams are sensitive to their environment. The modern fresh water "button clam," for example, when grown in quiet water has a smooth shell and in rough water has a corrugated or ribbed shell. The modern *Anomia* grown by various experimenters on the Pacific Coast has been found to be so sensitive to differences in environment that the young from a single female grown under different conditions of temperature, oxygen, turbidity, pressure, food, and other conditions, will produce several dozen different individual types, some of which were actually considered species by older workers. As natural laws are unchanging it is possible to transfer some of this data to our fossil *Plicatula.* As much of the water was shallow in the Comanchean sea and the shore line was oscillating somewhat, these *Plicatulas* were subjected to many different conditions of environment.

Starting with the simplest kind of facts we can safely say that those forms with smooth shells grew in quiet water, those with ribbed shells in rough water. and, in rare cases, as examination of the plate will show some individuals were subjected to rough water during part of their lives and to smooth water during the rest of the time. The demarkation of the annual rings is fairly clear in most specimens and observation shows that about three years represents the average life. With a lens much finer rings between the annual rings are observable. These are rings of growth each resulting from single socalled "meals" or feeding periods, as similar rings are observable in nearly all modern bivalves. An examination of a number of specimens under a lens will exhibit irregularities in the smaller growth rings and these irregularities sometimes have a distinctive enough sequence so that the same sequence can be detected on different individuals. In this way it is possible to observe that the third year of one individual, for example, was the first year of another. In this way and by using similar rings on various pectens, the writer has been able to build up continuous chronologies for considerable lengths of time. In this work he hopes to be able after much more detailed work to determine in terms of absolute time the rate of deposition of at least some of the marl seams of the Texas Comanchean.

Ostrea carinata (plate 8). This angular ribbed oyster is an important fossil in the upper part of the Washita division. Unfortunately the name assigned to it by Texas geologists is not precise as this name belongs to a European fossil species originally named by Linnaeus; and the Texas species resembles this only superficially, but the application of this name has become quite general and it serves after a fashion as a fully agreed upon handle.

Leiocidaris hemigranosus (plate 13). This sea urchin occurs in both the Denton and the Weno and is represented mainly by large numbers of the thick, ribbed spines with occasional fragments of the test. Perfect individuals similar to that figured are extremely rare and the writer knows of the existence of only five others besides the specimen figured here.

WENO

Nodsaria texana (plate 15). This species belongs to the lowest group of the animal kingdom known as the *Protozoa* and is the largest of these animals found in these rocks, all the others are microscopic and reference to them is reserved for the section on micrology. This species averages about one-half inch in length and when present in abundance is readily observed by the collector. Its zone of abundance in Denton County is in the upper part of the Weno, although it is well to mention that in southern and western Texas this species appears in a zone of abundance in the Del Rio clay, which corresponds in Denton County to the lower part of the Grayson. In Denton County the Grayson contains this species only rarely and then only as occasional isolated individuals.

Ostrea quadriplicata (plate 8). In Denton County this species occurs occasionally in the Weno but reaches the zone of abundance in the lower part of the Pawpaw. Specimens vary somewhat due to the original environmental influences but the majority have the typical four-angle appearance which gives the species its name.

Trigonia clavigera (plate 8). This species reaches a zone of abundance in the blue-gray shale near the middle of the Weno formation in Denton County. This abundance is only a relative one as this species is not as common as most of the others listed here and is included merely because the preservation in these blue shales is usually very fine and specimens, when encountered, are striking and attract the attention of even the casual collector.

Pecten georgetownensis (plate 10). This is representative of an interesting group of "split rib" pectens found in the Weno over a large area. Note the groove present in the rib. Even small fragments are diagnostic and of value in establishing the stratigraphy of a new exposure.

Gervilliopsis invaginata (plate 9). This is a species which belongs to a group related to the modern "razor" clams. It occurs in the lower Weno in Denton County in a zone of great abundance, the individuals being compressed against each other in a clay layer several feet thick. In spite of the abundance, good specimens which are nearly entire, are difficult to find. In fresh cuts and exposures of this clay member, these razor clams have a shiny silvery appearance and are known in Denton and Cooke counties by the local name of "petrified sardines."

Schloenbachia wintoni (plate 5). This small ammonite averaging rather less than six inches in diameter, marks the Weno throughout North Texas. It is rather difficult for the untrained person to distinguish this from certain other small ammonites, especially certain ones occurring in the Duck Creek, but a superficial distinction for this species is the presence of the notched tubercle at the outer end of each rib. In some cases in the Weno shales in Denton and Cook counties this ammonite is found preserved in the original nacreous shell and not as a mud cast. In this case the notched effect of the outer tubercles is obscured by the shell.

PAWPAW

Turrilites worthensis (plate 6). This is the most striking of the dwarfed species found preserved in pyrite in this formation. This species is a spirally coiled ammonite.

Scaphites hilli (plate 6). This is another of the dwarfed forms and is in the same subgroup of animals to which the ammonites belong. This obscure little species is of considerable scientific importance, as it is one of many used by geologist and paleontologist in linking the rocks of the Texas Comanchean with those of corresponding age in other parts of the world.

Pyritized ammonites, clams and corals (plate 3) of many species occur in the Pawpaw and are interesting mainly because of their dwarfage and will not be detailed here.

Fish teeth and vertebrae (plate 3) occur occasionally in rocks of all the formations in Denton County but are distinctly more abundant in the Pawpaw formation than in the others.

MAINSTREET

Turrilites brazoensis (plate 5). This large, spirally coiled ammonite marks the Main Street not only in North Texas but appears in a corresponding zone in rocks of the same age wherever they are exposed in central and western Texas. The species is a fairly abundant one and it is unusually favorable as a horizon marker because of its abundance. The relative abundance decreases somewhat toward the north although specimens occur in southern Oklahoma. The preservation is usually in the form of a mud cast and it is seldom that the suture pattern or annual growth marks will be preserved.

Pachymya austinensis (plate 11). This is the largest of the clams preserved in the lower Cretaceous rocks of Texas. It is readily recognized by its large size and characteristic contours. In Central Texas the mud cast often shows the shell markings but in Denton County the specimens are usually smooth.

Holectypus limitis (plate 13). This flattened sea urchin is the second species in this genus of importance in these rocks. It is distinguished from the species occurring in the Goodland by differences in size, slight differences in outline, and structural differences of a technical nature which need not be gone into here as the two species, because of their wide separation in the column, should never be confused with each other.

GRAYSON

The fauna of the Grayson formation is so rich and so highly varied that even a list of the species would be cumbersome. In this paper mention will be made only of a few common and diagnostic fossils.

Gryphea mucronata (plate 7). This oyster, the last of the *Grypheas* of the lower Cretaceous in this region reached an astonishing development in numbers and the species lived for a considerable length of time, as it is found in more or less abundance throughout the approximately seventy feet of the Grayson. As is the case with all oysters, both living and fossil, slight environmental changes are reflected in the shell and no two specimens are exactly alike. In fact identification of the *Grypheas* in the field usually calls for the collection of a dozen or more specimens and the search for general characteristics shared by all the specimens in the group. The examples of the different species which are figured here were carefully selected in order to exhibit typical appearance of each species. In the case of this species because of the fine preservation and the great abundance of individuals, striking variations are common.

Exogyra arietina (plate 11). This is an extreme example of the fossil oysters of this group having twisted beaks. This species occurs in Denton County mainly in the lower part of the Grayson, although in central and western Texas in the corresponding time zones of the Del Rio formation, the vertical extent of the species is considerably greater than in Denton County. Also specimens are usually larger than those encountered in the Grayson in Denton County.

Small *Turrilites* superficially resembling *Turrilites brazoensis* (plate 5) but much smaller occur in the Grayson of this region; and, in at least one important publication, individuals of this species have been figured with *T. brazoensis* as belonging to that species.

Echinoids occur occasionally in the Grayson and are different species (which will not be listed here) of some of the same genera previously described in connection with some of the lower formations. The most important of these is a species of *Enaslaster*.

Pyrite fossils in some variety occur in the Grayson in Denton County. As is always the case in these rocks the species are all dwarfed.

Pinna sp. (plate 9). This angular and thick clam occurs here and less often in the Goodland. There are several species, all superficially alike.

WOODBINE

Keelless ammonites about eight or nine inches in diameter and heavily ribbed, occur occasionally near the top of the Woodbine. Specimens are rare and will not be listed here.

Oysters of several species occur at different levels in the Woodbine, especially near the top. The hard ledge of material encountered in the excavation for the Garza dam, in some cases, contained so many oyster shells as to amount to almost a conglomerate in thin seams interbedded with the harder rocks.

Leaves and other plant remains (plate 2) occur in this formation although always in fragmentary form as the material is not marine in origin but was washed from the nearby land along with the sediments.

EAGLE FORD

Ostrea belliplicata (plate 8). This is merely one of a large number of species of oysters which occur in this formation and is selected to figure here because it is the most common and the most striking and is also easily recognized.

Ammonites occur near the middle and near the base of the Eagle Ford but are extremely rare and will not be listed and figured here. It is interesting to mention that occasional examples of ammonites in this formation are of very large size, although entire specimens have not been found in this county. The writer has seen fragments of the whorls of large ammonites in this formation which must have been broken off of individuals at least a yard in diameter.

AUSTIN CHALK

As only the lower part of this formation is exposed in Denton County and as most of the exposures are heavily weathered and covered with deep soil, the larger fossils characteristic of this formation will not be listed here. As is the case with all parts of the upper Cretaceous in North Texas, the micrology of the Austin Chalk is more interesting than its grosser features.

MICROLOGY[11a]

This new branch of geology has come into tremendous importance within the last few years and it seems well worth while to include with this paper short discussions of the microscopic characteristics of the rocks found in Denton County. Experience has shown that data of this nature can often be applied over a considerable area. The general features mentioned here refer to characteristics, particularly in the lower Cretaceous rocks, which will be more or less applicable to these formations anywhere between the Brazos and the Red rivers.

So far as the writer knows, only one previous paper[12] has discussed the microscopic characteristics of the lower Cretaceous rocks of Texas. Because of their greater importance as possible sources of petroleum, the upper Cretaceous rocks have been studied in some detail in the geologic laboratories of various oil companies, although very few of these studies have been published.

The methods used were extremely simple, following the general routine used in the subsurface laboratory of the Texas Bureau of Economic Geology.

Limestones and other harder rock have been sectioned by the simple process of rubbing down small chips to thin sections, on a sheet of plate glass which has been treated with emory powder and water.

Marls and clays have been prepared by concentrating, that is, gradually washing away the suspended silt in

[11a]The term Micrology is here used as applying to that which is revealed by the microscope.

[12]Udden, Johan A., Characteristics of Some Texas Sedimentary Rocks as Seen in Well Samples, Bulletin Amer. Assn. Petr. Geol., Vol. 5, No. 3.

bowls of water, leaving the minerals and micro-fossils in the basin.

Micrology of the Trinity Division

Trinity-Paluxy.—These sands are to be recognized in well samples mainly by their position and by a few minor characteristics which appear at certain levels; for example, the lower sands of the Trinity are white sands, fairly fine, characterized by remarkably rounded grains (see plate 22). Other features appear in various samples, but are always local. Some well series have shown frequent appearance of fruits of *Chara*, a green alga. Some disagreement exists among subsurface geologists as to the source of these fruits, one side holding that they are original in the rock, the other holding that they are washed in from surrounding ponds with the water used in drilling the well. The fruits are admittedly like those occurring today in Texas fresh water and it seems likely to the writer that these have been washed in. An added factor is that the Trinity sand is difficult to drill in because "the hole doesn't hold water," and an unusually large quantity of water is used in the drilling. Fossil wood occurs at intervals as has been referred to. Perhaps the remarkable constancy of the composition of the underground waters might properly be placed under this head, since an experienced worker can determine the approximate level reached in these sands by the analysis of the water.

The Glenrose Limestone, which occurs deeply seated in the eastern and southern parts of Denton County, is a characterless, granular limestone with some organic fragments, and not to be told in the present state of our knowledge from certain other limestones of the Comanchean.

The Travis Peak Limestone, which appears to be present in the extreme southern part of the county, deep in the Trinity formation, as found in diamond drill cores in Tarrant County, is a spongy, soft limestone and rich in organic remains.

Micrology of the Upper Fredericksburg and Lower Washita Formations

By C. I. Alexander

(Plates 14 and 23, Fig. 2)

Goodland.—The marl and shale members present a varied assortment of the most common generic groups of foraminifera, and also of certain small shelled crustacea known as *Ostracoda.*

The lower part of the Goodland is partly composed of dark, compact, laminated shales. These shales are usually referred to as marls, but often are actually shales. If small bits of the unweathered material are heated in a closed tube, water is deposited on the sides and a strong carbonaceous odor is given off.

These shales and marls are interstratified with ledges of soft white limestone. Sections of this limestone show a finely crystalline structure. Often many fragments of organic origin are present. Illustrations given elsewhere for other organic limestones in the column greatly resemble some of the limestone of the Goodland.

Concentrated samples of the lower softer members exhibit a large quantity of pyrite. Gastropoda, small clams are *Cythereis, Cytheridea* and *Paracypris* (plate 14). Most significant fossils are the *Ostracoda.* Important genera are *Cythereis, Cytheridae* and *Paracypris* (plate 18). Most of these Ostracoda are found also in the upper Goodland; but associated with considerable pyrite always should strongly suggest lower Goodland.

Echinoderms of many species have been used in the case of larger fossils marking horizons in the Goodland, and fragments of spines and plates are common in the microscopic material.

Foraminifera are not common, but occur in considerable variety.

The character of the Goodland sediments changes in the upper part of the formation. There is a greater proportion of limestone and a grayish marl forms the softer members instead of shales. Concentrates of this material show a great decrease in the amount of pyrite, although it is still present. The most striking feature is the presence of large numbers of echinoid spines and plates.

Inoceramus prisms, bryozoa and shell fragments occur throughout the formation.

Kiamitia.—This formation is composed of dark, almost black, shales with thin ledges of gray-white sandy limestone, often stained yellow with iron when exposed.

The concentrates of the softer material are much like those of the Goodland. The lower limestone ledges, in thin section, are coarsely crystalline, with the crystals of calcite heterogenous as to size, and with some sand showing.

The uppermost ledges resemble, in sections, those of the Duck Creek.

Duck Creek.—The most characteristic feature of this formation under the microscope is the appearance of the limestone. In thin sections, this limestone exhibits a peculiar composition that, in North Texas at least, is absolutely unmistakable. This is a sphero-crystalline structure, or rather an arrangement of crystals in spherical groups. Plate 23. Figure 2 is a section from a surface sample taken in the western part of Denton County.

As has been stated, this peculiar structure is found also in the uppermost ledges of the Kiamitia, but disappears at the Duck Creek-Fort Worth contact. The Duck Creek marls are fairly characteristic. Foraminifera are common. Some pyrite occurs throughout, but is not abundant.

Forth Worth (lower portion).—The Duck Creek-Fort Worth contact can be defined, as noted above, on the basis of differences in the limestone members alone. The Fort Worth limestones, in thin sections, exhibit a rather finely crystalline composition with considerable organic remains. The change from this type to the sphero-crystalline type of the Duck Creek is so abrupt as to serve as an admirable marker in any kind of subsurface work.

The large echinoderms which abound in the lower Fort Worth marls leave their mark on the microscopic material in the form of an abundance of fragments of tissue, spines and plates.

Peculiar and important foraminifera are *Vaginulina*, a *Nodosaria* and three characteristic species of *Textularia*.

Common Ostracoda are the three types of *Cythereis* shown in plate 14, figures 13, 14, 15 and 16. Less common, but characteristic and valuable as indicating the lower Fort Worth, are the two peculiar and striking species of *Cythereis* in plate 14, figures 9 and 12, and the species of *Cythere* in figure 17.

The Micrology of the Middle Washita Formations

By Sadie Mahon

(Plates 15, 24 and 25)

Upper Fort Worth.—The most interesting micrology of the upper Fort Worth is involved in the highly organic limestone of that part of the formation (plate 25, figures 1 and 2). The limestone is much harder than the soft chalky limestone nearer the base and contains many varieties of foraminifera.

A section of limestone from the ledge on north side of Clear Creek, south of Sanger (plate 25, figure 1) shows *Ostracoda,. Textularia, Cristellaria, Globigerina, Echinoid tissue, Inoceramus prisms, Anomalina, Echinoid spines,* etc.

Another section from a limestone ledge on the Denton-Gainesville road, one-fifth mile south of the Santa Fe tracks (plate 25, figure 2), is equally as fossiliferous and is very diagnostic of the upper Fort Worth formation. The marls are calcareous and the micro-fossiliferous matter is soft and crumbly.

Samples of Fort Worth marl from the escarpment on Helm School road, one mile west of Patterson Spur, Denton County. show *Textularia* (plate 19, figures 14 to 21), *Cristellaria* (plate 18, figure 8), several different species of *Nedosaria* (plate 19, figures 9 and 10), *Rammulina* (plate

17, figure 23), *Serpula*, *Quinqueloculina* (plate 17, figure 24), *Inoceramus prisms* (plate 27, figure 1), a few *shell fragments*, *calcite*, *hematite* and a little *pyrite*.

Samples from several other localities show most abundantly *echinoid spines* of the type shown in plate 15, figure 5. These may be spines of *Dorycrinus* or some like *echinoid*. There are also *echinoid caps*, *conodont teeth* (plate 15, figure 8) and two unidentified specimens. The one shown in plate 15, figure 1 is likely *Hyperammina* (?). The other shown in plate 24, figure 6 is a portion of a chain of small pitted objects, the median cavity and the upper and lower edge being bounded by short blunt spines. This specimen is also found throughout several of the other Cretaceous formations.

The marls also show pieces of *Pecten valves*, portions of *echinoid tests* of several different varieties and fragments of teeth.

Denton.—Like the larger fossils of the Denton the microscopic forms are somewhat restricted and only a few are constant.

The marl is bluish-gray in color and contains many shells and shell fragments. The shells are the juveniles of several different species of clams, the most characteristic being the *Gryphea washitensis* (plate 24, figure 7) and oyster-like fossils which form the *Gryphea* conglomerate at the top of the formation.

Besides shell fragments of the *Gryphea* there are present clams *resembling Pinna* (plate 15, figure 9), pieces of *ornate shells* possibly of Gastropoda, and portions of *salenid tests*.

Many of the Foraminifera of the Denton are of the same species as those of the overlying Weno marls.

Washings from basal Denton about one mile south of Krum, Denton County, show only *Cristellaria* (plate 18, figure 8), *Ostracoda* (plate 14, figure 2) and shell fragments; while samples from cores of the Trinity No. 1 drill hole at Arlington, Texas, show more of a variety of microscopic fossils. *Aristotle's lanterns* (plate 16, figure 1 and plate 24, figures 2 and 3) are very abundant. They are found in specimens showing only the five-rayed structure and in those showing a portion of the test under the apical system. Several types of *Vaginulina*, the most common of which is the long slender specimen show in plate 15, figure 7, are present. *Cristellaria* (plate 24, figure 10 and plate 18, figure 3), *Serpula, Frondicularia* (plate 24, figure 5), *pyritic gastropoda* (plate 24, figure 8), a few *pyritic Nodosaria*, several species of *Ostracoda* (plate 18, figure 14 and plate 14, figure 17) and a few fish vertebrae characterize these washings. Also there is present in this material a peculiar form of organic origin which the writer is unable to identify. It is an ovate body, with a flat, slightly granular surface, one end blunt, the other tapering. This specimen was noted only in the Denton washings.

There are a few *Textularia* and *Globigerina* present in the Denton, but they are for the most part very poorly preserved. A section from the limestone ledge near basal Denton, one and one-fifth miles south of Krum, reveals an abundance of *Echinoid spines*, some *Ostracoda, Echinoid tissue*, and *Cristellaria*. Sections from Trinity No. 1 hole at Arlington, Texas, show the same types.

As a whole the Denton formation is not rich in microscopic fossils.

Weno and Pawpaw.[13]—Although the Weno and Pawpaw formations do not show the great abundance of Foraminifera which marks some of the other Cretaceous formations, there are several representative species which can be depended upon in subsurface geologic investigations.

The marls of both formations are for the most part brown or yellow in color and contain several varieties of iron ores, chief of which are much weathered *pyrite* (both "oolitic" and cystalline) and *calcite* (plate 24), figure 13).

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[13]The micrology of the two formations does not differ enough to justify separation in so brief a description.

The characteristic brownish stain shown in sample washings is probably due to the *iron carbonate* which is present throughout the marl layers and often surrounds the nacreous material of the larger fossils of the Weno and Pawpaw and some of the other Cretaceous formations.

Washings from samples twenty-five feet below the top of the Pawpaw north of Denton (plate 24, figure 13) show bits of semi-pellucid matter with variously colored veins, probably *onyx*, a peculiar form of compact and hard lime deposit. Also there are present in this iron-stained material numerous microscopic organisms which are themselves brown in color and resemble the pupa of some insect. These are prevalent in the Cretaceous but have not yet been identified.

The basal sands of the Pawpaw seem to contain practically no microscopic fossils while the overlying clays are characterized by *fish vertebrae* in great abundance, *fish scales* (plate 16, figure 2), *fish bones* (?) (plate 16, figure 25), *Bryozoa* (plate 24, figure 4), *Echinoid spines* (plate 15, figure 3), *Nodosaria* (plate 16, figure 12), *Cristellaria* (plate 17, figure 2), etc.

The most fossiliferous marls of the Weno seem to be above or below the *Gervilliopsis ledge* at Katy Lake. Samples from both localities contain many *Echinoid spines* which illustrate two different kinds (plate 15, figures 3 and 5). The *Cristellaria* are mainly of the outside-suture type (plate 24, figure 10) although a few are of the smooth and more common type (plate 24, figure 2). Some very perfect original shells of *Gastropods* (plate 24, figures 1 and 9) of varied sizes, highly polished, flecked with brown, and very ornate, are present. In the vicinity of these are *pyritic Gastropoda* (plate 24, figure 8), and *pyritic Aristotle lanterns* (plate 24, figure 11), which are mouth parts of echinoderms, showing the typical five-rayed structure, and which have become detached from the plates. Several specimens are found in the Weno, Pawpaw and Denton formations, which show a portion of the test under the apical system (plate 24, figures 11 and 3). *Crustacean chela* (plate 15, figure 2) are also fairly abundant and *Frondicularia* (plate 24, figure 5) occur only in one species. These, together with *dermal plates* (?) (plate 24, figure 12) and the array of *fish vertebrae* typical of the Weno and Pawpaw, form the bulk of the washings. The limestones of the Weno and Pawpaw are not organic. The limestone that attracts attention is the ledge about nineteen feet below the top of the Weno, which is marked by vast numbers of *Nodosaria texana* (plate 15, figure 4).

Dr. Udden in his article on "Characteristics Seen in Well Samples," in the Bulletin of the American Association of Petroleum Geologists, states, "the best markers of the Del Rio clay are *Nodosaria texana* and *Exogyra arietina*. With the finding of both of these fossils there can be little doubt as to the identity of this horizon." This is true for West Texas but not for North Texas. The *Nodosaria texana* is a reliable marker for the upper Weno formation. One of the most constant micrscopic features of the two formations is the marked scarcity of *Globigerina* and *Textularia*.

MICROLOGY OF THE UPPER WASHITA

By Margaret Carpenter

(Plates 16, 17 and 23, Fig. 1)

Main Street.—The Main Street formation is composed of limestone layers interbedded with seams of marl, both members being rich in micro-fossils. The limestone is rather coarsely and irregularly crystalline. Among the fossils distinguished in a micro-section are shells (probably a *pelecypod*) *echinoid tissue*, *Ostracoda*, and such foraminifera as *Globigerina*, *Pulvinulina*, and *Cristellaria*.

The marl layers contain a variety of microscopic forms, the upper ones being more varied than the lower. Shell fragments and echinoid plates and spines (plate 15, figure 3) are found throughout the formation, as are also small vertebrae (plate 16, figures 24 and 25). *Ostracoda* are quite common and several genera occur. Small gastropods preserved in pyrite have been found at about the middle of the formation. Fish scales (plate 16, figure 2) were also found at this level and very small fish teeth at various levels.

Throughout the formation is found the unidentified form figured in plate 17, figure 14. This is shaped somewhat like a fragment of a cylinder and has a pitted surface both inside and out with a fluted or beaded edge at one end. It is constant in this formation and in the Grayson above as well as in lower ones.

Some fragments which appeared to be Crustacean chela were found. A few *Conodonts* or annelid jaws also occur. In this formation also are found some of the forms figured in plate 16, figure 1. These are thought to be echinoderm remains connected with the apical system. They are found also in the Grayson formation.

Of the foraminifera found the most constant are *Cristellaria*, *Globigerina*, *Nodosaria*, and *Anomalina*. The *Globigerina* are evidently of two or three species, the larger one having a characteristically pitted appearance (plate 17, figure 5). *Anomalina* occurs in a large and small form; and there are several *Cristellaria*, some completely coiled and some straightened (plate 17, figures 1 to 4), *Textularia*, *Ramulina* (plate 17, figures 22 and 23), and *Vaginulina* (plate 16, figure 9) are also quite common. Other foraminifera found are *Lagena*, *Triloculina* and *Truncatulina*.

Pyrite is very common in these marl seams and occurs in both the crystalline and "oolitic" forms. It is the material in which some of the fossils are preserved, notably *Textularia*, *Triloculina*, *Anomalina*, and *gastropods*. Jasper and calcite are also common and gypsum and marcasite were found but not to any notable extent.

Grayson—The Grayson formation is composed mostly of soft marls except the upper third which has several thin limestone ledges (plate 1). The entire formation, like the Main Street below it, is quite fossiliferous microscopically.

The upper part of the limestone, thought to represent the Buda limestone, is rather coarsely crystalline and extremely fossiliferous (plate 23, figure 1). In sections made from this part there have been observed echinoid tissue and spines, pelecypod shell fragments, *Globigerina, Anomalina, Cristellaria, Textularia, Ostracoda,* and others unidentified because of the difficulty in recognizing foraminifera in thin section. The lower ledges of limestone are more finely crystalline and not so fossiliferous as the upper.

Both the gray and the yellow marls of this formation are rich in fossils. In variety of forms as well as in number of individuals, the upper part of the yellow marl just below the limestone part of the formation seems to be richest. At this level are found all the fossils listed in the Main Street except *Truncatulina,* with the addition of *Quinqueloculina* (plate 17, figure 24), *Clavulina* (plate 16, figure 4), *bryozoa, serpula,* small *clams* (plate 16, figures 15 and 16), *Hammulina,* and a small *turrilite. Echinoid* plates (plate 16, figure 3) and spines are particularly abundant at this level. Here also are found a number of the forms figured in plate 16, figure 1 and described above in the Main Street. These are found also at other levels in the Grayson. Small vertebrate bones (plate 16, figures 24 and 25) are common here. Numbers of small pyrite gastropods are found at this level also (plate 16, figures 19 to 22).

At about the middle of the formation *Globigerina* and *Anomalina* seem to be particularly abundant, while in the basal part small vertebrae and their fragments and a great number and variety of *Textularia* (plate 17, figures 15 to 21) are the distinguishing features.

The formation as a whole contains many *echinoid* remains, shell fragments, *vertebrae,* small *vertebrate bones, Ostracoda* in variety, the unidentified form in plate 17, figure 14, *Cristellaria, Globigerina, Textularia, Nodosaria,* and *Anomalina.* Occurring less frequently are *Pulvinu-*

lina (plate 17, figures 11 and 12), *Vaginulina, Clavulina* (plate 16, figure 4), *Lagena*, and *Quinqueloculina*.

Just above the lowest limestone ledge were found a number of very small Pinnas (plate 16, figure 18) and the other small pelecypod figured in plate 16, figure 17. *Gastropods* are found frequently below the limestone.

Fish scales and very small fish teeth are found at various levels. *Conodonts* or *annelid* jaws are frequently found. Peculiar prisms, always in masses, and somewhat resembling *Inoceramus* prisms, are found throughout the Grayson as well as less frequently in the Main Street. *Bryozoa* are very common in the Grayson formation. By far the most common one is *Membranipora* (plate 16, figure 6), but others also occur. Common minerals, as in the Main Street, are *calcite, gypsum, jasper, marcasite*, and *pyrite* (rarely in "oolitic" form).

The writer has been unable to discover any marked or even recognizable difference in the micrology of the Main Street and Grayson formations. In microscopic samples the two appear very much the same and carry practically the same fossils. It is true that *Truncatulina* was found in the Main Street and not in the Grayson, and *Clavulina* and *Membranipora* were not noted in the Main Street; but none of these fossils were found to occur consistently enough or in great enough numbers to make sure of distinguishing any given sample as belonging to either formation merely by their presence or absence. Perhaps more study and careful working out of species may later establish a difference not now recognized.

Micrology of the Woodbine, Eagle Ford, and Austin Chalk

By W. L. Moreman

(Plates 18, 19, 26 and 27)

Woodbine Formation.—The Woodbine formation was formerly considered barren of microscopic fossils, but recently drill cores have revealed the presence of a large variety of Foraminifera, Ostracods, Gastropods, and fish remains such as teeth, scales, and vertebrae. The lower shaly beds of about one hundred feet seem to be richer in these fossils, while the upper red sandy members contain practically nothing of any importance.

A sample of the lower part is composed of a blue shaly material, and when concentrated only small fossils and minerals remain.

The fossils consist mainly of Foraminifera, preserved in calcite and pyrite. They are represented by *Globigerina, Textularia, Anomalina, Cristellaria, Nodosaria, Lagena*, etc. (plates 18 and 19). Several species of ostracods occur but are mostly common forms that may be found at almost any level in the Comanchean and Cretaceous. Three of these are illustrated on plate 17, figures 13, 14, and 15. Gastropods preserved in pyrite are numerous near the base of the formation, and represent several different genera and species. They are interesting due to the fact that they are so small, measuring only from one to two millimeters, through the greatest dimension, and still retaining the same elaborate structure that is found in the larger forms. At certain levels, notably about fifty or sixty feet from the base, *Inoceramus* prisms occur in great quantities. The fish remains are found throughout the whole formation, being more numerous of course at certain levels. They consist of shark teeth, pavement or pharyngeal teeth, vertebrae, and scales (plate 26). The scales are found in the form of amber colored plates, only occasionally showing any structure. Some of these fragments might possibly be *annelid* jaws, but none were observed to have structure enough to be classified in this phylum.

The minerals consist mostly of pyrite, found in both the crystalline and "oolitic" form (plate 24). A great deal of pyrite is found as would be expected from the appearance of the weathered material. Glauconite is common and at the top makes up a large part of one layer of sand giving it a greenish tint. Other materials, such as jasper and crystals of different kinds are numerous.

The upper beds are composed of red sands, the grains being mostly rounded. The angular type make some beds near the top. The average size of the grains is around .2 mm. One ledge at the middle of the formation averaged .12 mm. At the top of the Woodbine near the Eagle Ford contact, Foraminifera appear such as *Globigerina*, also *Inoceramus* prisms, and fish *teeth* which are mostly of the pavement type.

Eagle Ford Shale.—This formation is one of the richest of the upper Cretaceous group for the study of Foraminifera and microscopic fossils of all kinds. The Foraminifera, especially, are abundant at certain horizons and are present in a great variety.

The most interesting part is at the contact with the Austin Chalk formation. Here just below the first ledge of white massive limestone is a hard blue layer about one foot in thickness, which contains fish remains, Foraminifera, Ostracods, Gastropods, Pelecypods, annelid jaws (plate 26, figures 1 and 2) Bryozoa, etc. This is a distinct ledge that can be easily detected from any in the Eagle Ford or any other formation of the upper Cretaceous. It has been thoroughly worked from the Red River to the Brazos, and the most characteristic qualities noted. It has the same general appearance and texture from one end of the contact to the other.

When a sample is concentrated it consists of black and gray granules. The coarse screen contains shark teeth, vertebrae (plate 26), small clams, Gastropods, and Bryozoa. Jasper, kerogen and pyrite are also abundant. The medium screen contains small teeth, Bryozoa, a large Cristellaria known as *Cristellaria cretacea*, which is common throughout the Cretaceous, also a large species of Globigerina. Bituminous material, pyrite, kerogen and glauconite are abundant. The fine and very fine screen contains small teeth, scales, vertebrae, Foraminifera such as *Globigerina, Textularia, Cristellaria, Truncatulina, Pulvinulina, Frondicularia Nodosaria, Lagena* and others (plates 18 and 19). The Textularia are present in several species as is evidenced by those on plate 19, figures 14 to 22. The Ostracod *Cythereis* is abundant at this point, however, it is common through several formations (plate 18, figure 14).

The Gastropoda are preserved in pyrite and represent several genera and species.

The Pelecypoda are not so common but include two or three geuera.

A great diversity of fish teeth is found at various levels of the Eagle Ford (plate 26). The fish were very abundant at this time and represented a great many species.

The minerals consist of pyrite, glauconite, and bituminous material. The glauconite is in two forms; the ordinary dark green, and a bright green which is abundant in small pieces. The latter is more plentiful towards the top of the formation.

About fifty feet from the top, at what is known as the ammonite ledge, there may be found in washed samples, fish remains, *Anomalina, Globigerina, Textularis,* etc. Fish scales are numerous at this level. The number of species of fossils decreases downward and at the base only *Globigerina* and *Inoceramus prism* make up the entire concontrated sample (plate 27, figure 2).

Plate 27, figure 1, shows the variety of Foraminifera at the Austin Chalk contact in comparison with the Woodbine contact, figure 2.

Austin Chalk.—The Austin Chalk being a deep sea deposit, contains a large group of Foraminifera which are evenly distributed throughout the entire formation. Owing to this characteristic it is difficult to establish any well marked horizon as the one described at the top of the Eagle Ford. It was deposited as a hard, chalky limestone, interstratified with softer blue marly layers. Only the base of this formation is exposed in Denton County but samples from other localities show the same micrology. Sections have been examined from the middle at Austin and from the top at Garland.

Sections of the hard layers reveal traces of Foraminifera, Ostracods, and other organic materials. Globigerina, Textularia, and Anomalina are easily detected in the pictures of limestone sections. A large number of samples prepared in this way would no doubt uncover many more species of Foraminifera and other fossils. Some glauconite is found near the base of this formation.

The blue layers are softer and easily concentrated. The concentrate consists mainly of Foraminifera and Echinoid spines. The Foraminifera are of a large size and represent all of the genera and species shown on plates 18 and 19, and possibly others of more or less importance. The *Inoceramus* prisms described in the Woodbine and Eagle Ford formations are also found in the Austin Chalk. They seem to become more abundant in the upper beds of the Cretaceous.

WELL LOGS

Highland Park's Well

Log of Highland Park's well on Eugene Puchsy's farm, Denton County.

	Depth in Feet From	To
Soil	0	10
White shale	10	25
White lime	25	37
Blue shale	37	65
Brown shale	65	110
Blue lime	110	115
Black shale	115	170
White lime	170	175
Blue shale	175	205
White lime	205	250
White slate	250	265
White lime	265	275
Blue shale	275	330
White lime	330	340
Slate and lime shell	340	400

White lime	400	470
Black slate	470	485
White water sand	485	495
Black slate	493	503
Water sand	503	508
Blue shale	508	512
White water sand	512	525
White slate	525	615
White sand	615	640
White chalk	640	650
Quicksand	650	699
Gravel	699	720
Black slate	720	832
Hard sand	732	768
Blue slate	768	778
Soft water sand	778	808
Blue slate	808	826
Quicksand	826	851
Black shale	851	870
Blue lime	870	875
Blue slate	875	885
Blue shells	885	895
Water sand	895	920
Red clay	920	930
Blue shale	930	1,020
Blue clay	1,020	1,050
White lime	1,050	1,060
Water sand	1,060	1,070
Blue shale	1,070	1,100
White lime	1,100	1,115
Shale and lime shells, blue	1,115	1,140
Blue slate	1,140	1,160
Hard white sand	1,160	1,170
Brown shale	1,170	1,190
Blue shale	1,190	1,220
Blue sand	1,220	1,255
Lime shells	1,255	1,260
White sand	1,260	1,270
Red clay	1,270	1,300
Blue shale	1,300	1,305
Water sand	1,305	1,330
Gravel	1,330	1,355
Blue shale	1,355	1,370
Lime	1,370	1,383
Oil sand	1,383	1,390

Brown shale	1,390	1,415
Blue shale	1,415	1,465
Lime shells	1,465	1,470
Black shale	1,470	1,520
Red rock	1,520	1,620
Pyrites of iron	1,620	1,640
Blue shale	1,640	1,660
Red rock	1,660	1,690
Black shale	1,690	1,850
Red rock mixed with gray	1,850	2,000

Tippet and Darnall Well

Log of the Tippet and Darnall well, located six miles south of Denton, Denton County, Texas, on the Fritz Mathis farm.

	Depth in Feet From	To
Yellow mud	0	10
Sand	10	20
White shale	20	110
Lime	110	115
Blue shale	115	160
White shale	160	175
White shale	175	235
Sandy shale	235	250
White shale	250	325
Sandy shale	325	365
Black shale	365	405
White lime	405	480
Black shale	480	485
Water sand	485	495
Black shale	495	508
Water sand	508	510
White shale	510	520
Red rock	520	523
White shale	523	553
Water sand	553	600
Blue shale	600	620
Sand	620	630
White lime	630	663
Sand	663	695
Sandy lime	695	720
Red rock	720	725
Blue shale	725	740

White shale	740	760
White lime	760	790
Brown lime	790	805
White shale	805	810
Blue lime	810	835
Water sand	835	850
Blue shale	850	860
White lime	860	870
Blue shale	870	890
White lime	890	895
White shale	895	915
Lime shells	915	920
Water sand	920	945
Blue shale	945	960
Water sand	960	985
Blue shale	985	990
White lime	990	1,000
Water sand	1,000	1,010
Blue shale	1,010	1,020
White lime	1,020	1,030
White shale	1,030	1,040
Water sand	1,040	1,060
Red rock	1,060	1,065
Blue shale	1,065	1,070
Water sand	1,070	1,100
White lime	1,100	1,105
Red rock	1,105	1,120
White shale	1,120	1,135
Water sand	1,135	1,160
Water lime	1,160	1,165
Water sand	1,165	1,190
Red rock	1,190	1,210
Water sand	1,210	1,255
Blue shale	1,255	1,265
Water sand	1,265	1,280
Blue shale	1,280	1,302
Water sand	1,302	1,315
Blue shale	1,315	1,340
Water sand	1,340	1,415
Red rock	1,415	1,450
Lime	1,450	1,455
Blue shale	1,455	1,530
Sand	1,530	1,540
Blue shale	1,540	1,595
White shale	1,595	1,630

Red rock	1,630	1,660
Pyrites	1,660	1,662
Red rock	1,662	1,665
Shelly	1,665	1,675
Blue shale	1,665	1,675
Blue shale	1,675	1,700
Red rock	1,700	1,720
Brown sand	1,720	1,745
Red rock	1,745	1,750
Blue shale	1,750	1,775
White lime	1,775	1,780
Blue shale	1,780	1,790
Lime shells	1,795	1,801
Blue shells	1,801	1,821
Lime shells	1,821	1,825
Blue shale	1,825	1,845
Salt sand; flow salt water	1,845	1,865
Lime shells	1,865	1,875
Blue shale	1,875	1,885
Lime shells	1,885	1,890
Sandy shale	1,890	1,935
White shale	1,935	2,000
Hard sand	2,000	2,020
Sandy shale	2,020	2,055
Red rock	2,055	2,060
White shale	2,060	2,080
Sandy shale	2,080	2,110
Black shale	2,110	2,170
Blue shale	2,170	2,230
White shale	2,230	2,240
Blue shale	2,240	2,260
Black shale	2,260	2,280
Hard sand	2,280	2,300
White slate	2,300	2,310
Black shale	2,310	2,320
White shale, shelly	2,320	2,330
Dry yellow sand	2,330	2,345
Black shale	2,345	2,355
Black lime sand, shelly	2,355	2,365

Well abandoned September 15, 1915.

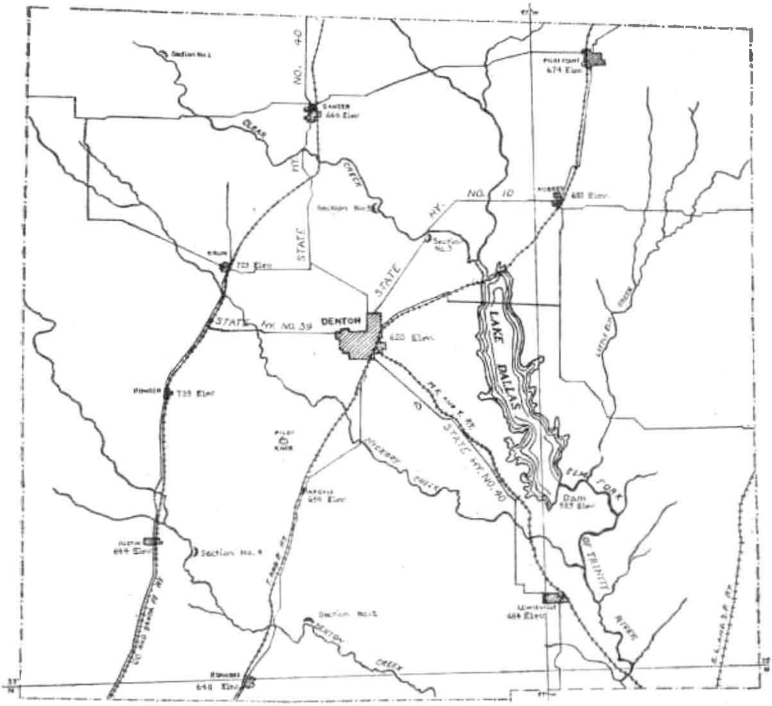

Figure 8. Outline map of Denton County, showing main highways, elevations, and locations of principal sections.

EXPLANATION OF PLATES 20 TO 27

Plate 20. Figs. 1-4. Artificial mud casts of marine Gastropoda. Figs. 5-7. Mud cases from Goodland formation. Fig. 8. Serpula. X1. Fig. 9. *Cerithium bosquense.* X½.

Plate 21. Fig. 1. Unidentified. X5. Fig. 2. Portion of Ornate shell (?). X5. Fig. 3. *Plicatula dentonensis.* X½. Different examples of this highly variable little clam from various formations. (Plate from Texas Christian University Bulletin, Vol. XX, No. 2.)

Plate 22. Above. Section of silicified wood (probably of a Gymnospermous plant) from the Trinity-Paluxy. X9. Below. Sand grains from water level in Trinity sand and Denton city well. X5.

Plate 23. Fig. 1. Section of Fort Worth limestone. X30 Fig. 2. Section of Duck Creek limestone. X30.

Plate 24. Fig. 1. Gastropod (original shell). X10. Fig. 2. Echinoderm (Aristotle's lantern). X2½. Fig. 3. Echinoderm (Aristotle's lantern). X2½. Fig. 4. Bryozoa (?). X5. Fig. 5. *Frondicularia.* X10. Fig. 6. Unidentified. X10. Fig. 7. Juvenile of *Gryphea washitensis.* Fig. 8. Pyritic Gastropod. X5. Fig. 9. Gastropod (original shell). X10. Fig. 10. *Cristellaria* with outside suture. X10. Fig. 11. Pyritic Aristotle's lantern. X5. Fig. 12. Dermal plate. X5. Fig. 13. Iron-stained Pawpaw. X6.

Plate 25. Figs. 1-2. Sections of "Buda" limestone from Grayson formation near Roanoke, Texas. X30.

Plate 26. Micro-fossils of the Woodbine and Eagleford. Figs. 1-2. Annelid jaws. X10. Figs. 3-4. Vertebrae. X10. Fig. 5. Pharynegeal tooth. X2½. Figs. 6 7. Otoliths. X10. Figs. 8-18. Shark and dogfish teeth.

Plate 27. Inoceramus prisms and Globigerinae from the Eagleford.

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Plate 1. Bluff showing entire section of Grayson formation. Three miles northeast of Roanoke, on farm of Mr. T. M. Jones.

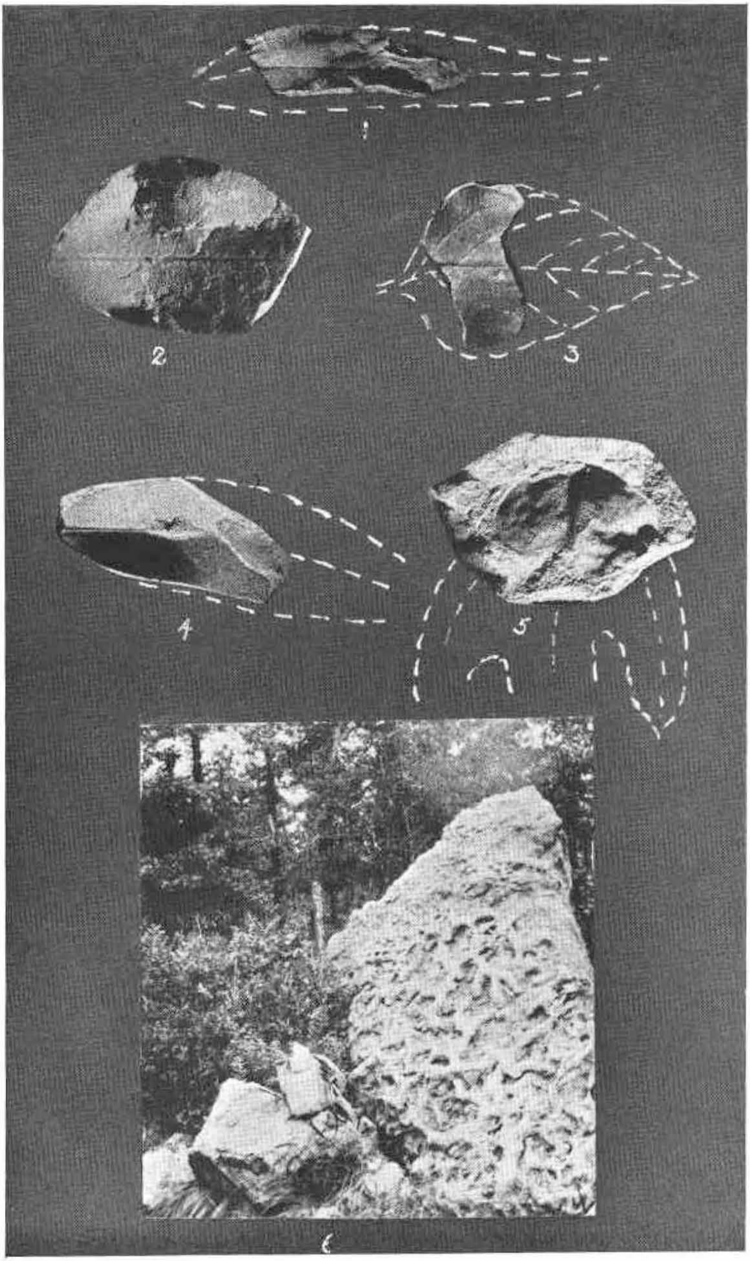
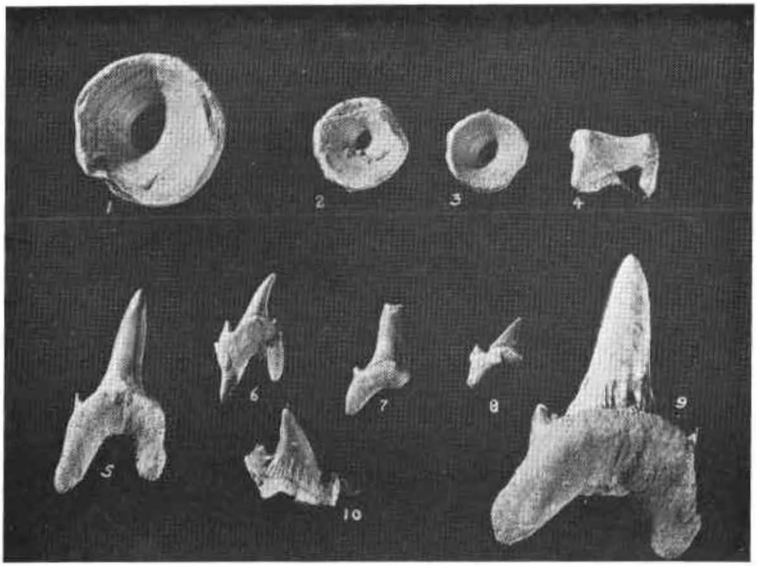


Plate 2. Figs. 1-5. Fragments of leaf impressions in Woodbine sandstone, east of Denton. X½. Fig. 6. Fucoid plant masses in Fort Worth formation.



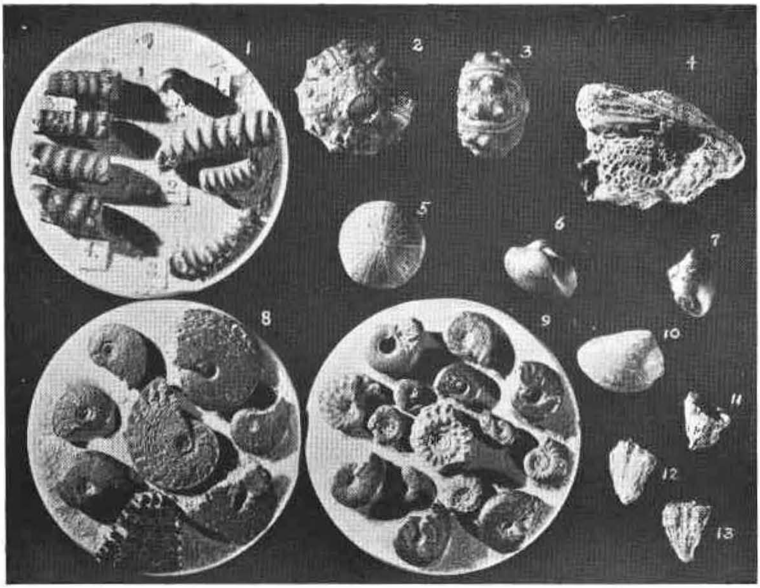


Plate 3. Above. Shark teeth and vertebrae from Pawpaw formation. X1. Below. Dwarfed ammonites, clams, corals, echinoids, etc., from the Pawpaw. X1.

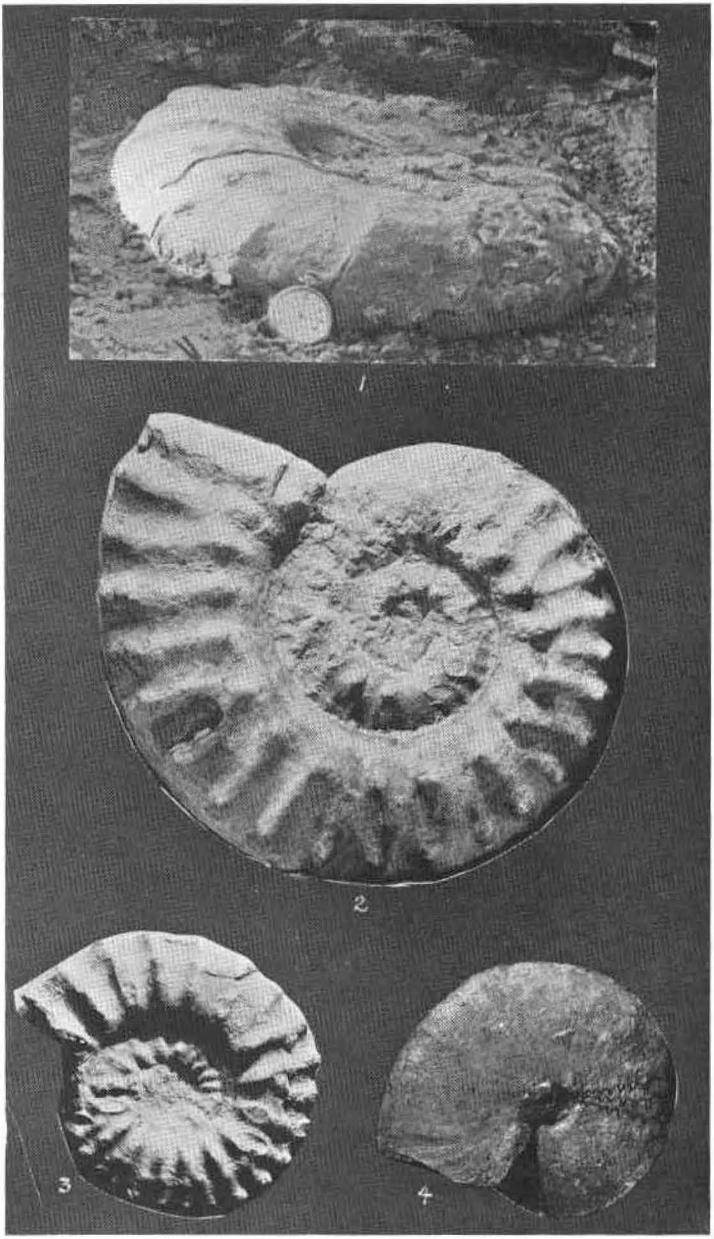


Plate 4. Fig. 1. *Desmoceras brazonse,* in situ. X1/6. Fig. 2. *Schloenbachia leonensis.* X1/5. Fig. 3. *Schloenbachia trinodosa.* X1/5. Fig. 4. *Engonoceras pedernale.* X1/2.

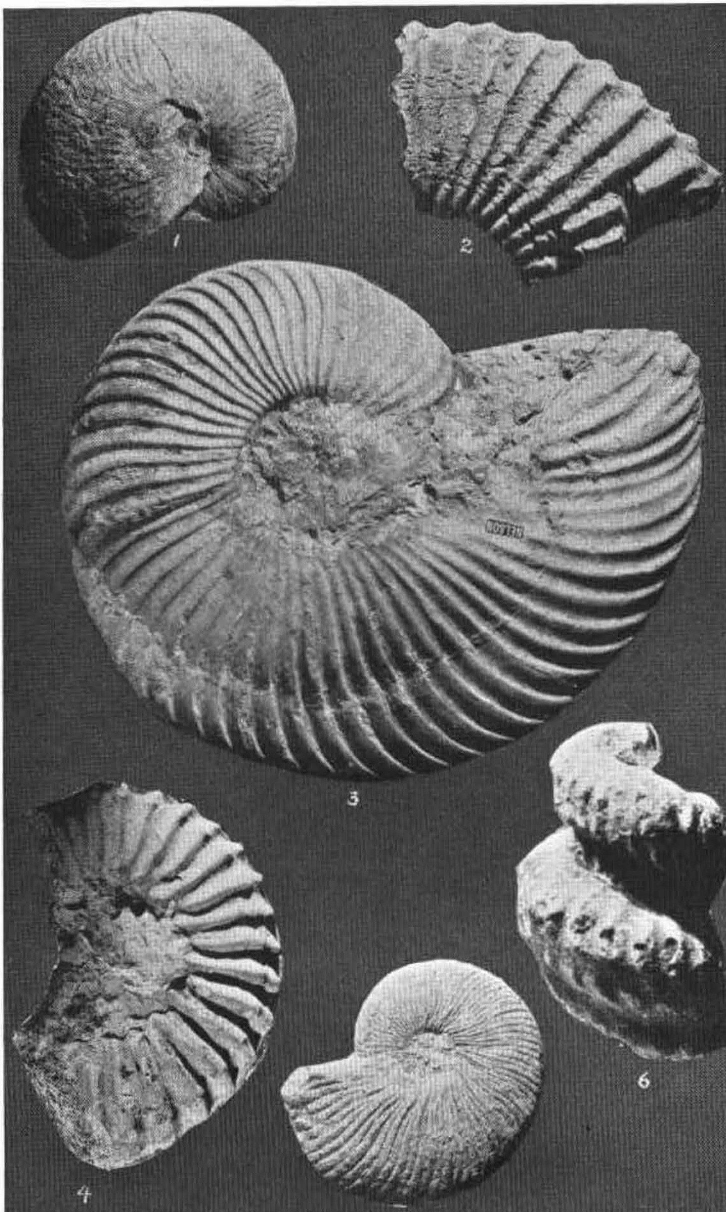


Plate 5. Fig. 1. *Nautilus texanus.* X1/3. Fig. 2. *Schloenbachia trinitensis.* X1/4. Fig. 3. *Schloenbachia belknapii.* X1/5. Fig. 4. *Schloenbachia wintoni.* X1/2. Fig. 5. *Schloenbachia acutocarinata.* X1/3. Fig. 6. *Turrilites brazoensis.* X1/3.

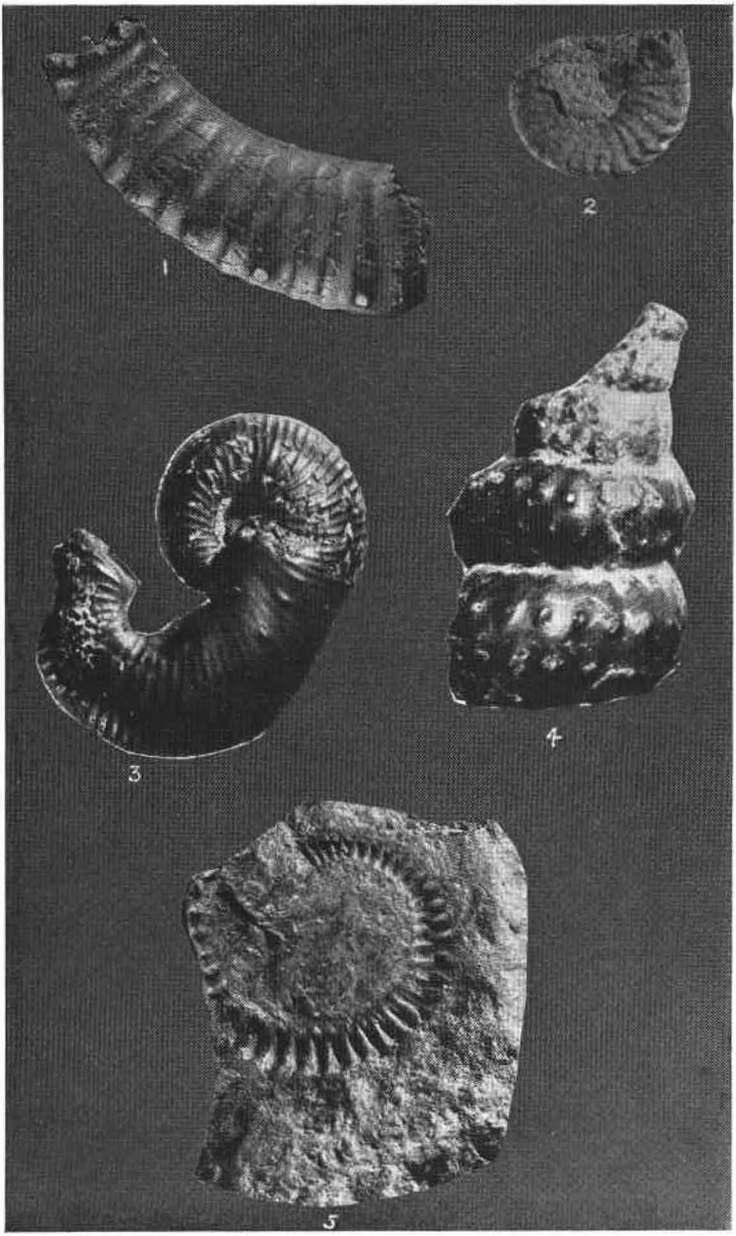
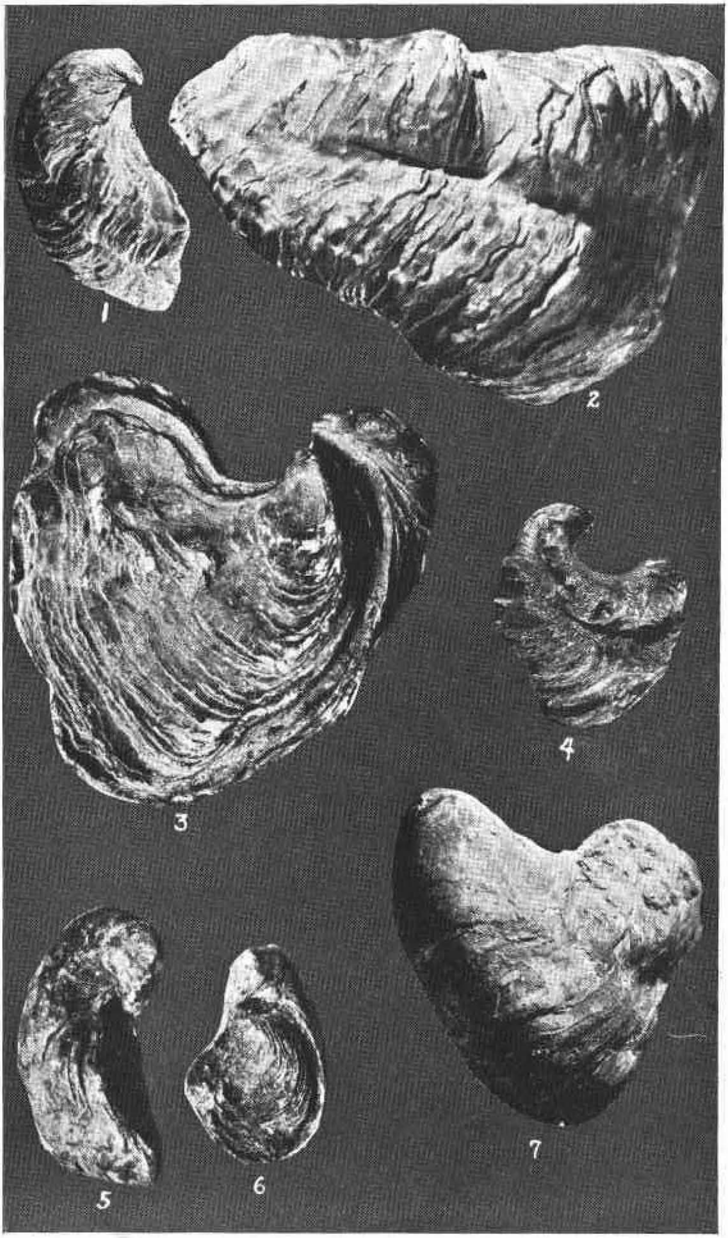


Plate 6. Fig. 1. *Hamites varians.* X4. Fig. 2. *Schloenbachia* aff. *inflata.* X½. Fig. 3. *Scaphites hilli.* X4. Fig. 4. *Turrilites worthensis.* X4. Fig 5. *Hamites comanchensis.* X½.



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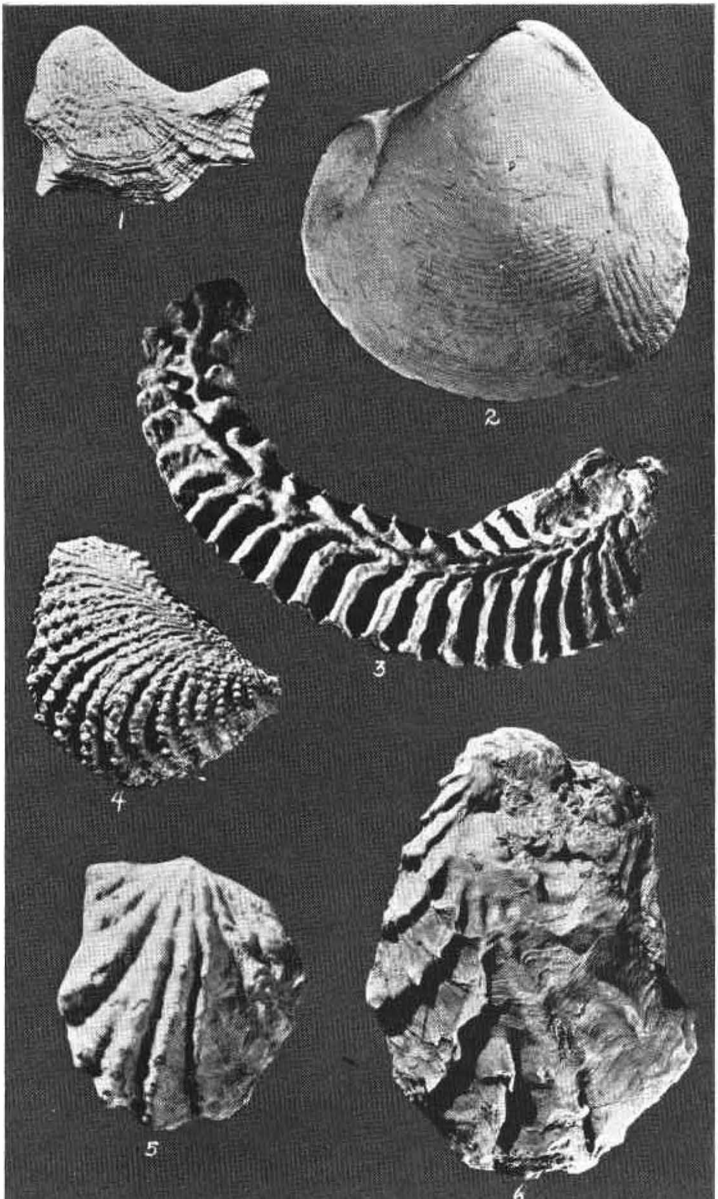

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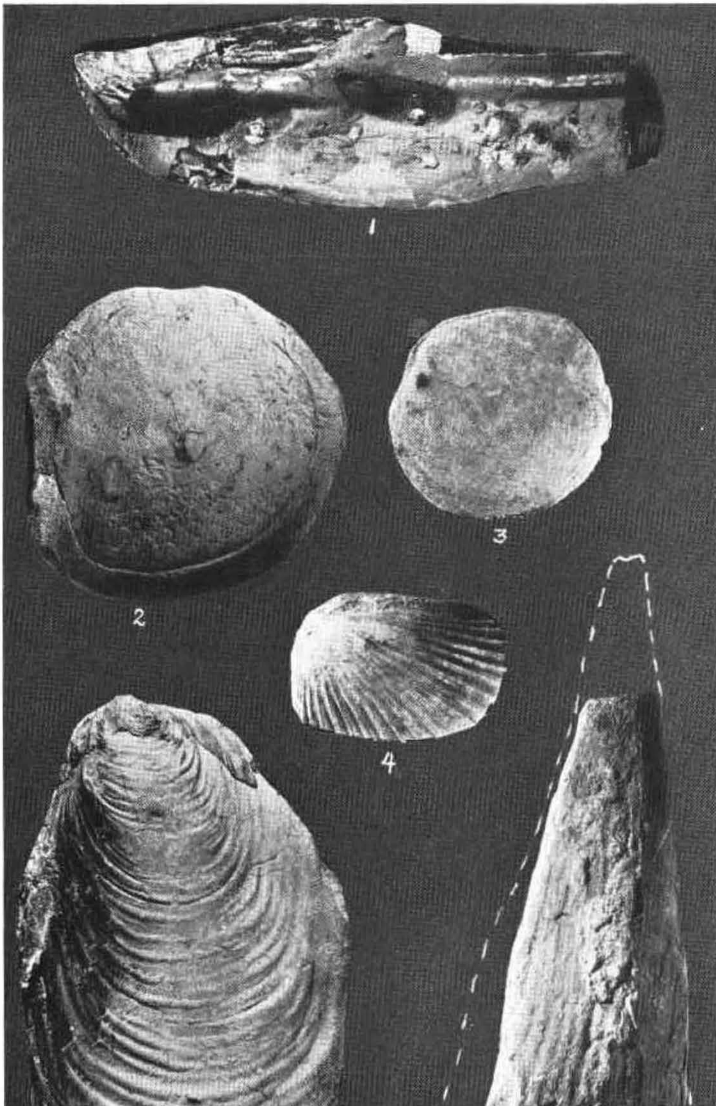

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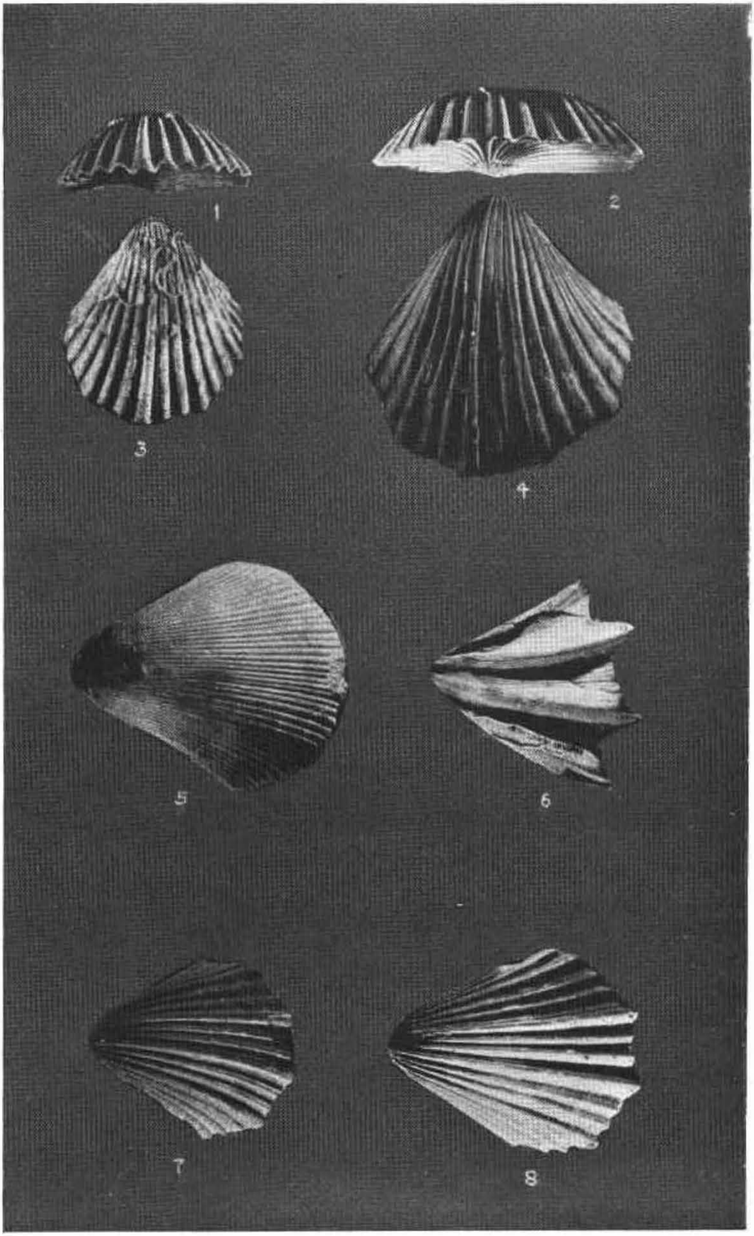

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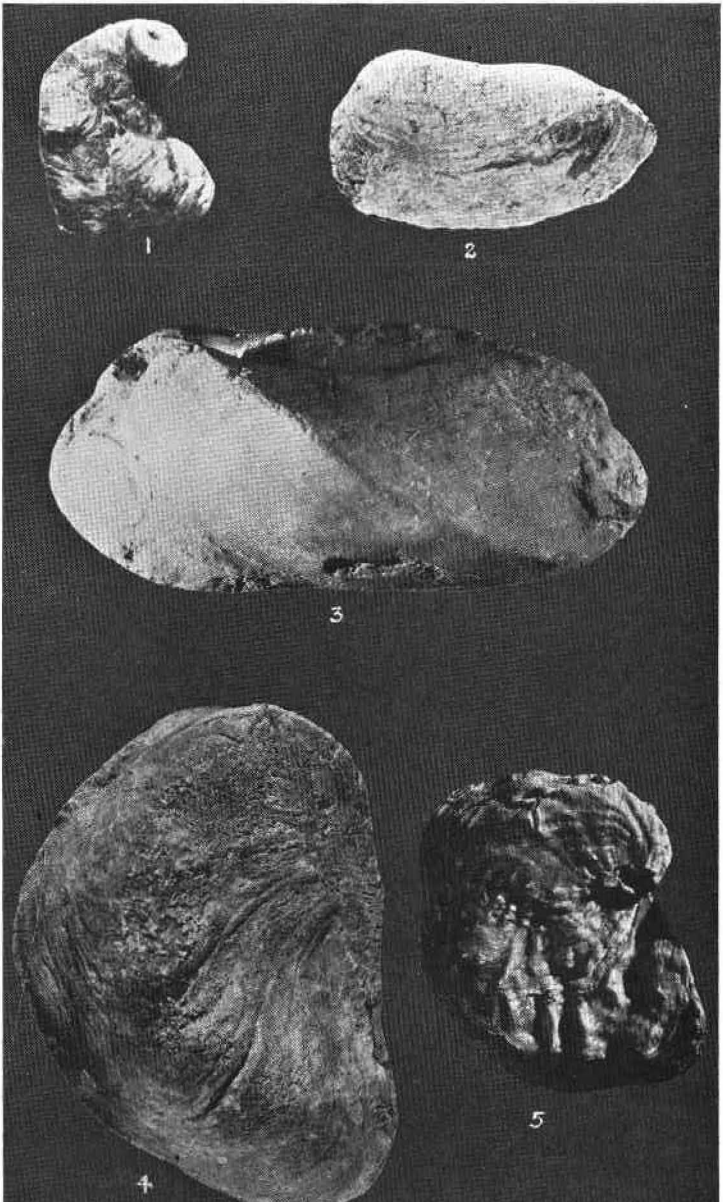

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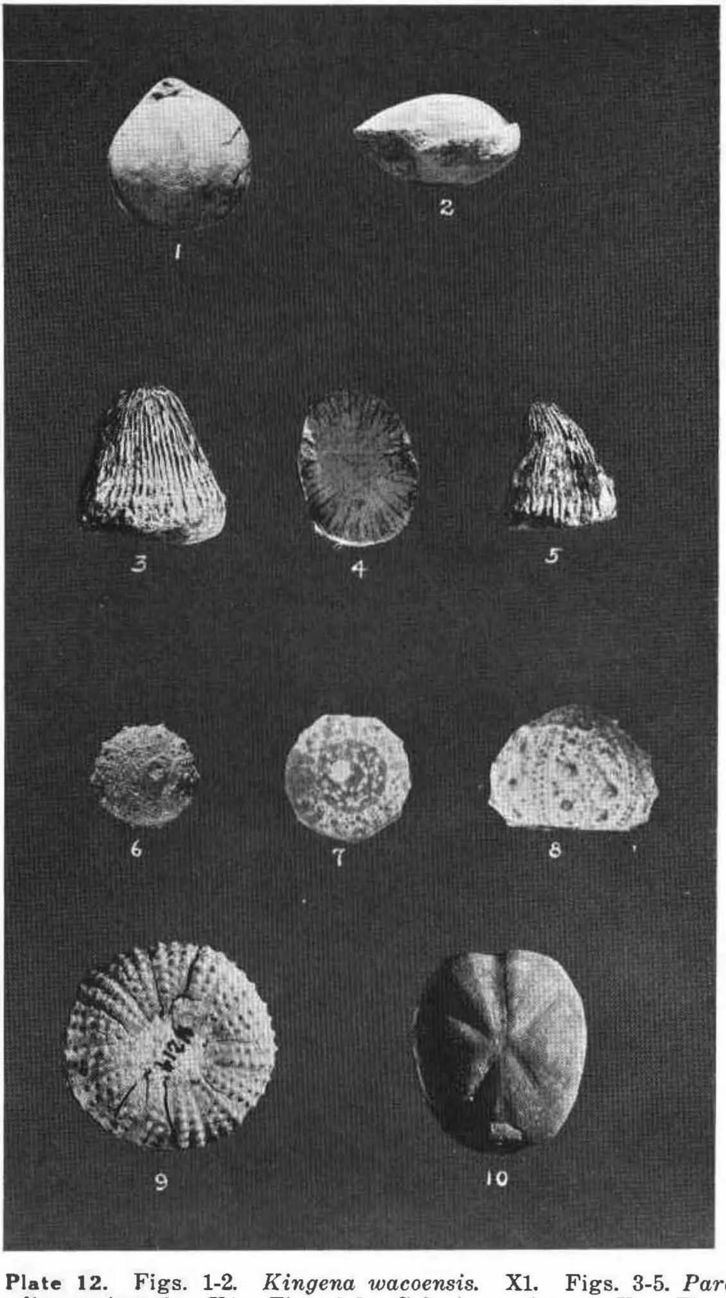

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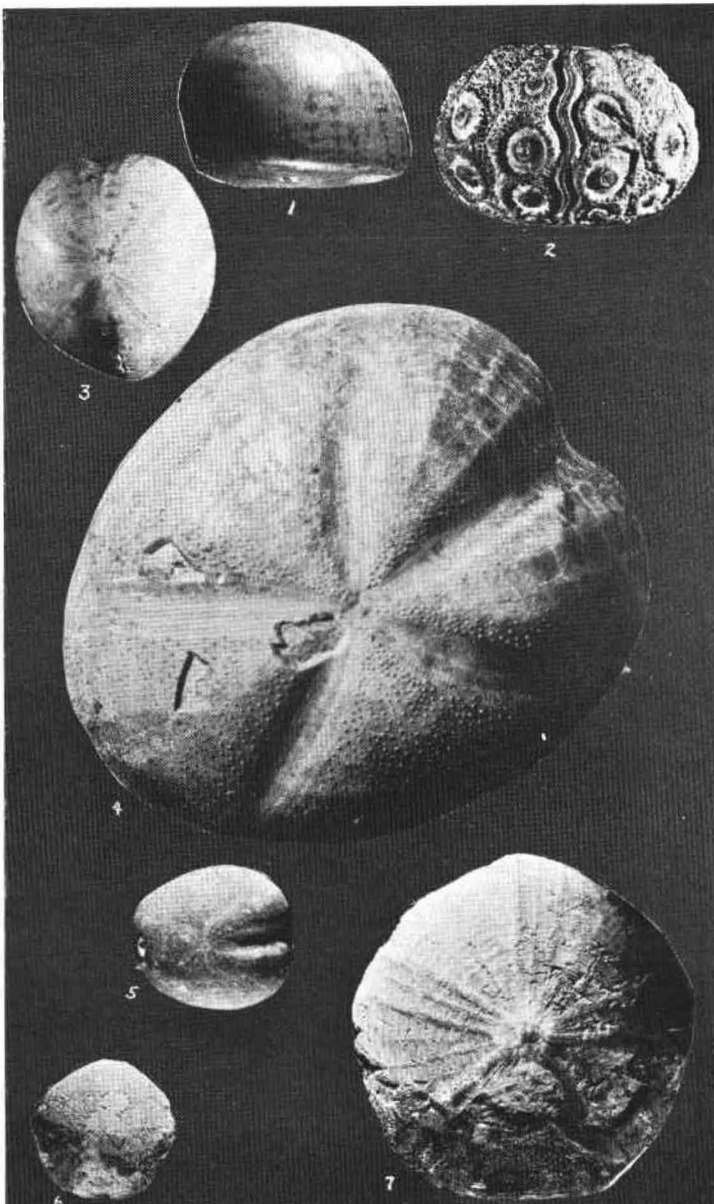

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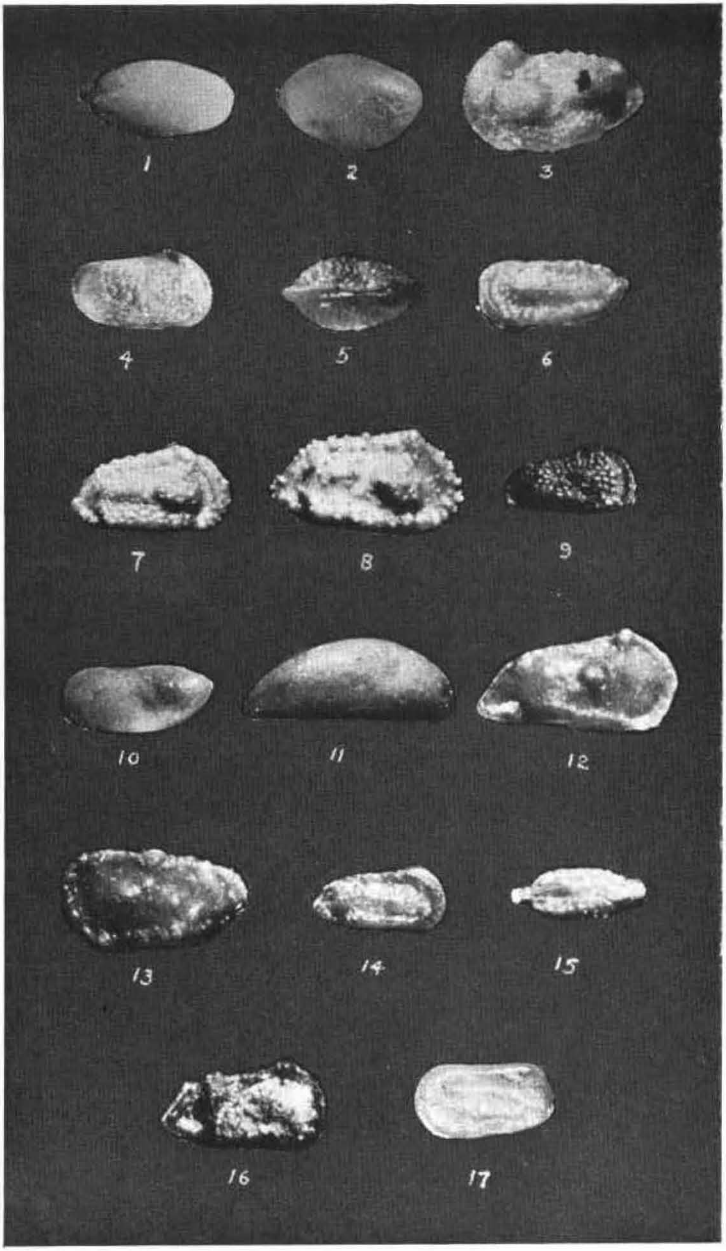


Plate 14. Ostracoda of the Comanchean. All X30. Figs. 1-2. *Cytheridae* (Kiamita). Fig. 3. *Cytheris* (Duck Creek). Fig. 4. *Cythere*, side (Duck Creek). Figs. 6-8. *Cythereis* (Duck Creek). Fig. 9. *Cytheresis* (Fort Worth). Fig. 10. *Bythocypris* (Fort Worth). Fig. 11. *Paracypris* (Fort Worth). Figs. 12-16. *Cythereis* (Fort Worth). Fig. 17. *Cytherella* (Fort Worth).

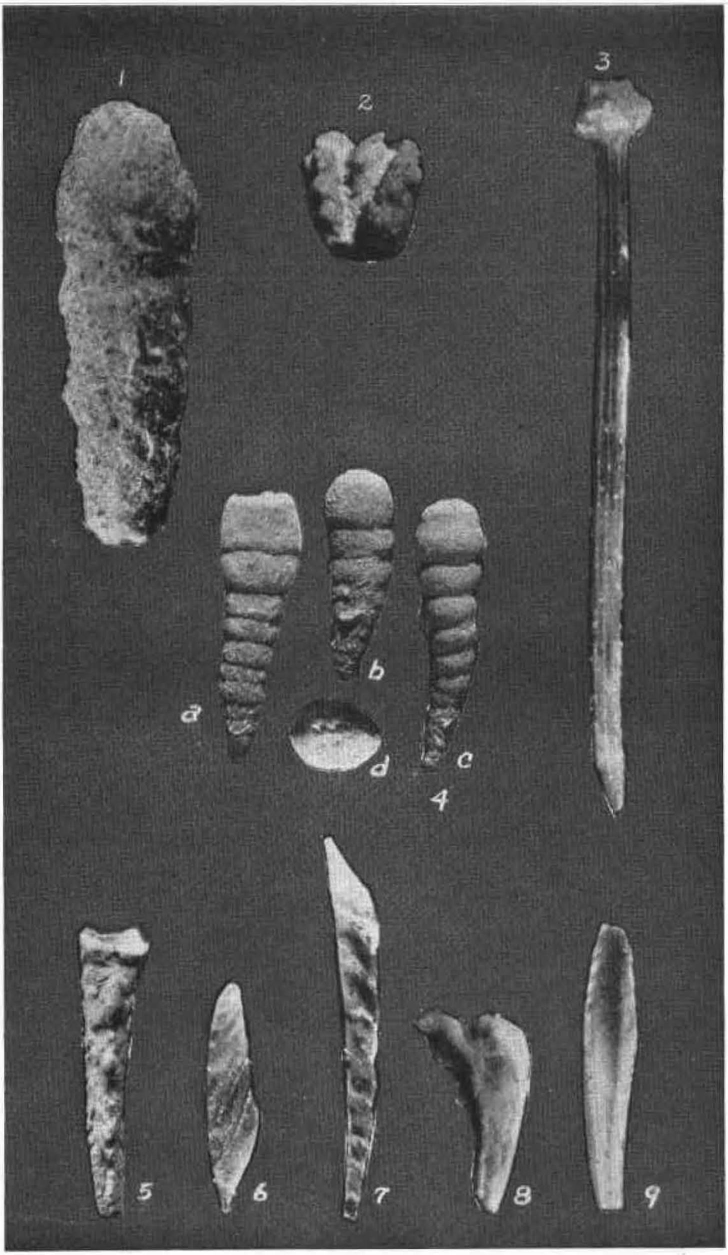


Plate 15. Fig. 1. *Hyperammina* (?). X20. Fig. 2. Crustacean chela (?) X10. Fig. 3. Echinoid spine. X30. Fig. 4 (a), (b), and (c) *Nolosaria texana;* (d) *Nodosaria texana* showing multiple mouths. X4. Fig. 5. Echinoid spine *(Dorycrinus ?)*. X10. Fig. 6. *Cristellaria.* X20. Fig. 7. *Vaginulina.* X20. Fig. 8. Conodont tooth. X10. Fig. 9. Unidentified clam. X10.

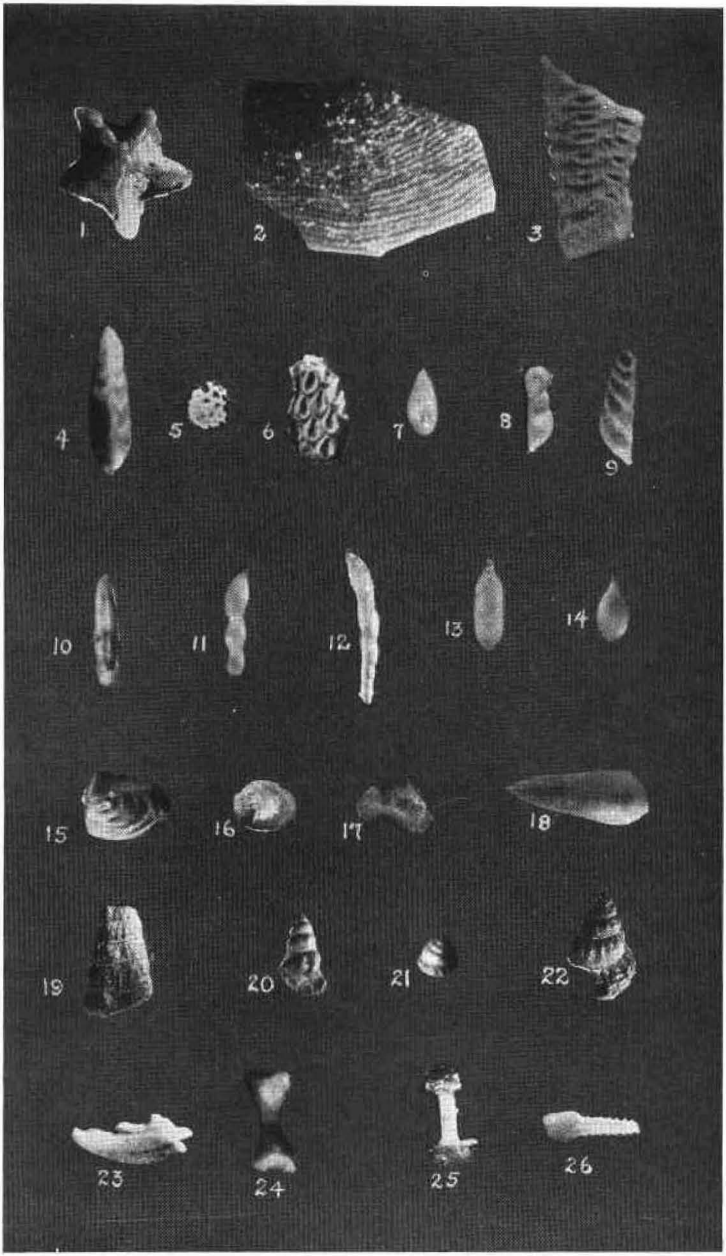


Plate 16. Micro-fossils of the Upper Washita. Fig. 1. Part of apical system of echinodern. X8. Fig. 2. Portion of fish scale. X20. Fig. 3. Fragment of echinoderm test showing ambulacral pores. X8. Fig. 4. *Clavulina.* X30. Fig. 5. Unclassed bryozoa. X20. Fig. 6. Membranipora. X8. Fig. 7. Unidentified. X20. Figs. 8-9. *Vaginulina.* X20. Figs. 10-12. *Nodosaria.* 10 and 12 at X30, 11 at X35. Figs. 13-14. *Lagena.* X35. Figs. 15-16. Clams. 15 at X5. 16 at X8. Fig. 17. Clam (?). X8. Fig. 18. Small sp. of Pinna X8. Figs. 19-22. Gastropods. X5. Fig. 23. Annelid jaw. X8. Figs. 24-25. Unidentified. X20. Fig. 26. Unidentified. X20.

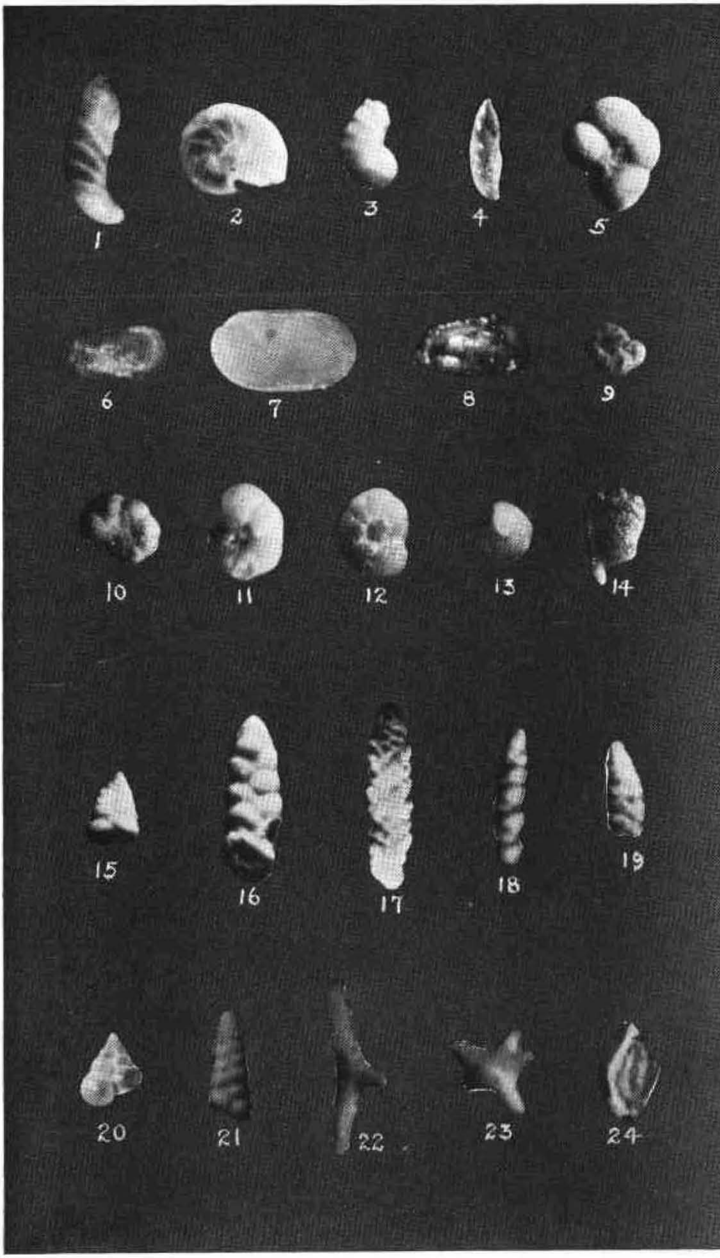
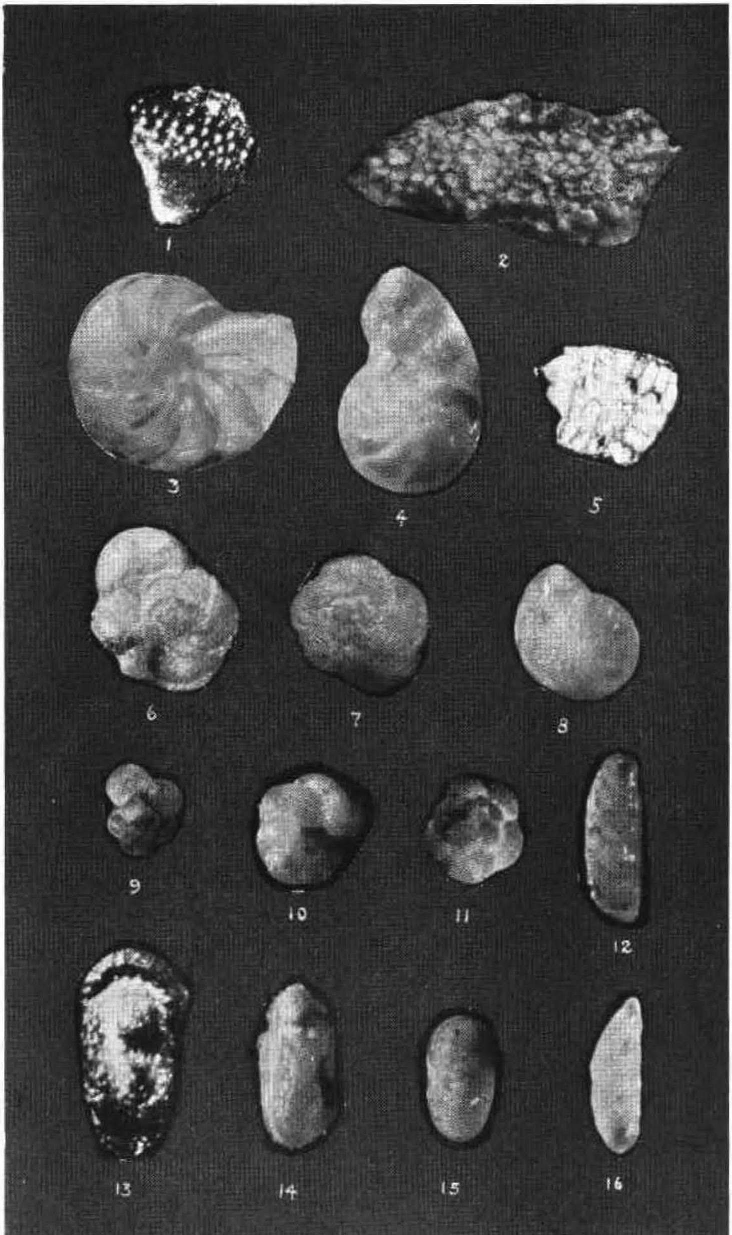


Plate 17. Micro-fossils of the Upper Washita. Figures 1-4. *Cristellaria.* X20. Fig. 5. *Globigerina.* X30. Figs. 6-8. Ostracoda. 6 and 7 at X30, 8 at X20. Figs. 9-10. *Annomalina.* X30. Figs. 11-12. *Pulvinulina.* X20. Fig. 13. *Truncatulina.* X30. Fig. 14. Unidentified. X20. Figs. 15-21. *Textularia.* 15, 16, 20, 21 at X30; 17at X20; 18 and 19 at X35. Figs. 22-23. *Ramulina.* X30. Fig. 24. *Quinqueloculina.* X30.



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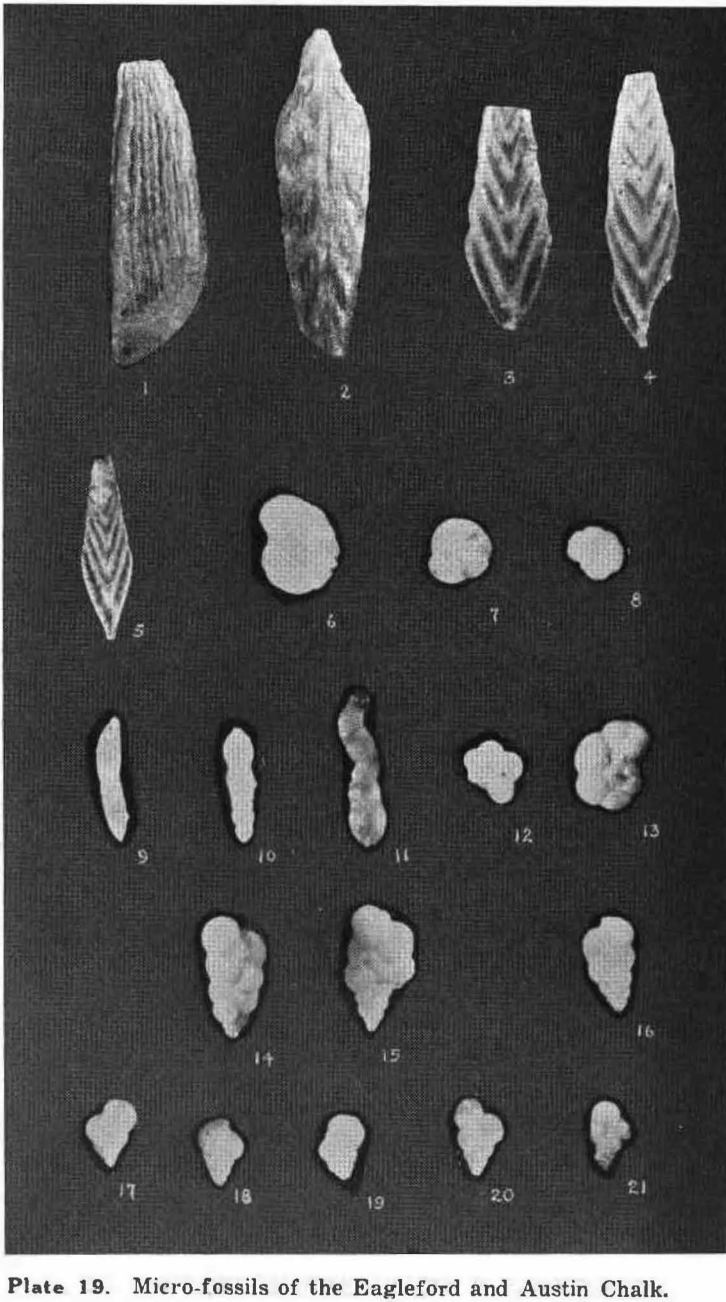
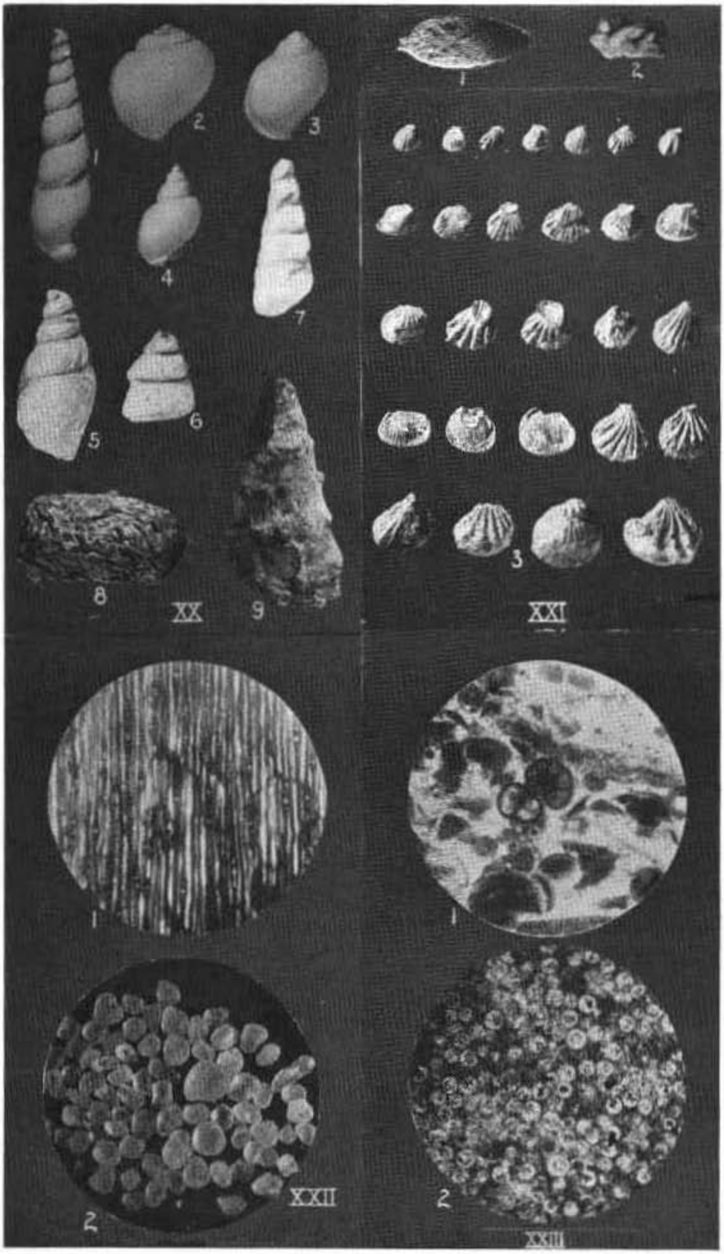
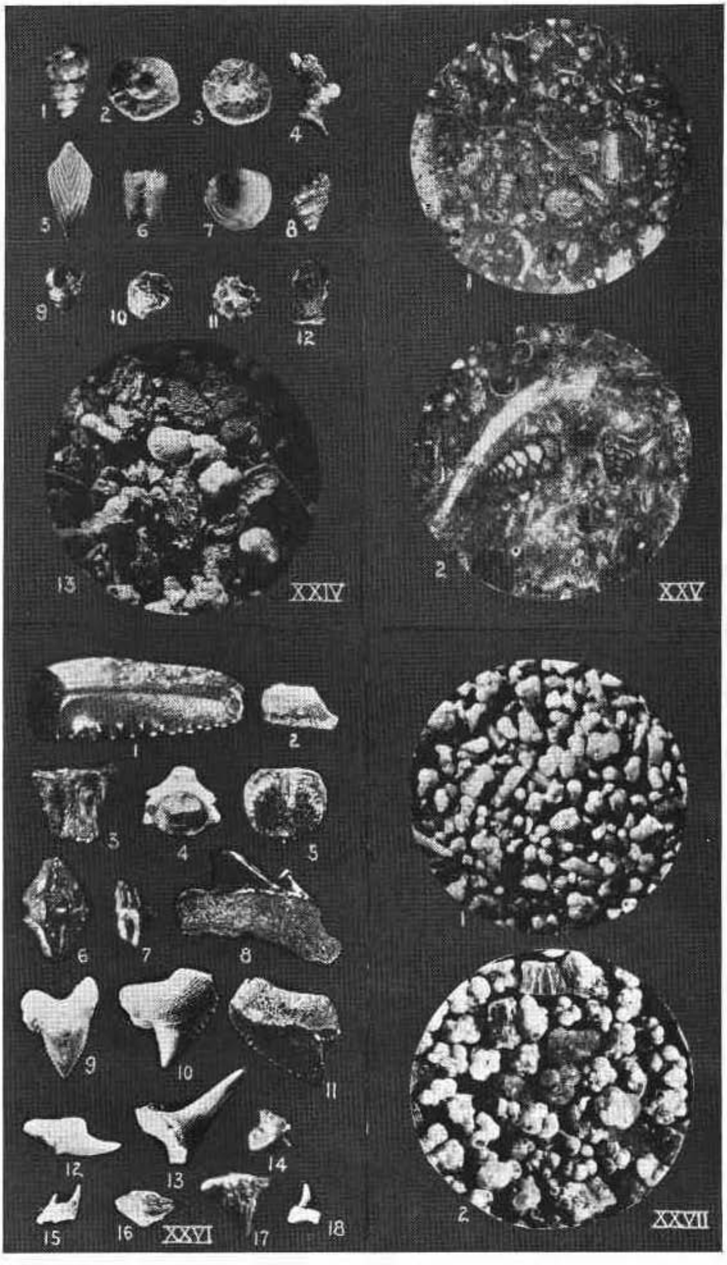


Plate 19. Micro-fossils of the Eagleford and Austin Chalk.



Plates 20 to 23. For description see page 84.



Plates 24 to 27. For description see page 84.