THE UNIVERSITY OF TEXAS BULLETIN

No. 3001: January 1, 1930

CONTRIBUTIONS TO GEOLOGY, 1930

Bureau of Economic Geology

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

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

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

Sam Houston

Cultivated mind is the guardian genius of democracy. . . . It is the only dictator that freemen acknowledge and the only security that freemen desire.

Mirabeau B. Lamar

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

The 1930 volume of "Contributions" has been published from the Paul Franklin Morse Memorial Publication Fund. This fund, contributed by Mr. and Mrs. W. C. Morse, the Geological Societies of Texas, and members of the Bureau staff, has been established to honor the memory of Paul Franklin Morse, a brilliant young geologist who devoted himself during the last years of his life to the study of Texas geology. It is gratifying that this revolving publication fund will continue to aid in advancing the science in which he was so much interested.

E. H. SELLARDS,
Associate Director.

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MEMORIAL

PAUL FRANKLIN MORSE

Paul Franklin Morse[1] was born in Wellston, Ohio, July 24, 1897. He was educated at Washington University, St. Louis; Mississippi Agricultural and Mechanical College; Ohio State Unversity; and the University of Chicago. He received his Bachelor's degree from Ohio

in 1920 and his Master's degree from Chicago in 1924. His geological interest began as a boy, when as companion and able assistant to his

[1]A more complete account of the career of Paul Franklin Morse has been published by the Ohio Academy of Science, Columbus, Ohio, 1930.

father, William Clifford Morse, he made frequent field trips to study the geology and paleontology of Ohio, Illinois, and Missouri. These associations brought an unusual breadth of field training and experience to the boy and an inspiration to the father that resulted in a most happy partnership.

After graduation from Ohio, Paul was appointed Assistant State Geologist of Mississippi, where he worked for more than a year. In 1922 he resigned to join his father in consulting work and became engaged in a thorough and painstaking investigation of the bauxite deposits of Mississippi. The work resulted in a complete authoritative report of 208 pages published by the Mississippi Geological Survey that constitutes a splendid memorial to his thoroughness and scholarly instinct.[2]

In 1923–1924 Paul was awarded a graduate fellowship at the University of Chicago and received his Master's degree at the end of that year, passing his examinations with honor and winning election into Gamma Alpha, Sigma Xi, and Kappa Epsilon Pi, honorary scientific societies.

Early in 1925 Paul left his graduate work in the University of Chicago to enter professional geologic work. Following a temporary position with Rycade Oil Corporation he worked for Humphreys Corporation (1925–1926), Moody Corporation (1926–1927), and in the spring of 1927 joined The Texas Company as district geologist in charge of the San Antonio district. At San Antonio he established a home shared by his wife Mary Yvonne Hamilton and their daughter Eleanor Yvonne, a happy association interrupted by his death on July 12, 1929.

Paul Franklin Morse was not only an outstanding geologist, a devoted husband and father, but a real man and a genuine friend. As a scientist he was a painstaking investigator as fully attested by his monograph on bauxite. As a petroleum geologist he was successful because of his thoroughness. It was his attention to detail that enabled him to map obscure structures overlooked by others and to recommend to his company the Darst Creek area before it was proved by a drill. It is fitting that his many friends have set up for the advancement of his science this memorial fund to his name.

F. B. Plummer.

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[2]Paul Franklin Morse, The Bauxite Deposits of Mississippi. Miss. State Geol. Surv. Bull. 19, December, 1923.

SUBSIDENCE IN GULF COASTAL PLAINS SALT DOMES

by

E. H. SELLARDS

INTRODUCTION

Salt domes present a wide variety of topographic expression. A few in regions of slight rainfall, as at Cordona in Northeastern Spain, are "mountains" of salt, the salt being exposed at the surface (Fig. 1) ; regions with rainfall sufficient to remove the salt as exposed, may nevertheless have the gypsum of the cap rock at the surface as in Falfurrias dome in Brooks County, Texas. More often at the surface is an upwards doming of the strata sufficient to form a mound, both salt and cap rock being covered and protected

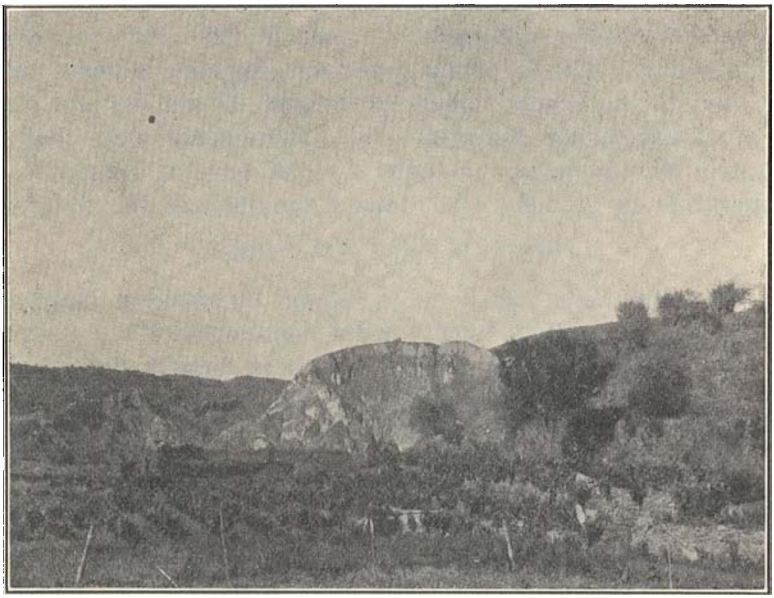

Fig. 1. Salt Mountain near Cordona in northeastern Spain. The salt of the salt dome, a part of which has been removed by erosion, and by mining operations, is seen in the central part of the picture. (Photograph by Sellards.)

Printed September, 1930.

by the overlying strata. Not infrequently, however, instead of a mound, the salt dome is marked by a more or less well defined depression formed by solution. In some instances the formation of depressions in domes has been hastened or caused by oil production or other mining operations. The removal of sulphur from the cap rock of the domes has in several domes been followed by subsidence at the surface. In 1924 subsidence occurred in the Goose Creek oil field which may be a deep seated salt dome, and in 1929 a sink formed on the Sour Lake salt dome. In this paper subsidence at Sour Lake is described together with notes on the Goose Creek depression.

SUBSIDENCE AT SOUR LAKE

On October 9, 1929, a sink formed in the Sour Lake oil field in Texas, and on October 12 the sink was enlarged by a second smaller depression formed at the north margin of the first. The following report on this sink is based on a visit to the locality made on October 27 and 28 and on data subsequently obtained. The observations were facilitated by courtesies extended by the several companies operating in the field. Mr. Ivan Fenn assisted the writer.

THE SOUR LAKE SALT DOME

The Sour Lake salt dome is located in southern Hardin County, Texas, about twenty miles west-northwest of Beaumont. The Sour Lake region has been briefly described by Hays and Kennedy[1] and by Fenneman.[2] Oil and gas seeps at this locality were observed from the date of the earliest settlements. Prospecting for oil began on the dome as early as 1893 and oil was produced in a small way from 1895 to 1902. Large producing wells were obtained in 1903 and the field has produced continuously since that date.

TOPOGRAPHY

The Sour Lake region, located in the Gulf Coastal Plains, presents but little variation in elevation. The drainage of

[1]U.S. Geol. Surv. Bull. 212, pp. 113–119, 1903.
[2]U.S. Geol. Surv. Bull. 282, pp. 38–48, 1906.

this immediate locality is through minor tributaries to the Neches River. Pine Island Bayou is two and one-half or three miles south of Sour Lake and little Pine Island Bayou is about an equal distance to the north. The Sour Lake salt dome is on the divide between these streams. The two streams unite about seven miles east of Sour Lake and flow into the Neches River. The bayou level at the northwest corner of Jefferson County, some three miles from Sour Lake, is near 38 feet.[3] The rise in elevation from the bayou to the divide is probably between 15 and 20 feet. The dome presents so slight a rise on this level plain as scarcely to be evident to the eye. An examination of the contour map (Pl. 1) will show, however, that while the 44-foot contour encircles the dome the high point of the dome rises to 56 feet. Whether this rise of 12 feet is due purely to differential erosion of the divide between the streams or to doming is not fully apparent, but it seems reasonable to interpret it as a slight doming.

The topography thus gives no very obvious indication of the existence of a salt dome at this locality. Of more significance as bearing on the probable presence of a dome is a small pool of water on the dome known as Sour Lake. This pool is fed by springs of mineralized water and was for that reason early utilized as a health resort.

On the dome, itself, there is appreciable diversity of elevation. The high point on the surface is slightly south of the structural high point of the dome and is near elevation 56. Sour Lake, which represents an old depression near the crest of the dome, is near elevation 45. On the east side of the dome is a salt marsh which Fenneman in 1906 refers to as being, at its lowest point, 20 feet below the high point of the dome. The sink which formed on October 9 created, of course, a much greater diversity in elevation.[4]

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[3]The drainage of Jefferson County by H. A. Kipp, A. G. Hall, and S. W. Frescoln. U.S. Dept. of Agriculture Bull. 193, 1915.

[4]Topography of this dome is from a map kindly supplied by the Rycade Petroleum Corporation, made in 1923 by D. C. Barton. Description of this sink with illustrations has been given by the writer in Mining and Metallurgy, August, 1930. The sink has been described also in the "Lamp," a serial issued by the Humble Oil and Refining Company.

STRUCTURAL FEATURES OF THE DOME

Structurally the dome, as revealed by drilling, presents features common to the salt domes of the Gulf Coast. The core or center of the dome is salt as shown by a number of wells drilled over an area one mile or more in width. The depth to the salt varies from 900 feet or less near the crest to 4000 feet or more on the sides of the dome. That the cap rock which overlies the salt is in places highly porous is shown by the well records and by the very large amount of oil that has been produced from it.

LOCATION OF THE SINK

An examination of the structural map will show that the sink is located on the dome about 1,500 feet northeast from the crest. It is, in fact, on a slight nose or ridge of salt which protudes northeastward. With regard to surface topography the sink is at the left side of the old drain from Sour Lake. The surface elevation in the area affected by the sink as shown on Barton's map is from 41 or 42 feet, the land slope being eastward to the drain. The topography as it exists following the formation of the sink is shown superimposed on the Barton map. To the Barton map has been added property lines for the Gilbert, Brooks, and other subdivisions and some leases. The sink is on the Brooks subdivision. (See Pl. 1.)

THE FORMATION OF THE SINK

As already stated the sink formed on October 9. That underground disturbance, however, had begun earlier is shown by the behavior of two wells. On October 8, Terry Oil Company well No. 1 which was then producing from 90 to 100 barrels of oil per day was found at 8:30 A.M. to be pumping water. At that time the Texas Company No. 150, offsetting the Terry well, was producing oil but at 9 o'clock of the same day Texas Company well was found to be producing water. In the afternoon of this day the piping in both wells was raised 5 feet without, however, restoring the flow of oil. It is reported also that late Tuesday afternoon a salt water ditch which crosses the area where the sink formed was seen to be spilling water over the sides. These observations indicate that as early as the morning of the 8th, earth was subsiding into an underground cavity sufficient to raise the underground water level near the sink, and late on that day to affect the surface elevation. About one week previous to the formation of the sink the flow of gas increased in Texas Company well No. 260. This well is located 1,000 feet south and 200 feet east of the sink.[5]

An account of the formation of the sink is given by Mr. George Anderson of the Texas Company. On the morning of the 9th of October at about 7:15 A.M. Mr. Anderson noticed a crack in the earth near Texas Company storage tank 681. The depression in the sink at this time, 7:15 A.M., he says was about 15 feet deep at the center and had a width of about 200 feet with gently sloping sides. Two sweet gum trees stood where the sink formed, and watching these he saw that they were gradually sinking, "not rapidly, but barely fast enough to see that they were moving." After

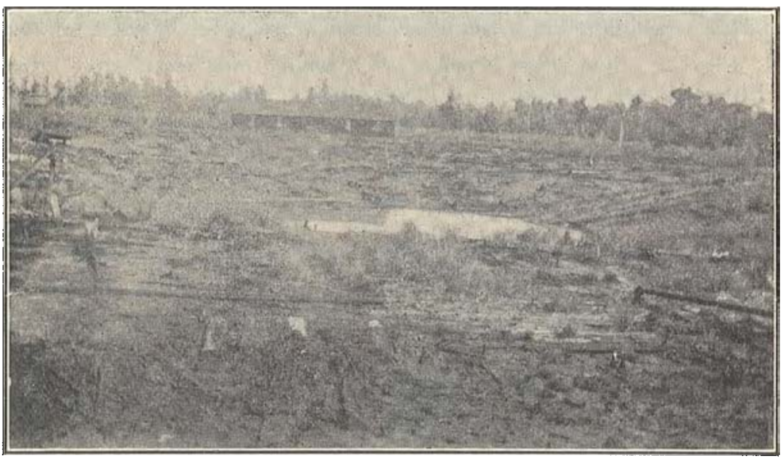

Fig. 2. View of sink looking northward taken by George Anderson about 9 A.M. October 9. Note boiler at left and power house north of the sink.

[5]All measurements for well locations are from the center of the sink.

going to the company office to report he returned at about 8:30 A.M. At that time the sink had a depth estimated at 50 feet. At 9 o'clock photographs were made by Mr. Anderson, one of which is here reproduced (Fig. 2). At this time the depth of the pit had increased and continued to increase until noon of that day. The sweet gum trees were still upright although then below the ground level.

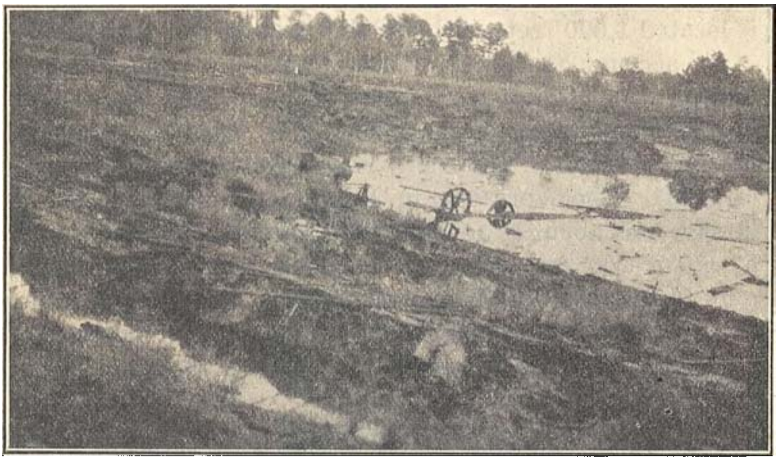

Fig. 3. View taken October 28 looking northeastward. Note boiler at water's edge. In photograph of October 9 (Fig. 2) this boiler is seen on undisturbed land, the bank having in the meantime slumped and the earth moved sinkwards. The power house seen in the previous photograph has been removed, the foundation having been disturbed by slumping. (Photograph by Fenn.)

The sink as originally formed was circular in outline. Its sides at first gradually sloping later broke with successive step-like divisions as shown in photograph taken at 9 A.M. October 9.

On Saturday, October 12, at about 3 or 3:30 P.M. a second sink formed in the northeast slope of the first sink. Mr. Anderson states that at this time he was standing well down the slope of the sink at its northeast side when he felt the earth tremble and about 25 feet farther down the slope saw the earth rise a few feet and open, discharging gas followed by fluid consisting of oil and water. Immediately the earth around the opening caved thus forming the second smaller sink which cuts the margins of the first giving an elongated depression. The depth of the second sink was not determined at that time as it filled immediately with water. (Fig. 4.)

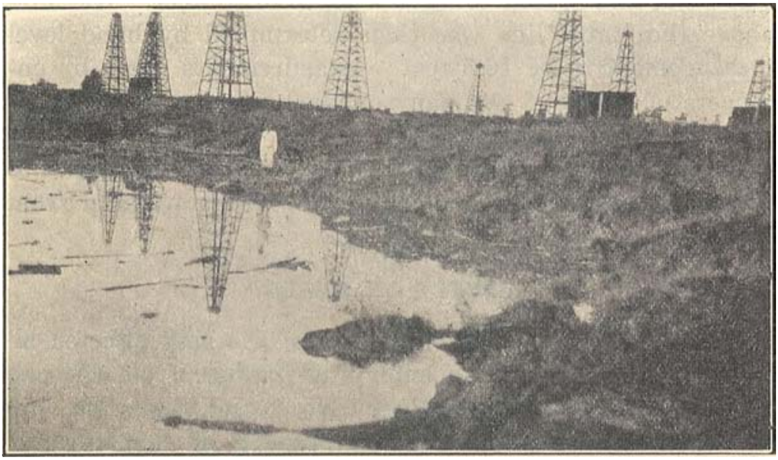

Fig. 4. View looking southward. Steep slope to the small sink formed at the margin of the larger sink is seen at the right. (Photograph by Fenn.)

The "blow out" accompanying the formation of the small sink was doubtless due to water and perhaps gas in an underground cavity, trapped and brought under pressure as a result of the gradual filling of the large sink.

An observation not well explained is reported as follows: An east-west pipe line at the north margin of the Texas Company lease, originally buried under ground, began as early as the spring of 1929 to bow up near but south of the place where this sink formed. Near Texas Company well 150 this pipe was as much as 10 inches above ground on October 8. When the sink formed on October 9 the pipe broke. At the time of my visit the line had been repaired and I was unable to examine the break.

The depth of the sink at noon on October 9 was estimated by Mr. Anderson as 90 feet and by one other observer as

70 feet. Mr. Wallace Pratt states that on October 10 approximate measurements made by him indicated a depth from ground surface to water level of 40 or 45 feet. He estimates that the depth of water at that time was at least 22 feet. On October 28 the water in the sink was found by Mr. Fenn and myself to have a depth of 21 feet. The sink above the water line was then determined by hand level measurement to be 16.5 feet. Measurements made by engineers of the Gulf Company on the same day gave essentially the same result.

From these records it is apparent that the sink began to fill almost as soon as formed due to earth moving in from the sides.

EFFECT ON WELLS

Cap Rock Wells: The formation of the sink affected all wells on the dome which enter and produce from the cap rock. The early effect on Terry No. 1 and Texas No. 150 by which both wells which were producing oil went to water on October 8 has already been mentioned. The following table summarizes the data obtained for wells which were adversely affected.

Distance from sink in feet	Well	No.	Making before sink formed	After sink formed
2750 S., 1150 W	Texas Co.	92	28 bbls. oil	Water only
1625 S., 2000 W.	Texas Co.	113	9 bbls. oil	Water only
445 S., 180 E.	Texas Co.	150	25 bbls. oil	Water only
2250 S., 2250 W.	Texas Co.	218	11 or 12 bbls. oil	3 or 4 bbls. Incr. water
2000 S., 2450 W.	Texas Co.	255	8 or 9 bbls. oil	Incr. water
375 S., 250 E.	Texas Co. Oliver	5	12 bbls. oil	7 or 8 bbls. Incr. water
400 S., 180 E.	Terry Fee	1	90 or 100 bbls. oil	Water only
655 S., 1640 W.	Minor Oil Co.	66	18 bbls. oil	Water only*
490 S., 1775 W.	Minor Oil Co.	84	8 bbls. oil	Water only
615 S., 1570 W.	Minor Oil Co.	40	5 bbls. oil	Water only†

*Now (December 12) making 6 bbls. oil.

†Now (December 12) making 5 bbls. oil. Information received June 26, 1930, indicates that the wells were producing at that time about as in December, 1929. The sink at that time was standing full of fresh water. The break in the earth near Texas Company tank 681 had opened slightly.

At least one well was favorably affected. This was the Gilbert Oil Company No. 89, which previous to the formation of the sink was producing about five barrels of oil per day. On the day following the formation of the sink, October 10, this well made 150 barrels of oil and continued thereafter making from 35 to 40 barrels per day. (Now, December 12, making 12 barrels.) This well is 135 feet north and 425 feet west of center of the sink. The increase of gas in Texas No. 260 which occurred about a week previous to the formation of the sink may or may not have a relation to the sink. Texas Company well No. 15, abandoned since 1926, made a slight show of gas and oil following formation of the sink.

Sand Wells: It is not definitely determined that any one of the wells terminating in sands above the cap rock was affected in flow either favorably or unfavorably except as injured by damage to casing.

Injury to Well Casing and Tubing: Owing to earth movements incident to the formation of the sink, the casing and tubing in several wells were more or less damaged. In Texas Company well No. 150 the tubing and casing were bent, the injury having occurred at depth 520 feet. Similar damage occurred in Terry well No. 1 at the same depth. Whether damage occurred in these wells on October 8 when both went to water, or later, is undetermined. In Gilbert Company well No. 106, located about 400 feet west of the center of the cavity, tubing was bent at 460 feet. The tubing was bent also in Gilbert Company 61. All of these wells are located near the sink and the injury was caused without doubt by sands creeping or flowing towards the sink.

CONDITIONS AFFECTING SINK FORMATION

The conditions to be more fully considered in connection with the formation of the sink may be summarized as follows: Underground conditions at the locality of the sink including thickness and character of sediments affected;

quantity of solids and fluids removed; character and thickness of cap rock; probable size of cavity; earth movement into cavity; earth movement other than that at the immediate locus of the sink.

UNDERGROUND CONDITIONS AT THE LOCALITY OF THE SINK

As already stated, the sink occurred on the salt dome 1,500 feet northeast of the crest. The succession of strata at and near the place of formation of the sink is shown in the following well log.

Log of Gilbert Oil Co. Well No. 89, Sour Lake Field

Located 27 feet from east and 628 feet from south line of Gilbert Oil Company lease; drilled 1920. This well is 135 feet north and 425 west of the center of the sink.

	Depth in feet		Depth in feet
Surface clay	30	Oil sand	822
Sand	80	Sand	859
Gumbo, light	92	Gumbo	884
Sand	200	Sand and sandy shale	894
Gumbo	235	Shale	961
Sand	389	Gumbo	983
Gumbo	444	Hard blue shale	1045
Sand flow	479	Gumbo	1142
Shale and boulders, rock	518	Slaty shale, hard	1145
Gumbo and "bad" boulders	556	Blue shale	1163
Muddy shale and boulders	772	Gumbo	1182
Pay sand, oil	796	Hard shale	1213
Gumbo	800	Gyppy shale	1216
Sand (water salt)	806	Cap rock	1217
Gumbo	815	Total depth	1221
Rock	816		

In this well the cap rock is reached at 1,216 feet. An equal depth to the cap rock would be expected at or near the north margin of the sink and a lesser depth probably under 1,000 feet at the south margin (see contouring on cap rock, Pl. I). The accompanying sketch (Fig. 5) gives a graphic representation of the strata in this well. Using the driller's terminology and measurements it will be seen that this 1,200 foot column consists of sand, eight strata, 430 feet; clay or shale, four or more strata, 458 feet; gumbo, ten strata, 317 feet; and rock (otherwise undefined), one foot. The driller's use of the terms clay, shale, and gumbo

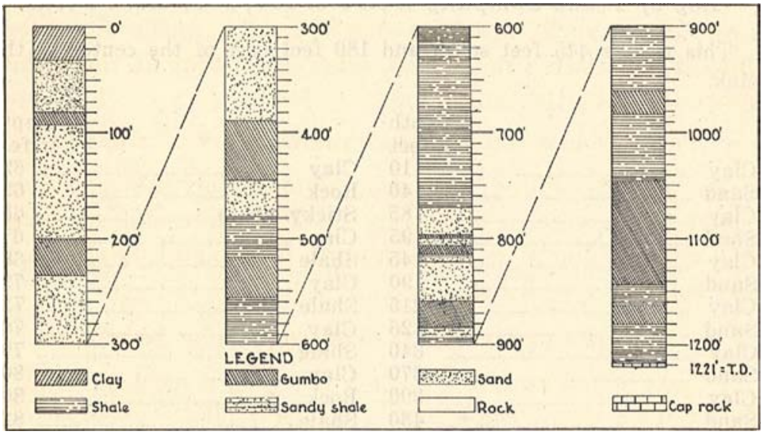

Fig. 5. Graphic log of Gilbert Oil Company well No. 89, located near the sink.

is seldom exact. In general the sticky clays are logged as gumbo and the harder clays as shale. Distinctly hard materials are logged as rock. The sands are for the most part incoherent. The log, while it cannot be relied on for exact rock classification or detailed measurements, nevertheless affords a fair record of the strata. The materials at the spot where the sink formed cannot be assumed to agree in detail and yet they certainly agree essentially with this well. Of one or more wells drilled immediately on the locality of the sink no log is preserved, but other logs indicate that the conditions shown by the Gilbert log are a fair average for the dome.

Conditions a few hundred feet south of the sink are indicated by the following log.

Log of Texas Company Well No. 150, Sour Lake Field

This well is 445 feet south and 180 feet east of the center of the sink.

	Depth in feet		Depth in feet
Clay	10	Clay	625
Sand	40	Rock	629
Clay	85	Sticky shale	654
Sand	95	Clay	674
Clay	145	Shale	684
Sand	190	Clay	724
Clay	215	Shale	734
Sand	325	Clay	784
Clay	340	Shale	794
Sand	370	Clay	801
Clay	390	Rock	804
Sand	430	Shale	824
Shale	465	Clay	833
Clay	592	Hard cap rock	850
Rock	596	Soft cap rock	862
Clay	612	Hard cap rock	876
Rock	615		

QUANTITY OF SOLIDS AND FLUIDS REMOVED

In the operations on this dome during the past twenty-five years very large quantities of salt have been removed in solution in water. The water from the cap rock is notably high in salt. So nearly saturated is this water that in places in the drain ditch salt is deposited from the running water. In view of the porosity of the cap rock and of its actual absence in places it may be safely assumed that the water comes in contact with the salt, and if not already saturated becomes so. Analyses were made by the Texas Company in 1926 from several of their cap rock wells. These analyses which have been kindly supplied are as follows:

Parts per million

Texas Company Well No.:	15	189	113	260	218	150	5
Calcium	3060.	3310.	3380.	2545.	3722.	2796.	3114.
Magnesium	271.2	378.	443.6	279.2	456.6	224.9	224.7
Sodium and potassium	33950.	36000.	35550.	28800.	33480.	29100.	34600.
Chlorine	54820.	59320.	58750.	45590.	56720.	16810.	55300.
CO_3	832.	635.5	625.	837.	572.	868.	763.
SO_4	3955.	3325.	3680.	3838.	3200.	3702.	4020.

The amount of water and salt that has been removed cannot be estimated since all of the wells produce more or less water and have done so for many years. Gas production from this dome has been limited.

In addition to water removed oil has been taken from this field since 1902 to the amount of about 73,340,000 barrels.[6] On the other hand the amount of solids removed from the cap rock not in solution as sand, clay, or rock, while no estimate has been obtained, is believed not to be large. Some sand is being continuously removed by flowing, pumping, bailing, and washing, and by gas blowouts. Most of this, however, is from above the cap rock. A lease east of the sink is said to have produced more sand in this way than have other leases. The drilling of wells, of course, brings to the surface a small amount of earth. In this part of the field, known as the "shoe string" area, wells were drilled in the early development of the field so close together that derrick platforms were in places contiguous or overlapping. Nevertheless, removal of solids in this way must be negligible in amount.

CHARACTER AND THICKNESS OF CAP ROCK

With regard to the cap rock much less is known than could be desired. In one well not far removed from the sink, Gilbert Oil Company No. 98, the cap rock is reported wanting, the salt immediately underlying the sands and clays at depth 939. Samples have been kindly supplied by the Humphreys Oil Company from a well drilled on the Blum lease, 400 feet south and 200 east of the center of the sink. The cap rock in this well at depth 883 to 918 is a well crystallized anhydrite with only a small amount of calcite at 901½ to 903½ and at 905½ to 909.

POROSITY IN THE CAP ROCK

That the cap rock in this field is in places highly porous and even cavernous is indicated both by well records and by the amount of oil that has been produced from it. It is

[6]The Oil Weekly, Vol. 56, Jan. 31, 1930, p. 160. Production to end of 1929.

reported that when the Minor Oil Company Well 84, located about 1,600 feet west of the sink was being drilled, the casing at one time dropped about 5 feet indicating a cavity in the cap rock of that size. It is also reported that a well drilled by the Terry Oil Company in the locality of the present sink entered a cavity in the cap rock amounting to 20 feet more or less. The loss of returns in drilling the cap rock were not infrequent. On the Gilbert Oil Company lease just west of the sink returns are reported to have been lost in wells No. 22, 54, 68, and 81. Following is a record of a well which reached a cavity of undetermined size.

Log of Gulf Production Co. Well in Tarver Lease

Located 600 feet south of north line and 225 feet east of west line of Tarver lease, Sour Lake dome.

	Depth in feet		Depth in feet
Surface clay	85	Gumbo and boulders	830
Sand	110	Gumbo	841
Blue gumbo	126	Shale and gumbo	863
Sand	140	Gumbo and boulders	910
Blue gumbo	220	Gumbo	967
Sand and shale	240	Shale, gumbo, boulders	1000
Sand	300	Rock	1003
Gumbo	340	Sand	1018
Shale and sand	368	Gumbo and boulders	1035
Gumbo	384	Gumbo	1045
Shale	405	Sand and boulders	1101
Gumbo	426	Shale	1106
Sand and shale	448	Sand	1140
Gumbo	468	Gumbo	1169
Shale and sand	500	Sand and boulders	1213
Shale and gumbo	520	Lost returns at 1213. Pumped mud, sawdust, moss, straw, and hay into well for 30 days; finally pulled casing and moved derrick 100 feet north.	
Gumbo	535		
Sand	545		
Gumbo	563		
Sand	615		
Gumbo	634		
Sand	654		
Shale and gumbo	674		

SIZE OF CAVITY

The size of the cavity is necessarily such as to receive the earth that has subsided. At the time the writer examined the locality, the bowl-shaped slightly elongated depression resulting from the formation of the sink had a maximum depth of 37½ feet, and a circumference of 1,400 or 1,500 feet. The amount of earth removed to form this depression is about 98,000 cubic yards. When first formed, the sink was much deeper, probably 70 feet or more, but of smaller circumference, hence probably not differing in cubic content. To this estimate, however, must be added some slight depression outside of the limits of the sink proper. To the northeast the land level was affected for at least 1,000 feet, the water flow in a ditch having been reversed for that distance. To the south for as much as 1,000 feet from the center of the sink breaks are seen in the earth with depression of the side towards the sink. The amount of subsidence outside of the sink proper, so far as recorded, varied from 4½ inches as seen on a well about 400 feet south of the sink to one-half or one inch at the outermost earth cracks. The total quantity of earth going into the cavity may be tentatively placed at 100,000 cubic yards. Continued slow adjustment of level is indicated by a break which appeared January 20, 1930, near Texas Company tank No. 680.

EARTH MOVEMENT INTO THE CAVITY

The sink at this locality formed slowly. In this respect it contrasts with some other sinks which are known to have formed by a sudden almost instantaneous collapse. The slow subsidence of this sink was caused doubtless in part by the considerable thickness of subsiding strata, 1,000 feet or more. It may have been due also to a restricted opening to the cavity into which the material was passing. Subsidence began doubtless by caving of the lowermost strata which rest upon the cap rock directly over the cavity. The uppermost strata were at first not noticeably affected. Such apparently was the condition as early as the forenoon of October 8, as water appeared at that time in the Terry well and in Texas Company well No. 150. In strata such as are found on this dome consisting of incoherent sands, clays, and gumbo, movement into a cavity would include not caving alone but also creep or flow from the sides. This horizontal movement would be most pronounced in the sands. To such lateral creep is to be attributed the movement of earth which allowed subsidence of the surface over a considerable area around the sink. Evidence of subsidence is seen at many places. In the crack near Texas Company tank 681 and 80 feet north of Texas Company well 260 the subsidence amounts to about one inch and the horizontal movement to one and a half inches. A subsidence of 1⅜ inches and horizontal movement of ¾ inch is seen in crack 20 feet west of Crosby Oil Company well 13. Nearer the sink the amount of subsidence is greater. At the Terry gas well 185 feet north by west of Texas Company No. 150 and 20 feet north of Texas Company line the ground dropped 4½ inches on Saturday, October 12, possibly incident to the formation of the second sink.

The logs indicate that at a shallow depth, from 10 to 30 feet, is a sand stratum from 30 to 50 feet thick. To creep in this sand is due apparently skidding of large blocks of the superficial material towards or into the sink. This movement sinkward is best seen immediately around the sink, particularly at the northwest side (Figs. 6 and 7).

The surface stratum overlying this sand is a sandy clay, the amount of clay being sufficient to give the stratum considerable coherence. When the depression began forming, this clay stratum at first accommodated itself to the depression, but later breaks formed along lines concentric to the sink, dividing this clay stratum into a series of blocks all of which moved slightly or appreciably sinkwards.

On the Gilbert Oil Company property from near the west margin of the sink, a ditch carrying water flowed northward. When the depression formed, this ditch reversed its flow and the water entering cracks saturated the underlying sands which are here found at a depth of 10 or 15 feet. As a result the sands moved towards the sink and the overlying clay stratum followed in large tilted blocks. In some instances a block has dropped lower than the one next towards the sink thus forming a graben. All the blocks are tilted sinkwards and frequently the downtilted

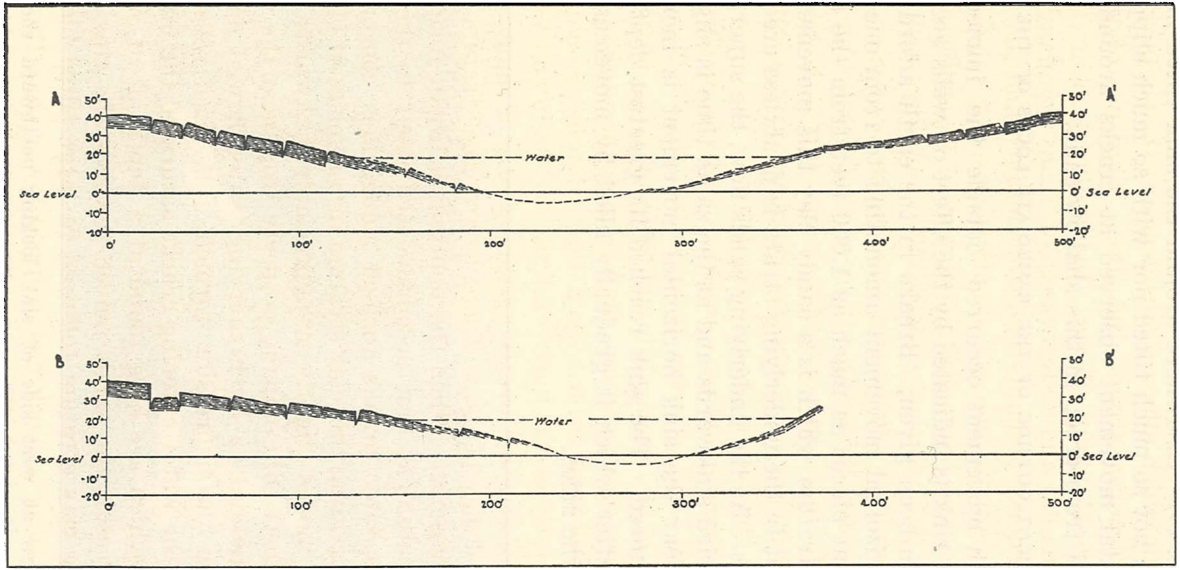

Fig. 6. Two sections across the sink in an approximately east-west direction. The location of the sections is indicated by the line A–A′ and B–B′ of plate 1. The breaking and tilting of blocks of earth is diagrammatically illustrated.

edge of a block is lower than the uptilted edge of the next block. (Fig. 6.) Elsewhere around the sink tilted blocks are seen but not so much tilted nor with so much slippage. The horizontal movement observed at cracks around the sink resulted from creep in this shallow sand.

EARTH MOVEMENT OUTSIDE OF THE IMMEDIATE LOCUS OF THE SINK

That earth movement occurred outside the immediate limits of the sink is indicated by the effect on wells account of which has been given. Breaks in the earth afford evidence of horizontal movement amounting to from one-half to one inch at places as much as 1,000 feet from the sink. In the top stratum which is a sandy clay this movement is *en masse*, but in the underlying strata is doubtless creep or flow of sands. As the underlying sands flow, the superficial earth is carried sinkwards and at the same time is slightly lowered. Near the sink horizontal movement is increasingly pronounced. The sink reached its greatest depth on October 9, after which it gradually filled by movement of earth from the sides.

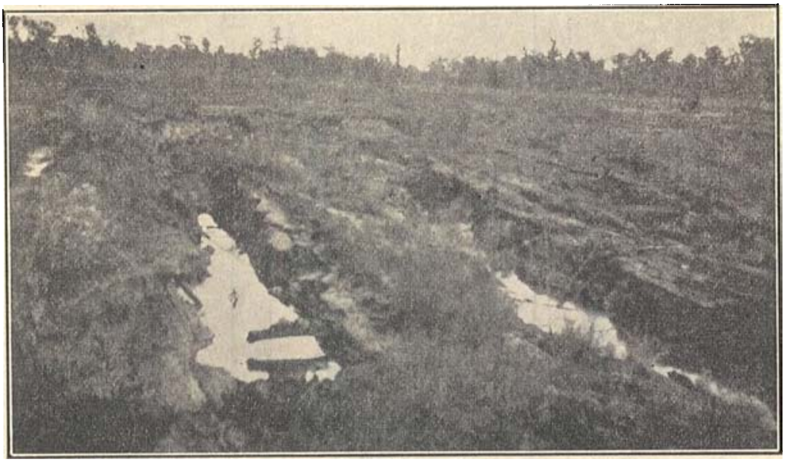

Fig. 7. View at west side of sink looking northward showing blocks of earth slumping sinkwards. This view is across the line of section A–A′ of plate 1. (Photograph by Fenn.)

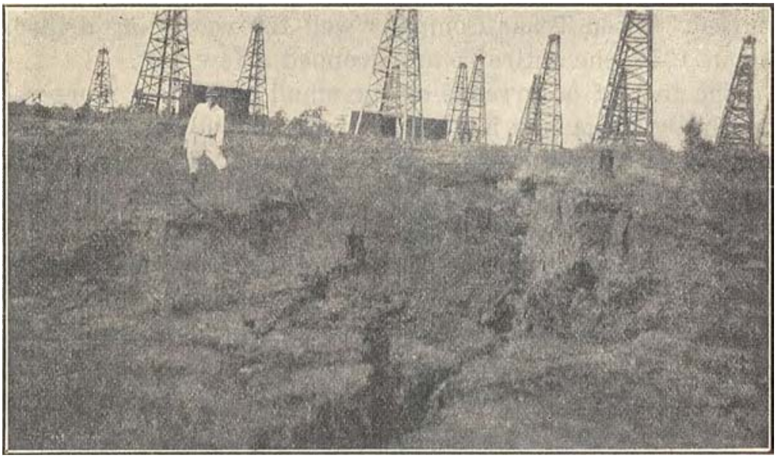

Fig. 8. View at west side of sink looking southward and showing graben. This view is across the line of section B–B′ of plate 1. (Photograph by Fenn.)

Evidence of subsidence is found for as much as 1,000 feet or more to the south, east, and northeast of the sink. The divide in the flow of water in the ditch that crossed where the sink formed is now about 1,000 feet northeast of the sink. Except near the margin of the sink no breaks are seen to the west and the extent of appreciable subsidence in that direction is less well known.

The well logs indicate an incoherent sand (marked "sand flow" in some logs) at a depth in the vicinity of the sink of 400 to 600 feet. To lateral movement in this sand stratum is due the injury to casing and tubing in Texas Company well 150 and Terry well No. 1, both at depth 520 feet, and in Gilbert Oil Company well 106 at depth 460 feet.

The information obtained at the field indicates that slight local sinking of land on the dome has previously occurred from time to time. This is illustrated by the following records: In 1924 a small sink, depth four feet, formed just west of the Joe Hardy well near, but southwest of, the present sink. This small sink was twice filled indicating continued subsidence. Near the Terry gas well in 1922 or

1923 a subsidence occurred in which a boiler was partly buried. When Texas Company well 155 was being drilled, about 1910, the entire rotary dropped a few feet.

The fact of occurrence of the small sinks and more recently the large sink is not to be taken as indicating formation of additional sinks. Such additional sink may occur but there is no information on which to expect an early recurrence of sink formation here.

The subsequent history of this sink will doubtless be that of gradual filling until probably in no great number of years it will become merely a bowl-shaped depression containing water all or a part of the year. This occurrence indicates how some of the bowl-shaped depressions of the flat lands of the Coastal Plains may have been formed.

CAUSE OF FORMATION OF SINK

The cause of the formation of the sink will perhaps remain in some degree a matter of speculation. That such sinks may form through natural causes is obvious, Sour Lake near the crest of this dome being apparently a sink formed previous to the occupation of this region by white men. Previous to oil operations on the dome, Sour Lake was supplied by springs of mineralized water, thus affording naturally an outlet for soluble salts. That springs and oil seeps occurred at this locality as early as Pleistocene time is shown by the fossil bones and teeth of Pleistocene animals described by Leidy from asphalt pits and springs of Sour Lake.[7] On the other hand in view of the very large amount of solids, chiefly salt, removed in connection with oil production it seems highly probable that the immediate cause of sink formation was the removal of solids in this way. The most probable explanation appears to be that a cavity developed in the salt body which continued enlarging until a thin porous and probably cavernous cap rock collapsed permitting subsidence of the overlying sediments.

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[7]Notice of some vertebrate remains from Hardin County, Texas. Proc. Acad. Nat. Sci., Phil. 1868, pp. 174–176. Contributions to the extinct vertebrate fauna of the Western Territories. U. S. Geol. Surv. Ter., Vol. 1, p. 260, 1873.

SUBSIDENCE AT GOOSE CREEK OIL FIELD

The Goose Creek oil field is located on San Jacinto Bay in the southeastern part of Harris County. The first oil well in this field was drilled in 1908, but it was not until August, 1916, that large commercial production was obtained since which time the field has been actively developed.[8] The production from the field to the close of 1929 was about 66,397,000 barrels.[9] The field has some of the characteristics of a salt dome, such as gas seeps and paraffin dirt but no wells have reached cap rock or salt although some have been drilled to depth 5,000 feet or more.

Subsidence began in this field as early as 1918.[10] By the close of 1925 near the center of the area the land had subsided three feet or more. Subsidence at this locality was particularly noticeable since the land is practically at sea level and the depression resulted in flooding land previously above tide water level.

This locality was visited by the writer in March, 1924, and again in October, 1925, at which time the following notes were made.

"The evidence that depression has occurred within this field within recent years is as follows: breaks in the earth; land now submerged that was formerly above water as shown by the government topographic map of 1916; dead trees standing in the water.

"*Breaks in the earth.*—Breaks which by their freshness are shown to have occurred within recent years are observed at or near the margins of this oil field. One of these breaks is located at the north side of the field and within the town of Pelley, being one or two blocks north of the road entering the town from the west. The downthrow at this break is on the south side. The break which extends in a general east-west direction can be followed a distance of some 500 or 600 feet. The downthrow is greatest near the middle

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[8]The Goose Creek Oil Field, Harris County, Texas, by H. E. Minor. Bull. Amer. Assoc. Pet. Geol., Vol. 9, 286-287, 1925.

[9]The Oil Weekly, January 31, p. 160, 1930.

[10]Pratt and Johnson, Journ. Geol., Vol. 34, p. 578, 1926.

of the break and is reduced at either end where the break passes into a gradual slope. In general the break is now overgrown with grass, although where protected from grass and rain, as under houses, it is still fresh. The maximum drop at this break is somewhat more than one foot. The drop accompanying this break was necessarily a sudden drop. The trend of the break is about N. 75 E., although at its eastern end it changes to approximately east-west.

"Two other breaks indicating depression in the oil field are found on Hog Island at the south side of the field. In these breaks on Hog Island the downthrow is to the north. The easternmost of these two breaks indicates a drop of from three inches to one foot or more. This break is sometimes compound, a drop of about one foot occurring in two or more parallel breaks. The break in the earth at this place can be followed a distance of 500 or 600 feet, the trend being slightly south of west. At places the break is reduced in amount or dies out and again increases in throw. The line is not continuous but in places offsets.

"A break farther west on Hog Island, examined in March, 1924, is essentially alike in character to those already described, the downthrow being to the north. These several breaks indicate depression of the land in the oil field with respect to the surrounding land.

"*Land formerly above water now submerged.*—The United States Geological survey in coöperation with Harris County made a detailed topographic map of Harris County, the surveying having been done in 1916. A comparison of the land in this field as it existed in 1916 with the land at the present time shows that depression has occurred, areas that were then low-lying lands being now under water. Instances of depression are as follows: The Valley of Goose Creek, which in 1916 was swampy land, is now entirely submerged, this submergence affecting the land from the mouth of the creek up to or nearly to the public road crossing, marked "Ferry" on the map. On the map there is shown also a peninsula near the mouth of Goose Creek not named on this map, but which on other maps bears the name of Gaillard

Peninsula. This peninsula, which in 1916, as shown by this map, was swampy land, is now submerged, although at places some grass is still projecting indicating the location of the peninsula. Immediately west of Gaillard Peninsula and in front of the mouth of Goose Creek is another peninsula projecting from Hog Island. This peninsula which was swampy land in 1916 is now partly submerged. That part of Hog Island which lies north of the breaks in the earth already referred to is likewise almost completely submerged at the present time.

"*Submergence as indicated by timber growth.*—At places in this immediate area are found trees which formerly grew on land but are now within the water, and have been killed by the salt water.

"These observations indicate clearly depression since 1916 within this immediate area. The breaks indicate abrupt depression.

"*The depression local.*—The depression causing the submergence is local in nature and not regional. This is shown by the following observations. In the topographic map to which reference has been made, the swampy land of the valley of Goose Creek extends somewhat above the public road crossing on the creek. The depressed area, however, scarcely extends to the public road crossing, and the swampy land of 1916 above this road crossing remains swampy land at the present time. At the south side of the field on Hog Island, as already noted, the swampy land in 1916 north of the break in the earth is now submerged, while land south of this break, which was swampy land in 1916, remains the same at the present time. These observations show that there was not a regional depression having a north-south trend.

"As already noted, the Gaillard Peninsula of 1916 is now submerged and the peninsula lying next west of it is now partly submerged. In going farther to the west at the inlet connecting Black Bay and the Ship Channel are now found three small islands. These islands are found unchanged at the present time, showing no depression, thus indicating

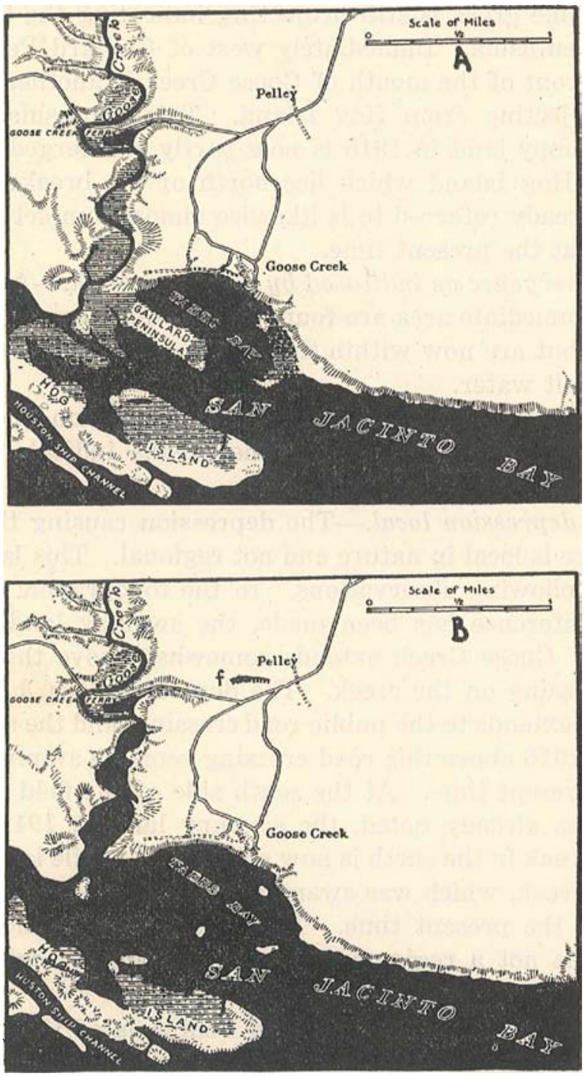

Fig. 9. Goose Creek area. A. Previous to subsidence. B. Following subsidence. (From Journal of Geology, Vol. 34, p. 579, 1926.)

the absence of regional depression with an east-west trend. From these observations it is believed to be reasonably certain that the depression is local in character.

"The width of the depression in a north-south direction approximates one and three-fourths miles. The length in east-west direction is less clearly defined but is probably between one and three-fourths and two miles. The depression includes the whole of the oil field and extends somewhat beyond actual producing wells.

"*Cause of subsidence.*—An examination of this area has not revealed any probable cause for the depression other than the removal of water and oil from the underlying strata. It is well known that the removal of solids from the earth may result in depression of the overlying materials. This is seen in some of the sulphur mines of the Gulf Coast, and is frequently seen in coal mines. In this instance there has been removed a large amount of liquids, possibly one hundred million barrels of water and oil, these liquids coming from varying depths.

"Just in what way the taking out of liquids results in compacting of strata may be a matter of opinion. Possibly with removal of liquids and gas originally under high pressure there has resulted a collapsing of such small cavities larger than capillary size as existed in the rocks; possibly as result of the removal of liquid, and the flow of the liquid through the rock, the sand grains may have had the opportunity of readjusting themselves so as to become more closely compacted; possibly co-incident with the removal of water and other liquids from the sand, water originally a part of clay and gumbo may have been squeezed out in the sands, allowing the gumbos to become more closely compacted occupying less space. Whether all of these and possibly other factors have operated is perhaps a matter of opinion. In any case no explanation other than the removal of the liquid has appeared as the reasonable cause of depression at this locality."

The subsidence in this field has been described by Minor, by Pratt and Sellards, and by Pratt and Johnson, and has been discussed by Snider. The explanation of the subsidence offered by Minor[11] is that the flow of fluids in the sand caused a readjustment and closer packing of the sand grains permitting a settling of the overlying beds. Pratt and Sellards in the brief abstract published give the removal of oil, water, and gas as the probably cause of subsidence.[12] Pratt and Johnson[13] regard the subsidence as due to the extraction of oil, water, gas, and sand accompanied by increased compacting of the clays allowing subsidence. They suggest also that other important factors are reduction of gas pressure, drying of clays with the escape of gas, and the removal of sand. They suggest but reject as improbable the removal of salt or other solids in solution with the water.

Snyder[14] while agreeing with previous writers as to the cause does not believe that the explanation of the subsidence offered by Pratt and Johnson is adequate and adds the suggestion that the oil, gas, and possibly the water occupied space in addition to the capillary space of the sands, as "free" oil or gas (or water).

The several writers are thus agreed that removal of oil, water, and gas[15] is the cause of the subsidence but are not agreed as to how the subsidence came about. In this connection it is worth while to note that the depression formed at Goose Creek is not unlike a depression that may be expected to result from sink hole formation at great deth in unconsolidated strata.

Observation shows that subsidence is affected by the character and thickness of sediments through which the break occurs. A sink-hole forming through shallow strata a few score feet may result only in vertical displacement of earth there not being sufficient pressure on the strata to force lateral or horizontal movement. The sink may

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[11] L. C., p. 297.

[12] Pratt, W. E., and Sellards, E. H., Pan-American Geologist, Vol. 45, p. 254, 1926.

[13] Journ. Geol., Vol. 34, pp. 577-590, 1926.

[14] Bull. Amer. Assoc. Pet. Geol., Vol. 11, p. 729-745, 1927.

[15] Sand is also mentioned but it is recognized that the amount removed is not significant.

and ordinarily does form quickly at least in its last stages as if by collapse of a roof. The earth moved is approximately a cylinder extending from the surface to the bottom of the sink. These shallow sinks may be accompanied by little or no horizontal movement of earth into the sink.

Sinks breaking through 1,000 feet more or less of uncompacted water laden strata as at Sour Lake may be expected to result in both vertical and horizontal movement of earth. Vertical movement occurs followed by horizontal movement, the unconsolidated strata by reason of their own weight moving or creeping laterally towards the opening. The final result is a basin the steepness of the sides of which is determined by the resistance of the sediments to horizontal slip and by the angle of repose. The ground involved in the adjustment is not a cylinder of earth but more nearly an inverted cone the apex of which in the Sour Lake depression is at or near depth 1,000 feet, and the base is 1,500 or 2,000 feet across. Earth adjustment takes place much more slowly than in a more shallow sink. In the Sour Lake sink adjustments began as early as October 8, 1929, and were last observed January 20, 1930.[16]

If a sink should form through a great depth of unconsolidated water bearing sediments as at Goose Creek it would seem that we should expect readjustment and subsidence to come about slowly as compared to more shallow sink formation; vertical displacement of earth would possibly scarcely appear being replaced by horizontal slip or creep of the strata under its own weight, the surface area affected would be larger and the basin more shallow than from a sink formed at lesser depth.

As already stated, no wells at Goose Creek have reached cap rock or salt. It follows, therefore, that the oil and water taken from the field did not come from the cap rock, unless possibly indirectly. It might be assumed that the removal of fluids facilitated water circulation from the deeper horizons possibly through faults, but this seems im-

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[16]Some slight adjustment near Texas Company tank 681 is reported as late as June, 1930.

probable. The subsidence is reported to have begun in 1918 at which time the production was largely from the 3,000 foot level or above, and hence more than 2,000 feet from the cap rock if such exists. Thus while the subsidence resembles that which may be expected to follow from sink formation at a great depth, no proof exists that it is due to sink formation, and the explanation must be sought in adjustments coming about as the result of removal of fluids and gas.

THE STRATIGRAPHY OF THE TRINITY DIVISION AS EXHIBITED IN PARKER COUNTY, TEXAS

By GAYLE SCOTT

INTRODUCTION

During the summer of 1929, the writer was assigned the task of mapping the areal geology of Parker County for the Texas State Bureau of Economic Geology. The mapping is now complete, but the report which it is planned to have accompany the map will not be finished for some time.

It happens that the county is a critical area for the study of the Glen Rose formation, since the beds composing it enter the south side of the county with a thickness of something over 200 feet and pass out of it on the northwest corner with a thickness of less than fifty feet. The formation also changes greatly in character through this distance.

This writer and his assistant, Mr. James W. Atchison, made a special effort to map the Glen Rose in as great detail as possible, and to study its outcrop and those of related beds as carefully as time and facilities would permit.

Information gathered seems to be of sufficient importance to merit early publication.

THE TRINITY DIVISION

The Trinity Division of the Cretaceous of Texas is composed from the base to the top of the Basement sands, the Travis Peak formation, the Glen Rose formation, and the Paluxy sands.

The Basement sands and conglomerates are not a formation of definite age, but are a transgressive series, varying greatly in age and passing upward without sharp contact to higher beds.

The Travis Peak formation of Central Texas is not found east of the immediate valley of the Colorado and its tributaries in northwest Travis County. It passes laterally to the Basement sands, and does not concern the area of Parker County.

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The Glen Rose at the type locality is given a thickness of 236 feet by Hill,[1] but Winton finds it considerably thicker a little south of the type locality. It thickens rapidly to the south and thins to the north, and is last seen a few miles northwest of Decatur in Wise County.

Limestones of Glen Rose age again appear at the outcrop in southeastern Arkansas.[2]

Everywhere toward the embed the Glen Rose is encountered in well borings—and in increasing thickness away from the old shore line.

The Paluxy sand makes its southernmost appearance as a mappable unit about Gatesville. It is not found in Travis County. It thickens greatly in a northeasterly direction, covers considerable areas in Somervell, Hood, and Parker counties, and in Wise County unites with the Basement sands over the lensing-out edge of the Glen Rose limestone, to form the Antlers sands of northeast Texas and Oklahoma.

The Paluxy is overlain, unconformably, by the Walnut formation of the Fredericksburg Division. The three terms, Basement sands, Glen Rose, and Paluxy, do not apply to three distinctly different groups of strata of definite and distinct ages, but are names which apply to three stages of a single depositional unit.

THE BASEMENT SANDS IN PARKER COUNTY

In the valley of the Brazos near the Parker-Hood County line the Basement sands lie upon the eroded edges of the lower Strawn (Millsap) beds. Northwestward through the county they overlap successively higher levels and in the northwest corner of the county are lying upon Pennsylvanian strata of lower Canyon age.

The thickness of the sands varies greatly, as would be expected. A good average is perhaps 100–150 feet, but it may be much thicker.

The Basement sands and conglomerates in Parker County

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[1]Hill, R. T., Geography and Geology of the Black and Grand Prairies of Texas [etc.], U. S. Geol. Surv., 21st Ann. Report, Pt. VII, p. 158, 1901.

[2]See Miser, H. D., and Purdue, A. H., Geology of the De Queen and Caddo Gap Quadrangles, U. S. Geol. Surv. Bull. 808, 1929, and earlier papers.

are almost pure quartz. It is remarkable to see that they contain almost no material from the Pennsylvanian over which they were deposited. In places, chunks of the quartz conglomerate may be found pasted to slabs of Pennsylvanian limestone in place, and yet contain none of it as separated particles. The conglomerates may be found lying directly upon Pennsylvanian conglomerates such as the Brazos River sandstone, and at the same time contain practically none of that material in their make up.

The basal part is coarse, often containing pebbles as much as three inches in diameter, but most of the particles are from the size of a pea down to the finest sand. All are quartz and well rounded in comparison with the underlying angular and heterogenous Pennsylvanian conglomerates. They are sometimes cemented by a siliceous, or less often calcareous cement, but over most of the area these gravels are unconsolidated and lie spread out over considerable territory.

The conglomerates grade upward into unconsolidated white pack sands, and thence to the sandy clays, clays, and limestones of the Glen Rose. The transition is so imperceptible that any number of levels in different localities may be taken as the contact. At many places it is possible to observe ledges of Glen Rose lensing out into the sands.

For the most part the sands are unusually pure, and free from salts or staining materials, but there are notable exceptions.

An interesting feature is to be found in the red beds which occur at certain levels and localities. These are excellently exposed along the escarpment of the Glen Rose one mile northwest of Summit Filling Station, and at numerous other places. So far as the writer knows these red beds have not previously been recorded. They are different from most so-called "red beds," in that they are of a deep royal purple color. While these "red beds" are unusual they are less striking than those of the Paluxy described on a later page.

In one area in the southern part of the county the sands are apparently saturated with iron salts since all the water containers soon become coated with a brown sediment.

An interesting area is found just on the edge of the village of Brock. Several wells are so charged with salt that their water is not usable, and in one spot the soil is so salty that it will not support vegetation. The writer is familiar with a similar but much larger and more pronounced area in Comanche County. It is thought that perhaps this salt has escaped from lower Pennsylvanian beds into the Basement sands, since salt in the Basement sands is not the rule. This answer, however, can scarcely explain the presence of considerable salt in the Paluxy of Parker County.

The writer found no identifiable fossils in the Basement sands of Parker County. A few bone fragments were collected but they are too poor for identification. There are occasional plant-bearing lenses, in which carbonized sticks and twigs abound, but no leaves were found. At a point in a stream bank where the Texas and Pacific Railroad makes its northern-most bend, this plant material is abundant in the upper part of the sands. Silicified wood, also, is often abundant in both the Basement and Paluxy sands. Often enormous logs are found. Several of these can be seen on the farm of B. L. Gill along the Weatherford-Dennis road. Sometimes this silicified wood collects in such quantities in fields that it is a positive hindrance to cultivation.

The outcrop of the Basement sands is flat or only slightly rolling, and is usually covered with post-oak timber.

The Basement sands of the county do not at present appear to be of great economic importance. The Basement gravels where properly sorted make excellent road gravels and may become important in activities in which quartz gravels are useful.

Some of the sands are of rare purity; and might, under proper conditions of manufacture, supply, and demand, be of some economic importance. Certain levels of the Paluxy sands, however, are probably more favorable.

The soils of the Basement sands are not rich and are not suited for the ordinary types of agriculture. They are, however, especially adapted to the growth of fruits, truck gardening of all kinds, and watermelons. The soils of these sands contribute largely to making Parker County the most important watermelon producing area in the State, and Weatherford the most important watermelon market.

The underlying Pennsylvanian rocks in places may carry petroleum, but the blanketing of the sands makes their exploration difficult.

THE GLEN ROSE FORMATION

The Glen Rose outcrop enters on either side of the Brazos River about the center of the southern boundary and passes, with a very dendritic outcrop, entirely across the county, leaving it at the very northwest corner. Besides the main outcrop there are a number of inliers, the most important of which are found along the valley of Walnut Creek in the northeast part of the county.

The Glen Rose grades downward and laterally up the dip into the Basement sands in a manner so imperceptible that it is impossible to find a uniform and satisfactory contact. Consequently measurements of thickness, at different localities and by different individuals, vary considerably.

Along the Brazos valley at the Parker-Hood County line the thickness of the Glen Rose is around 200 feet. In a carefully measured section, in the vicinity of Tintop some five miles north of the county line, 195 feet were assigned to the Glen Rose.

In the northwest corner of the county near the town of Whitt a section was measured and 50 feet assigned to the Glen Rose. The formation consists here of about three limestone ledges no one of which is over 6 feet thick, and the top one only is of a hard crystalline nature. Sands and sandy clays lie between the ledges.

As the Glen Rose leaves Parker County at the northwest corner its outcrop turns abruptly to the northeast, cuts the corner of Jack County and passes through Wise County, thinning rapidly.

A few thin ledges are exposed along the Decatur-Bridgeport road four miles west of Decatur, and typical Glen Rose fossils occur. These beds soon disappear at the outcrop a few miles northwest of Decatur.

Lithologically, the Glen Rose presents a bewildering array of limestones, clays, sandy clays, and sands, occurring in a great variety of combinations and thicknesses. No single member is ever very thick, or apparently persistent over large areas, so that it is difficult to recognize different levels.

In the lower part of the formation some of the calcareous layers are conglomeratic and appear to be made up of limestone pebbles rounded and recemented, but the material may simply be of a peculiar nodular character. Other layers are exceedingly earthy and tough, and weather out into iron-stained "honey-comb" rock. The sands lying between these levels are friable and often the "red beds" of a deep royal purple color are present. Some of the calcareous ledges are brown in color and exceedingly hard.

Many of the ledges throughout the formation are earthy, rotten limestones separated by layers of yellow clay, but toward the topmost of the limestone beds are massive and crystalline, forming prominent escarpments.

Ripple marks of many different sizes often in superimposed and interfering patterns are found at several localities and levels. Some of these are well exposed in a creek on the Henry Clark place in the west central part of the county. Mud cracks, worm trails, and pieces of carbonized wood are found even in the limestones. One piece of log in a bed of limestone near the top of the formation was full of clam *(Lithodomus?)* borings, and of the casts of the clams themselves. Nearly all levels of the Glen Rose in Parker County are fossiliferous, and most of the species that have been collected elsewhere are found. The well known scarcity of ammonites in the Glen Rose elsewhere also holds true for Parker County. No ammonites have been found and echinoderms are rare.

In spite of the abundance of fossils in the formation it is difficult to divide it into paleontologic zones, at least until a great deal more work is done on the fossils. Three paleontologic horizons seem to be fairly constant throughout the greater area of outcrop, in the southern part of the county. These are:

1. Near the base is a zone characterized by *Orbitolina texana* (Roemer), *Porocystis globularis* (Giebel), *Pecten stantoni* Hill, and *Trigonia stolleyi* Hill.
2. About the middle of the formation is another zone of *Orbitolina texana,* in which the species is very abundant, and associated with *Loriola texana* (Clark). *Pecten stantoni* has not been found at this level.
3. A third level is also recognizable in the southern part of the county, and its designation as a zone over this area seems justified. It is characterized by *Modiola branneri* Hill which in some places occurs as an agglomerate, and a small elongated species of *Porocystis (P. n. sp.).*

The lower zone is well exposed at the top of the escarpment on the B. L. Gill farm just east of the Weatherford-Dennis road, and thence south to Millican bluff on the Brazos. This level is interesting in Parker County since it carries numerous species of clams and some gastropods on which the entire shell structure has been preserved. This kind of preservation is rare in the Glen Rose since most of its fossils are only mud casts.

The middle level is well exposed in the bed of Sanchez Creek just above the bridge on the Weatherford-Dennis road. The limestones here are massive, and one bed about 2½ feet thick is a veritable agglomerate of *Orbitolina texana* (Roemer) with an occasional specimen of *Loriolia texana* (Clark). Many other fossils are found at this locality and level, but they are always preserved in the form of mud casts.

What is apparently this same level is well exposed between the Sinclair pipe line and Sanchez Creek on the John Long survey, about 12 miles south of Weatherford. Here the *Orbitolina* level appears to be much farther below the top of the Glen Rose than at the locality on the Weatherford-Dennis road. This is due to the fact that some of the ledges which further north are up in the Paluxy sands have here become an integral part of the Glen Rose. Immediately above the orbitolinas at this locality are limestone ledges rich in rudistids, mainly *Monopleura,* but with an occasional specimen of *Toucasia.* Other fossils are abundant, but in the form of casts only.

On the Leon County school land, and along the Granbury road the upper beds of the Glen Rose are beautifully exposed in some stream cuts. At a level about 30 feet from the top of the formation there exists a veritable agglomerate of *Modiola branneri* Hill accompanied by numerous specimens of a new species of *Porocystis,* much smaller than *P. globularis* and greatly elongated. This can be traced southward to the county line and as far north as the Weatherford-Mineral Wells Highway.

The most interesting feature of the Glen Rose in Parker and surrounding counties is the lensing out of its different elements, both above and below. In the case of the lower ones which lense out into the Basement sands the outcrops are closely confined to the outcrop of the base of the formation and are not mappable. The upper beds which are seen to lense out into the Paluxy sands are in some cases separated from the main body of the Glen Rose and from each other by thick beds of sand, and the outrops are mappable. At least three of them are shown on the map.* These lenses are properly a part of the Paluxy phenomenon and will be discussed there in more detail.

The Glen Rose in Parker County as elsewhere presents a rolling grass covered topography which is characteristic. It is only sparsely wooded with clumps of live oak and mesquite except along the stream banks. Its good grass lands support a number of prosperous ranches. Its soil is seldom tillable except in small areas where it has accumulated along stream valleys, and on occasional small flat uplands.

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*To be published subsequently

In the area north of the Weatherford-Mineral Wells highway its outcrop forms a westward facing escarpment, but in broad stream valleys the Glen Rose is often difficult to follow because of the overwash of sands from the Basement and Paluxy sands and sand lenses within the main body of the formation.

Some of these lenses are thick and extend far down the embed. One lens lies slightly below the middle of the formation, is 20 feet thick and under favorable topographic conditions would be mappable. It outcrops as a narrow wooded strip about half way down the hill from the Summit Filling Station on the Weatherford-Mineral Wells highway. Along the scarp north of the road a local unconformity may be seen at the top of this member.

North of the Parker County border in Jack and Wise counties thin ledges of the Glen Rose limestone cap several sandy sloped mesa-like outliers.

THE PALUXY SANDS

The thickness of the Paluxy sands in Parker County ranges from 100 to about 160 feet and is according to Hill[3] 120 feet at Weatherford. Most of the writer's data concerning thicknesses come from water wells, and are doubtless in part inaccurate.

This paper includes in the Paluxy all the sands above the Glen Rose limestones up to the base of the Walnut shell agglomerate; since, as already stated, everything below that level is a single depositional unit.

Hill,[4] describes the Paluxy as a homogeneous, fine-grained, porous, compact, but not indurated sand. It is at many places strongly cross-bedded and finely laminated. At certain levels, particularly near the base, it is often calcareous. For the most part it is unconsolidated, but some layers are more indurated than others. Fragments of silicified wood abound. Trunks of trees measuring 1½ feet

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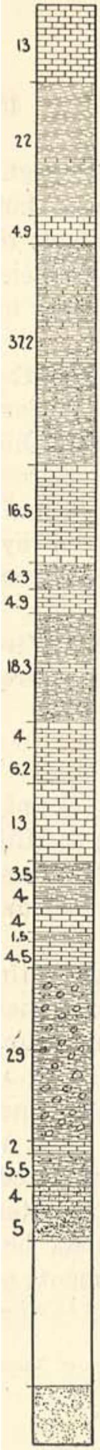
[3]Hill, R. T., Geography and Geology of the Black and Grand Prairies of Texas, [etc.], U. S. Geol. Surv., 21st Ann. Report, Pt. 7, p. 166, 1900.

[4]Hill, R. T., loc. cit., p. 166



Massive, gray, crystalline limestone rich in fossils. Forms top of the Glen Rose in this area.

Largely covered, but appears to be soft, limy marl; slope steep and wavy, showing presence of indurated layers; probably limestone.

Hard, gray limestone ledge; forms only slight prominence on slope.

Soft, sandy marl, with occasional soft limestone ledges, only feebly reflected on the topography.

Soft to hard crystalline gray limestone. Upper and lower ledges more massive. Fossils abundant but poorly preserved.

Soft, sandy marl.

Soft nodular limestone, poorly preserved fossils.

Soft, sandy marl, mostly covered; forms gently sloping terrace capped by next member. Thin limestone about middle forms low secondary scarp.

Iron-stained, nodular, resistant limestone.

Soft, yellow, marly lime, rich in Monopleura, Remondia, Cardita, gastropods.

Soft, grayish limestone; weathers yellow to white; is almost an agglomerate of Orbitolina.

Massive, gray limestone, forming fall and scarp.

Thinly bedded in certain places; occasional clay seams; rich in casts of large clams and gastropods.

Massive limestone.

Soft, gray, yellow marl; rich in fossils.

Prominent yellow ledge of tough limestone; weathers to spongy yellow limestone.

Soft, sandy clay, white, gray, and yellow; weathers to bad land type of topography.

Large yellow to brown clay and limestone concretions; tough, porous—no fossils.

Soft, yellow limestone; weathers into small irregular chunks; not prominent.

Sandy clay; weathers to a gentle slope.

Hard, sandy limestone, white to brown; weathers to a spongy, tough rock; a few fossils.

Yellow sand and sandy clay.

Covered by alluvium of Sanchez Creek; probably mostly sand.

Hard pack sand in bank of Sanchez Creek under bridge.

Fig. 10. A composite section of the Glen Rose formation taken from near the village of Tintop in southern Parker County, Thomas Smithers Survey.

in diameter and several feet in length are fairly common. Some of the lenses often contain large numbers of pyrite nodules or concretions some of which may be two or three inches in diameter.

Plant fossils have been described from the Paluxy of Parker and Wise counties by Torrey,[5] but good specimens are rare and no leaves were found by the writer. Except for the fossils of the Glen Rose lenses already mentioned, no other fossils have been found in the Paluxy.

Excellent exposures of the Paluxy sands may be seen around Advance, Veale Station, in the cuts of the T. & P. near Lambert, in and around Weatherford, and in many other places.

One mile south of Weatherford on the farm of Mr. Curtis there is an old "mine," shafts of which reach a depth of about 60 feet. Some of the specimens described by Torrey probably came from these shafts. The excavation was carefully explored by the writer, but nothing of importance was found.

It is usually considered that the Paluxy contains two water sands, but they may not be the same levels in all cases. Paluxy water is often hard.

An interesting feature of the Paluxy sands of Parker County is the presence in a number of localities of thick red beds of a deep royal purple shade. These are a little different from any other red beds that the writer has ever seen. They are exposed in many places, but are best seen in the magnificent bluff one mile east of Advance, a section of which accompanies this paper. The coloring is evidently due to the degree of hydration of the contained iron.

Such red beds, however, do not make up the main body of the sands which are usually white or only slightly iron-stained.

The lower beds of the sand are often heavily charged with salt. In some wells the water is unusable, while at places

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[5]Torrey, R. E., The Comparative Anatomy and Phylogeny of Coniferales, Part 3, Mesozoic and Tertiary Coniferous Woods. Mem. Boston. Soc. Nat. Hist., Vol. 6, no 2, 1923.

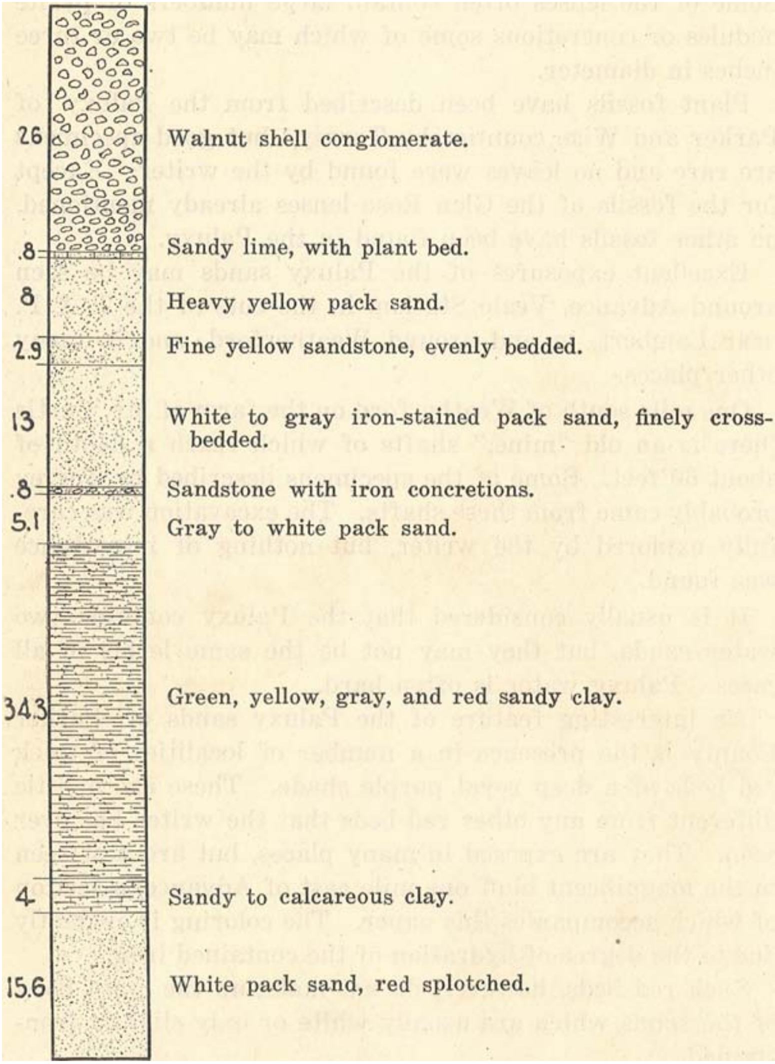
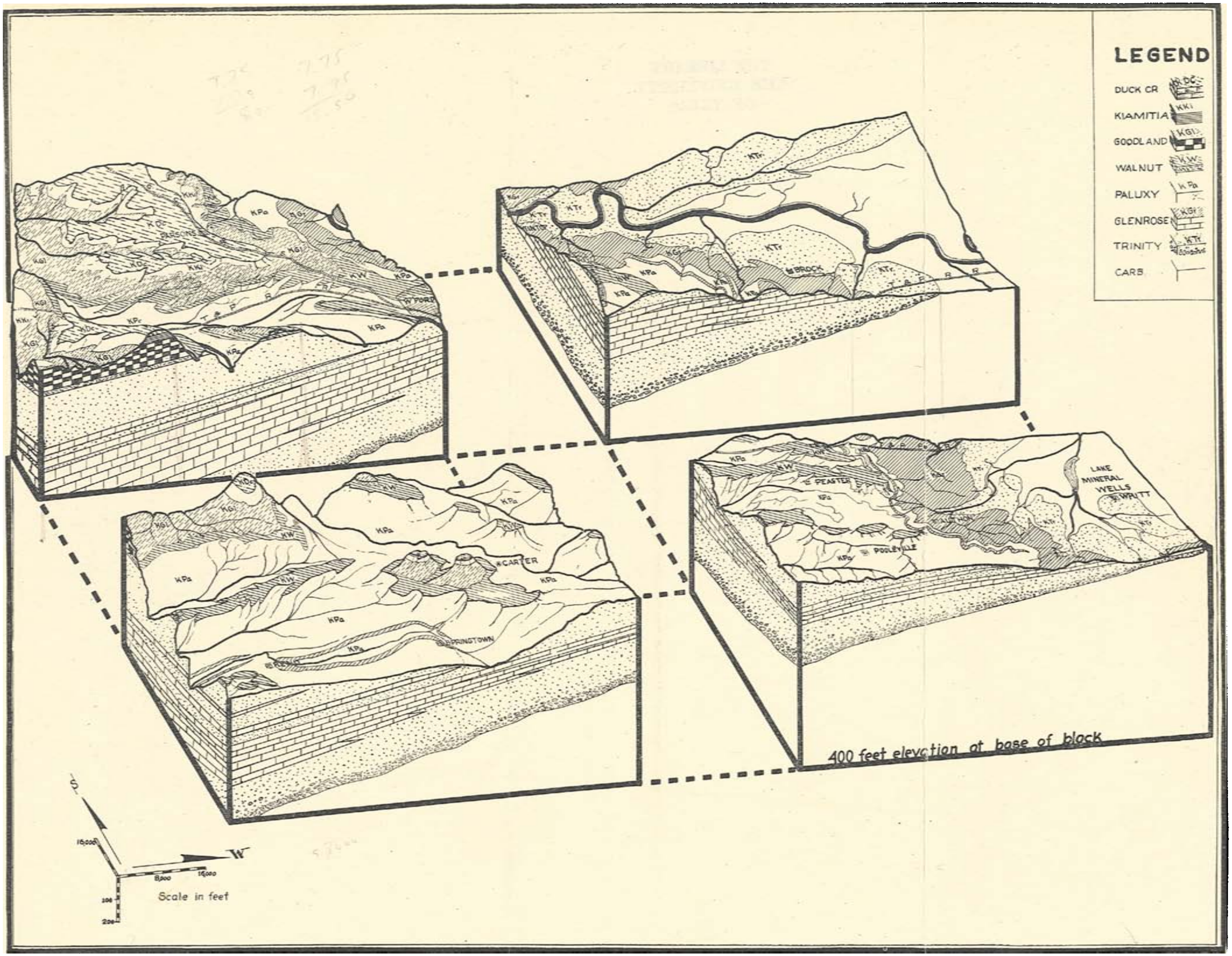


Fig. 11. A section of the Paluxy sand and Walnut formation as exposed in a bluff one mile east of Advance, Parker County, Texas.



A cabinet projection showing the Cretaceous stratigraphy of Parker County, Texas. (Drawn by John Peter Smith.)

on the outcrop no vegetation will grow, and there are salt licks, and encrustrations of the salt on the surface after water has evaporated.

This condition is seen in a number of places, but is best developed in the west central part of the county on the farm of Henry Clark. Here the salt stratum lies immediately on top of the main body of the Glen Rose. It is entirely probable that the salt has become entrapped in the lense-like fingers of the sand that lose themselves in the main body of the Glen Rose.

Thin lignite beds are common in both the Basement and Paluxy sands of Parker County.

The Paluxy outcrop covers enormous areas of Parker County and extends far down the valleys of the streams. The sands support, in the form of caps, numerous outliers of the Walnut shell beds.

The soil is sandy, but not as gravelly as the Basement sand soils. It is heavily wooded with post oak and black-jack timber where it has not been cleared for farming.

Over large areas, particularly in the northern part of the county, the soil has weathered badly, and no longer produces good crops of the ordinary types. It is, however, famous for its fine watermelons, fruits, and garden products.

It is understood that some of the sands have been analyzed with a view to determining their suitability for glass manufacture, and that the analyses were favorable; but up to the present time the sands have not been exploited for this purpose.

As already pointed out, the upper beds of the Glen Rose lense out toward the north and west into the main body of the Paluxy. In inverse manner, the lower levels of the Paluxy lense out toward the south and east into the main body of the Glen Rose. This relationship is especially well shown from Lambert on the Texas and Pacific Railway southeastward by way of Greenwood church and school to Spring Creek school, and in the northeast part of the county around Springtown and Reno.

In the latter area a thin calcareous sand appears just west of Springtown. Under the town square it has already assumed importance as a limestone ledge. It increases in massiveness until at three miles below the town it is a hard coquina about 8 feet thick. At the Walnut Creek bridge in Reno it dips under the bed of the stream. From well data it appears that this ledge is about 40 feet above the main body of the Glen Rose at Springtown.

On top of the second hill east of Reno another ledge about 60 feet above the former appears as a hard flint-like siliceous limestone. Where it passes into Tarrant County it is 7 feet thick and is about 20 feet above the bed of Walnut Creek. Both ledges carry characteristic Glen Rose fossils, but they are poorly preserved.

So far as it is possible at present to judge, the lense upon which Springtown is built is the same as the one outcropping at Greenwood. The upper one of the two ledges, if our underground data are correct, outcrops just south of Weatherford and pinches out into the Paluxy, but is not mappable as a separate unit in that area.

These fingers of limestone are usually very resistant, and their contacts with the sand, both above and below, are sharp.

Thus the upper members of the Glen Rose and the lower sands of the Paluxy alternately interfinger, and the contact does not represent a definite time level. The Paluxy makes up the shoreward sandy facies of the upper Glen Rose—an interpretation given by Hill[6] when he first described these beds.

The accompanying divided block diagram attempts to show the proper relationships of these interfingering strata, as well as the relationship of the Walnut shell agglomerate to the whole. The vertical scale, and consequently the dip, is, no doubt, inaccurate, and it is possible that some of the members have been confused, since it was impossible to follow the beds very far along the strike at the outcrop and

[6]Hill, R. T., loc. cit., p. 170.

much of the well information was unreliable. The correct relationship, however, is shown. (See Pl. II.)

The block diagram also shows the proper attitude of the Walnut shell agglomerate with respect to its sub-stratum. It is clearly a case of unconformity. The dip is measureably more in the Glen Rose than in the Walnut, and the Walnut overlaps the lensing out beds of the Glen Rose, extending over, and miles beyond some of them.

The unconformable contact is well exposed in the bluff one mile east of Advance, and in another bluff one mile west of Veale Station. At the Advance locality a plant bed three inches thick lies in the contact. The bed is full of sticks and twigs, but there are no leaves, since the material has been violently reworked. There are no fossils below this bed, but it is immediately overlain by the *Grypheas* of the shell agglomerate.

The diagram shows a slight anticlinal structure in the Glen Rose west of Springtown. This has not been confirmed in the field.

CONCLUSIONS

One is scarcely justified in drawing general conclusions from the study of so limited an area, but certain facts are evident from the material gathered.

1. Red beds of a peculiar shade are rather common in the Basement sands and are a characteristic feature of the Paluxy.

2. Considerable salt is found in the lower Paluxy sands. This salt makes the water of many wells unusable, and forms encrustations and salt licks in many places. Salt is also found in the Basement sands, but it could have come up from the Pennsylvanian.

3. Three fairly constant paleontologic horizons can be recognized in the Glen Rose in the southern part of the county.

4. So far as Parker County is concerned the thickening of the Glen Rose to the south and east is due to the thickening of its elements in that direction and the picking up of new members from both below and above.

5. The Paluxy thins toward the south because the successive lower beds lense out in the main body of the Glen Rose.

6. There seems little doubt that there is represented here in the Glen Rose and Paluxy a simple case of regressive overlap.

Evidently the sea, as it approached the end of Glen Rose time, withdrew by a series of steps from this entire region. In the retreat the Paluxy sands were deposited.

7. After the retreat of the sea, the low relief of the abandoned area was such that the sand (a great deal of it, at least) was not removed by erosion. The Fredericksburg sea then returned to the area to deposit the Walnut shell agglomerate in transgression and unconformity upon the sands.

The length of the hiatus involved in this contact is a part of a larger problem which must wait for its solution upon a more accurate determination of the age of the beds above and below it.

RIPPLE MARKS OF LARGE SIZE IN THE FREDERICKSBURG ROCKS WEST OF FORT WORTH, TEXAS

By GAYLE SCOTT

In 1926 the writer discovered some large ridges and alternate depressions in a road-side exposure a short distance west of Cresson, Hood County, Texas. Subsequent investigations have shown them to be gigantic ripple marks, with crests often as much as five feet apart, and heights of as much as five inches above the intervening depressions. They have also been found to occur over a considerable area west of Fort Worth, and at two levels.

The ripple marks occur in the lowest ledge of the Walnut formation of the Texas Comanchean, in Parker County around Peaster, Carterville, Weatherford, and Veale Station; and in a *Gryphea* shell bed about the middle of the Goodland in Tarrant, Hood, and Parker counties. They have been examined in a large number of localities, and in all places the direction of their crests is northeast-southwest, or in a direction approximately parallel to the old Cretaceous shoreline. Good exposures of those in the Walnut may be seen on the L. J. Francis farm in a ravine at the side of the Weatherford-Springtown road 3.5 miles southwest of Veale Station. They trend in a direction N. 50 E. Bearings taken at several other localities varied but little from these figures.

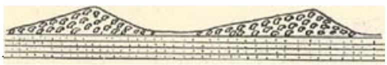


Fig. 12. Diagram, in cross-section, of the ripples in the Walnut formation as exposed on the L. J. Francis farm on the Weatherford-Springtown road.

The marks at this locality were studied with some care. Here and at other places examined they are in the basalmost ledge of the Walnut. The ledge is not more than six inches thick, is of dark brown iron-stained earthy limestone filled with fossil fragments, but has very few well preserved fossils. It is well consolidated, hard, and lies with apparent unconformity upon sands and sandy clays of the Paluxy.

The distance from crest to crest of the ripples averages about thirty inches though sometimes they spread to a greater distance, and again two crests may closely approach each other or even run together in typical ripple mark fashion. The height of the crests above the depressions averages three and one-half inches. The crests and troughs are markedly asymmetrical, the southeast side being the steeper. On the steep side the distance from the crest to the deepest part of the trough is ten inches. On the other side this distance is twenty inches. There is a predominance of finer material on the steep slope. These facts would seem to establish the current origin of the ripple marks at this level. The next layer above the ripple marks is composed almost entirely of the shells of *Gryphea marcoui* Hill and Vaughan which follow perfectly the ridges and depressions and with a pick are easily stripped away.

Ripple marks similar to these and at the same level were examined in a bluff one mile west of Veale Station where they are exposed in cross section; again, one mile southeast of Peaster on the farm of C. H. Dalton, and on the Fort Worth-Weatherford road in a small creek. Small exposures of them have also been seen at a number of other localities in the same area.

Fig. 13. Diagram, in cross-section, of the ripples in the Goodland formation at the road-side locality 3 mi. west of Cresson, Hood County.

The ripple marks occurring in the Goodland formation are larger than those in the Walnut and distributed over a larger area. They are in a thin oyster and *Gryhea* shell bed about the middle of the formation and rest conformably upon a massive ledge of white to gray limestone. Soft calcareous yellow clays lie in their depressions and over their crests. The shell layer of which they are composed is about five inches thick when measured at the crest of a ripple mark, but in the depressions may consist of nothing but a thin veneer of scattered shells pasted to the underlying limestone. Most of the shells are well pulverized, but there are numbers of fairly well preserved specimens.

All the ripple marks studied at this level appear to be of the oscillation type since they are perfectly symmetrical. At the locality west of Cresson they are regularly spaced and their crests are almost exactly four feet apart. Their height is about four inches.

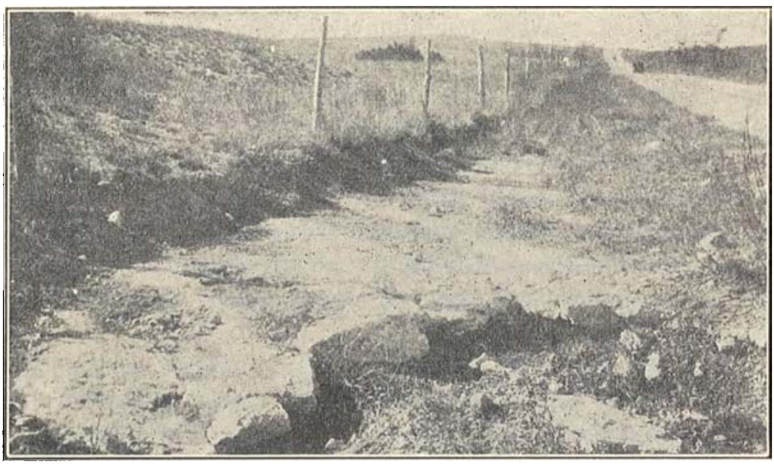


Fig. 14. Large ripples as exposed in the road-side locality 3 mi. west of Cresson, Hood County.

At the exposure on the Azle road 10.1 miles northwest of Fort Worth the crests are five feet apart in some cases, and the height of the crests over the depressions may reach five inches. Here the distances separating the crests is less regular, and a number of anastomosing ripples may be seen.

Good exposures of the ripple marks of this level may be seen in a flat-bottomed ravine fifty yards to the west of the Azle road 10.1 miles from the Court House at Fort Worth, at the road-side locality 3 miles west of Cresson in Hood County, and in a ravine at the side of the Fort Worth-Granbury road one hundred yards west of the bridge over Bear Creek. Small exposures have been seen at a number of other localities in Hood, Tarrant, and Parker counties.

The ripple marks of the two beds just described ought to give additional information on the depths of the sea in which the Fredericksburg rocks were deposited, and the paleogeography of the region in Cretaceous times, when examined and interpreted by an expert.

It is possible to imagine that in Texas during Goodland time there was a broad, but relatively shallow sea where friction on the bottom might have caused an abnormal development of waves, particularly during storms. These activities might have shifted the particles of the shell bottom back and forth so as to "windrow" the shells in the fashion described in these ripple marks.

If the ripples were nearer the broad flat shore, as perhaps was true in the case of those in the Walnut, the back-wash might have produced a current sufficiently strong, even at a considerable distance from the actual shore line, to build up the asymmetrical type of ripple mark found in the Walnut.

It should be noted that large ripple marks in the Comanchean of Texas have previously been reported by Udden;[1] and the large ripples of Ordovician to Mississippian age in Illinois, Ohio, Indiana, and Kentucky have been described and the whole problem of ripple marks and related phenomena have been discussed in a masterly fashion by Walter H. Bucher.[2]

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[1]Udden, J. A., Notes on Ripple Marks, Journ. Geol., Vol. 24, p. 126, 1916.

[2]Bucher, Walter H., "Large Current-ripples as Indication of Paleogeography," Proc. Nat. Acad. Sci., Vol. 3, pp. 285-291, 1917. *Ibid.*, Ripples and Related Sedimentary Surface Forms and their Paleogeographic Interpretations, Amer. Journ. Sci., Vol. 47, pp. 149-210, *ibid.* Pt. II, pp. 241-269, 1919.

A PRELIMINARY REPORT ON THE GEOLOGY OF MONTAGUE COUNTY, TEXAS

By FRED M. BULLARD[1] and ROBERT H. CUYLER[2]

INTRODUCTION

The Department of Geology of The University of Texas offers a course in field geology each summer. The purpose of the course is to give the advanced students an opportunity to do actual field work. The course lasts three months, and the students may stay the whole period or may elect to stay for only six weeks. Montague County was the area selected for study during the summer of 1928. A Permanent camp was established at Bowie and all parts of the county were covered in more or less detail. The work was under the supervision of the senior author assisted by the junior author. Mr. S. O. Burford was also a member of the instructing staff, his duties being confined to the teaching of instrument work. The actual mapping and detailed work was, for the most part, done by the students; however, it was carefully supervised and checked.

Montague County offers a wide range of geologic formations and conditions, and for this reason proved to be a very profitable area for a field course. The eastern half of the county is covered by Lower Cretaceous rocks, limestones, shales, and sandstones, and most of it is comparatively simple and easy to map. The western half of the county is covered by rocks of Upper Pennsylvanian age. The nature of the sediments in these areas makes mapping very difficult. The Pennsylvanian and Permian formations of central Texas consist of limestones, shales, and sandstones, but as these formations are traced northward the limestones pinch out or grade into other types of sediments, so that a formation in Montague County may

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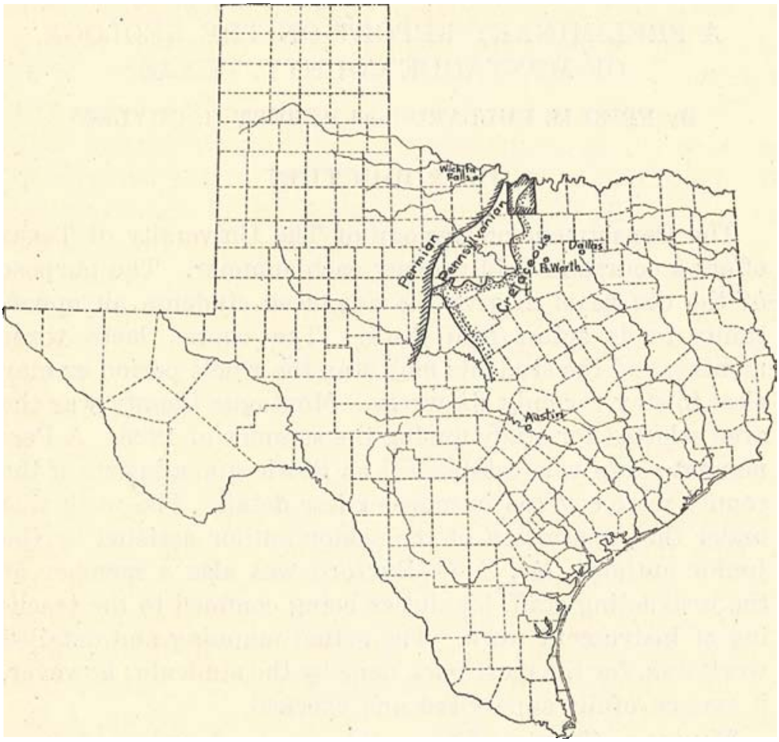

Fig. 15. Index map showing location of Montague County.

be entirely different from sediments of the same age farther south.

The most recent publication dealing with the Pennsylvanian of this part of Texas is by Plummer and Moore.[3] Their mapping extends only as far north as central Jack County, leaving a gap of about 30 miles between the northern boundary of their map and the southern boundary of Montague County. Because the sediments change rapidly in character it was necessary to begin in central Jack County, where the formations are known, and trace a known horizon into Montague County. After establishing

[3]Plummer, F. B., and Moore, R. C., Stratigraphy of the Pennsylvanian Formations of North-Central Texas, Univ. Texas Bull. 2132, 1921.

a known horizon in Montague County the formations both above and below were mapped with reference to this horizon.

The writers are fully aware that this preliminary report is extremely generalized, especially the part dealing with the Paleozoic, but the principal object of this paper is to present the map, is so far as it is completed, and to outline briefly the formations exposed in Montague County and the horizons on which the contacts were mapped. Details regarding the stratigraphy must await further work.

The Montague sheet of the United States Geological Survey Topographic Atlas covers all of Montague County except a strip about 6 miles in width along the southern border of the county. A photographic enlargement to a scale of two inches to one mile was made and used as a base on which to map the areal geology. For the part of the county outside the limits of the topographic map a plane table base, on the same scale as the remainder of the map, was made.

The following students assisted in the field work on which this report is based: Allen, S. R.; Beckley, W. B.; Bowling, Leslie; Garst, J.; Horne, S. W.; McCallum, Henry; Williams, E. D.; Boyles, J. M.; Brown, Edwin; Brown, J. G.; Crowley, J. M.; Dietert, Arthur; Emmons, D. E.; Fletcher, Claude; Gardiner, W. C.; Smith, J. K.; Stafford, Gerald; and Wendler, A. P. The writers wish to express their appreciation for the interest and efforts put forth by these students.

Montague County is located in the extreme north-central part of Texas. It is bounded on the north by Red River and Oklahoma, on the east by Cooke County, on the west by Clay County, and on the south by Jack and Wise counties. It is about 70 miles northwest of Fort Worth and about 50 miles east of Wichita Falls. Bowie, located a little southwest of the geographic center of the county, is the largest town. Nocona, in the north-central part of the county, ranks next to Bowie in size. Other towns are St. Jo, Forestburg, Montague, and Ringold.

STRATIGRAPHY

The surface formations in Montague County are of Cretaceous and Pennsylvanian ages. In the following pages a very brief description of each of the formations represented in Montague County is given.

PENNSYLVANIAN

The Pennsylvanian rocks of north Texas were divided by Plummer and Moore into the groups and formations as shown in the following classification:

Cisco group	Putnam formation Moran formation Pueblo formation Harpersville formation Thrifty formation Graham formation
Canyon group	Caddo Creek formation Brad formation Graford formation Palo Pinto limestone
Strawn group	Mineral Wells formation Millsap formation
Bend group	Smithwick shale Marble Falls limestone Barnett shale

The sediments of this series consist, as a rule, of shales, sandstones, conglomerates, coal beds, and limestones. In central Texas the limestones are rather prominent and make up a considerable part of the section, but northward they become thinner and many are replaced by shales and sandstones. In Montague County only the upper group, the Cisco, outcrops on the surface. This is due to the westward overlap of the Trinity sand which covers the remainder of the Pennsylvanian formations.

The classification given above applies particularly to central Texas and is based chiefly on certain limestone beds which serve as markers to separate the several formations. There seems to be a lack of diagnostic fossils and a marked similarity in the lithologic characteristics of the various formations. It was necessary, therefore, in order to be certain of the exact horizon, to begin in central Jack County, where the formations had been mapped and trace a known horizon into Montague County. The Ranger limestone at the top of the Brad formation was first selected and traced northward, but it passed beneath the Cretaceous overlap before reaching Montague County. The next horizon selected was the Gunsight limestone and the Avis sandstone separated by the Wayland shale. The Avis sandstone marks the base of the Thrifty formation and the Wayland shale the top of the Graham. The Avis was traced from the type locality in northern Jack County into Montague County until it passed beneath the Trinity sand. In this way it is believed that there can be no doubt as to the identity of the horizons in Montague County. The Jacksboro limestone, near the base of the Graham, was also traced from Jacksboro, Jack County, into Montague County and thus served as a check on the mapping.

CISCO GROUP

GRAHAM FORMATION

The basal formation of the Cisco division is the Graham. It is defined by Plummer as including those sediments between the top of the Home Creek limestone in the Canyon group and the base of the first massive sandstone, the Avis, above the Wayland shale and Gunsight limestone. In Jack and Young counties where the formation is best developed it is divided into the following members:

Graham formation	Wayland shale Gunsight limestone South Bend shale and sandstone Bunger limestone Gonzales Creek shale and sandstone Jacksboro limestone Finis shale and sandstone

In Jack County the formation consists of thick massive limestones, gray to buff shales and sandstones, the average thickness being about 600 feet. The formation as a whole is exceedingly fossiliferous; the limestone beds as well as the Finis and Wayland shales carry very prolific faunas. Of the members listed above only the two basal and the two top ones can be definitely identified in Montague County.

The Finis shale, the basal member of the Graham, lies immediately below the Jacksboro limestone. It is a gray to buff shale or clay and contains a very abundant fauna. Some idea as to the variety of the fauna may be obtained from the fact that students who were inexperienced collectors were able to secure more than 50 species in less than 40 minutes.

The Jacksboro limestone is well developed in and around Jacksboro, Jack County, where it consists of two limestone layers separated by about 12 feet of shale. The total thickness of the two beds of the Jacksboro does not exceed 25 feet. In Montague County the Jacksboro limestone members are much thinner than in Jack County and are separated by a greater thickness of clay. The limestones are rather impure and contain an abundance of fossils. Among the most important of these are *Campophyllum torquium* Owen, *Rhipidomella pecosi* Marcou, *Lophophyllum profundum* Milne-Edwards and Haime, *Astartella concentrica* Conrad, and *Fusulina* sp. The outcrop of the Jacksboro is indicated on the map by a broken line.

Section of the lower part of the Graham formation on the south side of Big Sandy Creek, one and one-half miles west of the C. R. I. and P. Railroad crossing, southwestern Montague County.

	Feet
Sandstone, massive, reddish-brown, hard, containing veins and streaks of iron	5.0
Clay, brownish, filled with ironstone masses and thin layers of soft sandstone; becomes grayish toward the top	24.3
Sandstone, red, in layers two to four inches in thickness separated by red sandy clay locally cemented with iron	2.4
Covered; upper three feet a deep red clay	8.2
Limestone (Jacksboro), hard, white to gray, contains *Composita* sp., Crinoid stems and Echinoid plates	1.4
Clay, gray, becomes brownish at top and contains many iron concretions	24.4
Limestone (Jacksboro), hard, unweathered surface brown, weathered surface yellowish, filled with *Fusulina* sp., Crinoid stems, *Chonetes* sp., *Productus* sp., *Spirifer* sp.	0.6
Sandstone, brown, hard	0.8
Clay, yellowish-brown	1.7
Sandstone, unweathered surface blue, weathers grayish-yellow	3.0
Clay, sandy, yellowish-brown	3.0
	74.8

The Gunsight limestone, in the upper part of the Graham formation, is one of the most persistent limestone beds in the whole Pennsylvanian section. It is a yellowish to buff colored, hard, dense, semi-crystalline limestone containing an abundance of fossils, including *Campophyllum torquium* Owen, *Fusulina* sp., *Pustula nebraskaensis* Owen, *Lophophyllum profundum* Milne-Edwards and Haime, *Composita subtilita* Girty, *Nuculopsis ventricosa* Hall, *Trepospira depressa* Cox, *Spirifer cameratus* Morton, crinoid stems, and other forms of minor importance. The limestone frequently weathers a peculiar chocolate-brown and often breaks up into blocks. The thickness rarely exceeds 18 inches.

The Wayland shale, the top member of the Graham formation, overlies the Gunsight limestone. It is usually about 75 feet in thickness, consists of gray sandy clay containing iron concretions, and is very fossiliferous, especially in the lower part of the clay zone. As has been mentioned before, the Wayland is missing in some sections, and the Avis sandstone rests directly on the Gunsight limestone.

Section of the upper part of the Graham formation, six miles south of Bowie and one-half mile south of the cross-road between the Briar Creek-Selma road and the Rock Hill school road, Montague County

	Thickness (estimated) Feet
AVIS:	
Sandstone, fine, brownish-white, and a brown sandy cherty conglomerate	25.0
GRAHAM:	
Covered, probably shale	15.0
Gunsight limestone, brown, hard, highly crystalline	0.7
Shale, bluish, contains no fossils	30.0
Sandstone, dark brown, thin, weathering in nodules	1.0
Shale, yellowish-green, with thin sandstone ledges *Myalina subquadrata* abundant	35.0
Sandstone, brownish, hard, weathered out in slabs	1.0
	82.7

THRIFTY FORMATION

The Thrifty formation lies immediately above the Graham formation. At the type locality, near the town of Thrifty, Brown County, Texas, the formation is subdivided as follows:

Thrifty formation

Breckenridge limestone member
Shale
Blach Ranch limestone member
Shale, sandstone, and conglomerate
Ivan limestone member
Shale and sandstone with locally a limestone lentil
Avis sandstone member

The formation is described, according to Plummer and Moore, as consisting of alternating more or less lenticular beds of shale, sandstone, and limestone with a thickness varying from 120 to 200 feet. In Montague County the limestones have disappeared from the section and the entire formation is made up of shales, sandstones, and conglomerates. Of the subdivisions noted above the only one that can be recognized in Montague County is the Avis sandstone, which is very well developed. It is a reddish-brown ferruginous sandstone, locally very conglomeratic. Its thickness is somewhat variable, but probably averages between 10 and 20 feet. It marks the base of the Thrifty formation and in normal sequence it should rest on the Wayland shale, the top member of the Graham formation. However, the Avis frequently rests directly on the Gunsight limestone, the Wayland being entirely absent. This, together with the locally conglomeratic nature indicates an unconformity at least locally, between the Thrifty and Graham formations.

The Avis sandstone has been traced continuously from the type locality, near Avis in Jack County, until it passes beneath the Cretaceous in south-central Montague County. The Avis is not especially difficult to follow, for the massive sandstone and conglomerate usually stand out as a ridge or escarpment. The particular sandstone or conglomerate in question can be verified as the Avis by locating the underlying Gunsight limestone.

HARPERSVILLE FORMATION

The Harpersville formation was named from the small town of Harpersville in Stephens County. In the Brazos

River valley Plummer and Moore recognized the following members:

Harpersville formation

Saddle Creek limestone
Shale and sandstone
Belknap limestone
Shale, sandstone, limestone, and coal
Crystal Fall limestone lentil
Sandstone and shale

The character of the Harpersville formation changes rather rapidly from place to place and for that reason it is difficult to make the various sections fit the classification given above.

In Montague County the Harpersville formation consists of basal beds of coarse thick sandstones, which grade in places into conglomerates; middle beds composed of an alternation of irregularly bedded sandstones and carbonaceous and ferruginous shales, and thin beds of coal; and upper beds consisting of thick massive sandstones. The conglomerates of the lower part of the formation are made up of hard, subangular pebbles of quartzite and chert in a matrix of brown sand. The carbonaceous shales in the middle of the formation frequently contain numerous bright red concretions of hematite, brown siderite, and black hematite nodules. A coal bed, which has been mined at a number of localities in Montague County, occurs in this middle zone. The coal is about three feet thick, is a poor grade of bituminous coal, and occurs about 75 or 80 feet from the top of the Harpersville. Many of the ironstone concretions found in the shales above the coal contain beautiful leaf impressions. In the extreme southern part of Montague County a second coal bed occurs somewhat lower in the section. It is uncertain whether this bed is in the Thrifty or Harpersville, but more likely it belongs to the Harpersville formation. The thickness of the Harpersville, according to Plummer and Moore, is from 200 to 275 feet. While no detailed sections were obtained it is believed that the thickness in Montague County will probably exceed that given by Plummer and Moore.

In the type area of the Harpersville in Young County, Texas, the upper and lower contacts of the formation are marked by limestone beds, the Saddle Creek limestone at the top, and the top of the Breckenridge limestone at the base. There are also several limestone lentils within the formation, the Belknap and Crystal Falls, which assist in locating the limits of the formation. In Montague County, where the formation contains only clastic sediments, shales, sandstone, and conglomerates, it is very difficult to determine the exact position of the limestone horizons on which the contacts are mapped in the area farther south. The Coal horizon was mapped throughout Montague County, and using it as a horizon of reference the upper and lower contact were established. About 75 or 80 feet above the coal bed is a series of massive sandstones. These beds mark the top of the Harpersville. The formation above the Harpersville, the Pueblo, is dominately a clay and gives rise to a gently rolling prairie. The upper sandstones of the Harpersville produce a very rugged, hilly topography supporting a thick growth of oak timber. The upper contact of the Harpersville can therefore be mapped on the timber line which makes a clear-cut division between the Harpersville and Pueblo formations.

The basal contact of the Harpersville was mapped on a massive conglomerate. Working down from the coal bed the first massive conglomerate, at most places some 200 feet below the coal, was selected as the Harpersville-Thrifty contact.

UPPER CISCO

In the Pennsylvanian area to the south of Montague County three formations of the Cisco group are recognized above the Harpersville formation. These formations are, in order from the oldest to youngest, as follows: Putnam, Moran, and Pueblo. In Montague County these three formations consist of red shales and sandstones. In the limited time available it was not possible to separate them and they are accordingly mapped as a unit.

CRETACEOUS

Comanche Series

The Cretaceous rocks of north Texas have been divided into two major groups, the Comanche series constituting the lower part and the Gulf series the upper part. Only the lower half of the Comanche series is represented in Montague County and the discussion will therefore be limited to that portion.

The Comanche series is divided into three divisions which, beginning with the oldest, are: Trinity, Fredericksburg, and Washita. Each division is in turn divided into formations, which are in turn divided into members and beds. In general, it may be said that in north-central Texas the Trinity is composed of sand and clay deposited in an encroaching sea; the Fredericksburg is a relatively pure white limestone deposited in a more or less stable sea; the Washita is composed of alternating thin bedded limestones and shaly marls with some sand in the upper part deposited in an oscillating and, in the main, a retreating sea.

The Comanche series, as a whole, has an average thickness of about 1,000 feet in north Texas.

General Stratigraphic Column for Cretaceous of North Texas

Cretaceous	Gulf Series	Montana Division	Navarro formation Taylor marl
		Colorado Division	Austin chalk Eagle Ford clay
		Dakota Division	Woodbine sand
	Comanche Series	Washita Division	Grayson marl Main Street limestone Pawpaw sand Weno clay Denton clay Fort Worth limestone Duck Creek formation Kiamichi clay
		Fredericksburg Division	Goodland limestone (including the Walnut clay zone)
		Trinity Division	Trinity sand

Of the formations listed above only the four basal ones are represented in Montague County, namely, the Trinity, Goodland, Kiamichi, and Duck Creek formations. The Walnut clay is present but is mapped with the Goodland. These formations have been described in previous publications and for this reason only a brief description is given.

For more detailed descriptions of these formations, the following references may be consulted:

Hill, R. T., Geography and Geology of the Black and Grand Prairies, Texas, U. S. Geol. Surv., Twenty-first Ann. Rept., pt. 7, 1901.

Stephenson, L. W., Contributions to the Geology of Northeastern Texas and Southern Oklahoma, U. S. Geol. Surv., Prof. Paper 120, 1918.

Winton, W. M., and Adkins, W. S., Geology of Tarrant County, Texas, Univ. Texas Bull. 1931, 1919.

Bybee, H. P., and Bullard, Fred M., Geology of Cooke County, Texas, Univ. of Texas Bull. 2710, 1927.

Bullard, Fred M., Lower Cretaceous of Western Oklahoma, Okla. Geol. Surv., Bull. 47, 1928.

TRINITY DIVISION

The Trinity division is represented in Montague County by a single formation, the Trinity sand. Farther south, in central Texas, the Trinity is composed of several formations consisting of limestone, shales, and sandstone, but in the marginal zone clastic sediments were deposited throughout Trinity time and the formations of central Texas cannot be identified.

TRINITY SAND

The Trinity sand of Montague County represents the near shore or beach deposit of the Comanche sea as it transgressed upon the land from the southeast. In its typical development the Trinity sand is a fine, white to yellow pack sand, occurring in massive beds 25 to 40 feet in thickness. Clay lentils varying from a few inches to 30 and 40 feet in thickness are found scattered throughout the formation. They range in color from yellow to purple and a mixture of variegated colors.

The base of the Trinity is marked by quartzose conglomerate composed of well-rounded quartz grains and pebbles ranging in size from that of a pea to an inch or more in diameter. The pebbles are variously colored, most of them being either red, white, or black. This bed was evidently deposited in clear water as indicated by the fact that there is practically no mud or silt in the conglomerate. The thickness of this stratum varies as it is traced across the country. Near Bowie, in the southwestern part of the county, the thickness is approximately three feet; however, just northeast of the town of Montague there appears to be two or three conglomerates in the lower part of the Trinity and extreme care must be used in mapping the base of the Trinity to be sure the conglomerate in question is the real basal conglomerate. Where there are several beds of conglomerate, the basal one is usually thicker than the upper ones. Good exposures of this conglomerate may be seen in the City Tourist Park at Bowie, Texas. The conglomerate usually caps small knolls and hills and outcrops frequently in the form of a low escarpment. Most of the isolated peaks near Bowie are capped by the basal conglomerate of the Trinity. Among the most prominent of these peaks are Queens Peak and Brushy Mound. The conglomerate appears to be everywhere present in the base of the Trinity and is a reliable and persistent horizon. The bed dips to the southeast, having a northeast strike. The underlying Pennsylvanian beds dip to the northwest. The conglomerate varies in color, composition, and thickness; however, its position in the Trinity is invariable.

In the underlying Pennsylvanian formations are other conglomerates; however, these are not likely to be mistaken for the Trinity since the pebbles in the Pennsylvanian are larger and are more angular than those in the Cretaceous. Chert is found much more abundantly in the older conglomerates. The Pennsylvanian conglomerates may be characterized as being dirty or muddy, whereas the Trinity is always clean. The Trinity conglomerate may be relied upon as being an easily traced and dependable marker.

Some nodular pieces of limestone were found lying loose on an outcrop of the Trinity east of Queens Peak. These pieces were nodular and contained fragments of fossils which established their age as Cretaceous. They apparently occur near the base of the Trinity but no ledge or bed could be found. Assuming that these fragments are the equivalent of the Glen Rose it would indicate that most of the Trinity of Montague County is of that age. This would be in accord with the evidence indicating a transgression of the sea to the north and west and the variation in age of the basal deposit as the sea advanced.

The most complete section of the Trinity observed in this region is on the Red River, north of Gainesville, in Cooke County, Texas. This section has been published[4] several times and will not be repeated here. The following sections measured in Montague County show the variable character of this formation.

Section of the Trinity Sand on Road One Mile West of Forestburg, Montague County, Texas

WALNUT CLAY	
TRINITY SAND	Feet
Clay, sandy, yellow	6.0
Clay, shaly at top, gray with yellow spots and limy streaks	4.0
Sand, cross-bedded, buff colored. A conglomerate about 16 feet below the base of the Walnut containing white angular pebbles of lime and quartz. The conglomerate is about 3 feet thick	6.0
Pack sand, fine, white	3.0
Clay, buff colored with small nodules and streaks of siliceous material	12.0
Clay, purple	1.0
Clay, sandy, yellow; red at top; contains numerous small iron spots near the base	8.0
	40.0

[4]Bybee, H. P., and Bullard, Fred M., Geology of Cooke County. Univ. Texas Bull. 2710, p. 12, 1927.

Section of Trinity Sand One-half Mile West of Dye Mound, Montague County, Texas

	Feet
WALNUT CLAY	
TRINITY SAND	
Sand, pack sand, and sandy clay, bluish to white in color	60.0
Pack sand, massive	9.0
Clay, gray, sandy, weathering a dull gray	3.0
Pack sand, massive, argillaceous; containing concretions of hard light gray sandstone with plant remains	22.0
Sand, fine, gray, containing many concretions of iron, indurated masses of sand, and lentils of red sandy clay	12.0
Clay, sandy, reddish-brown	3.0
Clay, sandy, greenish, fine (a lentil)	1.5
Clay, sandy, buff colored	4.0
	114.5

The total thickness of the Trinity, according to well records is about 600 feet. However, no outcrops could be found where a detailed section of more than 185 feet is exposed. The absence of definite horizon markers makes it difficult to connect isolated or disconnected sections.

The Trinity weathers easily forming a rolling to hilly topography covered by a thick growth of scrub oak and black jack. Small ravines and canyons in the Trinity develop very narrow deep gorges with practically vertical sides. A very striking example of this type of erosion may be seen where the St. Jo-Illinois Bend road crosses Cobb Hollow.

FREDERICKSBURG DIVISION

The Trinity sand is overlain by the Fredericksburg division, represented in Montague County by the Goodland limestone.

In central Texas the Fredericksburg is divisible into three rather well-defined formations: the Walnut clay, the Comanche Peak limestone, and the Edwards limestone. Some confusion has resulted from attempts by Hill and others to recognize the units of the Fredericksburg of central Texas in north Texas, particularly in regard to the Walnut clay.

The Walnut clay has not been recognized in Montague County as a separate formation, although the zone or horizon is present and can be identified by certain characteristic fossils. The Walnut clay zone consists of from 3 to 15 feet of yellowish clay marl containing thin nodular limestone lentils and dark brown indurated shell breccias. In northern Montague County the Walnut clay horizon is usually separated from the Goodland limestone by a bed of typical Trinity pack sand 15 to 20 feet in thickness. The Walnut clay zone is better developed in southern Montague County and usually occupies a position immediately beneath the Goodland limestone.

The fossils especially abundant and characteristic of the Walnut clay are: *Exogyra texana* Roemer, *Gryphaea marcoui* Hill and Vaughan, *Cyprimeria* sp., *Enallaster texanus* Roemer, *Holectypus planatus* Roemer, and *Neithea irregularis* Böse.

Section of the Walnut Clay on the Forestburg-Gainesville Road about Five Miles South of Forestburg, Montague County, Texas

GOODLAND LIMESTONE	
WALNUT CLAY	Feet
Limestone, impure, blue, weathers white	1.5
Marl, grayish-yellow, containing nodules of lime, fossiliferous	10.5
Clay, soft, yellowish-brown	.5
Shell breccia, yellowish-brown, lenticular, contains numerous *Cyprimeria* sp.	.4
Clay parting	.05
Limestone, impure, containing *Cyprimeria* sp.	.4
Clay, yellowish lenticular masses containing *Cyprimeria* sp.	1.1
Shell breccia, hard yellowish	.3
Clay, yellowish-brown	.7
	15.4

GOODLAND LIMESTONE

The Goodland limestone consists of from 20 to 30 feet of hard, pure, white, semi-crystalline limestone, which weathers almost a pure white. It is massively bedded, there being as a rule about 4 beds ranging from 4 to 6 feet in thickness. The lower portion is slightly chalky but the upper portion is a pure, hard, white limestone. A peculair characteristic of the upper portion is that of breaking or scaling off in thin plates. This gives the outcrop a more or less shattered appearance and also makes the Goodland practically worthless as a building stone.

Fragments of the Goodland exposed to weathering frequently develop a spongy appearance due to spots of calcite in the limestone which dissolve more easily than the main mass of the rock.

Section of the Goodland Limestone on the Forestburg-Gainesville Road about Five Miles South of Forestburg, Montague County, Texas

KIAMICHI CLAY	
GOODLAND LIMESTONE	Feet
Limestone, hard, white	4.7
Marl	2.5
Limestone, hard, white	1.9
Marl	1.9
Limestone, hard, white, weathers yellow	3.6
Limestone, hard, white, weathers yellow	4.3
Limestone, hard, white, weathers yellow	3.3
Covered	1.9
Limestone, hard, white, massive	2.9
Limestone, nodular, impure, weathering yellowish-white	4.5
	31.5

The outcrop of the Goodland limestone in Montague County is restricted to several parallel ridges whose long axes run northwest-southeast. These ridges occur in the eastern part of the county, and represent the troughs of synclines. This subject will be more fully discussed under the heading of structure.

Where the Goodland outcrops in contact with the Trinity sand steep cliffs and high escarpments result from the hard resistant limestone overlying the easily eroded sand. Outstanding examples of this type of topography may be seen in the vicinity of St. Jo, northeastern Montague County.

WASHITA DIVISION

Overlying the Fredericksburg is the Washita division, the highest division of the Comanche series. The Washita division is composed of marine shaly clays, marls, and subordinate limestones, having a total thickness of approximately 400 feet in northern Texas. The Washita division has been subdivided into a number of formations, as listed on page 67, of which only the Kiamichi and Duck Creek formations are represented in Montague County.

KIAMICHI CLAY

The Kiamichi clay[5] is the basal formation of the Washita division, resting directly above the Goodland limestone. It is composed of about 35 feet of dark yellow to olive-green to black shaly clay with thin platy lenses of a siliceous limestone in the lower portion; the top of the formation is marked by two or three ledges of an indurated yellowish shell breccia made up of a countless number of *Gryphaea navia* Hall and *Gryphaea corrugata* Say. This *Gryphaea* conglomerate is always present at the top of the Kiamichi, the individual beds ranging from a few inches to three feet in thickness. It is confined entirely to this horizon and is probably the most characteristic horizon of the entire Comanche series.

The Kiamichi outcrops in Montague County only in a rather restricted area in the southeastern corner of the county.

DUCK CREEK FORMATION

The Duck Creek lies directly above the Kiamichi clay. It received its name from the excellent exposures of this formation along Duck Creek, north of Denison, Grayson County, Texas. The Duck Creek consists of approximately 100 feet of limestone and gray to grayish-blue calcareous clay. In the lower 30 feet of the formation the limestone and shaly clay alternate in beds averaging from 6 to 12 inches in thickness in about equal proportions; in the upper 70 feet the clay greatly predominates, the limestone layers becoming thinner and separated by a greater thickness of clay. The lower Duck Creek is characterized by a number of easily recognized fossils, including *Pervinquieria trinodosa* Böse, *Inoceramus comancheanus* Cragin, *Hamites fremonti* Marcou. About 30 feet above the base of the Duck

[5]The evidence at present seems to indicate that the Kiamichi should be placed in the Fredericksburg rather than the Washita division.

Creek is the zone of large ammonites, *Desmoceras brazoense* Shumard.

In Montague County only the basal portion of the Duck Creek is represented, this being found in the extreme southeastern corner of the county.

STRUCTURE

In considering the structure of the rocks of Montague County it is necessary to consider separately the Cretaceous rocks and the Paleozoic rocks. Only very generalized statements can be made regarding the structure of the surface formations in this county.

PALEOZOIC ROCKS

The regional dip of the Pennsylvanian rocks is to the north and west. The strike of the Pennsylvanian formations in Jack County is to the north by a little east, but when the formations enter Montague County the strike takes a more nearly northeastward direction. This change in the direction of the strike is probably due to the influence of the Red River uplift causing the beds to swing around the "high" in northern Montague County.

CRETACEOUS ROCKS

The regional dip of the Cretaceous rocks is to the southeast at a rate averaging about 40 feet per mile. This regional dip is interrupted in many places by minor folds which, in general, trend northwest, parallel to the Arbuckle-Wichita Mountain uplifts. There are several features revealed on the geologic map which indicate the presence of minor folds in the Cretaceous and also probably in the underlying paleozoics of Montague County. Along the Trinity-Pennsylvanian contact there are two areas one near Montague and the other near Bonita, where the Pennsylvanian extends as embayments far into the Cretaceous area. These embayments could be either formed by unusually deep stream erosion, or by folds which brought the underlying beds closer to the surface than in the adjacent areas. It is believed that these two areas are a result of folds.

Another feature to which attention is directed is ridges of Goodland limestone in the eastern part of the county. These ridges, with few exceptions, trend in a northwest direction. It has been found in Grayson[6] and Cooke[7] counties, Texas, and in Love[8] and Marshall[9] counties, Oklahoma, that in the Cretaceous area a line of hills or ridges indicates a synclinal structure. Examples of this structural condition are found in the Marietta syncline in Love County, Oklahoma, the Sherman syncline in Grayson County, Texas, and in the Kingston and Cumberland synclines in Marshall County, Oklahoma. The general northwest trend of the Goodland limestone ridges, parallel to the major structural trends of this part of the state, also indicate that these ridges are structural in origin. If this relationship holds good for Montague County, and it is believed that it does, then the Goodland limestone ridges of eastern Montague County are synclinal and the intervening creek valleys are anticlinal in structure.

The structure section at the bottom of the geologic map shows the general structure of the surface formations of Montague County.

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[6]Bullard, Fred M., Geology of Grayson County, Texas, Unpublished Ms.

[7]Bybee, H. P., and Bullard, Fred M., Geology of Cooke County, Texas, Univ. Texas Bull. 2710, 1927.

[8]Bullard, Fred M., Geology of Love County, Okla., Okla. Geol. Surv., Bull. 33, 1925.

[9]Bullard, Fred M., Geology of Marshall County, Okla., Okla. Geol. Surv., Bull. 39, 1926.

NEW RUDISTIDS FROM THE TEXAS AND MEXICAN CRETACEOUS

By W. S. ADKINS

Primitive radiolites have been the object of considerable study and investigation, notably by H. Douvillé and F. Klinghardt. The Texas Comanchean rocks contain several levels of these fossils, more conspicuous in the southern, subtropical, rudistid-reef facies, but extending northwards at certain levels as stringers of rudistid-bearing limestone interbedded with marlier ammonite-bearing sediments. Of these radiolite levels, a prominent and persistent zone occurs at or near the top of the Fredericksburg division (Edwards limestone), and there are other lower Fredericksburg zones. At least three higher zones occur, in the Denton, the Main Street and the Buda levels, in Trans-Pecos Texas. These zones contain several species of *Eoradiolites, Praeradiolites* and other rudistids, discussed in this paper. In addition, the same zones, in both the Washita and the Fredericksburg divisions of the Texas Comanchean, contain a large fauna of Chamacea, including such genera as *Requienia, Toucasia, Monopleura, Plagioptychus, Caprinula, Polyptychus* (?) and *Planocaprina* (?). These Diceratidae, Monopleuridae, and Caprinidae will be discussed in a later paper.

The European equivalent of the Edwards (Upper Fredericksburg) is near the top of the middle Albian, at about the top of the ranges of the ammonite genera *Oxytropidoceras* and *Dipoloceras*, and at the bottom of the ranges of *Pervinquieria* and *Elobiceras*.

In addition there are described in this paper some rudistids from the Taylor formation in Texas and from the Mendez formation in the Tampico Embayment, state of Vera Cruz, eastern Mexico; both of these horizons are generally referred to the Santonian stage. Two species are described from the upper Austin chalk, probably lower Santonian in age.

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All types and figured materials are in the collections of the Bureau of Economic Geology of The University of Texas.

Edwards (Albian) Species:

Family **RADIOLITIDAE** GRAY

Subfamily **RADIOLITINAE** DOUVILLÉ

The test is prismatic in texture, composed of cone-in-cone like, funnel-shaped layers superimposed and crossed by vertical radial partitions; the form is generally elongated and in cross-section angulated; the siphonal bands are generally devoid of costellae.

Genus **EORADIOLITES** H. DOUVILLÉ 1909

Praeradiolites DOUVILLÉ, 1902. *(part.)* Sur la classification des radiolitidés. Bull. Soc. Géol. France (4), II, 461 (genotype: *P. fleuriaui)*.

Agria MATHERSON. TOUCAS, 1907 *(part)*. Études sur la classification et l'évolution des Radiolitidés. Soc. Géol. France, Mém. 36, pp. 17–27 (genotype: *Agria blumenbachi* STUDER).

Eoradiolites H. DOUVILLÉ 1909. Sur le genre *Eoradiolites*. Bull. Soc. Géol. France (4), IX, p. 77 (genotype: *R. davidsoni* HILL).

Sauvagesia G. BOEHM, 1898. Ueber Caprinidenkalke aus Mexiko. Zts. deuts. geol. Ges., Vol. L, p. 325. G. BOEHM, 1899. Beiträge zur Kenntnis mexicanischer Caprinidenkalke, in FELIX AND LENK, II, 146, text figs. 13 a-c.

Eoradiolites F. KLINGHARDT, 1928. Ueber sehr frühe Entwicklungsstadien eines Rudisten. N. Jahrb. f. Min., Beilage-Bd. XL, Abt. B, Heft 1, 173–178, pls. XV-XVI. KLINGHARDT, 1929. Die stammesgeschichtliche Bedeutung, innere Organisation und Lebensweise von *Eoradiolites liratus* CONRAD sp. Palaeontographica, LXXII, 95–104, pls. XII-XIV.

Radiolites C. F. PARONA, 1909. *Radiolites liratus* (CONRAD) e *Apricardia nötlingi* (Blanck.) del Cretaceo superiore dell Siria. Atti R. Acc. Sc. Torino, XLIV, p. 491.

See also the references under *Eoradiolites davidsoni* (HILL).

Description of genus.—Lower valve is a slender elongated, slightly curved, slowly expanding cone having (in most species) an angular contour; a few species are low, rapidly expanding cones. The cross-section ranges from circular *(E. choffati)* to triangular rounded *(E. triangu-*

laris) and quadrate *(E. plicatus)*. The two siphonal bands (E and S) are elongated and ribless, the interspaces are grooves of differing depth, generally smooth, but ribbed in a few species. The pedal fold (V) is in most species a sharply rounded ridge. Most species have 10 to 20 ribs on the posterior, dorsal, and anterior faces. These range in size, spacing, and doubling. All species have internally a ligamentary ridge, generally small, located about opposite the anterior siphonal band (E). The test is clearly prismatic in structure. The outer layer, forming the main bulk of the shell, consists of thin superimposed conical layers, each about ½ mm. thick, set at a high angle (about 50°) to the axis of the test. These are crossed by many vertical, radial thin septae, dividing this layer of the test into steeply tilted radial canals or prisms. There seem also to be a few scattered cylindro-conic septae. In most cross-sections the shell appears as a fine network of small squares bounded by thin calcareous septae.

Upper valve is operculiform, rounded to quadrate, often with the upper surface depressed. Its dentition and muscle attachments are essentially as has been figured by DOUVILLÉ (1910, Études sur les rudistes, p. 21), and by PARONA 1909.

Bournonia is rather similar in form to this genus, but differs in lacking the ligamentary ridge. *Biradiolites* likewise is elongate in form, but lacks the ligamentary ridge and differs in details of the siphonal bands. *Praeradiolites* differs in having the test composed of smooth, coarse, imbricated lamallae, in having the form short-conical, and E and S located in grooves.

Genotype.—Radiolites davidsoni HILL, Upper Edwards (Middle Albian), Belton, Texas.

Range of genus.—Albian (Europe, Lebanon, Persia, Mexico); Middle Albian (Texas); Upper Albian (Fort Stockton, Texas); Basal Cenomanian (Lebanon, Sinaï, Saint-Paul Convent in Arabia); a species has been reported from the Turonian (Italy) by Parona.

Key to Species

Cross-section circular; form cylindrical; no ribs; E and S
  smooth, elevated bands .... **E. choffati.**
Cross-section oval or triangular oval
  Usual (medium) length for genus; interband I between E
  and S costate.. **E. liratus**
  Test extremely long, slender; interband smooth.......... **E. davidsoni**
Cross-section triangular-rounded; species small, a rapidly
  expanding, low cone.. **E. triangularis**
  E. rousseli
Cross-section quadrate
  Practically no ribs on posterior, dorsal and anterior faces;
  siphonal bands low, interbands shallow........................ **E. plicatus.**
  Ribbed on all faces; siphonal bands tall; interbands deep
    Form thick; section taller than wide 6 anterior costae.....
    .... **E. quadratus**
    Form slender; section wider than tall; 1 anterior costa
    .... **E. angustus**

Two other species are recorded, *E. colubrinus* PARONA from the Turonian of Italy, and "*Sauvagesia*" sp. G. BOEHM, from the Albian at El Abra, west of Tampico, Mexico.

EORADIOLITES QUADRATUS n. sp.

Plate IV, Figures 1–4; Plate VI, Figure 5; Plate VII, Figure 5

Left valve a tall, expanding, curved tube, of roughly quadrate cross-section, prominently ribbed, with remote, coarse imbrications and numerous fine growth lines. The ventral face is straight, and bears the deep interbands and the flat-topped elevated siphonal bands. The anterior and posterior faces are almost straight and parallel, the dorsal face roughly perpendicular to them but somewhat convex, and these three faces bear about 14 ribs of differing form, strength, and spacing.

On the ventral side, the pedal fold (V) is a projecting narrow ridge, sharply rounded at its crest and lower than the posterior siphonal band (S); the anterior and posterior siphonal bands (E, S) are prominently elevated, smooth except for growth lines, and flat or slightly convex. The two interbands (between V and E, and between E and S) are deep and smooth. The first interband generally is shallower and wider than the second. Sporadically the first interband has one or two fine median costellae (as in the holotype), and the second has two. E is elevated, smooth, slightly convex (in many individuals flat), and wider than S. The second interband is generally as wide as E, and wider than the first interband.

The posterior siphonal band (S) is sharply elevated, about two-thirds the width of E, is smooth, slightly convex or almost flat.

E. quadratus typically has the following ribbing: on the posterior face, ventrally a smooth band (with two costellae) and dorsally three prominent costae; dorsal face five costae irregularly spaced, the posterior one being coarser; anterior face, six equal and equally spaced smaller costae, and a smooth band (some with few costellae) on the forward slope of V. The test between S and the dorsal midline bears seven principal costae. The ventral most two are larger, the others decrease in size dorsalwards. Three of these, and one or two costellae, lie on the posterior face. Between S and the first large costa there is a wide depressed space with a median costella, and dorsal to it a smaller one midway between it and the large costa. The second costa is somewhat more prominent than the first. The others range in size, and most of them are smaller than the first. In some individuals there is a costella between each two costae, or attached to a side of a costa. The dorsal face, in contour, is almost evenly rounded to the subparallel anterior and posterior faces. Between the dorsal midline and V, there are seven principal costae, which are smaller than the posterior costae. Between some of them are costellae. The dorsalmost two costae are larger, the other five smaller and subequal. Typically five costae lie on the dorsal face, and six subequal costae on the anterior face. On the anteriormost flat slope of V there are generally two low costellae and an intervening narrow, shallow depression. The species differs from *E. plicatus* in being ribbed instead of relatively smooth, in having E and S tall, and the interbands deeper. From *E. liratus* it differs in having a quadrate cross-section, E and S more prominently elevated and flat-topped, and generally in having smooth interbands. It differs from *E. davidsoni* in being typically shorter, in its quadrate cross-section, and in having the ribs elevated with sharply rounded tops instead of being linear-crested.

The upper valve is operculiform, quadrate and concave.

Uppermost Edwards: Nolan Creek, southeast of Belton. Holotype and paratypes in Bureau of Economic Geology.

EORADIOLITES aff. QUADRATUS ADKINS

Sauvagesia sp. G. BOEHM 1898. Über Caprinidenkalke aus Mexiko. Zts. deutsch. geol. Ges., L, p. 325. G. BOEHM, 1899. Beiträge zur Kenntniss mexicanischer Caprinidenkalke, in FELIX and LENK, II, 146, text fig. 13 a–c.

This massive, subquadrate *Eoradiolites* resembles *E. quadratus* in its form, the straightness of its ventral face, and the size, shape, and spacing of the siphonal bands. The cross-section is slightly oblique, and gives E considerable prominence; the shell is notably thick, and the ligamentary ridge well developed. The posterior face bears a medium-wide depressed space dorsal to S, and three strong ribs in the center of the face, an arrangement duplicated in Texas material.

El Abra limestone (Fredericksburg-Washita): "Sierra de la Boca del Abra bei El Chey," i.e., Choy Cave between Las Palmas and Taninúl, on the Tampico-San Luis Potosí railway, state of San Luis Potosí, Mexico.

At Taninúl tunnel, the following fossils occur: *Requienia* cfr. *texana, Caprinula* sp., *Pecten* sp. and corals. At Choy Cave: *Eoradiolites* aff. *quadratus, Caprinula* sp., *Chondrodonta* cfr. *munsoni*, gastropods, pelecypods, and corals. At the quarry 2 km. south of Las Palmas Station and about 4 km. north of Choy Cave, the following occur: *Caprinula* cfr. *anguis, Caprinula* sp. (thick), *Eoradiolites* cfr. *davidsoni, Requienia texana, Lima wacoensis, Trochus, Cerithium, Turritella, Kingena* cfr. *wacoensis*, and many other fossils. West of El Naranjo ranch: *Caprinula* 2 spp., *Pecten* cfr. *bonnellensis, Lima, Pecten* small sp., *Kingena, Plicatula* (?) sp.

EORADIOLITES sp. indet.

This Washita radiolite from the middle and upper cap rock near Fort Stockton, Texas, superficially resembles *E. quadratus*, but in the absence of more material has not been critically examined, and may represent a new species. It is associated with ornate Pectens of the reef type, *Chondrodonta, Nerinea, Actaeonella*, corals, sponges, and other fossils, and occurs in a rock of typical rudistid-reef lithology.

Denton (middle cap rock), and **Main Street** (upper cap rock) equivalents: mesas near Fort Stockton; Gaptank; elsewhere in Pecos and Crockett counties.

EORADIOLITES ANGUSTUS n. sp.

Plate V, Figures 1–7

This is an extremely slender species, more so than any other described species in the genus. Its ribbing is markedly reduced, and in this feature it is apparently constant and therefore differs from the nearly smooth variants of *E. quadratus*, in which the normal complement of costae is present but faint. Douvillé indicates that he considers such reduction of ribbing as specifically non-diagnostic. The shell is slender and curved. The features of the ribbing are: V smooth, a sharply rounded 60° angle; first interband narrow. E elevated and slightly convex, about five times as broad as either interband, second interband slightly broader and deeper than first, S about half the width of E, elevated and round-topped, remainder of contour to the dorso-anterior angle (which is prominent but more obtuse than V) bears eight subequal costae; anterior face with one strong costa dorsally and one (or more?) costellae in the wide smooth anterior slope of V. Cross-section nearly quadrate, anterior side longer than posterior. A slight ligamentary ridge is present. Most of the shells are from 6 to 12 mm. in diameter; at a diameter of 11.5 x 13 mm., the section has a characteristic transverse outline with the ventral face flattened and the anterior-posterior diameter greater than the dorso-ventral. The young has the characteristic "worm" stage; the exogyrate form has not been seen.

Upper Edwards: Belton. Holotype and paratypes in Bureau of Economic Geology.

EORADIOLITES sp. 3

In a single individual, the cross-section is typically tall (antero-posterior dimension 7 mm., dorso-ventral, 9 mm.), V is narrow, reduced, and rounded, and the two interbands are narrow (the second deeper than the first); E and S are slightly convex-topped, rounded elevations, E being twice as wide as S, and S somewhat taller than E. The rest of the shell is smooth, except for growth lines and a few longitudinal very faint striae. *E. choffati* is a smooth, cylindrical species; this species differs from it in being quadrangular in section. *E. plicatus* is nearly smooth, and in section resembles this species, but their identity cannot be settled with the material at hand.

Upper Edwards: Belton.

EORADIOLITES DAVIDSONI HILL

Text Figure 16

Radiolites davidsoni HILL, 1893. Proc. Biol. Soc. Wash., VIII, 106, pl. XIII, and text fig. 1 (on page 107). DOUVILLÉ, H., 1900. Sur quelques rudistes américains. Bull. Soc. Géol. France, (3), XXVIII, 218–220, text figs. 13–15. DOUVILLÉ, H., 1908. Sur la classification des Radiolitidés. Bull Soc. Géol. France (4), VIII, 309.

Praeradiolites davidsoni DOUVILLÉ, 1902. Classification des radiolitidés. Bull. Soc. Géol. France (4) II, 461. DOUVILLÉ, 1903. Notice sur les travaux scientifiques de M. Henri Douvillé, p. 54, figs. 67–69 (on page 51); Lille; same paper with date 1907 on cover. DOUVILLÉ, 1904. Sur les explorations de M. Morgan en Perse. Bull. Soc. Géol. France (4) IV, 541, text fig. 1.

Agria davidsoni TOUCAS, 1907. Études sur la classification et l'évolution des radiolitidés. Soc. Géol. France, Mém. 36, pp. 24–25, text fig. 1 bis; pl. II, figs. 1–1a. SCOTT, GAYLE 1926. Études stratigraphiques et paléontologiques sur les terrains crétacés du Texas, p. 172.

Eoradiolites davidsoni DOUVILLÉ, H., 1909. Sur le genre *Eoradiolites*. Bull. Soc. Géol. France (4) IX, p. 77 (original description of genus; genotype *E. davidsoni*). DOUVILLÉ, H., 1910. Études sur les rudistes. Soc. Géol. France, Mém. 41, pp. 14–15, 21–22, text figs. 9–10 (on page 15), pl. I, fig. 1. DOUVILLÉ, H., 1912. Description des rudistes de l'Égypte. Mém. prés. à l'Inst. égyptien, Tome VI, fasc. IV, p. 245. ADKINS, 1924, Univ. Texas Bull. 2340, page 36. ADKINS, 1927, Univ. Texas Bull. 2738, page 48. ADKINS, 1928, Univ. Texas Bull. 2838, p. 146. ADKINS, 1930, Univ. Texas Bull. 3016, page 39. PALMER, ROBERT H., 1928. The rudistids of southern Mexico. Calif. Acad. Sci., Occasional Papers XIV, pp. 19, 75.

Very elongate, slender, twisted shell, terminally flared; ribs flattened with age. Cross-section triangular- or quadrangular-oval, oblique to dorso-ventral axis. This species differs from *E. quadratus* in cross-section and in ribbing. In cross-section *E. davidsoni* is ovate-triangular, narrower dorsally, the anterior and posterior faces are not parallel; in *E. quadratus* the section is roughly rectangular, and the anterior and posterior faces are parallel. In *E. davidsoni,* the axis of the cross-section is oblique; in *E. quadratus* it is parallel to the ventro-dorsal axis of the shell and to the anterior and posterior faces. In *E. quadratus* V is more reduced and the anterior slope of V correspondingly narrower. *E. quadratus* has prominently elevated costae, whose crests are sharply rounded; *E. davidsoni* has typically broader, flattened costae with linear crests. The two species differ in the number and arrangement of costae, particularly on the anterior face. In *E. quadratus,* the anterior slope of V is typically a narrow band and dorsal to it on the anterior face there are six equal and equally spaced, elevated costae. In *E. davidsoni* the anterior slope of V is wide and smooth, and the anterior face bears a group of three or four irregularly spaced costae. The dorsal face of both species is about the same: it bears five or six elevated costae. S in both species is similar, hence the smooth band posterior to S is of the same width, and it is followed dorsally by three strong costae in each species. Some differences between these two species are:

E. quadratus	E. davidsoni
Section quadrate	Section oval-triangular
Section taller than wide	Section as wide as tall
Axis of section vertical	Axis oblique
V reduced	V prominent
Anterior slope of V narrow	Anterior slope of V wide
Anterior face typically bears 4-5 unequally spaced costae	Anterior face typically bears 6 equal and equally spaced costae
Costae elevated	Costae flattened in adult
Crests of costae sharply rounded	Crests of costae not rounded, sharply linear
E taller	E lower
Interband between V and E deeper (correlated with the reduced height of V)	Interband between V and E shallower

Upper Edwards limestone: Belton (type locality, holotype in Johns Hopkins University?). Generally distributed, at most places sparsely, at this level in central and southern Trans-Pecos Texas. The species has been reported from Persia. It probably occurs in northern Mexico.

Developmental stages of Eoradiolites

Some features seem quite variable individually; such are the straightness of profile of the ventral face and the relative height of E, the splitting of costae, and the presence, height, and spacing of costellae. Other features are variable with the age of the individual. Adults generally differ from young in the following features: (a) costae split, and are more widely separated; (b) form of costae changes from elevated to flattened; (c) E becomes more elevated; (d) the interbands may develop costellae; (e) E and S become more concave, or else more convex.

The developmental stages of rudistids have been very little studied.[1] The soft marl *Eoradiolites* level at Belton and elsewhere in central Texas affords innumerable examples of all stages of development of this rudistid shell,

[1]Klinghardt, F., 1928. Ueber sehr frühe Entwicklungsstadien eines Rudisten. N. Jahrb. f. Min., Beil.-Bd. LX, Abt. B, 173-187, pls. XV-XVI.

Klinghardt, F., 1929. Die stammesgeschichtliche Bedeutung, innere Organisation und Lebensweise von *Eoradiolites liratus* Conrad sp. Palaeontographica, LXXII, 95-101, pls. XII-XIV (juvenile stages from the Cenomanian of Mount Lebanon).

and the following is a brief, preliminary notice of this material.

1. Coiled stage.—The earliest observed stage of *Eoradiolites* is a flat, coiled, ostreiform shell tightly attached to the substratum, usually an adult rudistid, by its broadest face, and found in abundance in the upper Edwards marl at Belton and elsewhere in central Texas. Its shape is suggestive of the smooth species *Exogyra americana:* it is elongate-oval, in cross-section wedge shaped, thicker on the outside (convex) edge of the coil where there is a steep outer wall, thinning gradually towards the coiled side, which is notched at the point of inrolling of the initial globular chamber. The smallest individuals examined are about 1 mm. in diameter, but these minute stages are difficult to identity. Individuals 3×6 mm. in size, superficially resembling small, smooth Exogyras, are fairly common. The diameter at which the shells start growing straight is about 3.5 mm. (in cross-section). It should be noted that the exogyriform coils are considerably larger than this, but that the shell in attaching itself flares out considerably past the edge of the interior coiled cavity, which is visible on horizontal section. The largest coils thus reach 15 mm. or more in length. It is the left valve which is attached; the right valve is a thin, concave lid covering and fitting into the wide aperture.

2. Smooth, cylindrical shells ("worm stage").—The *Eoradiolites* marl level contains many small, smooth, worm-like, cylindrical tubes, which are the second stage of development of this rudistid. It is likely that this stage belongs only to slender individuals or species, because the exogyrate stage can be traced to a size which would preclude any worm-like tubes known from these beds. In slender species this stage is seen to be continuous at the initial end with stages showing fully developed radiolite features. The tubes have on two opposite sides zones of weakness corresponding to reduced wall thicknesses at these places, and almost all of them are crushed and flattened, with a depression running down the middle of each flat side. The tubes occur mostly loose in the sediments, but some lie against adult radiolites with only a thin film of Edwards marl between. They are about 3 mm. in diameter, and the usual fragments average about a centimeter in length. Some have a slightly bulbous initial end, frequently bearing several rounded, wartlike elevations.

No interbands are developed on this stage, unless the lines of weakness on the crushed faces correspond to them; the shells otherwise are smooth. In some individuals at a diameter of 2.6 mm. (length of fragment 7+ mm.) the quadrate cross-section is visible. By a diameter of 3.2 mm., elevations and depressions recognizable as the siphonal bands (E, S) and the interbands (I) are faintly developed, and the V crest is sharply angular.

3. Ribbed-banded stage.—In some individuals the tall exogyrate stage, in other, slender, individuals the smooth worm stage, is seen to pass into stages with the adult features recognizably developed. These take on prominent costae, the V, E and S bands are well developed but are more rounded than in the adult, and the interbands are deep but narrow. The finish of the worm stage, in which the costae and bands are still faintly developed and the cross-section is no longer rounded but has assumed its triangular or quadrate adult shape, is commonly separated from the next succeeding, strongly ribbed, stage by a pronounced growth imbrication or bracket ("ausgezeichnete Zuwachsstreifen" of Klinghardt). On one individual this transformation occurs at a diameter of 4.8 mm. (shell length 10+ mm.), in another at a diameter estimated at 5 mm. Past this imbrication the costae and siphonal bands suddenly appear in much increased strength, and by contrast give the impression that the earlier part of the shell is smooth. The ligamentary ridge is present before the appearance of the bracket, how much earlier was not discovered; Klinghardt in another species traces it back to a shell height of about 8 mm.

In summary, by a diameter of 4.8 mm. this rudistid has developed the following features:

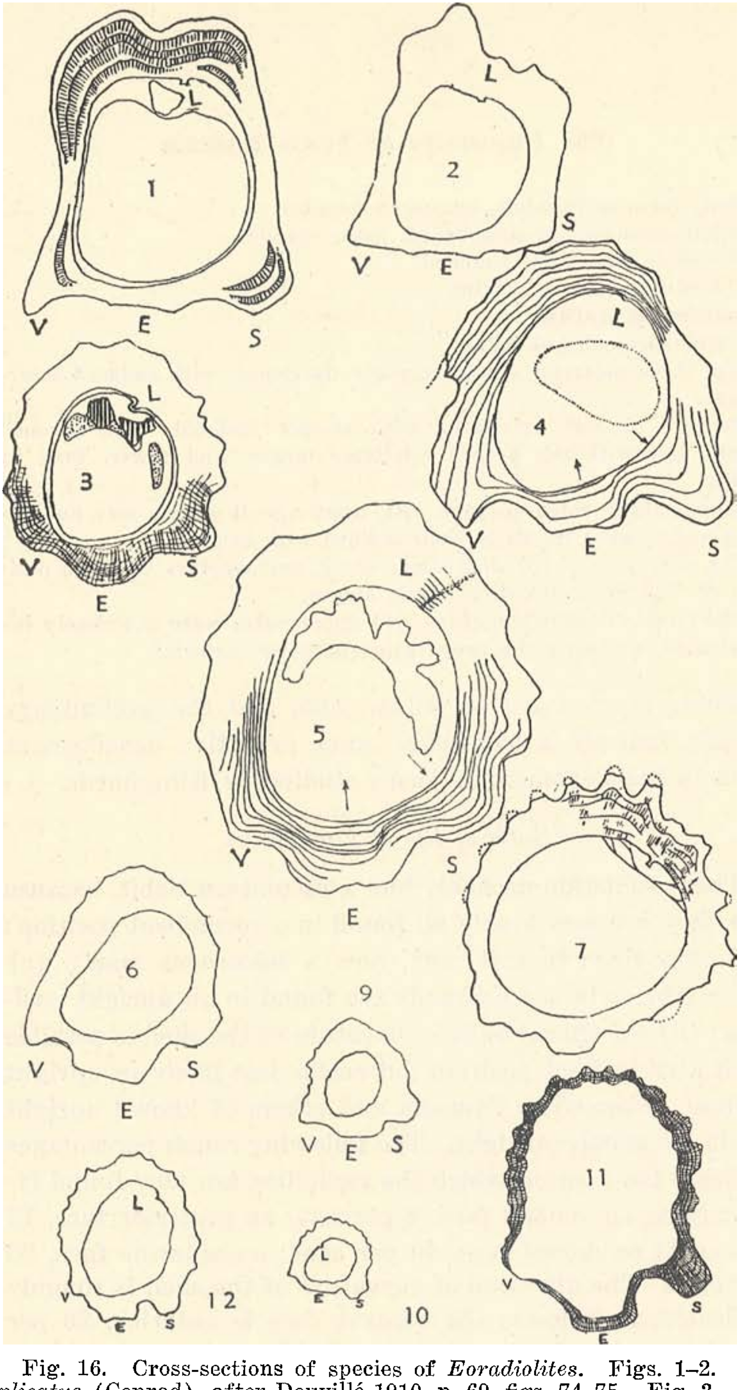

Fig. 16. Cross-sections of species of *Eoradiolites*. Figs. 1–2. *E. plicatus* (Conrad), after Douvillé 1910, p. 69, figs. 74–75. Fig. 3. *E. davidsoni* (Hill) after Toucas 1907, p. 10, fig. 1. Figs. 4–5. *E. davidsoni* (Hill) after Douvillé 1910, p. 14, figs. 9–10. Figs. 6, 9. *E. davidsoni* (Hill) holotype, after Hill 1893 (the ligamentary ridge is not shown). Fig. 7. *E. liratus* (Conrad) after Douvillé 1912, p. 245, fig. 6 (enlarged). Fig. 10. *E. angustus* Adkins, holotype. Figs. 11–12. *E. quadratus* Adkins, holotype, upper and lower ends. All figures except fig. 7 are slightly reduced.

Body form as in adult, but more rounded.
Adult cross-section established, more rounded.
V visible, but more rounded.
E and S present but faint.
Interbands shallow.
Costae present but faint.
The three posterior costae strongly developed, with reduced interspaces.
Texture of test prismatic, with steeply inclined "cone-in-cone" layers, but with the prisms relatively larger, and fewer, than in adult.
Ligamentary ridge present. At what age it starts was not determined because the early shell is filled with calcite.
The curvature of the shell starts early, and together with the position of V, aids in orienting young stages.
The muscle supports, sockets, and upper valve were not closely investigated, awaiting the preparation of more material.

These species are of Albian age, and the preliminary results indicate a somewhat more primitive development than in the Cenomanian forms studied by Klinghardt.

Habit of life of Eoradiolites

These rudistids probably had a recumbent habit, because (a) they are now nearly all found in a recumbent position; (b) they lived in soft mud, now a calcareous marl; (c) other species in the Edwards are found in an upright position; (d) the characteristic curvature of the shell is possible with a recumbent position but seems less likely in upright forms. *Hippurites, Tampsia* and others of known upright habit are mostly straight. The following rough percentages indicate the face on which the radiolites are now found lying: lying on ventral face, 8 percent; on posterior face, 12 per cent; on dorsal face, 40 per cent; on anterior face, 20 per cent. The direction of curvature of the shell is roughly indicated as follows: the concave face is anterior, 20 per cent; posterior, 20 per cent; dorsal, 16 per cent; ventral, 20 per cent; no curvature, 24 per cent.

A further argument for recumbent position is that the young are found attached (a) transversely to the adult, and therefore presumably in an upright position (about 80 per cent transverse; about 10 per cent parallel) ; and (b) along the entire length of the adult, which would be improbable were the adult partially buried in the mud. The coarse, detrital nature of the marl, the proximity of ripple marks, and the fauna, all indicate shallow water environment.

On the theory that the animals grew and curved in a recumbent position, those lying on the anterior or posterior face should have either the dorsal or the ventral face concave, and this is true: those lying on the anterior face have the concave face in the ratio of three dorsal to two ventral, and none anterior or posterior. Those lying on the posterior face have the concave face dorsal or ventral in equal numbers. Those lying on the dorsal face (the most numerous group) have the concave face in the ratio of two posterior to one anterior. Those lying on the ventral face are more irregular; most of them have the anterior face concave, some the posterior and some the ventral. On the theory that the shells fell into their present position, many of them would rest with the plane of curvature horizontal, because that is a position of equilibrium in soft mud, but many should fall with their concave face down, because as the animal grew the shell became more top-heavy in that direction. A glance at the percentages given will show that almost none lie with the concave face down. The growth habit of these radiolites is not established, and the above mentioned ideas are merely certain probabilities. The fossils occur in a marl bed less than a foot thick, which lies between two strata of nearly pure, white, mostly crystalline reef limestone containing the same rudistids, *Chondrodonta, Goniopygus, Pecten,* gastropods and other fossils as the marl layer.

Genus **PRAERADIOLITES** Douvillé[2]

PRAERADIOLITES EDWARDSENSIS n. sp.

Plate IV, Figures 6–8

Form a low cone, quadrangular in outline, curved, thick-walled; dimensions of holotype, greatest height, anterior-posterior dimension 85.0 mm., at top, 43.1 mm., dorso-ventral dimension at top, 50.8 mm. The shell is imbricated into a few coarse lamellae, three in the holotype. These form projecting zig-zag angles, with the V's directed basally over the pedal fold (V) and at the front edge of the depression S, apically at the rear ends of E and S. In the middle of the anterior face the imbrications show a wide, apically-directed angle, and in the middle of the dorsal face, a broad, rounded basally-directed angle. V is a rounded right-angled ridge. E and S, following current descriptions, are considered as depressed bands, E being shallower and narrower. The interband (I) is a strong, rather flat-topped elevated band; the ridge posterior to S is a tall, sharply elevated band with a narrow truncated crest. The posterior face bears about three low, equal, and equally spaced, round-topped costae. The dorsal face, connected to the posterior by a rounded angle, apparently bears a few, low, rounded costae. It is separated from the anterior face by a sharply rounded obtuse angle. The anterior face bears one or two (?) low remote costae or low ridges. The holotype is slightly curved: the dorsal face is concave.

Ligamental ridge prominent, opposite E.

Texture of test tubular-prismatic, as in *Eoradiolites*. The laminae however, are more wavy, as in certain species of *Durania*. The inner layer is compact-prismatic, nearly a millimeter thick, smooth, and longitudinally striated. The outer layer is thick, and has the usual cone-in-cone struc-

[2]*Praeradiolites* H. Douvillé 1902. Classification des Radiolites. Bull. Soc. Géol. France (4), II, 461. Douvillé, H., 1910. Études sur les Rudistes. Soc. Géol. France, Mém. 41, pp. 21–22, 48, 73–74. Douvillé, H., 1912. Description des Rudistes de l'Egypte, Mém. prés. à l'Inst. Égyptien, VI, fasc. IV, 247–249. Toucas, A., 1907. Mém. 36, Soc. Géol. France, pp. 28–46. Genotype: *P. fleuriaui* (D'Orbigny). Recorded range: Cenomanian-Danian.

ture, except for the coarsely projecting imbrications, which represent mainly local thickening of the individual cones. The cortical layer is smooth except for growth laminae and *Clione* borings.

The cross-section is subquadrate, with the ventral face nearly a straight line. The other three faces form a roughly rounded rectangle, with the dorso-anterior angle sharper than the others. The cross-section of the body cavity is a short oval, somewhat pinched ventrally.

Hinge structure and right valve not seen.

This genus resembles *Eoradiolites* in possessing a ligamentary ridge, but differs in having a low-conical instead of elongate form, in having E and S as grooves and not smooth, and in having the test made up of coarse imbrications. This species has the form of *P. fleuriaui* and *P. sinaiticus,* both from the Cenomanian.

Edwards *(Eoradiolites* level) : Belton. Holotype in Bureau of Economic Geology. Another species of *Praeradiolites* from the Edwards cap of Double Mountain, Stonewall County, Texas, is represented by one individual in the collections of the Bureau of Economic Geology.

Taylor and Mendez (Santonian) species:

Subfamily SAUVAGESINAE Douvillé

Test cellular or reticulate in texture, composed of numerous, inclined, superimposed laminae of cellular structure, with radial canals, some branched; form cylindro-conic, ornamented with rather regularly spaced longitudinal costae, periphery not greatly angulated; siphonal bands generally, but not always, costulate.

Genus DURANIA Douvillé 1908[3]

The ligamentary ridge is lacking in species of this genus.

[3]*Durania* H. Douvillé 1908, Sur la classification des radiolitidés. Bull. Soc. Géol. France, (4), VIII, p. 309. H. Douvillé 1910, Études sur les Rudistes, Soc. Géol. France, Mém. 41, p. 23. Genotype: *Bir. cornupastoris* Desmoulins 1826. Douvillé states that the Sauvagesias lose their ligamental ridge in the upper Cenomanian, but fossils described by Stephenson and by the present writer show them to persist to the Mendez (supposedly Santonian, in part at least). Conversely *Durania* starts early, as was shown in the Grenoble region (Léon Moret, Sur la presence des

DURANIA TERLINGUAE n. sp.

Plate VIII, Figures 2-3

Colonial: type consists of portions of three individuals in a colony. Lower valve large, slightly curved, robust, cross-section of body cavity subcircular. Wall thick, especially opposite the siphonal bands, somewhat thinned at the bands. Inner prismatic layer less than 1 mm. thick, its surface marked by numerous, fine, circular and longitudinal striae. The main portion of the wall is composed of thin, subhorizontal laminae with fairly coarse cellular structure and scattered radial canals, many of them branched terminally. Distal surface of valve is marked by coarse, elevated reticulation.

There is no ligamental ridge.

Siphonal bands inconspicuously excavated. The anterior band (E) corresponds to a thinned portion of the shell wall, and apparently is marked by a group of slightly finer and more irregular longitudinal costellae. The posterior band (S) appears to be marked by a slightly indented shell margin and by wavy laminae. The interband is a broadly elevated area with costellae somewhat finer than on the opposite side of the shell.

The rest of the shell bears numerous, fine, low, round-topped, longitudinal costellae, somewhat narrower than the interspaces. These costellae average about 4.3 per cm. of shell perimeter, or about 190 for the entire perimeter. Some of the costellae, irregularly scattered, are coarser, and a few consist of finer pairs. They are crossed by numerous fine growth imbrications, which produce a zig-zag effect.

Upper valve unknown.

Rudistes dans le Vraconnien de la Fauge, près Grenoble, et sur la phylogenie du genre *Durania* Douvillé, C. R. Soc. Géol. France, 22 Juin 1925, 170-172). The two lines, *Sauvagesia,* and *Durania* derived from it with loss of the ligamental ridge, ran concurrently through the upper Albian on to the Santonian, at least in middle America.

The species has certain similarities in form to the Turonian *Durania arnaudi* Choffat[4] and its var. *expansa.*[5] However its numerous equal costae distinguish it from the published species known to the writer.

Austin chalk equivalent: Three miles north of Terlingua, Brewster County, Texas, west of the Alpine road; collected by Dr. J. A. Udden and Mr. D. D. Christner; colony (largest the holotype, other two paratypes) in the Bureau of Economic Geology.

DURANIA AGUILAE n. sp.

Plate VII, Figures 1–2

The holotype is apparently solitary, cylindro-conic and slightly curved, large, ribbed, and of nearly circular cross-section. The holotype has the following dimensions: length, 190 mm., diameters at larger end, 111.5 and 97.8 mm., thickness of shell ranges from 8 to 16 mm. The section appears to be somewhat flattened, and the surface is worn. On one of the flattened faces are two parallel shallow grooves with costellae, which probably are E and S. The anterior of these is about 14 mm. wide and bears about 12 costellae, which are low and flat and appear like a plane surface divided by equally spaced fine, narrow, straight grooves. About 28 mm. farther posterior is a deeper, narrower, and more sharply excavated groove 11 mm. wide, bearing about 13 fine and slightly unequal costellae. Between E and S are two raised subequal costae, each secondarily grooved. The remaining perimeter of the shell bears about 18 unequal round-topped broad costae. These are irregular or compound, and are crossed by arcuate growth lamellae whose convex arcs point basally.

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[4]Toucas, Ar., 1907. Études sur la classification et l'évolution des Radiolités. Soc. Géol. France, Mém. 36, 93, pl. XVIII, figs. 3–7. Douvillé, H., 1910. Études sur les Rudistes. Soc. Géol. France, Mém. 41, 50, pl. III, fig. 1. Douvillé, H., 1912. Description des Rudistes de l'Égypte. Mém. Inst. Égypt., VI, fasc. IV, 252, pl. III, fig. 1. Choffat, P., 1902. Faune crét. Port. 4 sér., I, 138, pls. VI–VII.

[5]Choffat, P., 1902. Faune crét. Port., sér. 4, I, 144, pl. VIII, figs. 9–12. Pruvost, Pierre, 1913. Note sur les rudistes turoniens du nord de la France. Ann. Soc. Géol. du Nord, XLII, 83 95, pls. II–III.

Ligamentary ridge absent.

The texture of the test is cellular, and in general as in the subfamily Sauvagesinae. The cross-section is a short oval, compressed dorso-ventrally. The species appears to differ from *Durania manuelensis* Stephenson in having E and S differently disposed and the space between them broader, and in having more and more irregular costae. Stephenson mentions that his species has about a dozen costae. Superficially the species somewhat resembles *Sauvagesia degolyeri* Stanton in ribbing, but has fewer and more irregular costae. There seems to be no described American species into which this form fits. In form it has resemblances to same African species, as *D. blayaci* or *D. pervinquierei* Toucas from the Cenomanian, but it seems to have no close affinities with any described species known to the writer.

Upper valve and dentition unknown.

Mendez red foraminiferal clay (probably Santonian): near Rayon, state of Tamaulipas, Mexico. Coll. Cia Mexicana de Petroleo El Aguila.

DURANIA HUASTECA n. sp.

Plate VI, Figures 1–4

Species apparently gregarious: the holotype has attached near its base a small fragment of another individual. Lower valve of medium size for the genus, conical, twisted, slender. The cross-section of the body cavity is nearly circular. The wall is thick except in the region of the two excavated siphonal bands, where it thins abruptly and markedly, particularly at the anterior band. The inner prismatic shell layer is less than ½ mm. thick and its inner surface is marked by numerous fine longitudinal, and numerous fainter circular, striae, which produce a faintly cancellated surface. The main portion of the wall is composed of thin, conical laminae with a medium-fine cellular structure and sparse radial veins, most of them unbranched. The cellular structure mainly consists of numerous fine, straight, parallel, radial rows of hexagonal cells. At the apical end of the shell these are exposed as an irregular raised network.

There is no ligamental ridge, nor is its position marked in any way, by elevations or by a slit in the shell wall.

The siphonal bands are excavated channels, the anterior one (E) somewhat broader than the posterior one (S); the two are separated by the angularly raised narrow inter-band, a crest bearing three longitudinal ridges and four grooves all subequal in size. The channels have bottoms sharply concave at the edges and lightly concave across the centers. They are smooth except for numerous arcuate, slightly irregular, apically concave, growth lines.

The rest of the exterior of the shell is of evenly ovate contour, slightly compressed dorso-ventrally, without plications, and bears about 80 subequal, longitudinal, fine, low, straight, rounded ridges. A few of these near the siphonal channels are somewhat coarser than those on the opposite side, and there occur at a few places several interspersed ridges of smaller size. Dorsally the ridges are somewhat finer and more crowded than elsewhere. This species is exceptional in having the anterior and posterior bands smooth.

Mendez (upper 100 feet; in place): Hacienda Cacalilao, state of Tamaulipas, Mexico. Collected by Mr. O. B. Knight. Holotype in Bureau of Economic Geology, from Mr. J. B. Dorr of the Huasteca Petroleum Company.

This species resembles in single characters certain previously described species, but in general appearance is unlike any which has come to the attention of the writer. For example it resembles *Durania ga'ensis* (DACQUÉ[6]) from the Turonian[7] of the Abou Roash uplift west of Cairo, in having the anterior siphonal band deeply excavated and the shell beneath it unusually thin. The Egyptian species however is more slender and more sharply ribbed than the Mexican, and lacks the numerous low costae.

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[6]Dacqué, E., 1903. Mittheilungen über den Kreidekomplex von Abu Roash bei Kairo. Palaeontographica, XXX, 374, pl. XXXV, figs. 7-9.

[7]Douvillé, Henri, 1912. Description des rudistes de l'Égypte. Mém. prés. à l'Institut égyptien, VI, fasc. IV, 240, 253, pl. II, figs. 4-7.

Genus **SAUVAGESIA** BAYLE 1878[8]

This genus differs notably from *Durania* in possessing the ligamentary ridge.

SAUVAGESIA MORGANI n. sp.

Plate VIII, Figure I; Plate IX, Figures 1–2

Colonial: material consists of two crushed and incomplete individuals, and a small fragment, all in one colony. Lower valve large, straight, long, conical, of nearly circular cross-section (crushed slightly in type). Wall of medium thickness, not markedly thinned at siphonal bands. Inner prismatic layer thin, its inner surface marked by numerous fine longitudinal striae. The main portion of the wall is composed of thin conical laminae with medium-fine cellular structure. On longitudinal section the laminae are seen to be crossed by longitudinal boundaries of translucent calcitic material, making such a section appear as a fine rhomboidal network.

Ligamental ridge present, extends about 7 mm. into body cavity, terminally slightly thickened.

Siphonal bands prominent, excavated; the anterior band (E) is a broad, shallow, V-shaped depression about 17 mm. wide at bottom (broken) end of type, and 30 mm. wide at top, situated on a slightly raised platform. The concavity of the band bears several longitudinal, subequal, round-topped, fine riblets, and a few scattered transverse growth imbrications, of inverted V shape. The posterior band (S) is a narrower, flat-bottomed channel, bounded on both sides by a sharp, straight-sided plication. The bottom of S bears five subequal, round-topped, low, longitudinal riblets, and is crossed by remotely spaced, coarse growth imbrications. The interband is broad, and bears three coarse, subequal, longitudinal ridges, V-shaped in cross-section. The rest of the shell bears about 18 coarse, V-shaped, straight-sided,

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[8]Sauvagesia Bayle 1878; H. Douvillé 1886, Essai sur la morphologie des rudistes. Bull. Soc. Géol. France (3), XIV, 389–404. Toucas, A., 1907. Études sur la classification et l'évolution des Radiolitidés. Soc. Géol. France, Mém. 36, p. 81. Genotype: *Sauvagesia nicaisei* Coquand.

longitudinal ridges. Those near the siphonal bands are coarser, and those on the opposite side are subequal and finer. Between the ridges are straight-sided, V-shaped valleys, so that the whole contour of the shell is composed of these straight, sharp plications. In ribbing, this species somewhat resembles *Sauvagesia coloradensis* Stephenson.

Mendez (lower part; in place): Hacienda Las Flores near Manuel, state of Tamaulipas, Mexico. Collected by Mr. O. B. Knight.

Austin chalk species:

SAUVAGESIA aff. DEGOLYERI

STANTON 1921. A new Cretaceous rudistid from the San Felipe formation of Mexico. Proc. U. S. Nat. Mus., Vol. 59, 453–454, pls. 96–97.

A specimen from near Austin, Texas, resembles Stanton's species more than any other described. It is a corroded fragment of the following dimensions: height 100 mm., dorso-ventral 98 mm., antero-posterior 103 mm. at the larger end. It has about 53 narrow, subequal ribs, whose intersections with the growth lamellae show the finely zigzag network figured by Stanton. The ligamental ridge is prominent on the hollow interior. Details of E and S could not be ascertained. The cross-section is short oval-quadrate, and longer antero-posteriorly in the body cavity than at the exterior (measurements given above). This is because of the extra thickening of the shell wall dorsally, where the wall reaches 25 mm. thickness, as compared to 16 mm. ventrally.

Austin chalk: Farm of Mr. W. Tom Wells, 10 miles north of Big Walnut Creek, Travis County, Texas. Stanton's species is from the San Felipe limestone.

SAUVAGESIA ACUTOCOSTATA n. sp.

Plate VII, Figures 3–4

Lower valve only; species apparently solitary; holotype practically straight, conical, medium sized, ribbed, cross-section a short oval. The wall is of medium thickness, thin at E and S, thickest dorsally. Inner shell layer thin, smooth, superficially marked by a rectangular network of circular and longitudinal faint striae. The thick middle layer of the shell has a cellular texture and is composed of the usual conical laminae. The cortical layer is thin and smooth, except for faint growth lines and faint longitudinal striae.

Ligamental ridge prominent, about 4 mm. tall, with a broadened flange at its tip.

The two siphonal bands (E and S) are sharply excavated V-shaped channels with practically smooth sides. Between them is a strongly elevated V-shaped ridge, whose narrow top bears a narrow furrow. The rest of the contour of the shell bears about 16 irregularly spaced, elevated, principal costae, each of which is doubled (a few tripled) at the crest, and between which, in the intervening depressions are differing numbers of continuous, low costellae. For instance, in the depression following the main costa immediately posterior to S, there are two main costellae. Following the next costa there is a depressed, broad, flat band bearing three prominent costellae. Most of the succeeding interspaces over the dorsal face are devoid of costellae. On the anterior face there are six or seven split costae, the interspaces being smooth. In this species the costae are straight, unbranched, and sharp-topped. At remote intervals they are crossed by more pronounced growth lines, which produce a zig-zag effect.

This species differs from *Sauvagesia coloradensis* Stephenson and *S. degolyeri* Stanton in having the siphonal bands consisting of narrow V-shaped excavations devoid of costellae, instead of flat costulate bands; and from *S. belti* Stephenson in having the main costae unbranched and devoid of secondary ribs.

Upper Austin chalk (probably basal Santonian): Travis County, Texas, on Little Walnut Creek, about one-fourth mile downstream from bridge of Austin-Cameron road; collected by Mr. R. W. Cumley, 1929.

TEXAS COMANCHEAN ECHINOIDS OF THE GENUS MACRASTER

By W. S. ADKINS

The echinoid genus *Macraster* of the family Brissidae was described in 1888 by Ferdinand Roemer from a single species *Macraster texanus* found in the middle portion of the Washita division[1] at Georgetown, Texas. Typical Macrasters seem, so far as is known, to be confined to the Washita division; except for a few species which have been referred to this genus from Europe, they are reported principally from Texas and northern Mexico. The nine species known from Texas are excellent zone fossils, and occur in three general levels:

Pawpaw-Weno: *M. wenoensis, M. obesus, M. subobesus*
Denton–Fort Worth: *M. texanus, M. aguilerae, M. elegans, M. pseudoelegans, M. nodopyga*
Duck Creek: *M. kentensis*

As has been proven for *Heteraster,* the best general guides for separating species of *Macraster* are the measurement and comparison of certain proportions of the test, notably the proportionate width, height, position of apical

[1]Roemer states that all his fossils came from a white chalk marl together with fossils which occur at Fredericksburg, *Exogyra texana, Gryphea pitcheri* and *Natica pedernalis.* R. T. Hill (1889, On the occurrence of *Macraster texanus,* Amer. Nat., XXIII, 168) denies the Fredericksburg age of Roemer's species and states that it "makes a well defined horizen near the very top of the immense thickness of lower marine Cretaceous in Texas, and does not occur, as Dr. Roemer infers, from the specimens which accompanied it to Germany, with the *Exogyra texana* fauna, a statement which has been verified by Mr. George Stolley, the collector." Hill lists its horizon as "Washita" (i.e., Georgetown) limestone in the two check lists: Check List of the Invertebrate Fossils from the Cretaceous Formations of Texas, accompanied by notes on their geographic and geologic distribution, Part I, Austin (1889), p. 8; and A Preliminary Annotated Check List of the Cretaceous Invertebrate Fossils of Texas. Geol. Surv. Texas, Bull. 4, p. 2. He states: "This conspicuous species . . . is characteristic of and peculiar to the uppermost horizon of the Washita division and extends from Fort Washita, through Denison, Fort Worth, Salado, Georgetown, Austin, and southwestward." It is probable that in Roemer's material Washita and Fredericksburg collections were mixed. Following his well-known misconceptions of the stratigraphy, Roemer erroneously considered the Georgetown (Washita division) material equivalent to that from Fredericksburg (Fredericksburg division) and practically equivalent to that from the waterfall of Guadalupe River at New Braunfels (upper Cretaceous).

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system, and position of periproct; an inspection of certain features of the ambulacra, the length, width, and depth of the ambulacral grooves, the number and arrangement of pores; and certain features of tuberculation of the test. A study of several hundred individuals shows that the species during the Washita underwent certain developmental changes, and the most tangible way to record these and to indicate (as in the tabulations following) the limits of variation of each feature in each species, is by percentage measurements. These supplement the information derived from inspection of the characters less amenable to measurement, and assist in stating precisely the relations of any given individual to the type of the species.

Family BRISSIDAE COTTEAU, in LAMBERT 1905

This family of the sub-order Spatangoida has the apex compact, the plastron amphisternous, the paired ambulacra petaloid and situated in grooves. The following is an artificial key to the recorded Texan genera:

Peripetalous fasciole not distinct, generally absent
  Unpaired ambulacrum has pores of a pair separated by a granule .... **Epiaster**
  Unpaired ambulacrum has pores without granules between .... **Macraster**
Peripetalous fasciole distinct
  Ambulacral grooves prominent; unpaired ambulacrum with a granule between the pores of a pair .... **Hemiaster**
  Ambulacral grooves deeply excavated, test *Schizaster*-like .... **Proraster**

Genus **Macraster** FERDINAND ROEMER, 1888

Roemer, F., 1888. Macraster, eine neue Spatangoiden-Gattung aus der Kreide von Texas. N. Jahrb. f. Min. [etc], I, 191–195, pl. VI.
Böse, Emilio, 1910. Monografía geológica y paleontológica del Cerro de Muleros [etc.], Inst. Geol. Mexico, Bol. 25, p. 172.
Lambert, J., 1920. Études sur quelques formes primitives des Spatangides. Bull. Soc. Sci. Hist. Nat. de l'Yonne, Année 1920, p. 28.
Lambert and Thiéry, 1924. Essai de nomenclature raisonnée des échinides, p. 472.

Lambert, J., 1927. Considerations sur les échinides de la Comanche série du Texas. Bull. Soc. Géol. France, XXVI, fasc. 3–5, p. 272.
Adkins, W. S., 1928. Handbook of Texas Cretaceous Fossils. Univ. Texas Bull. 2838, pp. 294–297.

Roemer's generic definition follows:

Shell large, convex, cordiform in outline. Mouth situated on the flat lower face near the anterior margin, transversely oval, without projecting labrum; periproct supramarginal, situated on posterior flattened surface. Apex compact, with four genital pores; ambulacra petaloid, open below, situated in grooves. Posterior ambulacral grooves as long as the anterior. Ambulacral pores located in narrow transverse clefts or slits. Upper surface of test covered with scattered small granules. No fascioles. The only known species: *M. texanus*, from the Upper Turonian chalk marl at Georgetown, Texas.

Form and size.—Of the nine species recorded from Texas the smallest are *M. nodopyga* and *M. wenoensis*, each about 50 mm. long, and the largest is *M. obesus*, length up to 106 mm.[2] There are two lines of development in the genus: (a) test elongated, decidedly constricted posteriorly: *M. kentensis*, *M. pseudoelegans*, and *M. obesus;* (b) test oval, posteriorly rather evenly rounded, and not much constricted: the other six species (*M. nodopyga* and *M. elegans* are slightly constricted posteriorly, but can be identified by other features). In the first line of development the species increase in size and in height. In the second line, the Duck Creek species are mostly smaller than the Denton species, and the last developments of the genus, in the Weno, include giant obese species. *M. texanus* forms a special, low, flat-topped line. In most species the test has an angular perimeter, obscured somewhat in the obese and inflated forms. A flattened vertical band or facet marks the end of each paired ambulacrum, each side of the test between the paired

[2]The other dimensions are computed as a percentage of the length, except the periproct, whose height above the base of the test is computed as a percentage of the total height of the test. Some compilations have been made to determine the normal ranges of each feature in each species, but these are incomplete because of the small number of individuals studied; however, empirically, a deviation of as much as 10 points is generally significant. L = length of test in millimeters; H, W, A = respectively height, width, and distance of apical system behind anterior margin, as percentages of the length; P = height of periproct above base as a percentage of height of test.

ambulacra, the front of the test on each side of the unpaired ambulacrum, and the posterior periprocteal truncation. There is a posterior median carina.

Tuberculation.—Most species of the genus are sparsely tuberculate. The most strongly tuberculate development is in the special deep-grooved line of *M. elegans.* The smoothest developments are in the *aguilerae-wenoensis* line. The tubercles are small, and apparently perforate. Between them are many, fine scattered granules.

Ambulacra.—The ambulacral grooves of *Macraster* extend to or almost to the edge of the aboral face, and are straight or slightly curved, depending somewhat on the height of the test and the convexity of the aboral face. Flat-topped forms *(M. texanus)* and forms with short grooves *(M. nodopyga)* have nearly straight grooves. Elevated species *(M. elegans,* tall forms of *obesus)* have the anterior ambulacra slightly curved. The posterior ambulacra are nearly straight in all species. The ambulacral pores are mainly transverse and elongated. They are generally *en chevron* at the two ends of the ambulacrum, and more strikingly so in the unpaired ambulacrum; in some species, as *M. nodopyga,* this feature is more pronounced. A few pore-pairs nearest the apex are generally small and circular.

The posterior ambulacra are nearly as long as the anterior. Length of groove is correlated with shape of test, and number of pores with length of groove. Depth of groove is a diagnostic and recognizable character, though difficult to measure. The grooves are notably deep in *M. kentensis, M. pseudoelegans* and *M. elegans.* In these, particularly the last, the interambulacra are notably elevated and convex. The grooves are quite shallow in *M. wenoensis,* and fairly shallow in *M. texanus, M. aguilerae, M. obesus* and *M. subobesus.* The ambulacra are narrow in *M. nodopyga* and *M. wenoensis;* they are broadest in *M. obesus* and *M. subobesus.*

These approximate and non-measurable differences are roughly expressed in the following table:

Ambulacral Grooves of Texas Species of Macraster

Elongate species:	*Length*	*Depth*	*Width*	*Curvature*
kentensis	long	deep	wide	straight
pseudoelegans	long	deep	narrow	straight
subobesus	long	medium	wide	straight
Oval species:				
nodopyga	short	medium	narrow	straight
aguilerae	long	shallow	narrow	straight
elegans	long	deep	wide	curved
texanus	long	shallow	wide	straight
wenoensis	long	shallow	narrow	curved
obesus	long	shallow	wide	curved

Fascioles.—None are clearly observable in Texas species of *Macraster,* except perhaps traces in certain individuals of *nodopyga.* In some specimens there are faint, intermittent granulated areas devoid of tubercles, which suggest that perhaps fascioles are obsolescent in the genus. Lambert and Thiéry[3] state that: "Certain individuals show traces of a more or less diffuse peripetalous pseudofasciole."

Apical system.—Its position in Macraster is quite constant, in front of the center of the test (.39–.48); is compact; has four genitals and five oculars, as figured in the literature. The madreporite is prominent; in one individual examined, the madreporic perforations cover both right-hand genitals.[4]

Peristome.—The sub-family Palaeostominae Loven, to which *Macraster* is currently assigned, has the peristome pentagonal. In certain Texas species as *M. wenoensis,* the peristome is roughly pentagonal, with the posterior angles less, and the anterior angles more, rounded. Roemer describes the peristome as transversely oval. It is elevated but not distinctly labiate behind, and in front is strongly depressed.

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[3]Lambert and Thiéry, 1924. Essai de nomenclature raisonnée des échinides, p. 472.

[4]Munier-Chalmas, 1885. Note sur l'appareil apical de quelques échinides crétacés et tertiaires. C. R. Acad. Sci. (Paris), Vol. 101, p. 1074. Janet, Charles and Cuénot, L., 1891. Note sur les orifices génitaux multiples, sur l'extension des pores madréporiques hors du madréporite, et sur la terminologie de l'appareil apical chez les oursins. Bull. Soc. Géol. France (3) XIX, 295-304.

Periproct.—The periproct in this genus has a considerable range in shape, size, and position, and some of these differences appear to be of specific value. The position of the periproct is listed in the measurements. The largest species, *obesus*, *subobesus*, and *texanus* have the smallest periprocts; *kentensis* and *pseudoelegans* have the largest; other species have periprocts of medium size. These differences are probably to be correlated with as yet unstudied food habits, whether the species were carnivorous or scavengers, or subsisted upon microscopic organisms. Size of periproct should be studied in relation to size of mouth parts, Aristotle's lanterns, and inner organization of the test, a research not yet attempted on Texan echinoids.[5]

Artificial Key to Texas Species of Macraster

Test elongated, prominently constricted behind
  Periproct small, test tall........................**subobesus**
  Periproct large, test lower
    Test more elongated and more constricted posteriorly......**kentesis**
    Test more oval, less narrowed........................**pseudoelegans**
Test oval, not (or only slightly) constricted posteriorly
  Ambulacral grooves short ....**nodopyga**
  Ambulacral grooves long
    Test large, obese, about as wide as long........................**obesus**
    Test medium to small, longer than wide
      Test low, flat-topped ....**texanus**
      Test taller than 50%, round topped
        Ambulacral grooves shallow; test sparsely tuberculate
          Small species; ambulacra curved........................**wenoensis**
          Larger species; ambulacra nearly straight..........**aguilerae**
        Ambulacral grooves deep, interambulacra elevated;
          test prominently tuberculate ....**elegans**

I. ELONGATED, POSTERIORLY CONSTRICTED SPECIES

MACRASTER KENTENSIS n. sp.

Plate XI, Figures 1–3, 5

Test.—Form elongate-cordate, of medium elevation (.555), sides inflated and rounded, perimeter vaguely angu-

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[5]Klinghardt, Franz, 1911. Uber die innere Organisation und Stammesgeschichte einiger irregulären Seeigel der obern Kreide. Jena, 1911. Dawson, J. W., 1867. The food of the common sea-urchin. Amer. Nat., I, 124. Scott, F. H., 1902. Food of the sea-urchin. Sess. Paper 22-A, pp. 49–54 (Ottawa).

lar, having flattened faces at ends of each paired ambulacrum, on each side between the paired ambulacra, on each side of the unpaired ambulacrum, and a narrow periprocteal truncation (nine in all) ; test elongated posterior to apex, and rapidly narrowed to the edges of the posterior truncation, which is bordered on each side by a vertical row of about ten faint tubercles or transverse crenulations. Highest point of test behind apex on the prominent median carina. Broadest part of test forward of apex, at front end of lateral interambulacral facet. Apex anterior to center of test (.430). The test is more elongated, more sharply constricted posteriorly, and has a narrower posterior truncation than in *M. pseudoelegans* or any other Texas species. The test is rather evenly and sparsely covered with small apparently perforate tubercles, and between them, minute granules.

Ambulacra long, deep, wide, straight; interambulacral areas somewhat rounded and elevated, but less so than in *M. pseudoelegans* or *M. elegans*. Pores of unpaired ambulacrum about 55 sets of slit-pairs of which the eight nearest the apex are circular pore-pairs, the following ones nearly transverse slit-pairs, and the outer five or so are short slit-pairs *en chevron*. In some individuals, the pore-pairs in the outer half of the ambulacrum are arranged distinctly *en chevron*, and some, both near the apex and at the forward end, have a small granule between the pores of a pair, as well as granules on the plates between the pore-pairs. Anterior ambulacral pore series about 78, of which the 14 or so nearest the apex are nearly circular pores, the outer four or five short slit-pairs *en chevron*, the rest transverse, elongated slit-pairs. Posterior ambulacra somewhat longer than anterior, with about 68 pore-pairs, a few near the apex and the outer two or three pairs being short slits *en chevron* (or rounded), the rest long transverse slit-pairs.

Peristome transversely oval, in shape very rounded-pentagonal. Peristomeal area depressed, especially in front; elevated but not distinctly labiate behind; the raised ambulacral pores border the depressed area in a star-shaped, floscelle-like pattern. Plastron narrow, elongate-triangular, details of plates not visible on holotype.

Periproct submedian in position (.429), situated on narrow, slightly concave posterior truncation, in shape a vertically elongate oval, pointed at top. The periproct is lower than in *M. pseudoelegans*, and much larger than in *M. subobesus*. The truncation is inclined outwards at its top.

Holotype: Duck Creek-Fort Worth, escarpment just south of Texas and Pacific Railway, at station, Kent, Culberson County, Texas. Collections of Bureau of Economic Geology.

Range: Fort Worth and Duck Creek formations; common at Kent, Boracho, numerous localities near Fort Stockton; rare in central Texas.

The following are measurements on two individuals of this species:

	L(mm.)	H%	W%	A%	P%
Holotype	84.8	.555	.861	.430	.429
II (Kent)	77.2	.541	.851	.414	.38

MACRASTER PSEUDOELEGANS n. sp.

Plate X, Figures 1, 5; Plate XI, Figure 4

Test.—Form elongate-cordate, of medium elevation, sides inflated and rounded, periphery with vaguely defined angularity, test elongated and narrowed posteriorly (less so than in *kentensis* and *subobesus*, more so than in *elegans)*; periproctеal truncation narrow. Highest point of test just behind apex, on prominent median carina; broadest part of test anterior to apex, at front end of lateral interambulacral facets. Apex anterior to center of test (.41–.46). The base is rather flat, except that the plastron is inflated posteriorly and the peristomeal area sharply depressed. The aboral face is strongly convex. The surface is covered with scattered small tubercles and numerous minute granules, producing a smoother appearance than in *M. elegans*, but rougher than in *M. aguilerae*.

Ambulacra long, deep, narrow, straight. Interambulacral areas sharply elevated and rounded, less so than in *M. elegans* (neotype) but more so than in other species. Unpaired ambulacrum with about 70 series of slit-pores arranged *en chevron,* of which a few at each end are short slits or circular. Anterolaterals with about 69 practically transverse slit-pairs, a few at either end being smaller or circular. Posterolaterals with about 61 pairs arranged in faint chevrons, the end ones small. Granules are scattered irregularly, not generally between pores of a pair. Around the peristomeal region the elevated crater-like pores have the usual "floscelle" arrangement.

Peristome transversely oval, only faintly rounded-pentagonal, depressed in front, elevated but not decidely labiate behind.

Periproct submedian (.42–.49), situated in narrow truncation, which is bordered by vertical rows of a few, coarse, faint tubercles. The periproct is a vertically elongate oval, medium in size (smaller than in *M. kentensis,* larger than in *M. subobesus).*

Holotype: From the Denton formation on Belton-Salado road, 3 miles south of Belton, Bell County, Texas. Collections of Bureau of Economic Geology.

Range: Fort Worth formation, occasional; Denton, abundant and widespread. It is the commonest species in the genus. At the Denton-Weno contact, it is supplanted by *M. obesus* and its varieties. *M. pseudoelegans* is quite variable, or else other species exist in the group: some individuals are broad like *M. texanus* yet have a height of more than 50 per cent, the limit apparently not exceeded by that species. Some resemble the smaller and more elongate forms of *obesus.* The holotype has been purposely chosen as an extreme of tallness and elongation, to leave a broad range to anyone who feels impelled to place further species in this assemblage.

This species differs from *M. elegans* neotype in being less prominently and less densely tuberculate, decidedly less tall, interambulacra on average less elevated, test somewhat more pointed posteriorly, periproct lower and less elongate vertically. It differs from *M. kentensis* in being somewhat broader and posteriorly less pointed, and in having the periproct slightly smaller. It will be readily distinguished from *M. subobesus* in being less pointed behind, and in having narrower ambulacra. From *M. aguilerae* it differs in being more elongate and taller, in having broader ambulacra and more elevated interambulacra; the periproct is larger. On an average it is at least 10 per cent taller than *M. texanus*.

The following are some measurements on this species:

L(mm)	H%	W%	A%	P%	
79.1	.579	.943	.417	.49	holotype
74.6	.569	.938	.458	.455	
78.4	.554	.917	.428	.459	
83.7	45.4	78.0	37.6	19.3	
	.542	.932	.449	.42	

MACRASTER SUBOBESUS (ADKINS)

Macraster subobesus (ADKINS) 1920, Univ. Texas Bull. 1856, 110, pl. 11, fig. 3.

This Weno species is at once recognizable by its elevated form, rather shallow ambulacral grooves, and its marked posterior elongation and narrowing.

Dimensions of holotype: 88.4 mm.—.631—.881—.381—.381.

II. OVAL SPECIES, NOT GREATLY NARROWED POSTERIORLY

MACRASTER NODOPYGA (LAMBERT)

Macraster nodopyga (LAMBERT) 1920, Bull. Soc. Sci. Nat. et Hist. de l'Yonne, page 28. CLARK 1915, U. S. Geol. Surv., Mon. LIV, pl. XLII, figs. 1 a–h (as *Hemiaster elegans)*. ADKINS 1928, Univ. Texas Bull. 2838, p. 296, pl. VIII, fig. 4.

This species is generally recognizable by its short ambulacral grooves. The test is low (.475), the periproct submedian (.44), somewhat ovoid and vertically elongate, located on a prominent truncation which is bordered by low circular nodes or tubercles (this feature occurs in several other species of *Macraster*). It is distinguishable from juvenile *M. pseudoelegans* through its lack of angularity, its narrow, straight ambulacra, and its lack of posterior elongation. *M. aguilerae* is more oval, about ten per cent taller, and has a smoother test. *M. nodopyga* is the smallest species in the genus except *M. wenoensis,* which has long, straight ambulacral grooves.

Horizon: Fort Worth formation, rare; type locality "Fort Worth."

The following are measurements on three individuals:

	L(mm)	H%	W%	A%	P%
type	50.5	.475	.9	.44	.44
A	50.0	.552	.96	.408	.54
B	47.1	.544	.934	.435	.64

MACRASTER ELEGANS (B. F. SHUMARD)

Hemiaster elegans (B. F. SHUMARD) 1854, Expl. Red River La. (Marcy), 184, pl. II, figs. 4 a–c. ADKINS and WINTON 1920, Univ. Texas Bull. 1945, 53, pl. 8, figs. 3–4.

In deciding the identity of Shumard's species, as judged from his figure and description, the following species may be eliminated: *M. kentensis, subobesus, texanus, wenoensis,* and *obesus.*

The short ambulacral grooves of Shumard's figure might suggest *M. nodopyga,* the only described Texan *Macraster* having this feature. But Shumard's figure, having the proportions 47 mm.—.51—.96—.49—.62, differs from *nodopyga* in being less elongate, having the periphery distinctly angulated instead of rounded, having the test eight per cent higher and the periproct 18 per cent higher, than in *nodopyga.* The text states the ambulacra extend to the margin of the test, and therefore the artist was in error in portraying them as short. At any rate, Shumard's species is not *M. nodopyga.* It differs from *M. aguilerae* in having a more angular contour, more coarsely tuberculate test, broader and deeper ambulacra, and in having the periproct 12 per cent higher. It differs from *M. pseudoelegans,* a species with which it has many similarities, in shape, periproct, and tuberculation. It does not belong to the group having the test elongated and constricted posteriorly, and thus is distinctly more oval than *pseudoelegans*. The periproct is 13 per cent higher than in *pseudoelegans*. The test is strongly tuberculate, more so than in *pseudoelegans* or any other recorded Texan species.

It appears that the Shumard material has not been recovered from the collections presumably stored in the St. Louis Academy of Science and now being unpacked and displayed at Washington University.[6] Pending the recovery and definite identification of Shumard's original specimen of *elegans* (which now seem unlikely), the writer proposes to establish as the neotype of the species the individual figured by Adkins and Winton,[7] now in the collections of the Bureau of Economic Geology. The following measurements refer to Shumard's material and to the neotype:

Measurements on Macraster elegans (Shumard)

	L(mm)	H%	W%	A%	P%
Shumard's pl. II, figs. 4 a-c	47.0	.51	.96	.48	.62
Shumard's "largest specimen" p. 184	68.4	.555	.926	-------	-------
neotype	68.0	.659	.934	.434	.60

The neotype is only slightly more elongated than Shumard's figure, probably not enough to be significant, and the shape is essentially the same, agreeing in the angularity of the contour, the relatively broad posterior truncation, and the rounded sides. The neotype differs from Shumard's

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[6]Professor David M. Delo informs me that the old Shumard collections were found to be in bad condition and that no species likely to be the one under consideration came to light in the unpacking of the fossils. Dr. Delo says: "There are no labeled Shumard fossils in the collection. It seems that at the time of the removal of the fossils to the University the persons who packed them up did not keep the labels and fossils together. The result is a mess of unlabeled fossils and Mr. Gregor says that he knows of no Shumard *Macraster* in the collections." It seems improbable, in view of the poor figure and lack of definitely stated measurements of the type, that an unlabeled fossil could be definitely identified as the original of Shumard's figure.

[7]Adkins, W. S., and Winton, W. M., 1920. Paleontological correlation of the Fredericksburg and Washita formations in north Texas. Univ. Texas Bull. 1945, pl. 8, figs. 3-4.

figure in having wider ambulacra, probably in consequence of artist's errors, because one ambulacrum figured is as wide as in the neotype. The most significant difference is that the test of the neotype is 15 per cent taller than in Shumard's figure. The two strikingly agree in form, in the characteristic elevation of the interambulacra, and in the strong tuberculation of the test. In view of other inaccuracies, Shumard's statement that "this exceedingly elegant species occurs in great numbers in the Cretaceous strata at Fort Washita" is to be taken only as indicating that many Macrasters occur near Fort Washita. In fact, individuals like the neotype are rare at all places collected, including Fort Washita.

MACRASTER TEXANUS ROEMER

Macraster texanus ROEMER, 1888, Neues Jahrbuch für Mineralogie (etc) I, 191–195, pl. VI.

Topotypes from Georgetown show the essential features described and figured in Roemer's 1888 paper. The test has nearly a flat top and a flat bottom, the sides are nearly vertical and only slightly convex, with a sharply rounded basal curvature and a somewhat more gentle aboral curvature. The plastron is slightly elevated posteriorly, and the peristomeal region is depressed. The apical region is slightly depressed; a low posterior carina marks the tallest part of the test. The apex is subcentral (.39–.45). The test is broadest in front of the apex, at the forward end of the lateral interambulacral facet. The surface is rather thickly covered with small tubercles and minute granules, but these appear sparser than in *M. elegans* neotype.

Ambulacra long, shallow, wide, and straight. The pores are numerous, and consist of long, transverse slit-pairs, except at the ends of the ambulacra, where there occur some few short slit or circular pores arranged *en chevron.*

Periproct about median (.46–.50), situated on a prominent, fairly narrow, vertical truncation bounded by obscure, low tubercles. The periproct is small and practically circular. The peristome is transversely oval, and situated as is usual in the genus.

This species in some respects resembles the more oval and lower forms of *M. pseudoelegans*, but its seems in conformity with the type and with material found at Georgetown to restrict *texanus* to individuals whose height is less than 50 per cent.

Holotype: "chalk marl at Georgetown," doubtless middle Georgetown limestone. At Georgetown and other localities examined, the species is restricted to the Fort Worth and Denton formations. It is not very common. Böse reported the species from the Fredericksburg, between the two railroad bridges at the Smelter at El Paso. His determination was based on a single fragment, having the dimensions: length 63.5 mm., width uncertain, about 58 (?) mm., a percentage width of about 0.92. The height is not stated and the fragment is not specifically determinable. From its appearance it might as well be *M. aguilerae,* commonly found at this locality; and because of its position in the Kiamichi with *Gryphea navia* and *Oxytropidoceras belknapi,* it is probably a Washita fossil fallen out of place. The test is short oval-rounded posteriorly, the ambulacra are apparently narrow and deep, most of the pores transverse, and the interambulacra only slightly elevated.

The following are measurements on some individuals of *Macraster texanus:*

	L(mm)	H%	W%	A%	P%
holot.	81.0	.476	.95	.395	.50?
B	89.4	.458	.912	.44	?
C	88.8	.466	.90	.388	.44
D	89.7	.479	.944	.428	.52
E	73.8	.471	.948	.464	.46
F	77.4	.501	.95	.457	.41
L	84.5	.467	.942	.448	?
24–5					
S	76.0	.558	.980	.447	.505

MACRASTER AGUILERAE (BÖSE)

Epiaster aguilerae (Böse) 1910, Inst. Geol. Mexico, Vol. 25, p. 173, pl. XLVII, figs. 2–4, 6–7; pl. XLVIII, figs. 1–2, 4. LAMBERT and THIÉRY 1924, Essai de nomenclature raisonée des échinides, p. 472. LAMBERT 1927, Considérations sur les échinides, p. 272 (as *M. elegans*) ADKINS 1920, Univ. Texas Bull. 2838, p. 296.

Böse's holotype of *M. aguilerae* is certainly close to *M. texanus* Roemer, from which it differs principally in being about 3 per cent higher and 5 per cent longer; it resembles *texanus* in being well rounded posteriorly and in having fairly broad ambulacra. The individuals here studied are still taller than Böse's *aguilerae,* are like *texanus* less elongate, and have narrow ambulacra. For comparison, the proportions of *M. aguilerae* holotype, *M. texanus* holotype, and *M.* cfr. *aguilerae* plesiotype from central Texas, are given.

	L(mm)	H%	W%	A%	P%
texanus type	81	.476	.95	.395	.50?
aguilerae type	77.2	.505	.895	.431	.50?
cf. aguilerae plesiotype	67.2	.571	.951	.458	.404

It would possibly be preferable to put *M. aguilerae* Böse as a synonym of *M. texanus* Roemer and create a new species for the very oval smooth form here called *M.* cfr. *aguilerae,* but this course has not been followed here. Böse states that his holotype differs from Roemer's species in its much shorter posterior ambulacra, its less linear pores, and by differences in shape. As noted above, the measurements show that it is slightly taller and slightly longer. *M. aguilerae* is specifically distinct from *M. wenoensis,* as is pointed out later. The following are some measurements on *M. aguilerae:*

	L(mm)	H%	W%	A%	P%
Böse, p. 174	77.2	.505	.895	.431	-------
Pleisotype, Fort Worth	67.2	.571	.951	.458	.404?
Pleisotype, Ocee	65.7	.583	.942	.457	.46
Ind., Bell County	67.0	.669	.937	.412	.42

(taller than usual)

The holotype differs from the plesiotypes in being less tall, narrower, and in having wider ambulacral grooves; from *M. pseudoelegans* in being lower, narrower, less elongate posteriorly, and in having shallower ambulacra; and from *M. texanus* in being taller and longer.

MACRASTER WENOENSIS (ADKINS)

Hemiaster wenoensis ADKINS 1920, Univ. Texas Bull. 1856, p. 105, pl. 6, fig. 6.

This species and *M. nodopyga* are the smallest in the genus. This species is further distinguished by its almost smooth test and its long, narrow, straight, shallow ambulacra. It differs from *M. aguilerae* in being smaller, more elongate, in having narrower and shallower ambulacral grooves, in having the sides of the test more nearly vertical, and less inflated, and in being even smoother and more sparsely tuberculate than *M. aguilerae*.

The following are some measurements on *M. wenoensis:*

	L(mm)	H%	W%	A%	P%
Holotype	56.3	.575	.91	.40	.45
Ind. 2	54.4	.575	.91	.44	.44
Ind. 3	54.0	.579	.96	.44	.53

Many other individuals in the collection have proportions within one or two per cent of those shown by the holotype. The species is remarkably constant in form. It is confined to the Weno formation. The type locality near Fort Worth.

MACRASTER OBESUS n. sp.

Plate X, Figures 2–4; Plate XI, Figure 6

This is the largest species in the genus. Test short cordate-oval, in the holotype and in most individuals practically circular but the width ranges from 91 per cent to 102 per cent of the length. Test tall (.6), bottom nearly flat except for the convexity of the plastron and the sunken peristome, top gently convex, sides rather straight, sharply rounded at base, slanting outwards towards top, where the margin is more gently rounded; contour of test only vaguely angulated. Apex anterior to center (.38–.45), highest point of test on broad, low, posterior carina; broadest part of test in front of apex, just behind the anterolaterals. The test is well rounded behind, with an obscure, narrow periprocteal truncation bordered on each side by a vertical row of 4–5 widely spaced, broad, faint swellings. The surface is rather evenly and sparsely covered by small, low tubercles and minute granules. No fascioles.

Ambulacra long, shallow, wide, and curved; interambulacral areas slightly rounded and elevated. Unpaired ambulacrum with about 53, anterolaterals with about 83, and posterolaterals with about 75 or more, pairs of pores. Those nearest the apex are circular, the ones farther out are transverse slit-pairs. The ambulacral plates bear scattered large granules. The posterior ambulacra are somewhat shorter than the anterior.

Peristome transverse, rounded-pentagonal, with the posterior angles sharper than the anterior. The posterior margin is raised but not distinctly labiate, the anterior margin depressed. Pores surrounding the periproct have the usual star-like arrangement. Plastron narrow-triangular, somewhat elevated posteriorly, details of plates not visible.

Periproct low (mostly .29–.37), on narrow inclined truncation. The periproct is a vertically elongate oval, pointed above, of medium size for the genus.

Holotype: Weno formation, Smith Creek about one mile east of Salado, Bell County, Texas. Collections of Bureau of Economic Geology.

Range: Apparently confined to the Weno; fairly common in central Texas; McLennan, Bell, and Tarrant counties.

This species is somewhat variable, or else more than one species exists in the group. The form ranges from a low, flattened, broad subcircular test, with breadth 102 per cent and height 50 to 60 per cent of the length, to tall tests whose height is 99 per cent of the length. Some individuals are elongated and somewhat pointed posteriorly (W=.91). A common form has medium height (.6–.7), a medium breadth

(.95) and a low periproct. In view of the extensive variation in this group of echinoids from the same horizon, it has been considered inadvisable to establish more than one species, and the holotype has been selected in the upper part of the range for height and breadth, and with the usual low periproct. This species differs from *M. wenoensis* in being large, having broad, curved ambulacra and elevated interambulacra, and in being much more tuberculate; it has a larger and lower periproct. *M. aguilerae* differs in being smaller, smoother, and in having narrower ambulacra.

The following are measurements in millimeters and *percentages* on some individuals of *Macraster obesus:*

	L(mm)	H%	W%	A%	P%	
Holotype	105.7	63.9	102.5	46.0	18.7	
		.605	.97	.435	.29	
1	81.8	.647	.96	.433	.32	
		58.8			22	
B	98.2	.60	1.02	.41	.37	
*C	94.7	.768	.987	.41	.31	
8-8	98.1	56.9	91.5	.42	.31–	
Cedar Ck	1.0	.58	.933	.428	.54–	(damaged; prob. low)
7-6	106.	64.6	103	47.7	.24	compare with I. and N.
		.61	.972	.45	.37	
G	91.9	54.5	88.9	40.2	27	
7-6		.593	.967	.437	.50	
F	97.8	59.5	90.9	39.2	17.5?	
		.608	.929	.401	.29?	
H	96.2	51.8	90.7	43.4	23.6	
		.539	.943	.431	.456	
I	87.2	46.6	79.5	33.9	14.4	
		.534	.912	.389	.31	
J	95.2	49.3	88.8	41.4	20.8	
		.518	.933	.435	.42	
*K	83.4	57.2	82.4	35.4	22.5	
24-5		.686	.988	.425	.393	

N	73.1	46.5	71.2	31.9	19.2	
		.636	.974	.436	.41	like K but 5 points lower
P	78	46.2	77.3	32.5	?	identical with G.
24-30		.592	.991	.417	?	
Kde						
Q	84.7	45.5	81.	36.	22.2	identical with H.
		.537	.956	.425	.49	
R	76	47.2	76.7	31.4	19.3	compare with B.
		.621	1.01	.413	41	

III. OTHER SPECIES REFERRED TO MACRASTER IN LITERATURE

EPIASTER WASHITAE (LAMBERT)

Macraster washitae LAMBERT) 1920, Bull. Soc. Sci. Hist. et Nat. de l'Yonne, Année 1920, p. 28.

Lambert has consistently referred this species to *Macraster*. However it differs strikingly from all other Texas species of the genus in several features: it is small; in the unpaired ambulacrum, the pore-pairs have a prominent granule between the pores of a pair; and the pores are arranged in strong chevrons, whereas in typical Macrasters they are mostly transverse. In these features it agrees with the described Texas Epiasters. Fascioles are generally absent, but some individuals have traces of a peripetalous fasciole-like band. Except for the absence of a fasciole, the species has a striking similarity to the prominently fascioled *Hemiaster comanchei* Clark (Glen Rose-basal Fredericksburg), but differs in: (a) lacking the fasciole; (b) the posterior truncation lacks marginal tubercles; (c) the periproct is lower, larger, and is circular instead of vertically elongate; (d) the paired ambulacra are broader and shallower.

Comanche Peak limestone, common: Benbrook, Fort Worth, Valley Mills, and generally in north-central Texas.

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*Tall phase.

MACRASTER SILVATICUS LAMBERT

Macraster silvaticus LAMBERT, 1924, in LAMBERT and THIÉRY, Essai de nomenclature raisonée des échinides, p. 472, pl. XI, figs. 9–10.

This species has a ten-sided contour, periproct on inclined truncation plainly visible from above; ambulacra broad, in the unpaired one there is a tubercle between pores of a pair (according to the figure). This species looks very different from all Texas Macrasters, and if referred to this genus at all it will have to be put into a special section. From the figure it has the peristome like *Macraster*, but its petals are extremely broad, as in *Palhemiaster*, from which it seems to differ in the absence (?) or faintness of the fasciole. Without material it is idle to discuss this species, except to state that it is markedly different from all Texan Macrasters known to the writer.

Aptian: Ain Akial (Constantine, Algeria).

MACRASTER ROBERTI LAMBERT

Macraster roberti LAMBERT, 1924, in LAMBERT and THIÉRY, Essai de nomenclature raisonée des échinides, p. 472, pl. XII, figs. 1–2.

This broad, flattened species with rounded-angular contour has (so far as can be judged from the figure) no fasciole, very broad ambulacra (different from any known Texan species), the pores strongly circumflex, with a granule (?) between pores of a pair. The same remarks apply to this species as to the last.

Vraconnian: Jaen, Tir nacional, Andalusia.

Besides these, Lambert refers to the genus the following species: *M. polygonus* Agassiz *(Micraster)* from the Albian; *M. restrictus* Gauthier, from the Aptian of Algeria, *M. gauthieri* Lambert from the Cenomanian of Algeria; *M. punicus* Lambert[8] from the Cenomanian of Tunis.

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[8]Later referred to *Epiaster* (Lambert and Thiéry 1924, Essai, p. 478). The species, *E. rousseli* Cotteau, which Roemer (p. 194, footnote) referred to *Macraster*, is also placed in *Epiaster*.

PLATES IV TO XI

Plate IV

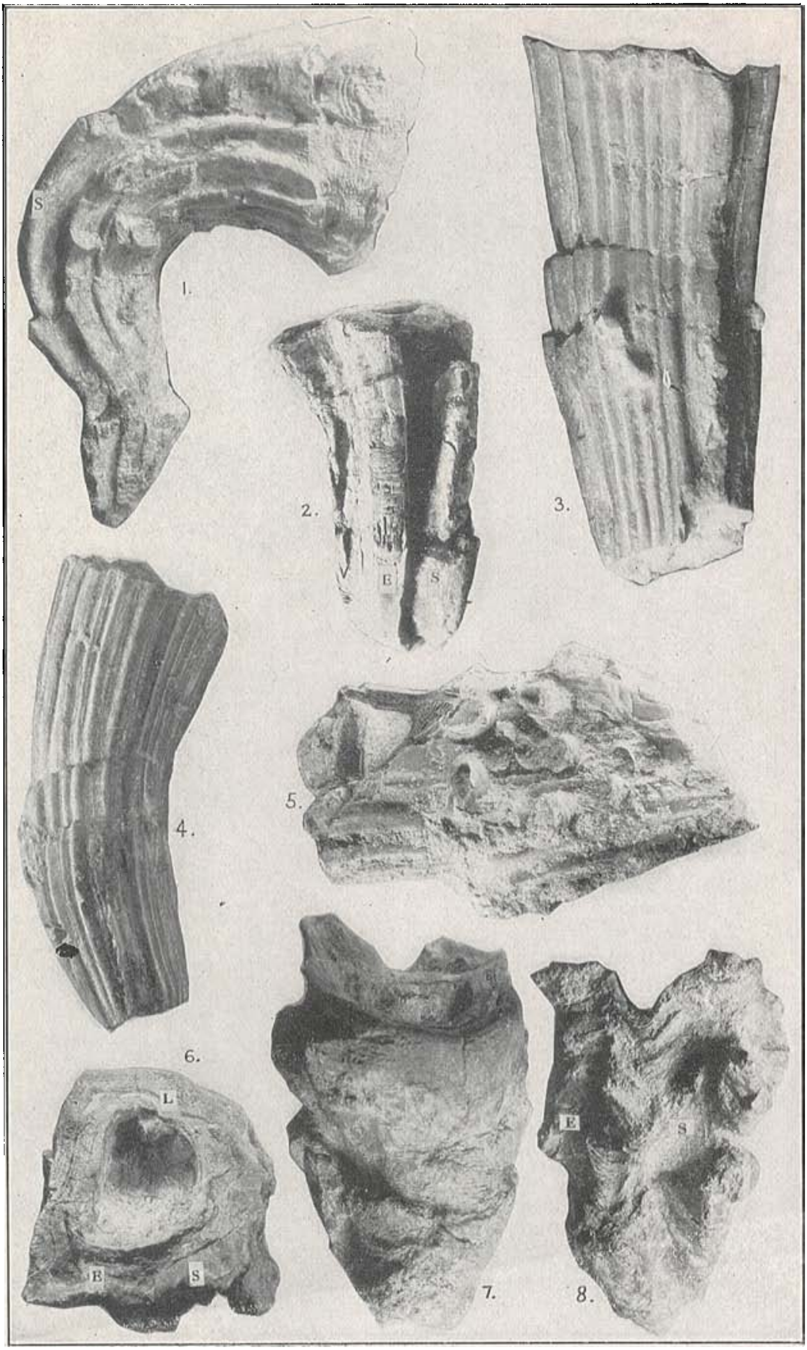
Figs. 1–4. Eoradiolites quadratus n. sp. .... Page 80
Fig. 1. Paratype, posterior view × 0.8.
Fig. 2. Same, ventral view × .75.
Fig. 3. Holotype, anterior view × 0.8.
Fig. 4. Holotype, dorsal view × 0.8.

Fig. 5. Eoradiolites sp. juv. × ⅔ showing exogyrate stage.

Figs. 6–8. Praeradiolites edwardsensis n. sp., holotype × ⅔ . Page 92
Fig. 6. Apertural view.
Fig. 7. Dorsal view.
Fig. 8. Ventral view of left valve of holotype.

In these figures of Rudistids, the following abbreviations are used:

E = anterior siphonal band,
S = posterior siphonal band,
I = interband,
V = pedal fold,
L = ligamentary ridge,
P = pseudopillar-like structures.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S
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Plate V

Figs. 1–7. Eoradiolites angustus n. sp. × ⅔ .... Page 83
Fig. 1. Paratype, ventral.
Fig. 2. Holotype, ventral.
Fig. 3. Paratype, ventral and posterior.
Fig. 4. Two paratypes, dorsal.
Fig. 5. Paratype, ventral.
Fig. 6. Holotype, dorsal.
Fig. 7. Paratypes, mostly ventral.

Figs. 8–14. Eoradiolites sp., juvenile stages × 2.
Figs. 8, 12, 13. Worm stage.
Fig. 9. Exogyrate stage.
Figs. 10, 11, 14. Stage with E and S developed.

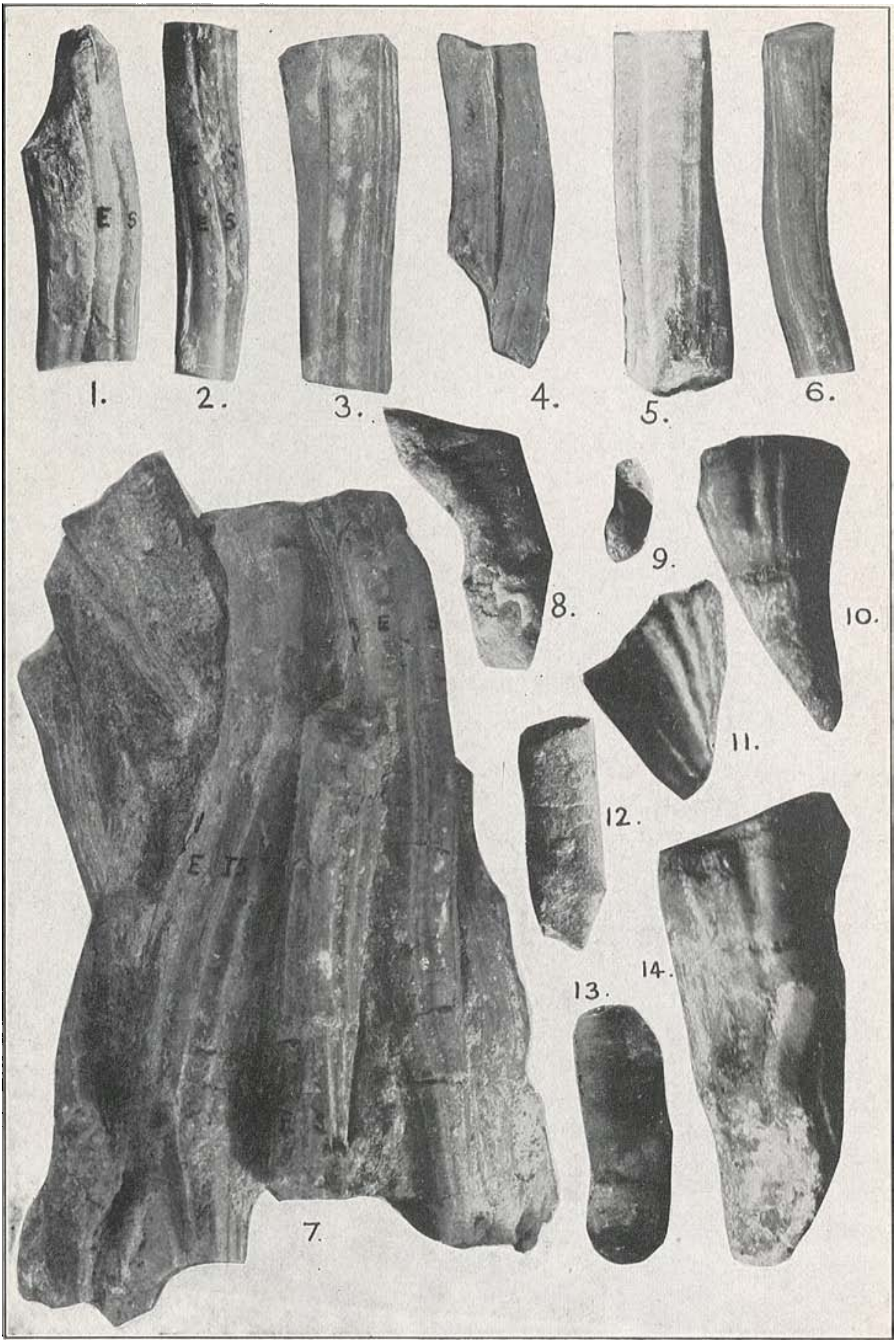
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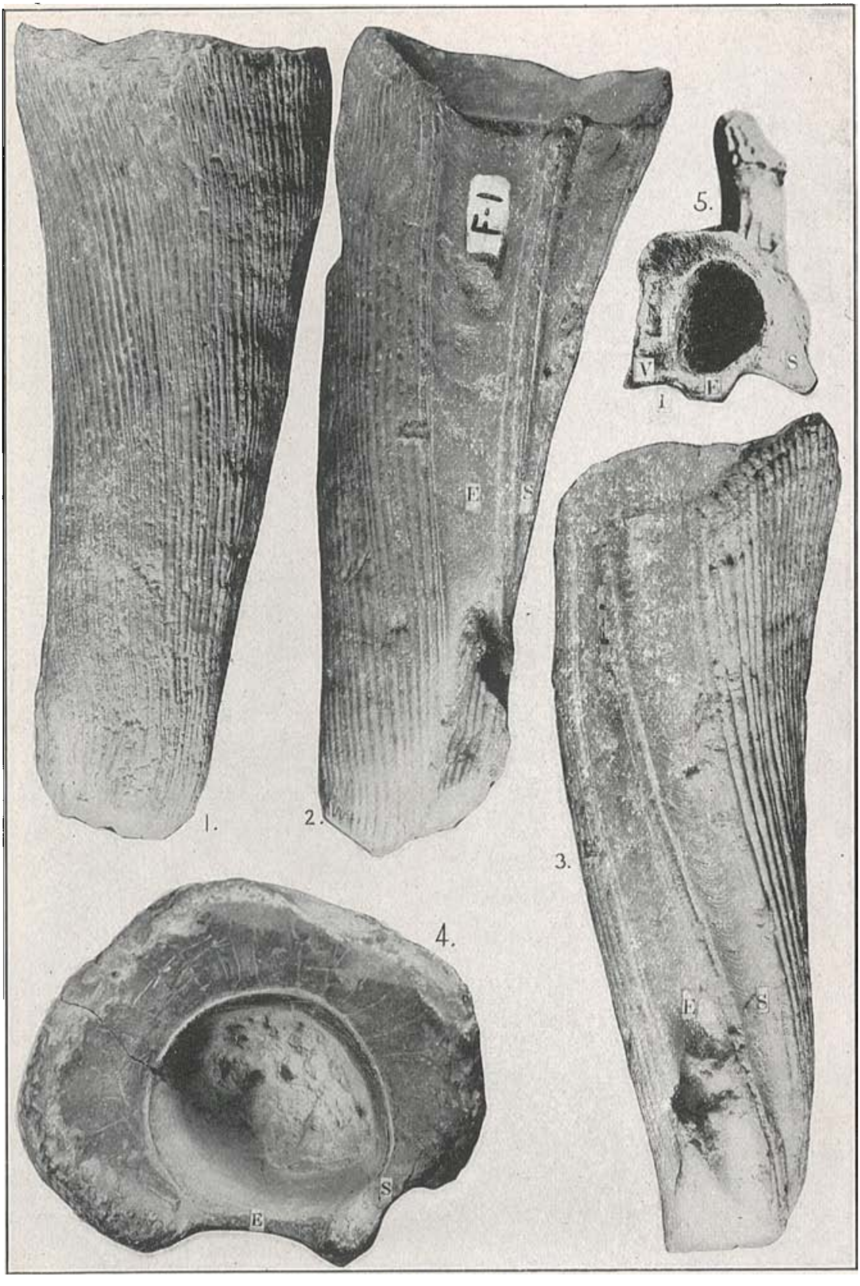
Plate VI

Figs. 1–4. Durania huasteca n. sp., holotype × .55 ....Page 96
Fig. 1. Dorsal view.
Fig. 2. Ventro-anterior showing E.
Fig. 3. Ventro-posterior showing S.
Fig. 4. Aperture, × 0.8.

Fig. 5. Eoradiolites quadratus n. sp. ... .Page 80
Paratype, aperture × ⅔.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2.
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E
S
4.
E
S
5.
V
E
S

Plate VII

Figs. 1–2. Durania aguilae n. sp. holotype .... Page 95
Fig. 1. Ventral view, × 0.6.
Fig. 2. Apertural view, × ⅔.
Note pseudopillar-like structures (p) and quartz pebbles in Mendez clay matrix (qu).

Figs. 3–4. Sauvagesia acutocostata n. sp., holotype × ⅔ ......Page 99
Fig. 3. Ventral view.
Fig. 4. Cross section.

Fig. 5. Eoradiolites quadratus n. sp., paratype .... Page 80
Posterior view, × ⅔.

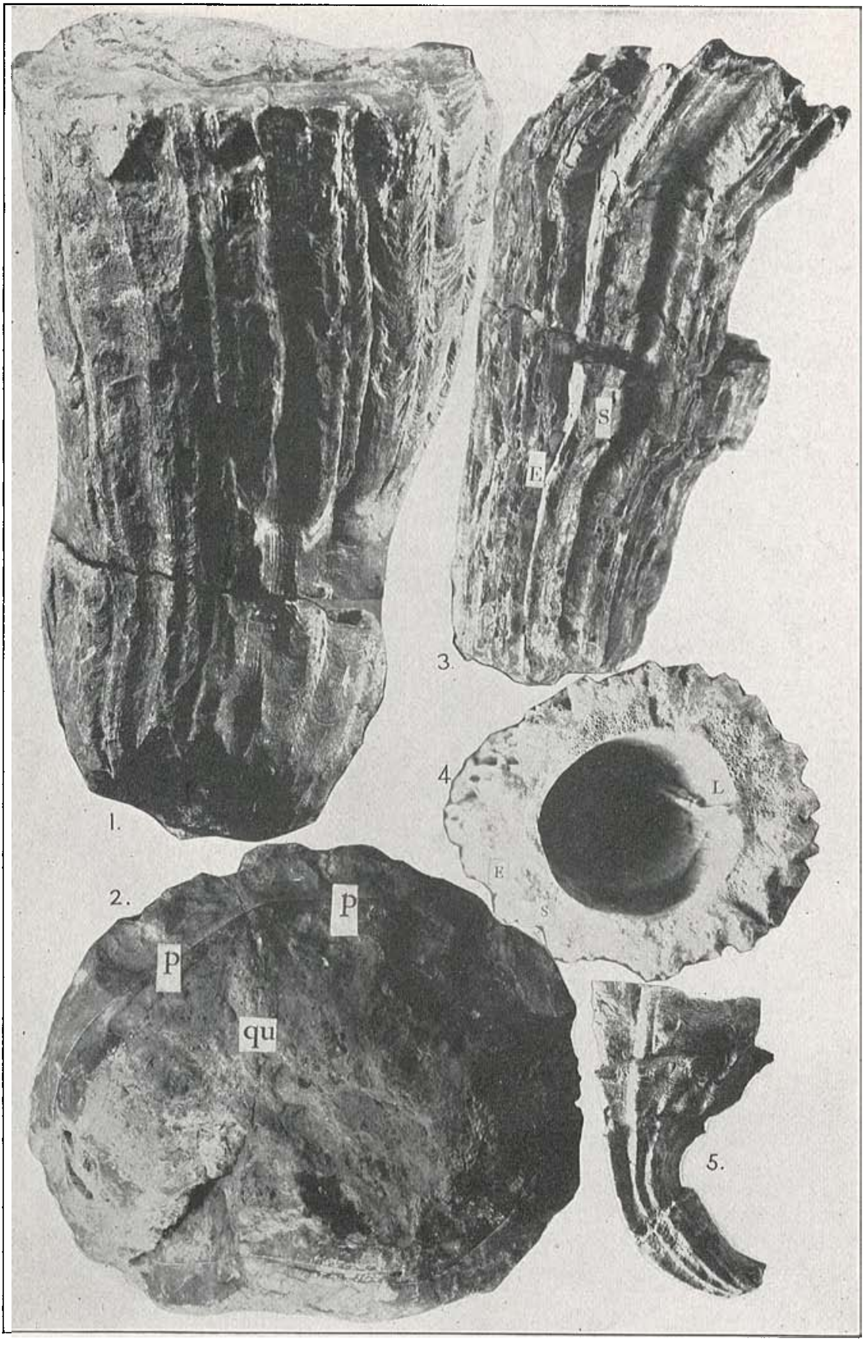
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Plate VIII

Fig. 1. Sauvagesia morgani n. sp., holotype, apertural view × 0.4 .... Page 98

Figs. 2–3. Durania terlinguae n. sp., holotype × ⅜ .... Page 94
Fig. 2. Apertural view.
Fig. 3. Side view.

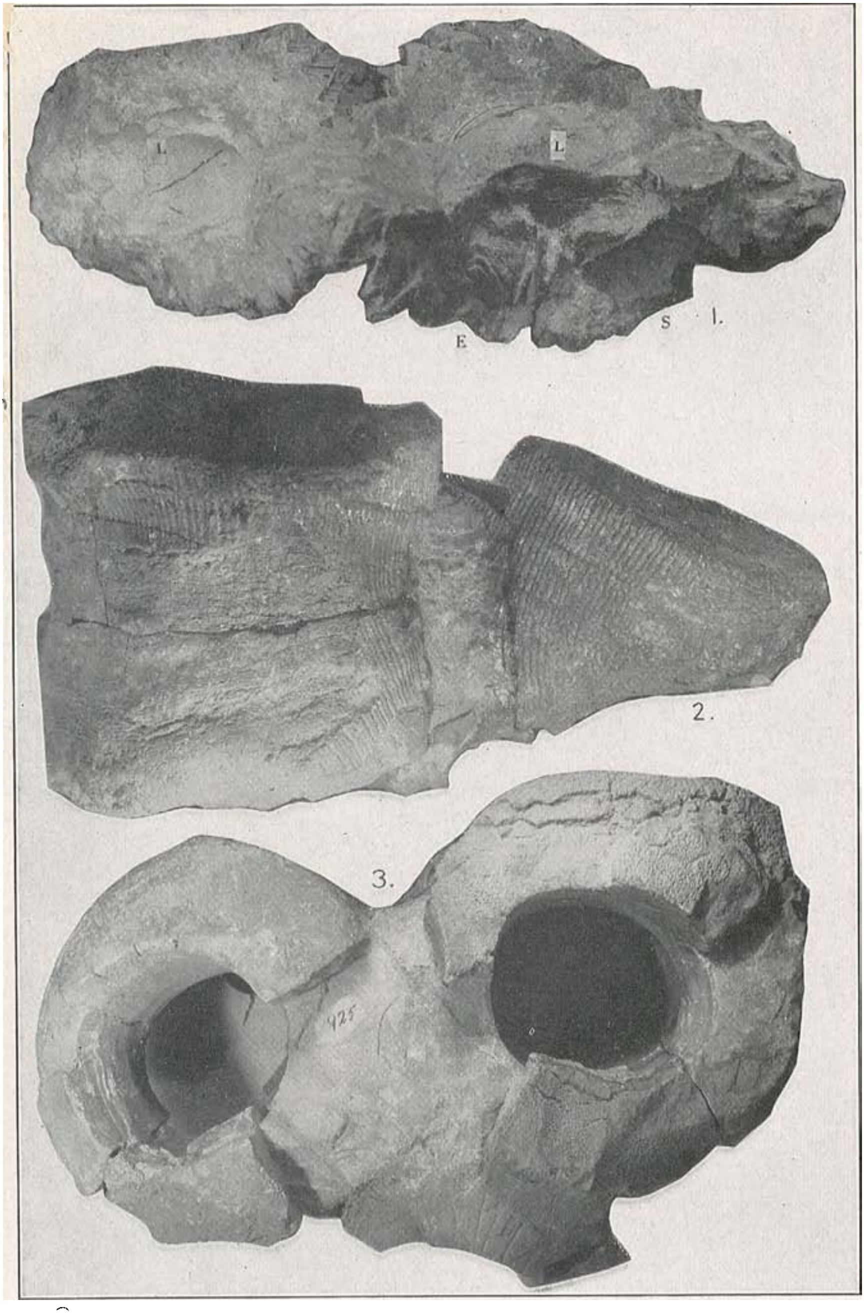
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Plate IX

Figs. 1–2. Sauvagesia morgani n. sp., holotype × ½ .... Page 98
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Fig. 2. Ventral view.

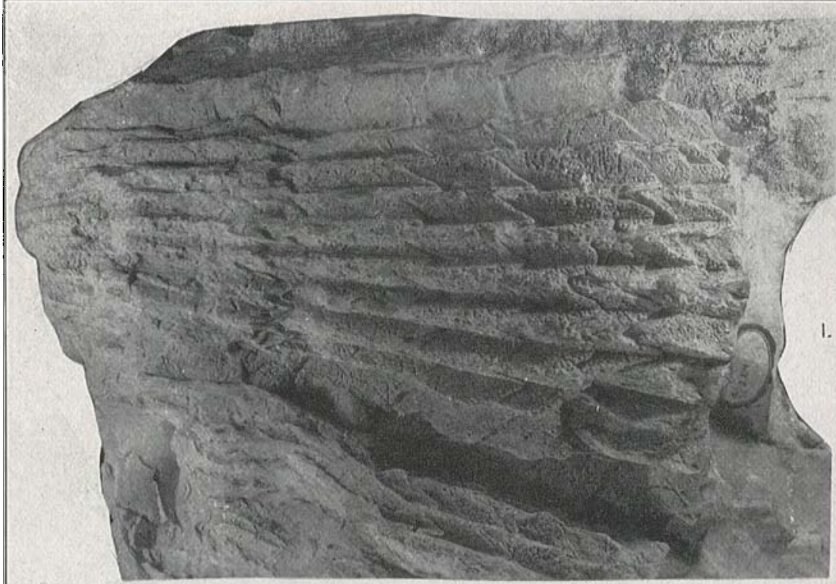

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Plate X

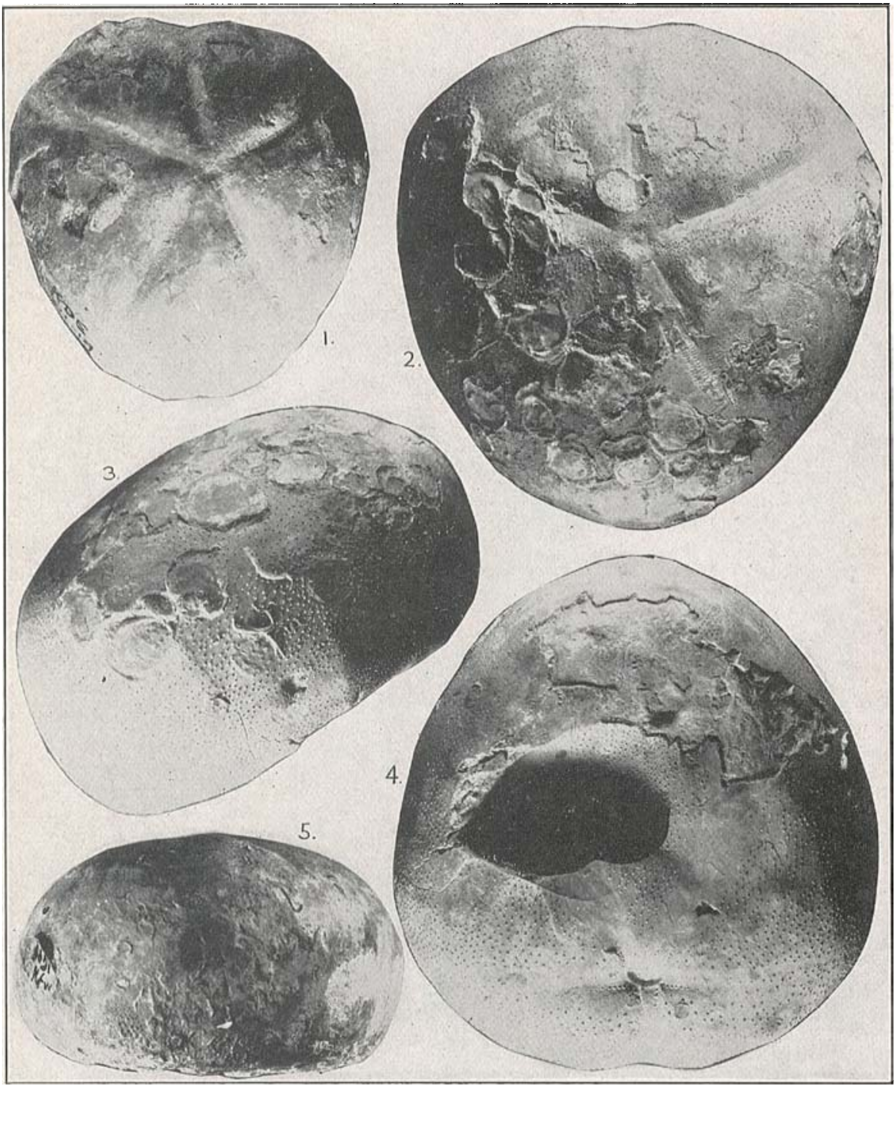
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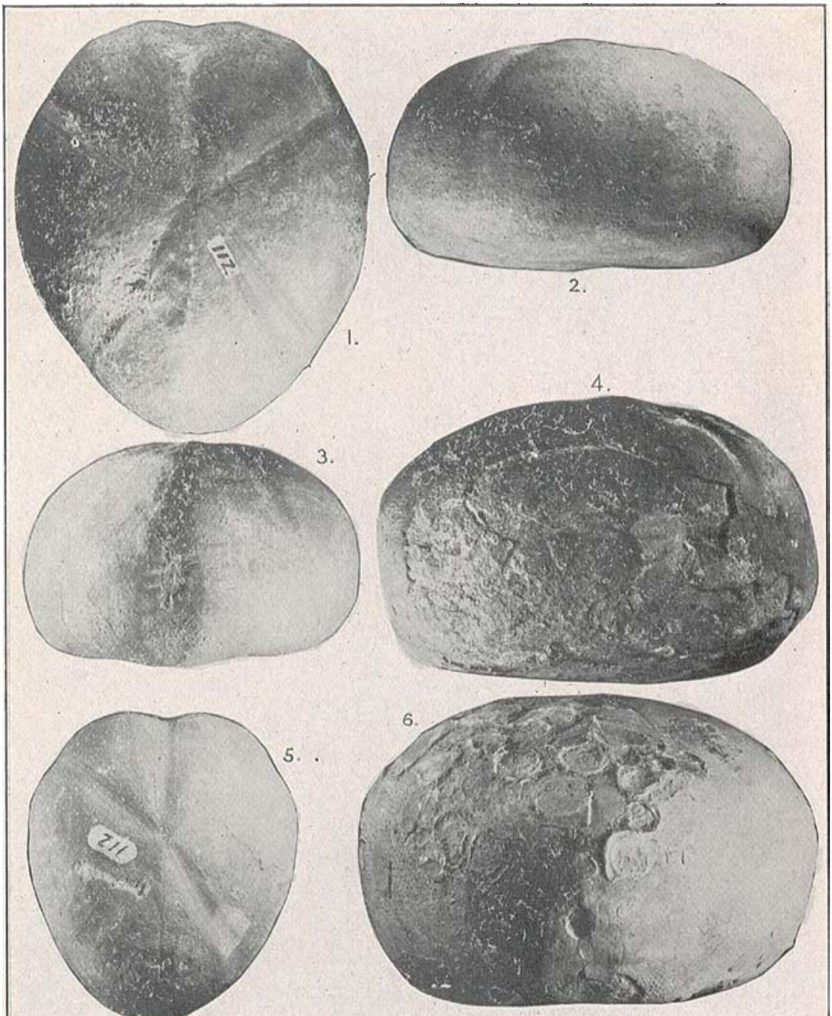
Plate XI



CORRELATION OF FIVE OIL WELLS IN NORTH-CENTRAL TEXAS

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University of Iowa, Iowa City, Iowa

Introduction

In 1927 the California Company of Texas submitted to the Department of Geology, University of Iowa, the samples of well cuttings from the following five wells:

1. C. M. Adams No. 2–6, located in the northwest quarter of Mitchell County; surface elevation, 2127′; depth, 3075′; samples every five or ten feet.
2. G. C. Magenhimer No. 1, located near the center of Fisher County; surface elevation 2004′; depth 3546′; samples every five or ten feet, some missing.
3. R. J. Anderson No. 1, located in the southeast quarter of Fisher County; surface elevation, 1924′; depth, 3387′; samples every five or ten feet, many missing.
4. Midwest-Thornton No. 2, located in the southwest quarter of Jones County; surface elevation, 1887′; depth, 2595′; samples every five or ten feet, some missing.
5. I. H. Spikes No. 2–1, located in the east-central part of King County; surface elevation, 1719′; depth, 3380′; samples every five or ten feet, some missing.

The location of these wells in north-central Texas is shown in figure 17.

The samples were studied with the object of making subsurface correlations of the well sections with each other and with the surface outcrops, and of locating the subsurface Permian-Pennsylvanian contact.

Acknowledgments are due to Drs. A. C. Trowbridge, A. O. Thomas, A. C. Tester, and F. F. Osborn of the State University of Iowa for suggestions and criticisms during the course of the work. Thanks are due also to F. B. Plummer, Dr. R. C. Moore, and E. C. Edwards for the reading and criticism of the paper. The author is indebted to the

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California Company of Texas for the opportunity of studying this material and of offering the results for publication.

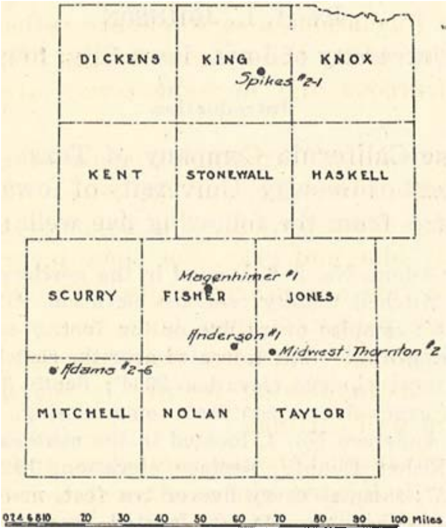

Fig. 17.—Index map showing locations of California Oil Company wells from which samples have been studied.

General Geology and Stratigraphy

The wells under consideration are located along the east side of the Permian basin, which covers the western and north-central parts of Texas. The Permian and underlying Pennsylvanian formations of the area dip westward and northwesterly at a rate of about forty feet per mile. The Permian beds are conformable with the underlying Pennsylvanian strata. The Cisco group (upper Pennsylvanian) in its upper portion consists of limestones and shales, which merge into the overlying Wichita-Albany division (lower Permian) without any distinct break.

The Permian beds consist mainly of red and blue shales, gypsum, anhydrite, dolomite, salt, and sandstone. On the eastern side of the basin the Wichita-Albany division contains limestone that thins laterally northward and changes to shales. In the Clear Fork division limestone grades westward into, and is replaced by, dolomite. The Permian beds change laterally in color and composition, and only a few beds are lithologically persistent over any great area. The Permian formations as a whole are rather nonfossiliferous; however, along the eastern margin of the basin the beds are calcareous and in some places are exceedingly fossiliferous.[1]

The Pennsylvanian formations consist of conglomerate, sandstone, shale, limestone, and dolomite. The limestones and shales are fossiliferous. The color of this series is predominantly blue and gray, but some layers are red or brown, and a few are nearly white. The Pennsylvanian formations are persistent over large areas and are more constant in lithologic character than are the Permian formations. A distinguishing feature is the abundance of fossils even in well cuttings.

The Pennsylvanian-Permian contact is, and will continue to be, arbitrarily located, since sedimentation continued uninterruptedly from the Pennsylvanian through Permian times. The contact now generally recognized is marked to some extent by a slight lithologic change and also by the composition of the calcareous layers, the limestones in the upper Cisco group being composed of calcium carbonate and those of the lower Wichita-Albany series being magnesium-calcium carbonate (dolomitic). The contact in some places is marked by a water-bearing sand.[2]

Results of Examination of Samples

Color break.—The color of the shales in the upper part of the section is red or variegated; lower down they change abruptly to blues and bluish grays. This change is called by west Texas geologists the "color break" or "color change." Examination by the microscope shows the color break in the wells at the following depths:

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[1]R. C. Moore, personal communication dated Sept. 24, 1929.

[2]E. C. Edwards, personal communication dated Aug. 6, 1929.

Midwest-Thornton No. 2	1000′
Anderson No. 1	1400′
Magenhimer No. 1	1650′
Spikes No. 2–1	1380′
Adams No. 2–6	1500′

The color break increases in depth steadily in the first three wells listed above at the rate of about 40 feet per mile. Westward from the first three wells the horizon of the color break rises (fig. 18). It is evident that the color

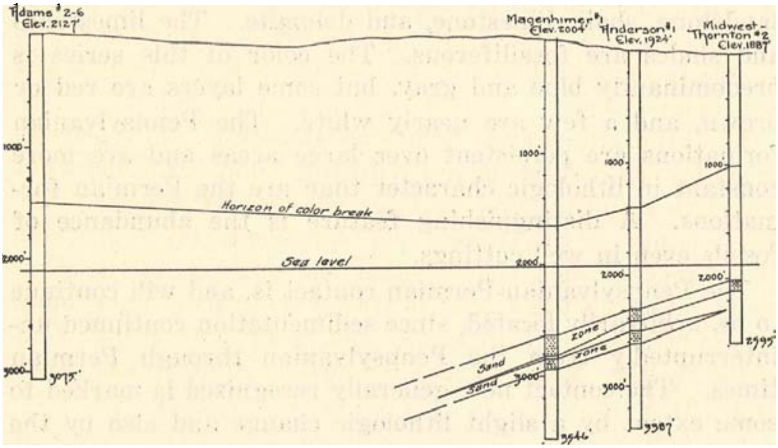

Fig. 18.—East-west section showing horizon of color change in sediments and the sand zones.

break is not of much value in correlation over large areas, but it may be of some value in certain areas for short distances.

Change from predominating shales to predominating dolomites.—The samples were cleaned by screening, the particles were classified lithologically and counted under the microscope, and the percentage composition from these figures was determined. In this way the depths at which the shales change to dolomitic limestone were ascertained for the wells, as follows:

Midwest-Thornton No. 2	1085′
Anderson No. 1	1495′±
Magenhimer No. 1	1950′±
Adams No. 2–6	1540′±
Spikes No. 2–1	1950′±

Sandy zones were found at the following depths:

Midwest-Thornton No. 2, a calcareous sand containing water, 2015′–2125′
Anderson No. 1, 2330′–2425′ and 2500′–2630′
Magenhimer No. 1, 2650′–2940′
Spikes No. 2–1, 2300′–2500′

The sediments in the Spikes No. 2–1 are rather persistently shaly throughout the entire depth, and the lithologic break from the shale series to the dolomitic series is not distinct. The almost continuous dolomitic limestone in the Adams No. 2–6 from 1,540 feet to the bottom of the hole (3,075 feet) is broken only by some thin beds of shale and a little anhydrite.

The lithologic change from predominantly shaly beds to those predominantly dolomitic in the Adams well does not correlate with the same lithologic change in the other wells. This change in the Adams well represents the top of the "Big Lime" of west Texas, which outcrops west of the other wells. As the "Big Lime" is traced eastwardly it is found to grade laterally into shales and is present probably as shale in the Magenhimer, Anderson, and Spikes wells (fig. 19).

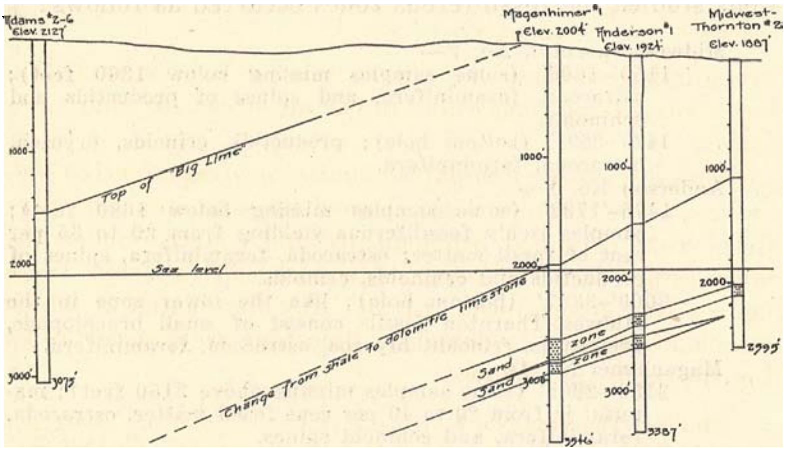

Fig. 19.—East-west section showing the change from shale to dolomitic limestone, and positions of sand zones and "Big Lime."

Fossil zones.—Two distinct fossiliferous zones were located in the well sections: an upper zone, called the upper fossiliferous zone; and a lower zone, called the lower fossiliferous zone. The two zones are separated by approximately 275 feet of barren strata (fig. 20). The lower zone

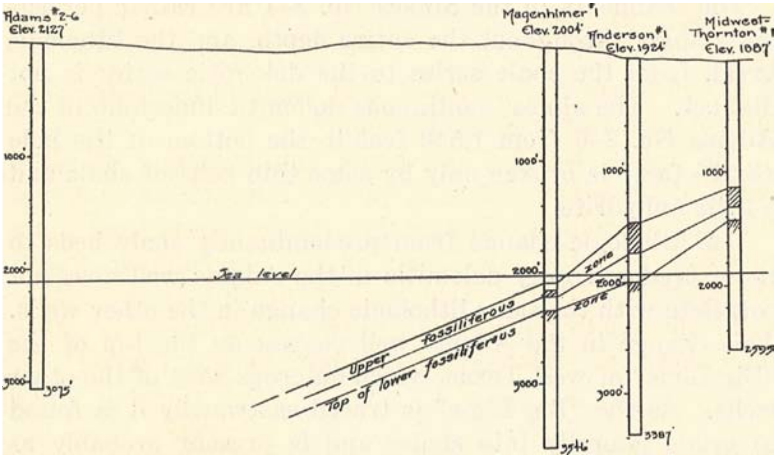

Fig. 20.—East-west section showing positions of fossiliferous zones.

is the thicker and the more richly fossiliferous. In the wells studied the fossiliferous zones occurred as follows:

Midwest-Thornton No. 2—
- 1150′–1300′ (some samples missing below 1300 feet); ostracoda, foraminifera, and spines of productids and echinoids.
- 1425′–2595′ (bottom hole); productids, crinoids, bryozoa, ostracoda, foraminifera.

Anderson No. 1—
- 1475–′1732′ (some samples missing below 1680 feet); samples richly fossiliferous yielding from 20 to 35 per cent of fossil matter; ostracoda, foraminifera, spines of productids and echinoids, crinoids.
- 2000′–3387′ (bottom hole); like the lower zone in the Midwest-Thornton fossils consist of small brachiopods, productids, crinoids, bryozoa, ostracoda, foraminifera.

Magenhimer No. 1—
- 2150′–2205′ (some samples missing above 2150 feet); material is from 20 to 40 per cent fossil matter, ostracoda, foraminifera, and echinoid spines.
- 2350′–3546′ (bottom of hole); fossils much the same as those from the lower zone in the two preceding wells though less plentiful.

Spikes No. 2–1—

2110′–2120 (samples missing for 55 feet below this interval; material is about 35 per cent fossil matter, ostracoda, foraminifera, productid and echinoid spines.

2260′–3380′ (bottom hole); crinoids, productids, bryozoa, ostracoda, foraminifera. *Fusulina* is represented by numerous specimens and this zone is the only one in which this form was observed in the well sections.

Adams No. 2–6—

No fossils were seen in samples from this well.

A number of the ostracoda that occur in the lower zone are confined to the lower Permian.[3]

The Spikes No. 2–1 is located approximately 65 miles north of the other wells. A careful microscopic examination of the samples indicates that the fossil and sand zones correlate with the same zones in the Magenhimer No. 1. Correlations with the other wells indicate that the Spikes well is diagonally down the dip of the subsurface beds rather than along the strike, as was at first thought (fig. 21).

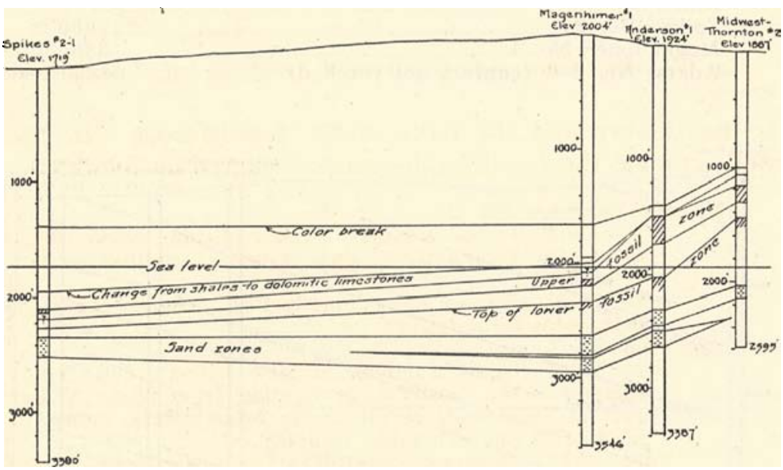

Fig. 21.—North-south section showing correlations.

Blue-gray correlation member of the Clear Fork division.—Study of the samples in these five wells reveals a persistent blue-gray member in the Clear Fork division (fig.

[3]Robert Roth, personal communication to Dr. A. O. Thomas, dated Nov. 8, 1929.

22). In the easternmost wells this member is a compact, hard, blue shale, which thickens westward and grades laterally into a blue-gray to brownish, shaly dolomite. The top of this member occurs in the wells at the following depths:

Midwest-Thornton No. 2	615′
Anderson No. 1	850′
Magenhimer No. 1	1270′
Adams No. 2–6	2920′

Determination of the Pennsylvanian-Permian contact.—The determination of the Pennsylvanian-Permian contact is based on fossils, on the calcareous sand zone, on a small series of thin red beds, and on the general lithologic character of the formations, which either indicate, or are characteristic of, the contact on the outcrop in this part of west Texas. On a basis of these criteria, the contact lies in the wells as follows:

Midwest-Thornton No. 2	2100′
Anderson No. 1	2400′
Spikes No. 2–1	2900′±
Magenhimer No. 1	2800′±
Adams No. 2–6 (contact not reached)	4200′ est.

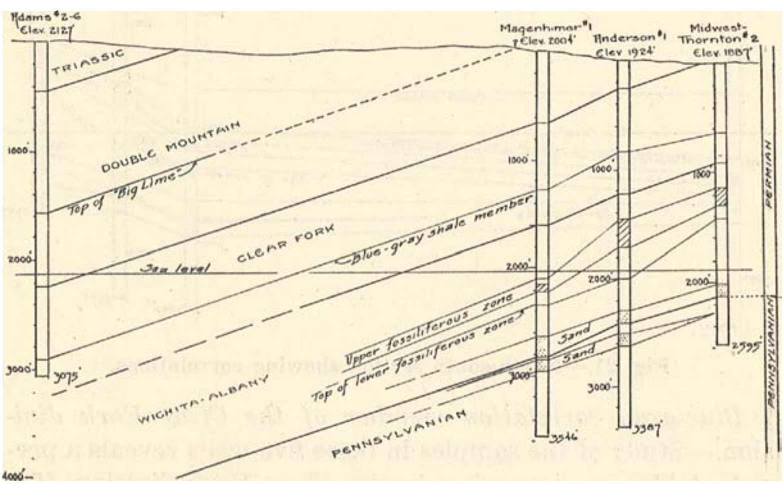

Fig. 22.—East-west section showing correlation of Permian divisions and the position of the Pennsylvanian-Permian contact.

Correlation of well sections.—Microscopic examination of samples from these five wells has established definite planes of correlation for west Texas, as follows:

Permian-Pennsylvanian contact, a lower fossiliferous zone near the base of the Wichita-Albany division, and a persistent blue-gray member of the Clear Fork division (fig. 22). All four key horizons chosen are applicable for determining subsurface structure and should prove valuable to other workers in this area.

PRODUCING HORIZONS IN THE BIG LAKE OIL FIELD, REAGAN COUNTY, TEXAS

by

E. H. SELLARDS, H. P. BYBEE, and H. A. HEMPHILL

The Big Lake oil field is located on lands of The University of Texas in the southwestern part of Reagan County, about 90 miles west by south of San Angelo, Texas. The Kansas City, Mexico, and Orient (now Santa Fe) Railroad passes through the field. It is the farthest east of the major oil pools in the Texas Permian Basin except the Chalk field in Glasscock and Howard counties.

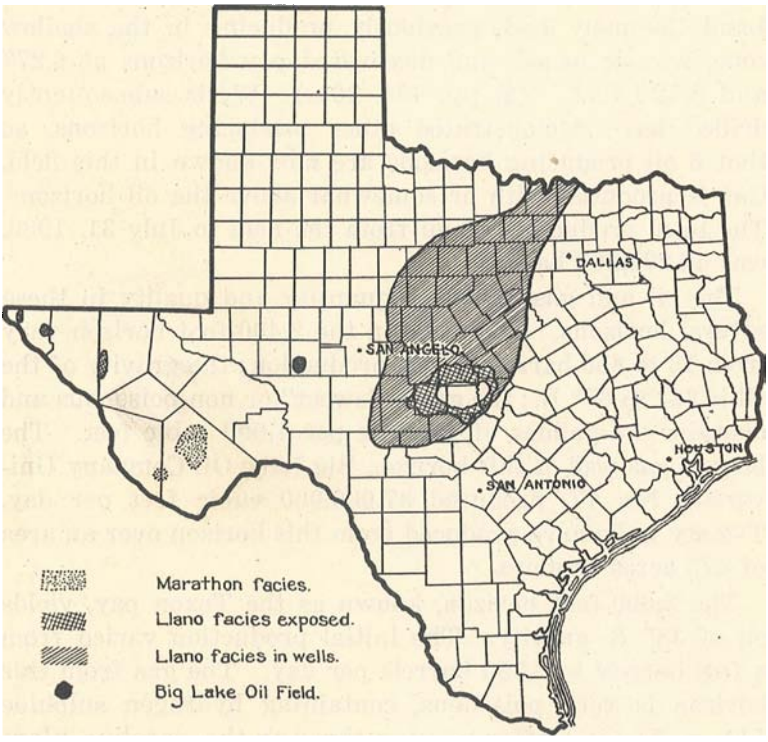

Fig. 23. Sketch map of Texas to show location of the Big Lake oil field. The map also shows by shading exposures of Ordovician of the Marathon facies and exposures and known underground distribution of Ordovician of the Llano facies.

Printed September, 1930.

This field was discovered in 1923, the first well having been completed in June of that year. Drilling progressed slowly and it was not until February of 1924 that the second well reached production. Thereafter, the field developed more rapidly and by the close of 1925 there were 75 producing wells in the field, having a combined production in excess of 30,000 barrels daily. The principal producing horizon as developed at that time was at a depth varying according to the location of the well on the dome and other conditions from 2,850 to 3,150. Production was obtained also from sands at depth between 2,400 and 2,500 feet.

During 1926–27–28 one of these wells, Texon Oil and Land Company 1–B, previously producing in the shallow zone, was deepened, and discovered pay horizons at 6,277 and 8,525 feet. (**8**, pp. 175–201.) Wells subsequently drilled have demonstrated other producing horizons, so that 6 oil producing horizons are now known in this field. Gas is produced with or somewhat above the oil horizons. The total production of oil from the field to July 31, 1930, was 47,274,207 barrels.

The oil and gas varies in quantity and quality in these several horizons. The wells in the 2,400-foot horizon vary from 13 to 856 barrels initial production; the gravity of the oil is 36° to 37° B.; the gas is "sweet" or non-poisonous and contains 2.5 gallons of gasoline per 1,000 cubic feet. The largest gas well of this horizon, Big Lake Oil Company University No. 17, produced 87,000,000 cubic feet per day. Twenty wells have produced from this horizon over an area of 275 acres or more.

The 3,000-foot horizon, known as the Texon pay, yields oil of 38° B. gravity. The initial production varied from a few barrels to 8,750 barrels per day. The gas from this horizon is very poisonous, containing hydrogen sulphide (**11**, p. 7), and after passing through the gasoline plant is burned in the open air. However, a carbon black plant is now being built and hereafter this gas will be used in making carbon black. This gas yields about 4.5 gallons of gasoline per 1,000 cubic feet of gas.

From depth 6,277 Texon Oil and Land Co. 1–B produced a total of 1,235 barrels of oil, gravity 41° B. The other wells have not produced at this level. From the next deeper horizon, approximating 8,200 feet, production has been obtained as follows: Texon 2–B, at depth 8,131, initial 250, settled 70 barrels per day; Big Lake Oil Company 2–C, at depth 8,187 and 8,232, initial 354 to 600 barrels,[1] settled 100 barrels per day; Big Lake 3–C, at depth 8,379, initial 190 barrels, settled 105 barrels per day; Big Lake 4–C, at depth 8,220, initial 327 barrels, settled 70 barrels per day. The production at this level being small, all of these wells either have been or are now being drilled deeper and some are now producing from a deeper horizon. The gravity of the oil at this level is from 55° to 63° B. depending upon the amount of back pressure maintained. This horizon is here named the Big Lake Pay.

In Texon Co. 3–B a small production was obtained at depth 8,536 feet amounting to 125 barrels initial in 22 hours, and representing an additional producing zone.

From the deepest known pay horizon, 6 wells are now producing as follows: The discovery well, Texon Oil and Land Co. 1–B, depth 8,525; 2–B, depth 8,456–89; Texon Co. 3–B, depth 8,633; Big Lake Oil Company 1–C, depth 8,664–70; 2–C, depth 8,603; and 3–C, depth 8,816. (See fig. 26.) Texon Oil and Land Co. 1–B which came in on December 1, 1928, has had a remarkable record of production through 1½ years, having increased from initial production of a few barrels December, 1928, to a maximum of 2,926.40 barrels of oil on May 18, 1930, and from 1,040,000 initial gas to 27,877,000 on February 12, 1930. At the end of the twentieth month, July 31, 1930, this well had produced 1,538,949.18 barrels of oil and 14,451,821,879 cubic feet of gas. During June, 1930, the well produced 84,895.98 barrels of oil and 825,320,000 cubic feet of gas. The gravity of the oil from this horizon when producing under pressure is 60° B. When produced without back pressure the gravity is

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[1]The production for the first six months was from 500 to 600 barrels per day.

somewhat less, average 55° to 56° B. This horizon may be known as the Continental pay. The amount of oil recovered at this horizon is possibly increased by the application of back pressure obtained by partly shutting in the well. On the other hand, as would be expected, the amount of gasoline that the gas will yield is reduced as back pressure on the well is applied. Thus when the back pressure is 600 pounds, the gasoline content is approximately .6 gallon per 1,000 cubic feet, and when 400 pounds is 1 gallon per 1,000 cubic feet of gas.

The gas production from the deep wells is in such quantities that it has heretofore been impossible in the one gasoline plant operating in the field to treat all of it for gasoline. However, two additional plants with a capacity of 30,000,000 cubic feet of gas daily each are now nearing completion so that the capacity hereafter will be sufficient to treat all the gas.

GEOLOGIC SECTION

The geologic section in this field to depth 6,000 feet was given by Sellards and Patton in 1926 (**7**, pp. 368–377). The deeper sediments were described by Sellards and Williams in 1929 (**8**, p. 189) at which time the character of the rocks was indicated to depth 8,525 feet. Owing to the absence of distinctive fossils, however, the age of the deeper formations was at that time imperfectly determined, although microfossils obtained from cuttings below 7,640 were regarded by Harlton as of Pennsylvanian age,[8] and deep production, 8,525 feet, was regarded by Hennen (**3**, pp. 512 and 533) as probably from pre-Pennsylvanian. Additional information on the geologic section has since been obtained by the discovery of Permian, Pennsylvanian, and Ordovician fossils as indicated below.

ORDOVICIAN FOSSILS

Early in April, 1930, cores were obtained from Big Lake Oil Company 1–C at depth 8,431–8,658. Fossils obtained

[8]Univ. Texas Bull. 2901, p. 190, 1929.

from these cores at depth 8,451 and 8,479, submitted to E. O. Ulrich of the United States Geological Survey, enabled him to identify the formation as of Chazyan age, representing a horizon well down in the Simpson of Oklahoma.[4]

Microfossils obtained from cuttings enabled Bush and Harlton independently to identify Ordovician in the deep wells. Harlton's results were published in the May, 1930, issue of the Bulletin of the American Association of Petroleum Geologists, pages 616–618. The identifications made by Bush have not been published but Harlton states (loc. cit. p. 616) that Bush made correlations similar to his own at the time of the completion of the discovery well. John E. Miller in February, 1930, recognized Ordovician in the wells and placed samples in his possession in the hands of S. W. Lowman who identified Silurian and Ordovician (**4**, p. 618; **5**, p. 34).

The identifications made by Ulrich were as follows:

Identification of Fossils from Cores from Big Lake Oil Company Well No. 1–C by E. O. Ulrich

Depth 8,451:	Cystid plates and columnal of undetermined genus and species. Similar fragments are known from Chazyan deposits in New York and Oklahoma.
Depth 8,451:	*Girvanella occellata* Seely and *Orthis* cf. *costalis* Hall.
Depth 8,454:	*Batostoma* sp. and *Orthis* cf. *costalis*.
Depth 8,479:	*Orthis* cf. *ignicula* Raymond and *Hebertella* cf. *vulgaris* Raymond.

All these fossils indicate rocks of Chazyan age, and the species most resembled by them occur in the lower part of the upper Chazyan in New York and in the Falls formation of the Simpson group of Oklahoma.*

CARBONIFEROUS FOSSILS

In cuttings from Big Lake Oil Company No. 1–C Fusulinidae have been obtained at 2 horizons, depths 7,670–7,701 and 8,325–8,336. These Fusulinidae have been sectioned by H. A. Hemphill and examined by C. O. Dunbar whose description is as follows:

[4]News Letter from Bureau of Economic Geology, April, 1930. These cores were made available by C. E. Byers, General Manager of the Big Lake Oil Company.

*Fossils subsequently submitted to Ulrich from 2–B, depth 8,225 to 8,441, have not yet been reported upon except to recognize "Criner beds present in some of the cores" and "no Silurian present." (Letter from W. C. Mendenhall, August 13, 1930.)

Identification of Fusulinidae from Big Lake Oil Company Well 1–C by C. O. Dunbar

Depth 7,670–7,689: The most significant specimens are from zones at depths 7,670–7,689 and 7,689–7,701 feet, both of which seem to be of early Permian age. From the zone of 7,670–7,689 feet there are two axial sections of small specimens of *Fusulina*, both probably juvenile individuals. These may represent the microspheric and the megalospheric form of a single species or they may belong to distinct species, but at any rate they are dissimilar in several features. One of these (slide A) is remarkable in having an exceptionally large proloculum. Chomata are present only in the first volution and the septa are so strongly and deeply fluted that the meridional chambers are divided into chamberlets. It seems unsafe to make a specific identification of this young shell which had only attained between three and four volutions, but the characters noted are strongly indicative of a Permian stage of fusulinid evolution. They are not to be expected in the Pennsylvanian, and certainly not in the lower part of the Pennsylvanian.

Depth 7,689–7,701: In zone 7,689–7,701 feet there are two sections, one axial and the other sagittal, which seem to be immature individuals of a species of *Schwagerina*, probably *S. fusulinoides*. The sagittal section (slide C) shows best the important generic character. Fortunately it is well centered so as to show even the position of the aperture of the proloculum, though the wall has been replaced by silica and the alveolar texture of the keriotheca is nearly all obliterated. This structureless wall is not to be confused with that of *Fusulinella* which, although not alveolar, has a distinct structure embracing tectum, diaphanotheca and secondary deposits. In this section the first three and one quarter volutions are closely coiled, as in *Fusulina*, but a rapid inflation ensues so that the fourth volution is more than twice as high as the third. This inflation is diagnostic of the Permian genus *Schwagerina*. Even with a pocket lens the tightly coiled nucleoconch is easily identified and contrasted with the inflated volutions which follow.

The axial section (slide D) is not well preserved at the center and the details of its nucleoconch cannot be made out well, though it seems to have embraced but little over two volutions. The inflated outer volutions agree well in height with those of slide C and the probability is that the two specimens are conspecific, though this could not be proved under the circumstances. This axial section shows the septa to be very strongly and evenly fluted as they are in *S. fusulinoides* and I suspect that this is an immature specimen of that species. *Schwagerina* is confined to the Wolfcamp horizon in western Texas.

Depth 8,320–8,330: The slides from zones 8,320–8,325 and 8,325–8,330 contain juvenile fusulinids of such small size that they cannot be specifically identified.

Depth 8,330–8,336: From the zone 8,330–8,336 feet there are axial and sagittal sections of well-preserved, rather small fusulinids, each showing evidence of about six volutions. The sagittal section is tangential to the proloculum and does not indicate the full diameter of that chamber. The clubbed and curved ends of the septa show that strong septal fluting reached to the middle of the shell and this would suggest *Fusulina* rather than *Triticites*, though the presence of chomata extending into the third volution makes the evidence rather equivocal.

The axial section from this zone is somewhat oblique and its characters therefore are not very distinctive. Its walls are much thinner than those of the sagittal section and it is probably not conspecific with that shell. Neither of these can be specifically identified and they might be of Cisco or of early Permian age, though probably not of early Pennsylvanian age. If there were lower Pennsylvanian (zone of *Chaetetes* and *Chonetes mesolobus)* present, it should be represented by the absolutely diagnostic presence of *Fusulinella* which characterizes the lower part of the Gaptank, the Des Moines group, and the Pottsville and Allegheny. That genus is not represented in the samples from the Reagan County well.

Fossils obtained from cores from well 2–B at depth 8,140–8,223 have been identified by F. B. Plummer.

Identification of Fossils from Cores from Big Lake Oil Company Well 2–B by F. B. Plummer

Depth 8,140: *Marginifera* cf. *muricata* Norwood and Pratten.

(Spiny variety. See U. S. Geol. Surv. P. P. 16, Pl. V, fig. 7, from the Maroon formation of central Colorado.)

Depth 8,141: *Orbiculoidea missouriensis* Shumard and *Lingulipora.*

Depth 8,144: *Lingulipora, Orbiculoidea missouriensis* Shumard.

Depth 8,145: *Lingulipora* and *Lingula carbonaria* Shumard.

Depth 8,146: *Lingulipora.*

Depth 8,147: *Composita* ?, *Lingulipora* and *Pleurophorus subcostatus* ?, Meek and Worthen.

Depth 8,217: *Productus inflatus* McChesney.

Depth 8,219: *Productus* cf. *semireticulatus* var. *hermosanus* Girty.

Depth 8,220: *Productus* sp.

Depth 8,221: *Productus* cf. *semireticulatus* var. *hermosanus* Girty.

Depth 8,222: *Lingula carbonaria* Shumard.

Depth 8,223: *Acanthopecten carboniferus* Stevens and *Lingula carbonaria.*

These are long range species indicating Pennsylvanian but not lower Pennsylvanian. They resemble forms of the Rocky Mountains province more closely than those of the Mississippi valley.

In figure 24 is given graphic representation of the section to depth 6,000 feet. The Cretaceous as indicated may vary in thickness from 300 to 600 feet and the Triassic from 100 to 500. The "Red Bed" series containing usually three salt horizons and some thick anhydrite beds as well as red sands and clays is approximately 2,000 feet thick. The dolomitic limestone series underneath the "Red Beds" has a thickness of about 800 or 900 feet and is succeeded by the Permian black shale and limestone series with some sand which passes without appreciable break at lower depth into the Pennsylvanian.

In figure 25 the section is continued from depth 7,580 based on Big Lake Oil Company Well No. 1–C. The shale series Permian and Pennsylvanian continues to depth 8,341. The interval between 6,000 feet and 7,580 feet not represented in these graphs contains largely dark shales with some thin limestone and some fine sand. It is not possible at the present time to determine the dividing line between Permian and Pennsylvanian, *Schwagerina* as indicated above is found to depth approximating 7,700 and this depth is taken provisionally as the base of the Permian. Fossils obtained at depth 8,140 to 8,223 indicate Pennsylvanian but not lower Pennsylvanian, which is absent in these wells.

That part of the graph of Figure 25 based on cuttings is necessarily generalized as contacts are obscured, the samples being mixed by caving. For this reason it is impossible to definitely separate out the individual strata.

Silurian, identified in this well by B. H. Harlton at 8,341–8,346 (**2**, p. 617), is absent in wells high on the structure, as 2–B, and is probably thicker in some wells low on the structure. The Ordovician beginning in well No. 1–C at or somewhat below 8,346 continues to the bottom of the hole, 8,670. Within the Ordovician three stratigraphic units are recognized which in this well have thicknesses as

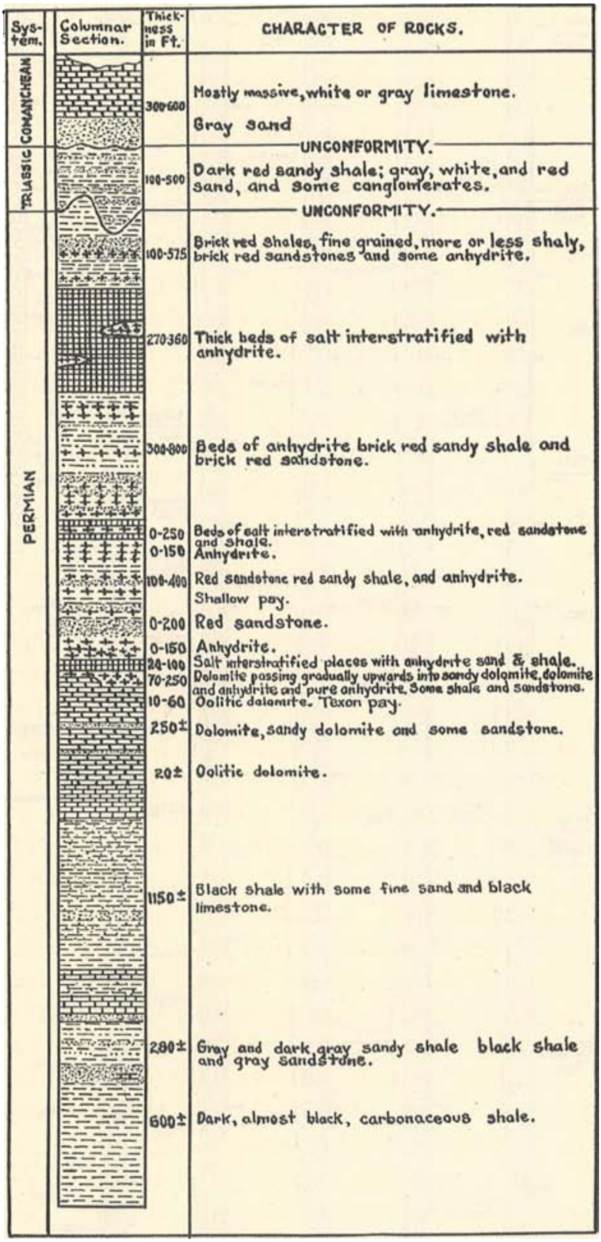

Fig. 24. Generalized section in Big Lake oil field to depth 6,000 feet. Vertical scale 1 in. = 1,000 feet. Modified from Sellards and Patton (**7**, p. 369).

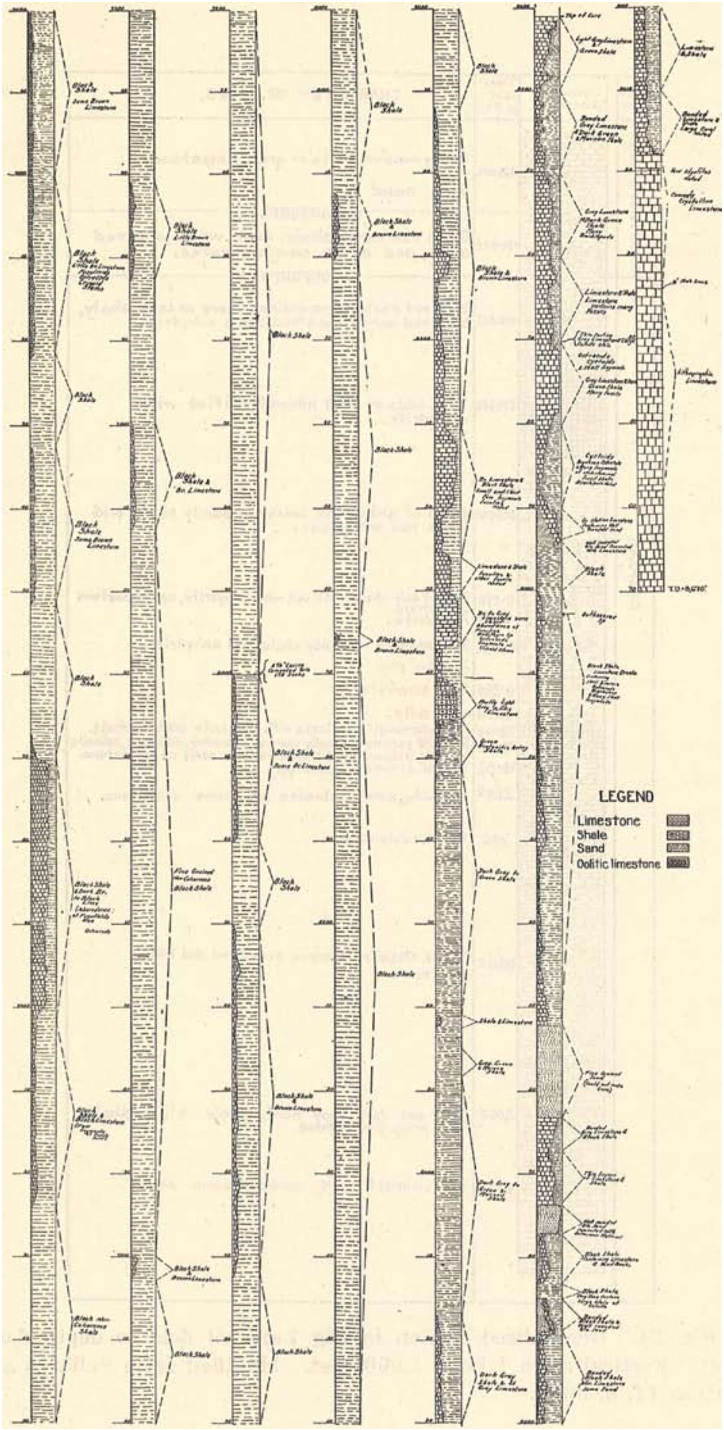

Fig. 25. Graph of Big Lake Oil Company Well 1-C from 7,500 to 8,670 based on cuttings to 8,431; cored from 8,431.

follows: green sandy shale with some limestone, 142 feet; dark shales with rounded quartz sand and some limestone, 130 feet; and dolomitic partly porous and partly fine grained limestone in which the well terminates, full thickness not known.

UNCONFORMITIES

At the base of the Cretaceous is an unconformity which represents early Cretaceous and all of the Jurassic.

The Triassic of this region probably represents the latter part of the period. If this is true the unconformity at the base of the Triassic represents the early part of that system and probably a part of the Permian.

In 1926 Sellards and Patton (**7**, p. 381) suggested the probability of an unconformity at the base of the "Red Bed" series, the top of the "Big Lime." Subsequent developments have supported this interpretation of the section (Hennen, **3**, p. 515). There are probably, in addition, minor unconformities within the "Red Bed" series.

At the base of the Pennsylvanian is an unconformity representing all of Devonian, Mississippian, and early Pennsylvanian time. In some of the wells, Silurian may be present, although in other wells the Pennsylvanian rests directly upon the Ordovician of Simpson age. Four or five major unconformities are crossed in drilling these wells.

AGE OF PRODUCING HORIZONS

The shallow producing zone in the Big Lake oil field depth of 2,400 to 2,500 feet, falls within the Red Bed series of the Permian (see fig. 24). In Texon Oil and Land Co. 1–B, production was found in this zone at depth 2,469 which is about 1,600 feet below the top of the Permian, 811 feet below the base of the first salt bed, and 450 feet above the Texon pay. The sands probably lie within the Double Mountain series.

The 3,000-foot horizon, Texon pay, is also Permian, being near the top of the "Big Lime" series of the basin. Traced eastward this horizon, or its equivalent, would probably fall within or near the Blaine formation of the Double Mountain series.

From horizon 6,277 feet, but one well, Texon Oil and Land Co. 1–B, has produced. As previously stated, the fusulinids indicate that the Permian extends to at least 7,600 or 7,700 feet. This production at 6,277 feet is therefore within the Permian and not less than 1,300 feet above the base of that system.

Production from Texon Co. 2–B at depth 8,131 is* from the Pennsylvanian approximately 100 feet above the base, which in this well is at 8,225. Production from Big Lake Oil Company 2–C at depth 8,232 feet is regarded by Lowman as from the Hunton (4, p. 618), but seemingly comes from the Pennsylvanian 48 feet above its base. Production from 3–C, depth 8,379 is according to our interpretation 6 feet above the base of the Pennsylvanian.

Texon Oil and Land Co. Well No. 3–B produced from the Ordovician at depth 8,536. Production at this depth being small, the well was mudded and drilling continued, and has now obtained production at depth 8,633.

The deepest known producing zone, Continental pay, is Ordovician in age. According to Ulrich, fossils from Big Lake 1–C depth 8,451 to 8,479 represent Chazyan, equivalent to the Falls formation of the Simpson group. The deep producing horizon in 1–C is found at depth 8,664 to 8,670. Whether at this depth the formation is Chazyan or is to be placed in an older series, the Beekmantown, is yet to be determined. The production occurs just below a stratigraphic break where alternating dark shales and sands with some limestones give place to limestone suggesting a formational break. No fossils have been obtained from this lower limestone. The stratigraphic position of the deeper producing horizons is shown in figure 26.

*Lowman (6, p. 804) identifies this horizon as Chimneyhill, Silurian, but our cores contain a Pennsylvanian fauna to 8,225 feet. (See p. 173.)

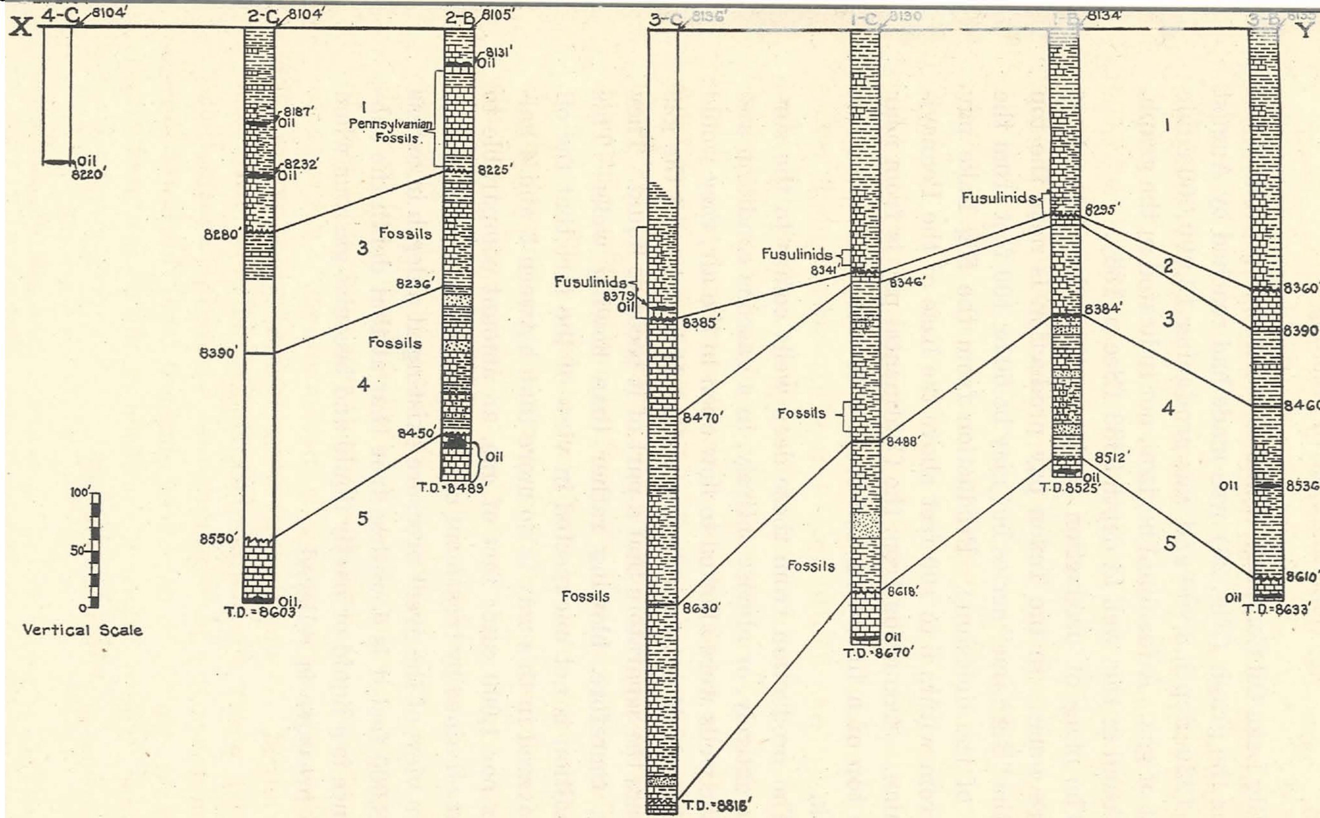

Fig. 26. Pre-Pennsylvanian section in the deep wells. The line X–Y is drawn at —5,400 feet, sea level datum. 1. Pennsylvanian from which production is obtained in 2–B, 2–C, 3–C, and 4–C. 2. Silurian reported present by Harlton and Lowman in 1–B, 1–C, and 3–C; believed by the writers to be absent in 2–B and 2–C; no production. 3. Ordovician green sandy shales and some limestone; no production. 4. Ordovician dark shales with well-rounded quartz sand and some sandstone and limestone; production in 3–B. 5. Ordovician limestone; production in 1–B, 2–B, 3–B, 1–C, 2–C, and 3–C.

Big Lake Oil Company Well 3–C which was drilling at the time the graph (Fig. 26) was made had reached by August 16, 1930, depth 8,909 and was producing 12,000,000 cubic feet of gas. A fusulinid horizon, not indicated in the graph, is found in this well at depth 8383 (See p. 183).

The place of production varies more or less in each of these zones. In the Texon pay production is near the top of the "Big Lime" series but may be 50 or 100 feet from the top of the limestone. Production from the Big Lake pay is from within 6 to 100 feet above the base of the Pennsylvanian. Production from the Continental pay is from near the top of a limestone but from a few to 52 feet in this rock.

The production from these deep wells comes to the surface entirely, or almost entirely, in a gaseous condition and if the wells were allowed to flow open in the air, they would be largely if not entirely gas wells. It is not until the gas enters the separators that a part of it becomes liquid. They are, therefore, blowing rather than flowing wells. This condition is not unexpected in view of the fact that the oil recovered in this way is no more than between 3 and 4 gallons per 1,000 cubic feet of gas, an amount comparable to that obtained by treatment of other gases in gasoline plants.

In view of the great pressure existing at a depth in excess of 8,000 feet it is doubtless true that at that depth the substance is a liquid or partly liquid and becomes gaseous when the pressure is relieved.

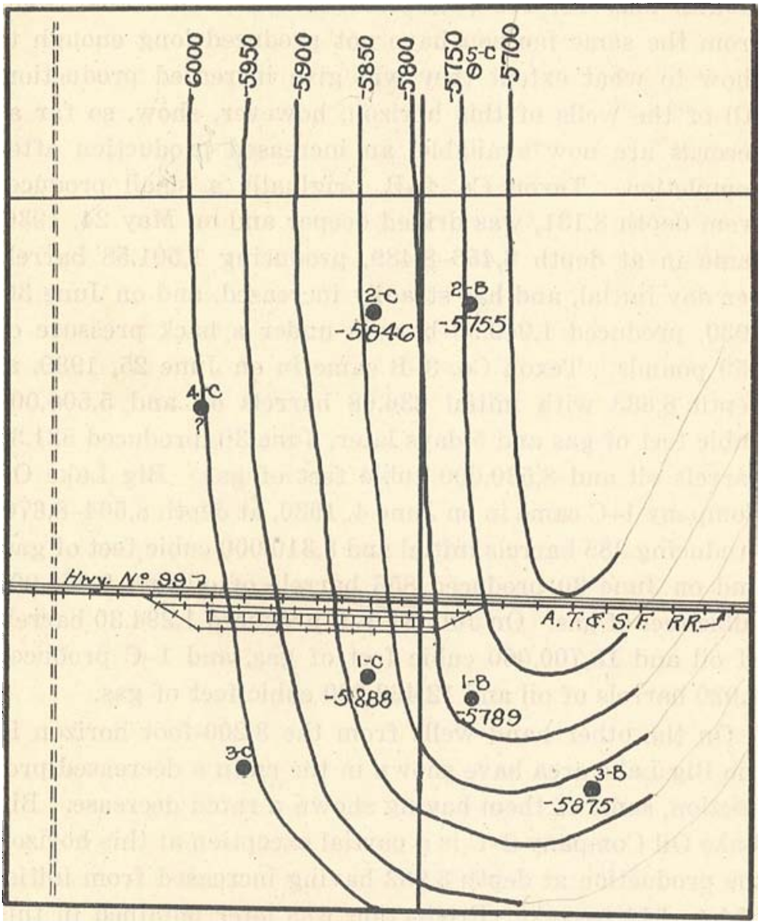

Fig. 27. Structure map of Ordovician at level of Continental pay.

PRODUCTION CURVE

A graph showing production in the first of the deep wells drilled, Texon Oil and Land Co. 1–B, may be found in The University of Texas Bulletin 2901, page 178, figure 15. This graph shows a rapid increase in production during the first few months and thereafter a gradual increase, the maximum of oil having been reached in 13 to 18 months, the largest daily production having been in the eighteenth month, May 18, 1930, 2,926.40 barrels. The other wells from the same horizon have not produced long enough to show to what extent they will give increased production. All of the wells of this horizon, however, show, so far as records are now available, an increased production after completion. Texon Co. 2–B, originally a small producer from depth 8,131, was drilled deeper and on May 24, 1930, came in at depth 8,456–8,489, producing 1,501.58 barrels per day initial, and has steadily increased, and on June 30, 1930, produced 1,949.90 barrels under a back pressure of 450 pounds. Texon Co. 3–B came in on June 25, 1930, at depth 8,633 with initial 236.08 barrels oil and 5,500,000 cubic feet of gas and 5 days later, June 30, produced 531.36 barrels oil and 8,530,000 cubic feet of gas. Big Lake Oil Company 1–C came in on June 4, 1930, at depth 8,664–8,670, producing 385 barrels initial and 8,310,000 cubic feet of gas, and on June 30 produced 856 barrels of oil and 9,300,000 cubic feet of gas. On July 31 3–B produced 1,294.30 barrels of oil and 15,700,000 cubic feet of gas, and 1–C produced 1,020 barrels of oil and 12,438,000 cubic feet of gas.

On the other hand wells from the 8,200-foot horizon in the Big Lake area have shown in the main a decreased production, some of them having shown a rapid decrease. Big Lake Oil Company 2–C is a partial exception at this horizon the production at depth 8,232 having increased from initial 354 to 644 barrels. Production was later obtained in this well from depth 8,456–8,489 as stated above.

Professor Roswell H. Johnson, who has given careful attention to production in the Texon Oil and Land Co. 1–B, has recently made the following statements in regard to this deep well.

RATE OF PRODUCTION IN VERY DEEP OIL AND GAS WELLS[5]

By Roswell H. Johnson, Pittsburgh, Pa.

Abstract

The fact that the very deep well 1–B at Big Lake, Texas, increased its production for several months after completion and has so far shown no decline has attracted attention and led to some speculation as to its cause. Professor Sellards and others have suggested that it is due to "blowing itself in"; i.e., an enlargement of hole in the sand. It seems to me that this explanation is not only adequate but necessary.

The purpose of this note is to go a step farther and predict that all very high-pressure wells, and therefore all or nearly all very deep producing wells, will have the same experience. It follows that at some intermediate depth there may be an approach to equilibrium between the pressure decline and the cavity enlargement factors, so that a well may show a history of several months with no very large gain or loss. Of course, since the shapes of the two curves are necessarily different, an equilibrium in the the sense of no variation in yield for a prolonged time is not to be expected.

There is another factor in enlargement of the hole—the resistance of the rock to this erosion is a variable also. Therefore the extent to which a well may increase its yield naturally is a function not only of the pressure above a "threshold" adequate to erode but also a function of the resistance of the rock to erosion. This is, of course, a well known phenomenon in California where wells may increase their yield even though not very deep.

The two factors then point to the following well-erosion law: "For any given resistance to erosion of an oil or gas reservoir rock, there is a depth below which the initial pressure is great enough to produce erosion. This erosion continues as long as the pressure exceeds the requirement and as a result for that period decreases the rate of decline of the well. Below another and greater depth the influence of the erosion exceeds the influence of the decline of pressure and the well increases in yield until the equilibrium is reached by the decreasing erosion."

It follows from (a) the well-erosion law, (b) the greater extractability at greater depths because of higher pressure, (c) the greater extractability at greater depths because of more gas in solution where it is available, (d) lesser loss by faults, fissures, artesian "washing," mud volcanoes, and springs, that deeper horizons have

[5]Presented at Annual Meeting of the American Institute of Mining and Metallurgical Engineers, New York, N.Y., Feb. 17–21, 1930. Subject to author's revision.

larger reserves, other things being equal, than shallower horizons until the optimum level is reached.

We have here the explanation of the fact that although there would seem to be a law of diminishing returns for petroleum and natural gas, judging by the increasing percentage of dry holes and the average depth of holes, we do not find such a result in the average size of new wells.

The most important economic consideration is that we should estimate higher extractabilities and higher yields with greater depths, up to the optima. Of course, with still greater depths we pass the optimum extractability for these reasons:

a. The quantity and type of source materials become less favorable probably mainly because of the lesser resistance to rapid decomposition of the more primitive organic tissues, as in the Cambrian period.

b. The porosity becomes less as the amount of metamorphism becomes greater with depth, as in the Paleozoic and below generally.

c. With greater depths, the greater heat and pressure and the time available has increased the amount of gas relative to oil contained, as in the Cambrian.

One warning is necessary in the study of the records of very deep producing wells which increase in yield. A back pressure is usually maintained and this is manipulated to cause the well to produce in adjustment to the facilities available for disposal or the estimated strength of equipment. Where the back pressure is known, and the amount of mineral sediments is recorded, as well as the oil and gas for each time unit, it is probable that a prediction of yield can be made while the well is increasing or is constant, as well as while declining, as is now possible. In the future, then, as the appraiser must predict the yields of these wells, he must be provided with more variables than in the past and have correspondingly a more difficult but not insurmountable task.

HISTORY OF DEEP DRILLING IN THE BIG LAKE OIL FIELD

The discovery horizon of the Big Lake oil field, the Texon sand, is found at depth approximating 3,000 feet, and until near the close of 1928 production was entirely from this horizon, plus a small production from a more shallow horizon at about 2,400 feet. However, as early as 1924, the Texon Oil and Land Company made explorations for deeper production, having drilled at that time to a depth of 6,000 feet without success (**7**, p. 376). Again in August, 1926, the Texon Company began preparations to deepen a well which was then producing from depth 2,469 feet. On

December 1, 1928, this well, Continental (Texon) 1–B, was completed as a producer at a depth of 8,525 feet. The history of this well has been given in previous publications (**3**, pp. 501–502; **8**, pp. 176–179). Soon after the completion of Texon 1–B, a controlling interest in the Texon Oil and Land Company, including this well, was acquired by the Continental Oil Company.

The Texon Oil and Land Co. has since drilled two additional deep wells, 2–B and 3–B.* In addition, the Big Lake Oil Company has drilled or is drilling the following: Big Lake Oil Company 1–C, 2–C, 3–C, 4–C, 5–C, and 179. The location of all of these wells, all of which are on lands of The University of Texas, is given in figure 28.

THE CHARACTER OF THE SEDIMENTS

The character of the sediments in this field given in part in earlier papers (**7**, pp. 368–377; **8**, pp. 179–189) is supplemented by description of samples in the following pages from several of the deep wells. The surface deposits in this field to a depth of 400 or 500 feet are chiefly sand with a small amount of limestone and calcareous marl representing the basal Cretaceous of this region. The Triassic, which underlies Cretaceous and is of continental origin, consists largely of fine red and gray sands and clays, with some coarser sands varying to conglomerates. The Permian underlying the Triassic having a thickness of 7,000 or more feet, presents much variation in sediments. The first approximately 2,000 feet is of the red bed facies, including red and gray fine sands and clays and several thick salt and anhydrite beds. An account of the Cretaceous, Triassic, and Permian red bed series as developed in the adjoining county will be found in The University of Texas Bulletin 2801.[6]

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*These wells, 1–B, 2–B, and 3–B are owned by Group No. 1 Oil Corporation, the controlling stock of which is owned by the Texon Oil and Land Company and Continental Oil Company.

[6]Core Drill Tests for Potash in Midland County, Texas, by E. H. Sellards and E. P. Schoch. Univ. Texas Bull. 2801, pp. 176–188, 1928.

Underneath the red beds is a thick dolomitic limestone series commonly known as the "Big Lime," which in this region has a thickness approximating 800 feet. Below the "Big Lime" is a series of black shales and limestones of Permian-Pennsylvanian age which has a thickness approximating 4,500 feet. The change from these shales and limestones is abrupt to the early Paleozoics in which the deep wells terminate. The character of the rock and the geologic section of each of the deep wells is more fully given below.

RECORD OF DEEP WELLS

TEXON OIL AND LAND COMPANY WELL NO. 1-B

Located 250 feet from W. line and 2,725 feet from N. line of Sec. 36, Bl. 9. Casing record: 15½ in. to 769 feet; 12½ to 1,820; 10 to 2,590; 8¼ to 2,825; 6⅝ to 3,080; 5 3/16 to 6,176. Elevation 2,734. T. D. 8,525. Drillers log of this well is published in Univ. Texas Bull. 2901, pp. 191–201, 1929.

The production record of this well by months from the Continental pay is as follows:

Date	Production of oil in barrels	Production of gas in cubic feet
1928		
December	29,541.47	134,399,000*
1929		
January	48,609.06	407,097,000†
February	53,503.06	541,032,972
March	66,944.52	662,061,000
April	70,137.87	680,066,000
May	78,544.46	778,713,907
June	78,410.44	721,213,000
July	83,064.48	776,410,000
August	84,066.92	793,510,000
September	82,975.94	772,145,000
October	86,880.12	776,480,000
November	84,303.05	783,918,000
December	88,306.98	832,830,000
1930		
January	89,067.72	833,295,000
February	80,256.03	763,714,000
March	88,643.62	848,396,000
April	86,092.66	818,775,000
May	88,931.78	849,018,000
June	84,895.98	825,320,000
July	85,773.02	853,428,000
Totals	1,538,949.18	14,451,821,879

*Record on gas incomplete, 16 days lacking.

†Record on gas incomplete, 9 days lacking.

Temperature

The following temperature tests on this well have been made by E. M. Hawtof as part of American Petroleum Institute Project 25, Determination of Geothermal Gradients in Oil Fields.*

Depth in feet	Degrees F.
6,500	135.97
7,000	143.92
7,500	153.29
8,000	162.50
8,300	171.71

Description of Samples from Cuttings

Pennsylvanian

	Depth in feet
Black shale. Five samples	7,980–8,040
Black shale and some brown limestone. Six samples	8,040–8,120
Black shale and some limestone. Eight samples	8,120–8,248
Black shale and brown limestone with fragments of fossils. Three samples	8,248–8,275
Brown limestone and black shale containing fusulinids, ostracods, and fragments of other fossils. Five samples. Base of Pennsylvanian	8,275–8,295

Silurian

Light gray crystalline limestone and black shale	8,295–8,300
Light gray oolitic crystalline limestone	8,300–8,305

Ordovician

Dark green to gray shale. Three samples	8,305–8,330
Dark gray to green and maroon shale and some limestone	8,330–8,335
Dark gray sandy shale and some gray limestone. Four samples	8,335–8,384
Dark gray to green shale some limestone and well-rounded sand	8,384–8,390
Shale and limestone varying from black to green. Some sand. Four samples	8,390–8,411
Dark gray shale and some limestone and sand	8,411–8,476
Well-rounded quartz sand and some limestone and shale. Two samples	8,476–8,484
Dark gray to black shale and some limestone and sand. Four samples	8,484–8,506
Dark gray to green shale and gray limestone	8,506–8,512
Mostly light crystalline gray limestone and some shale and sand	8,512–8,514

Samples below 8,514 not obtained.

*The full report on Mr. Hawtof's work on this project is now being published by the American Petroleum Institute.

Summary of Record (See Figures 24 and 26)

	Depth in feet	Thickness in feet
Cretaceous	Surface to about 510	
Triassic	510– 840	330
Permian "Red Bed" series (shallow pay at 2,469)	840–2,780	1,940
Permian "Big Lime" series (Texon pay at 2,910)	2,780–3,834	1,054
Permian shale with dark limestone and some sand	3,834–7,700±	3,866
Pennsylvanian	7,700–8,295	595
Silurian[7]	8,295–8,305	10
Ordovician green sandy shale and limestone	8,305–8,384	79
Ordovician dark sandy shale with rounded quartz sand and some limestone	8,384–8,512	126
Ordovician limestone[8]	8,512–8,525	13

TEXON OIL AND LAND COMPANY WELL NO. 2–B

Located 250 feet from W. line and 4,655 feet from S. line of Sec. 36, Bl. 9. Elevation 2,705 feet. Casing record: 20 in. to 67 ft.; 13⅜ to 3,026; 9⅝ to 5,914. Drilled by cable tools to 8,131; cored 8,131 to 8,489. T. D. 8,489.

Texon Co. 2–B was started November 6, 1929, as a deep well and by April 14, 1930, had reached depth 8,127 (Big Lake pay) where it obtained production of gas to the amount of 17,000,000 cu. ft. per day. On April 22 the well at depth 8,131 produced 250 barrels of oil and 16,000,000 cu. ft. of gas.[9] By April 28 production had fallen to 90 barrels of oil and 12,000,000 cu. ft. of gas. Since production was small the well was deepened by coring from 8,131 to 8,489. At depth 8,456 to 8,489[10] it gave on May 24 initial production of 1,501.58 barrels of oil and 32,000,000 cu. ft. of gas. Production of oil has shown an increase, being now, June 30, 1949.90 barrels of oil and 29,320,00 cu. ft. of gas.

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[7]Assigned to Silurian on identification made by B. H. Harlton (2, p. 617).

[8]It has been found difficult to determine the top of the limestone, the samples being mixed with cavings from above, but the limestone is believed to be present in the sample at 8,512.

[9]Lowman places this production as Chimneyhill, Silurian (6, p. 804). However, below this level in the cores of this well we have the Pennsylvanian fossils listed on page 155.

[10]Production occurred within this interval of 33 feet, but not necessarily entirely through the interval.

The production record of this well by months is as follows:

Date	Production of oil in barrels	Production of gas in cubic feet
April, 1930	1,238	147,413,000
May, 1930, (Ordovician production from May 24)	12,741.56	256,500,000
June, 1930	53,225.60	901,220,000
July, 1930	61,457.52	929,109,000
Totals	128,662.68	2,234,242,000

Description of Samples

Permian and Pennsylvanian

Cuttings

	Depth in feet
Black shale with small amount of sand and some limestone. Ten samples	5,700–5,960
Black shale and gray sandstone	5,960–5,970
Mostly all gray sandstone with some black shale	5,970–5,980
Black shale and some sandstone. Three samples	5,980–6,020
Black shale. Two samples	6,020–6,060
Black shale and some gray sandstone. Four samples	6,060–6,110
Mostly brown to dark limestone and some shale and sand. Two samples	6,110–6,130
Black shale. Two samples	6,130–6,150
Black shale and some gray sandstone	6,150–6,160
Black shale	6,160–6,170
Black shale and some limestone. Four samples	6,170–6,220
Gray fine-grained calcareous sandstone	6,220–6,240
Black shale with some sandstone and limestone	6,240–6,290
Mostly black shale	6,290–6,310
Black shale and sandstone. Two samples	6,310–6,340
Black shale. Two samples	6,340–6,360
Mostly black shale. (Only one sample in this interval)	6,360–6,700
Black shale and some gray sandstone. Four samples	6,700–6,740
Black shale	6,740–6,780
Gray sandstone and some black shale	6,780–6,800
Black shale. Two samples	6,800–6,910
Black shale and some brown limestone. Four samples	6,910–6,960
Black shale	6,960–6,970
Mostly black shale and some brown limestone. Three samples	6,970–7,040
Black shale	7,040–7,050
Black shale and some brown limestone. Six samples	7,050–7,390
Black shale and some limestone	7,390–7,400
Black shale	7,400–7,430
Black shale and some brown limestone	7,430–7,440
Black shale and one-third limestone and small amount of chert	7,440–7,450

	Depth in feet
Black shale and some brown limestone; also chert. Eight samples	7,450–7,570
Black shale	7,570–7,580
Black shale and brown limestone and some chert (fragments of fusulinids)	7,580–7,590
Black shale	7,590–7,600
Black shale and some brown limestone. Two samples	7,600–7,620
Brown limestone and one-third black shale. Some fragments of fossils. Two samples	7,620–7,640
Black shale and some limestone. Two samples	7,640–7,660
Black shale. Four samples	7,660–7,780
Brown limestone and black shale. Two samples	7,780–7,800
Black shale. Two samples	7,800–7,850
Black shale and brown limestone. Two samples	7,850–7,870
Black shale	7,870–7,960
Brown limestone and one-third black shale	7,960–7,970
Black shale and some brown limestone. Two samples	7,970–8,000
Black shale and some brown limestone. Six samples	8,000–8,130

Cores

Porous brown to gray crystalline limestone containing a few fragments of crinoid stems. Some stylolite markings in the rock. Oil producing horizon	8,131–8,135
Similar rock with increased amount of crinoid stems	8,135–8,138
Same with abundant crinoid stems. Stylolite present	8,138–8,139
Same with abundant crinoid stems and a few ostracods	8,139–8,140
Black very slightly calcareous shale containing crinoid stems, *Orbiculoida missouriensis*, and some other fossils	8,140–8,141
Similar black shale containing *Orbiculoidea missouriensis*, *Lingulipora*, ostracods and other fossils	8,141–8,143
Dark gray shale containing abundant, mostly indistinct fossils including *Lingula carbonaria*, *Pleurophorus subcostatus*, *Orbiculoidea missouriensis* Shumard, *Composita* ?, and *Lingulipora*	8,143–8,154
Brown to gray crystalline limestone with an abundance of crinoid stems and a few ostracods. Stylolite present. Similar to limestone at 8,131–8,138	8,154–8,203
Similar brown limestone with thin bands of black shale. Contains crinoid stems	8,203–8,206
Similar brown to gray crinoidal crystalline limestone containing stylolites	8,206–8,214
Similar brown to gray crystalline limestone alternating with bands of dark shale. Contains large crinoid stems and other fossils	8,214–8,215
Dark gray shaly limestone. Contains an abundance of crinoid stems	8,215–8,216
Dark gray to black shale with a few limestone streaks. Contains an abundance of crinoid stems, large numbers of productid spines, and one well-preserved *Productus inflatus* McChesney	8,216–8,218
Dark shale with bands of limestone. Contains *Productus semireticulatus* Girty, crinoid stems, and productid spines	8,218–8,220

	Depth in feet
Similar rock containing *Productus* cf. *semireticulatus* var. *hermosanus* Girty, *Lingula carbonaria* Shumard, productid spines, ostracoda, and crinoid stems	8,220–8,223
Black slightly calcareous shale containing *Lingula carbonaria* and other fossils. Base of Pennsylvanian	8,223–8,225

Ordovician

	Depth in feet
Light green calcareous sandy shale containing a few brachiopods and fragments of other fossils	8,225–8,228
Hard green shale	8,228–8,230
Hard greenish-gray calcareous sandy shale	8,230–8,233
Hard greenish-gray shale containing brachiopods	8,233–8,235
Hard greenish-gray shale with small inclusions of maroon shale	8,235–8,235½
Maroon shale with some inclusion of hard green shale	8,235½–8,236½
Green shale with thin bands of fine grained gray limestone	8,236½–8,239
Gray to brown limestone with some green shale	8,239–8,243
Dark green slightly calcareous hard shale	8,243–8,246
Dark maroon shale streaked with green shale	8,246–8,248
Gray to slightly green sandy limestone	8,248–8,253
Gray limestone with some green hard shale	8,253–8,255
Gray limestone streaked with green shale	8,255–8,260
Gray limestone streaked with green shale and with maroon staining. Brachiopods at 8,263	8,260–8,264
Gray limestone with streaks of green shale. Contains small brachiopods	8,264–8,267
Banded gray limestone and green shales. Contains brachiopods and crinoid stems	8,267–8,270
Green shale and gray limestone in alternating bands	8,270–8,273
Dull green sandy shale with some limestone. Brachiopod at 8,276	8,273–8,278
Hard green shale with bands of gray limestone. Brachiopod at 8,282	8,278–8,287
Banded gray limestone and sandy green shale	8,287–8,306
Gray to brown limestone with some green shale. Some brachiopods present	8,306–8,315
Dark shale with some gray limestone	8,315–8,318
Green shale with some limestone. Brachiopods at 8,318	8,318–8,320
Dull green sandy shale mixed with limestone	8,320–8,323
Sandy green shale with bands of gray limestone	8,323–8,326
Dark gray to green shale with some limestone. Contains bryozoans and brachiopods, and other fossils	8,326–8,327
Mostly dark green sandy shale with some limestone. Squeezed and slickensided	8,327–8,328
Dark green shale streaked with gray limestone. Contains brachiopods and other fossils. Some pyrite observed	8,328–8,330
Dark green noncalcareous shale, in places very fossiliferous	8,330–8,331
Gray sandstone with calcareous cement and well-rounded quartz grains. Contains brachiopods	8,331–8,332

	Depth in feet
Dark gray to black shale containing well-rounded sand grains	8,332–8,334
Gray sandstone with calcareous cement. Contains abundant brachiopods	8,334–8,336
Mostly dark black shale with thin bands of well-rounded quartz sand. Brachiopods at 8,337	8,336–8,345
Dark shale	8,345–8,350
Dark gray to black shale containing small calcareous concretions	8,350–8,355
Black shale with a little limestone	8,355–8,368
Gray limestone containing limestone pebble inclusions and a few fossils	8,370–8,373
Black shale and limestone with limestone pebbles	8,373–8,377
Black limy shale	8,377–8,379
Black sand with occasional small calcareous concretions	8,379–8,383
Black shale with thin bands of limestone	8,383–8,387
Black shale and dark gray limestone	8,387–8,392
Brownish-gray, shaly limestone	8,392–8,396
Black shale with some brown to dark gray limestone. Fragments of fossils in the limestone	8,396–8,405
Dark gray limestone and some shale	8,405–8,406
Alternating bands of shale and limestone	8,406–8,413
Sandstone with well-rounded quartz grains; calcareous cement	8,413–8,417
Well-rounded quartz sand included in black shale	8,417–8,420
Black limy shale	8,420–8,423
Mostly gray sandy limestone with some greenish shale	8,423–8,424
Gray to light-brown sandy limestone containing fragments of fossils	8,424–8,427
Brown to gray crystalline sandy limestone containing brachiopods	8,427–8,429
Dull green shale and brown limestone	8,429–8,430
Well-rounded quartz grains mixed in shale and limestone	8,430–8,431
Gray to brown limestone	8,431–8,434
Limestone with some shale and well-rounded quartz grains	8,434–8,438
Black shale containing corals	8,438–8,441
Gray limestone with some well-rounded quartz grains	8,441–8,442
Gray limestone and shale	8,442–8,445
Dark slightly greenish, limy shale	8,445–8,449
Light brown to gray crystalline limestone	8,449–8,450
Light gray to slightly brownish limestone. High porosity at 8,463. Stylolite at 8,471	8,450–8,471
Fine grained gray limestone	8,471–8,474
Imperfect recovery. Few pieces obtained were fine-grained limestone	8,474–8,489

Summary of Record (See Figures 24 and 26)

	Depth in feet	Thickness in feet
Cretaceous, Triassic, Permian, and Pennsylvanian approximately as in 1–B	Surface to 8,225	
Ordovician green sandy shale and limestone	8,225–8,326	101
Ordovician dark shale, rounded quartz sand, and some limestone	8,326–8,450	124
Ordovician limestone	8,450–8,489	39

TEXON OIL AND LAND COMPANY WELL NO. 3-B

Located 930 feet from W. and 2,240 feet from S. line of Sec. 36, Bl. 9. Elevation 2,734.88. T.D. 8,633. Drilled by rotary.

Casing Record

Size of pipe in inches	Depth landed in feet	Cemented with sacks of cement
20	104	150
13⅜	3,037	1,200
9⅝	5,812	1,200
7	7,995	600

This well was started November 8, 1929, and obtained production June 18, 1930, at depth 8,536. It produced 125 barrels during the first 22 hours and later 125 barrels in 19 hours. This production being small, the well was drilled deeper and on June 25 at depth 8,633 produced 236.08 barrels and 5,500,000 cubic feet of gas which increased by June 30 to 531.36 barrels of oil and 8,530,000 cubic feet of gas. On July 31, the production from this well was 1,294.30 barrels of oil and 15,700,000 cubic feet of gas.

The production record of this well is as follows*:

Date 1930 June	Production of oil in barrels	Production of gas in cubic feet
24		4,150,000
25	236.08	5,500,000
26	357.68	5,150,000
27	407.28	6,150,000
28	466.86	6,150,000
29	531.50	6,660,000
30	531.36	8,530,000
July 1–31, inclusive	31,772.42	394,650,000
Total	34,303.18	437,040,000

Description of Samples from Cuttings

Pennsylvanian

	Depth in feet
Black shale and some limestone. Four samples	8,000–8,040
Black shale and some limestone and chert. Two samples	8,040–8,060
Black shale and some limestone. Eight samples	8,060–8,270
Black shale and brown limestone. Five samples	8,270–8,320
Black shale and brown limestone and some chert. Two samples	8,320–8,340
Black shale and brown limestone Fusulinids	8,340–8,360

*Production is from the Continental pay. The small production from depth 8,536 is not included.

Silurian?

	Depth in feet
White crystalline limestone and some black shale	8,360–8,370
White crystalline limestone	8,370–8,380
White crystalline limestone and some black shale and well-rounded sand	8,380–8,390

Ordovician

Black and green shale with some limestone and sand	8,390–8,400
Dark gray and green shale and some limestone and sand	8,400–8,410
Dark gray and green shale and some gray limestone. Four samples	8,410–8,460
Gray to brown limestone, green to gray shale and well-rounded quartz sand. Two samples	8,460–8,510
Dark gray to green shale and little gray limestone. Oil production at 8,536. Two samples	8,510–8,540
Mostly crystalline gray limestone and little shale. Two samples	8,540–8,560
Mostly gray to white crystalline limestone with a few grains of well-rounded sand and a little shale	8,560–8,570
Mostly gray to white crystalline limestone with a little shale	8,570–8,590
Gray to light brown crystalline limestone and some black shale. Two samples	8,590–8,610
Mostly gray crystalline limestone with some black to gray shale and some well-rounded sand. Oil production at 8,633. Two samples	8,610–8,633

Summary of Record (See Figures 24 and 26)

	Depth in feet	Thickness in feet
Cretaceous, Triassic, Permian, and Pennsylvanian	Surface to 8,360	
Silurian ?	8,360–8,390	30
Ordovician sandy green shale and limestone	8,390–8,460	70
Ordovician dark shale with rounded quartz sand and some limestone	8,460–8,610	150
Ordovician limestone	8,610–8,633	23

BIG LAKE OIL COMPANY WELL NO. 1-C

Located 250 feet from E. and 2,550 feet from N. line Sec. 1, Bl. 2. Elevation 2,730. Drilled to 8,430 feet with cable tools, and to 8,658 with rotary. Cored from 8,431 to 8,658. T.D. 8,670.

Casing Record

Size of pipe in inches	Weight	Kind	Depth landed at in feet	Remarks
22	112	Lapweld	522	Pulled
18⅝	87½	Lapweld	833	Pulled
16 A.P.I.	84	Lapweld	2,652	Pulled
11¾ A.P.I.	60	Seamless	3,710	Pulled and mudded
9 A.P.I.	45	Seamless	6,970	Cmtd. 625 sks.
6⅝	28	Seamless	8,000	Cmtd. 175 sks.

This well was started February 20, 1929, and was completed June 4, 1930. The pay horizon is at depth 8,664 to 8,668. Initial production from this horizon was 385 barrels oil and 8,310,000 cu. ft. gas. The production has gradually increased and on June 30 under 450 pounds back pressure was 856 barrels of oil and 9,300,000 cu. ft. of gas. Production continued to increase gradually and on July 25 under 300 pounds back pressure was 1,013 barrels of oil and 11,600,000 cu. ft. of gas.

Production from this well by months from the Continental pay is as follows:

1930	Production of Oil in barrels	Production of Gas in cubic feet
June (4–30)	15,836	245,300,000
July	29,503	341,428,000
Total	45,339	586,728,000

Description of Samples

Permian and Pennsylvanian

Cuttings

	Depth in feet
Fine grained, noncalcareous black shale with some small pieces of limestone. Four samples	7,319–7,364
Black and brown shale with some pyrite in the brown shale. Two samples	7,364–7,389
Black, noncalcareous shale. Two samples	7,389–7,408
Black noncalcareous shale with pieces of limestone	7,408–7,418
Black noncalcareous shale	7,418–7,431
Black shale and one-third dark brown limestone. Fusulinids and ostracods noted	7,431–7,445
Black shale; very little brown limestone; few fragments of fusulinids. Two samples	7,445–7,465
Mostly black shale with some brown limestone. Two samples	7,465–7,490
Black shale. Three samples	7,490–7,538
Black noncalcareous shale and brown limestone. Ostracods and fragments of other fossils noted	7,538–7,551
Black shale and some brown limestone	7,551–7,600
Black shale with some brown limestone. Contains fusulinids, ostracods, and crinoid stems	7,600–7,622
Black shale	7,622–7,633
Black shale and some black limestone	7,633–7,651
Black shale	7,651–7,670
Black shale and dark brown to black limestone. Contains fusulinids, ostracods, and crinoid stems	7,670–7,701
Black shale and black limestone. Contains a few fragments of fossils	7,701–7,724
Black noncalcareous shale	7,724–7,772
Black shale and some brown limestone	7,772–7,782
Black shale	7,782–7,799
Black shale and brown limestone	7,799–7,813

	Depth in feet
Fine-grained noncalcareous black shale	7,813–7,900
Black shale and brown limestone	7,900–7,903
Black shale	7,903–8,000
Black shale and some brown limestone	8,000–8,020
Black shale	8,020–8,031
Black shale and some brown limestone	8,031–8,072
Black shale	8,072–8,112
Black shale and brown limestone	8,112–8,120
Black shale	8,120–8,165
Black shale and brown limestone	8,165–8,166
Black shale	8,166–8,272
Black shale and some brown limestone	8,272–8,311
Brown limestone, black shale, and a small amount of chert. Contains fragments of fusulinids	8,311–8,330
Brown to gray limestone with some chert, fusulinids, ostracods, and crinoid stems	8,330–8,336
Black shale and brown and gray limestone and some chert	8,336–8,341

Silurian

Light gray oolitic limestone and black shale	8,341–8,346

Ordovician

Fine-grained soft green shale with some dark shale	8,346–8,351
Green and gray shale	8,351–8,382
Green shale with some limestone	8,382–8,383
Gray to green and maroon shale	8,383–8,417
Dark, greenish-gray shale and gray limestone	8,417–8,430

Cores

Light gray crystalline limestone streaked with small amount of green and gray shale	8,431–8,432½
Gray limestone and green and gray shale (broken shell noted)	8,432½–8,433
Light gray limestone mixed with green shale	8,433–8,435
Banded gray limestone and green shale	8,435–8,440
Alternating bands of gray limestone and dark green shale	8,440–8,443
Banded gray limestone and dark green and maroon shale	8,443–8,447
Mixture of gray limestone and green to gray shale. (Lime breaks contain fragments of shells)	8,447–8,450
Mixture of gray limestone and green to gray shale containing *Girvanella occellata* Seely, *Orthis* cf. *costalis* Hall, *Batostoma* sp. and cystid plates and columnals, and other fossils	8,450–8,462
Gray limestone and some shale	8,462–8,463
Mostly dark gray limestone with dark green to gray shale containing brachiopods, and ostracoda. Two samples	8,463–8,475
Light gray crystalline limestone containing an abundance of brachiopods and ostracoda	8,475–8,477
Dark gray limestone and shale containing *Orthis* cf. *ignicula* Raymond, *Hebertella* cf. *vulgaris* Raymond, and other fossils	8,477–8,479

	Depth in feet
Banded gray limestone and gray shale	8,479–8,488
Banded gray limestone and shale. A few streaks of well-rounded quartz sand noted	8,488–8,489
Gray limestone and shale with increase of well-rounded sand	8,489–8,492
Well-rounded quartz sand cemented with limestone and shale. Brachiopods noted in sand	8,492–8,494
Dark green to black slightly calcareous shale	8,494–8,500
Dark gray shale with irregular limestone bands. Fewer fossils noted in this limestone	8,500–8,510
Dark gray shale with irregular limestone bands. Thin section showed ostracods, crinoids, bryozoans, and fragments of other fossils	8,510–8,530
Dark gray to black shale with irregular limestone breaks	8,530–8,553
Fine sand. Recovered as loose sand	8,553–8,564
Alternating thin layers of gray limestone and dark gray to black shale	8,564–8,574
Well-rounded quartz sand with calcareous cement	8,574–8,577
Black shale and gray limestone with streaked well-rounded sand	8,577–8,583
Black shale, very fine texture with scattered crystals of calcite	8,583–8,585
Black shale streaked with well-rounded quartz sand	8,585–8,589
Mostly black shale, banded with irregular breaks of lime	8,589–8,600
Mostly black shale with irregular limestone breaks	8,600–8,610
Mostly black shale with limestone breaks. Some of the limestone breaks contain ~~corals~~ Ischadites	8,610–8,616
Mostly gray limestone with dark green to gray shale breaks	8,616–8,618
Light gray crystalline limestone. Thin section at 8,620 feet showed texture rather coarse in parts of the section, while the other portion showed very fine texture. Large scattered rhombohedral crystals were noted to have dark centers; fragments of fossils noted	8,618–8,623
Light gray crystalline limestone	8,623–8,630
Light gray fine textured limestone. Thin sections showed very fine texture. Two samples	8,630–8,658

Cores not obtained from 8,658 to 8,670.

Summary of Record (See Figures 24 and 26)

	Depth in feet	Thickness in feet
Cretaceous, Triassic, Permian, and Pennsylvanian	Surface to 8,341	
Silurian[11]	8,341–8,346	5
Ordovician green sandy shale with some limestone	8,346–8,488	142
Ordovician dark shales with rounded quartz grains and some limestone	8,488–8,618	130
Ordovician limestone	8,618–8,670	52

[11]Referred to Silurian on identification made by B. H. Harlton (2, p. 617).

BIG LAKE OIL COMPANY WELL NO. 2–C

Located 250 feet from E. and 625 feet from N. line of Sec. 1, Bl. 2. Elevation 2,704. Drilled by rotary to 5,500; by cable to 8,200, and by rotary to 8,232. T.D. 8,603.

Casing Record

Size of pipe in inches	Weight	Kind	Depth landed at in feet	Remarks
15½	70	Lapweld	238	Cmtd. 105 sks.
10¾ A.P.I.	45½	Seamless	2,896	Cmtd. 300 sks.
7	26	Seamless	5,472	Mudded
5 3/16	20	Seamless	7,950	Cmtd. 175 sks.

This well was started March 10, 1929. On January 3, 1930, the well obtained small production from 8,187 to 8,190. On January 28 the well flowed 354 barrels of oil and 8,314,000 cu. ft. gas at 8,232. Production increased, and on March 4 the flow was 644 barrels 60-gravity oil and 13,000,000 cu. ft. gas; on April 9, 646 barrels oil and 13,000,000 cu. ft. gas; May 5, 571 barrels oil; May 28, 472 barrels oil; June 9, 440 barrels oil and 8,500,000 cu. ft. of gas.[12]

Owing to decline in production to about 100 barrels daily from this horizon the well was deepened and on July 7, 1930, obtained production initial 524 barrels per day and 22,100,000 cu. ft. of gas at 8,603 feet.

Production from this well by months is as follows:*

1930	Production of Oil in barrels	Production of Gas in cubic feet
January	2,142	48,289,000
February	16,496	348,266,000
March	20,205	398,400,000
April	18,758	354,400,000
May	16,647	371,700,000
June	4,640	130,931,000
July	43,989	698,817,000
Total	123,077	2,350,803,000

Description of Samples from Cuttings

Permian and Pennsylvanian

	Depth in feet
Black sandy shale mixed with some gray sandstone and limestone. Two samples	5,690–5,720
Mostly black shale	5,720–5,730

[12]Lowman places this producing level as Chimneyhill, Silurian (6, p. 804). Our interpretation places the horizon in the Pennsylvanian about 48 feet above the base.

*From Big Lake pay to July 6 and from Continental and Big Lake pays combined after July 6.

	Depth in feet
Black shale with some gray sandstone	5,730–5,745
Mostly fine-grained gray sandstone with some black shale	5,745–5,765
Mostly black shale with some limestone	5,765–5,790
Black shale. Two samples	5,790–5,860
Black shale and some gray sandstone	5,860–5,875
Mostly gray sandstone with some black shale	5,875–6,040
Black shale	6,040–6,090
Mostly gray sandstone with some black shale	6,090–6,105
Black shale and sand	6,105–6,120
Brown crystalline sandy limestone and some black shale	6,120–6,130
Gray sandstone	6,130–6,150
Black shale and some sand	6,150–6,245
Mostly gray sandstone and some black shale. Two samples	6,245–6,295
Black shale and one-third gray sandstone	6,295–6,360
Black shale	6,360–6,400
Black shale and some brown limestone	6,400–6,420
Black shale	6,420–6,430
Black sandy shale and some gray sandstone. Three samples	6,430–6,465
Black shale. Two samples	6,465–6,535
Black shale and some gray sandstone and brown limestone. Four samples	6,535–6,780
Mostly black shale and some sandstone. Four samples	6,780–6,880
Mostly black shale	6,880–7,000
Black shale and some brown limestone. Six samples	7,000–7,070
Black shale. Two samples	7,070–7,140
Black shale and some brown limestone. Two samples	7,140–7,156
Black shale. Two samples	7,156–7,355
Black shale with some dark green shale	7,355–7,375
Black shale and brown limestone. Fusulinids and crinoid stems. Two samples	7,375–7,395
Black shale	7,395–7,415
Black shale and brown limestone. Fragments of fossils	7,415–7,425
Black shale and brown limestone. Four samples	7,425–7,525
Black shale and brown limestone. Fusulinids found	7,525–7,540
Black shale and brown limestone and a small amount of chert, ostracoda, and crinoid stems. Two samples	7,540–7,570
Black shale and some limestone. Four samples	7,570–7,630
Black shale and brown limestone. Fusulinids and crinoid stems. Two samples	7,630–7,650
Black shale and brown limestone. Eight samples	7,650–8,005
Black shale and some brown limestone and chert. Two samples	8,005–8,020
Black shale	8,020–8,030
Black shale and brown limestone and some chert	8,030–8,035
Black shale. Four samples	8,035–8,150
Black shale and some brown limestone and chert	8,150–8,165
Black shale and some limestone. Three samples	8,165–8,185
White crystalline limestone and some black shale; contains fossils. Oil production at 8,187 to 8,190	8,185–8,190
White crystalline limestone with some black shale and some chert	8,190–8,196
Black shale mixed with white limestone and chert	8,196–8,201

	Depth in feet
Light gray to white limestone and some black shale. Two samples	8,201–8,213
White crystalline limestone and some black shale and a few grains of well-rounded quartz sand. Five samples. Oil production at 8,232	8,213–8,280

Ordovician

	Depth in feet
Green and maroon sandy shale and some white limestone	8,280–8,290
Green and dark shale, gray limestone and sand. Two samples	8,290–8,310
Green sandy shale and some limestone. Two samples	8,310–8,340
Gray crystalline limestone and sandy green shale	8,340–8,510
Well-rounded quartz sand, dark shale and limestone. Four samples	8,510–8,535
Gray limestone, dark shale, and sand	8,535–8,540
Gray crystalline limestone, green to dark gray shale. Some sand	8,540–8,550
Gray crystalline limestone (some sand and shale probably as cavings)	8,550–8,577
Samples not obtained	8,577–8,603

Summary of Record (See Figures 24 and 26)

	Depth in feet	Thickness in feet
Cretaceous, Triassic, Permian, and Pennsylvanian	Surface to 8,280	
Ordovician green shale and some limestone	8,280–8,390	110
Ordovician dark limy shales and sands	8,390–8,550	160
Ordovician limestone	8,550–8,603	53

BIG LAKE OIL COMPANY WELL NO. 3–C

Located 2,250 feet from S. and 925 feet from E. line of Sec. 1, Bl. 2, Big Lake oil field. Elevation 2,736. Drilled with cable tools to 8,576; rotary from 8,576. T. D. 8,923.

Casing Record

Size of pipe in inches	Weight	Kind	Depth landed at in feet	Remarks
15½	70	Lapweld	521	Pulled
12½	50	Lapweld	578	
10	40–45	Lapweld	2,694	
8¼	32	Seamless	3,524	Cmtd. 100 sks.
6⅝	26	Seamless	6,251	Mudded
5	18	Seamless	7,806	Cmtd. 125 sks.

This well, formerly a producer from a more shallow horizon, was deepened and October 11, 1929, obtained production at 8,379 in the Big Lake pay. Initial production in this zone was 190 barrels oil and 5,000,000 cu. ft. of gas. The well is now being drilled to a deeper pay. Our interpretation places the producing horizon at 8,379 in the Pennsylvanian, small fusulinids being found to depth 8,383.

Production from this well from the Big Lake pay is as follows:

1929	Production of Oil in barrels	Production of Gas in cubic feet
October	875	45,600,000
November	1,619	12,068,600
December	2,320	49,095,300
1930		
January	1,622	10,795,000
February	113	2,568,400
March	Not recorded	Not recorded
April	798	30,849,480
May	2,732	68,537,000
June	2,439	65,340,000
July	1,043	30,874,000
Total	13,561	315,727,780

Increased production of oil and gas was obtained late in July at 8,800 to 8,816. On August 15, 1930, at depth 8,892 production of 12,000,000 cu. ft. of gas was obtained.

Description of Samples from Cuttings

Pennsylvanian

	Depth in feet
Black noncalcareous shale and very small amount of brown limestone	7,825–7,869
Black shale	7,869–7,884
Black shale with very small amount of limestone	7,884–7,891
Black shale. Two samples	7,958–7,984
Black shale with some limestone and chert	7,984–8,023
Black noncalcareous shale and some limestone	8,084–8,090
Black shale	8,090–8,093
Black shale with very little chert. Six samples	8,093–8,213
Brown limestone and one-third black shale. Oil production at 8,379. Two samples	8,379–8,385

Fusulinids present at 8,383.

Silurian

Green and black shale and white and brown limestone and small amount of sand. Three samples	8,398–8,411
White to light gray crystalline limestone. Four samples	8,411–8,427

Ordovician

Dark gray to green shale with a little limestone. Six samples	8,540–8,548
Dark gray to green shale and a little maroon shale. Two samples	8,548–8,555
Dark gray and green and maroon shale and a little limestone	8,555–8,557

	Depth in feet
Dark gray, green, and maroon sandy shale and some gray limestone. Four samples	8,557–8,576
Dark gray, green, and maroon shale	8,576–8,581
Dark gray, green, and maroon shale and a little limestone	8,581–8,612
Dark green shale and some limestone	8,612–8,630
Dark gray to green shale and some gray limestone and a few grains of well-rounded quartz sand	8,630–8,635
Dark gray to green shale—about ¼ gray limestone—fragments of brachiopods, bryozoans, and ostracoda	8,635–8,640
Dark green and gray shale—some limestone; few grains of well-rounded sand	8,640–8,645
Dark gray to black and green shale, some gray limestone and fragments of fossils	8,645–8,655
Dark gray to black and green shale with some gray to brown limestone	8,655–8,695
Dark shale and some limestone, few grains of sand	8,695–8,700
Dark gray to black and green shale—little limestone	8,700–8,747
Dark gray to black shale, some limestone and sand	8,747–8,753
Dark gray to black and green shale and some limestone	8,753–8,760
Dark shale and some sand	8,760–8,765
Dark gray to black shale, some green shale, and limestone	8,765–8,775
Dark gray to black shale, some green shale, some well-rounded sand and some gray limestone	8,775–8,785
Dark gray to black and green shale, some gray limestone and much well-rounded quartz sand	8,785–8,790
Dark gray to black and green shale and some sand and limestone	8,790–8,805
Dark gray to black and green shale, few fragments of light gray to white limestone and some sand	8,805–8,810
Dark gray to black and green shale, some light gray limestone and sand	8,810–8,815

Summary of Record (See Figures 24 and 26)

	Depth in feet	Thickness in feet
Cretaceous, Triassic, Permian, and Pennsylvanian	Surface to 8,385	
Silurian[13]	8,385–8,470	85
Ordovician green shale and some limestone	8,470–8,630	160
Ordovician dark shales with rounded quartz sand and some limestone	8,630–8,820±*	190
Ordovician limestone	8,820–8,923	103

BIG LAKE OIL COMPANY WELL NO. 4–C

Located 1,175 feet from E. and 1,025 feet from N. line of Sec. 1, Bl. 2, Big Lake oil field. Elevation 2,704. Drilled to 8,220 with cable tools.

[13]Referred to Silurian on identification made by S. W. Lowman (4, p. 619). Lowman also places the next 70 feet as Sylvan which he includes in Silurian. (Given as 58 feet in his log 6, p. 803.)

*It is difficult to determine the top of the limestone in this well, but is believed to be between 8,805 and 8,820.

Casing Record

Size of pipe in inches	Weight	Kind	Depth landed at in feet	Remarks
15½	70	Lapweld	525	
13⅜ A.P.I.	54½	Seamless	1,061	
10¾ A.P.I.	45½	Seamless	2,553	
8⅝	32	Seamless	2,961	
6⅝	24	Seamless	3,819	Mudded
5 3/16	24	Seamless	7,837	Cmtd. 400 sks.

This well was started July 25, 1928, and obtained first production November 8, 1929, at depth 8,220. Production on November 10 was 327 barrels oil and 6,000,000 cu. ft. gas from the Big Lake pay. This production declined to about 70 barrels daily and the well is now being deepened.

Production on this well by months from the Big Lake pay is as follows:

	Production of Oil in barrels	Production of Gas in cubic feet
1929		
November	4,660	85,058,000
December	5,599	179,768,782
1930		
January	6,144	135,341,000
February	6,033	126,870,584
March	4,332	152,736,000
April	3,693	142,382,000
May	3,602	127,197,000
June	1,843	112,354,000
July	598	70,485,000
Total	36,504	1,132,192,136

Description of Samples from Cuttings

	Depth in feet
Black shale	7,505–7,542
Black shale and some brown limestone containing productid spines	7,542–7,555
Black shale	7,555–7,630
Black shale and some brown limestone	7,630–8,000
Black shale, some limestone and chert	8,000–8,080
Black shale	8,080–8,105
Black shale, some limestone, fragments of fusulinids	8,105–8,125
Black shale	8,125–8,200
Black shale with some light gray limestone containing oolites	8,216–8,219
Black and gray shale	8,219–8,220

BIG LAKE OIL COMPANY WELL NO. 5-C

Located 250 feet from W. and 625 feet from S. line of Sec. 25, Bl. 9, Big Lake oil field. Elevation 2,697. Drilled by cable tools.

This well was begun June 9, 1930, and is now drilling.

BIG LAKE OIL COMPANY WELL NO. 179

Located 660 feet from S. and E. lines of Sec. 10, Bl. 2. Elevation 2,690.

This well was started December 30, 1929, and is now drilling.

STRUCTURAL CONDITIONS

The 6 wells producing from the Ordovician make it possible to draw some tentative conclusions in regard to the structural conditions in the Ordovician. These wells appear to be located at the west and south sides of the structural dome. The dip in the Ordovician as indicated by these wells is rapid from the crest of the dome both to the south and west. The westward dip from 2–B to 2–C is 101 feet in 600, the top of the Ordovician limestone in 2–B being at —5,745 and in 2–C at —5,846. From 1–B to 1–C the dip is 110 feet in 600, the top of the Ordovician limestone in 1–B being at —5,778 and in 1–C at —5,888. The westward dip thus approximates a rate of 880 feet per mile. The southward dip is apparently almost equally rapid being 97 feet between wells 1–B and 3–B, the top of the Ordovician limestone in 1–B being at —5,778 and in 3–B at —5,875. The dip from 1–C to 3–C, about 875 feet, is 181 feet or at the rate of approximately 1,000 feet per mile. The Ordovician rocks particularly the shales show the effect of squeezing being not infrequently slickensided and distorted. On this account the actual rate of dip can scarcely be determined with accuracy from the cores.

In the Pennsylvanian the doming is by no means so pronounced. The dip in the Pennsylvanian from 2–B to 2–C is not in excess of 56 feet, the base of the Pennsylvanian in 2–B being at —5,520 and in 2–C at —5,576. It is possible, of course, that the dip is less than 56 feet since individual strata cannot be followed through and earlier strata may come into the section at the side of the structure. The dip in the Pennsylvanian between 1–B and 1–C is not in excess of 40 feet, the base of the Pennsylvanian in 1–B being at —5,561 and in 1–C at —5,611. The southward dip on the pre-Pennsylvanian floor from 1–B to 3–B is 64 feet. These records indicate that the unconformity between the Pennsylvanian and pre-Pennsylvanian on this dome is angular.

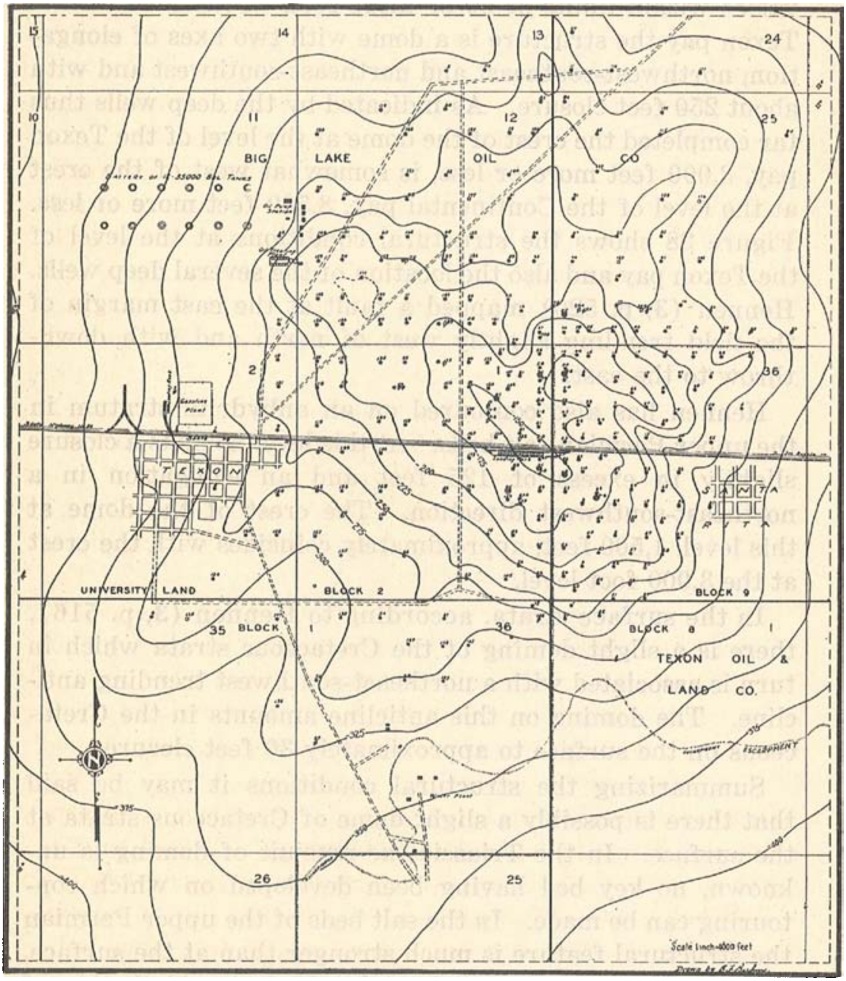

Fig. 28. Map showing location of all wells in the Big Lake oil field and structure contours at the level of the Texon pay. See also Fig. 27, p. 163.

The lowest Permian horizon on which the structural conditions can at present be contoured is the Texon pay near the top of the "Big Lime" series, 4,700 feet or more above the base of the Permian. This horizon is not entirely a definite level since the depth of production in the limestone varies within limits of 50 or more feet. Contoured on the Texon pay the structure is a dome with two axes of elongation, northwest-southeast and northeast-southwest and with about 250 feet closure. As indicated by the deep wells thus far completed the crest of the dome at the level of the Texon pay, 3,000 feet more or less, is somewhat west of the crest at the level of the Continental pay, 8,500 feet more or less. Figure 28 shows the structural conditions at the level of the Texon pay and also the location of the several deep wells. Hennen (**3**, p. 520) mapped a fault at the east margin of the field trending slightly west of north and with downthrow to the east.

Hennen has also contoured on an anhydrite stratum in the upper Permian salt beds. At this level he finds a closure slightly in excess of 125 feet and an elongation in a northeast-southwest direction. The crest of the dome at this level, 1,500 feet, approximately coincides with the crest at the 3,000 foot level.

In the surface strata, according to Hennen (**3**, p. 516), there is a slight doming of the Cretaceous strata which in turn is associated with a northeast-southwest trending anticline. The doming on this anticline amounts in the Cretaceous on the surface to approximately 30 feet closure.

Summarizing the structural conditions it may be said that there is possibly a slight dome of Cretaceous strata at the surface. In the Triassic the amount of doming is unknown, no key bed having been developed on which contouring can be made. In the salt beds of the upper Permian the structural feature is much stronger than at the surface, having a closure of approximately 125 feet. At the top of the "Big Lime" depth, approximately 3,000 feet, the structure is again intensified, the closure approximating 250 feet. The structure at the deep producing zone in the Ordovician is as yet imperfectly known but is shown by the few records available to be intensified over that found at the 3,000-foot level and will doubtless show a much larger closure. Wells have not yet been drilled to show the effect in the Ordovician of the faulting at the east margin of the field recognized in the Permian by Hennen (**3**, p. 521).

PRODUCTION

Detailed production figures for the Permian horizons, the Texon pay and shallow pay are found in the table which follows, giving a total of 45,013,211 barrels to July 31, 1930. From the Permian at depth 6,277 feet, a small production, 1,235 barrels, was made at the time of discovery of the horizon. Later production from this zone is unrecorded or is included (after December 1, 1928) with that from the Ordovician. Production from the Pennsylvanian, Big Lake Pay, is merged with that from the Ordovician as the casing in the wells rests above this level. The total production from the deep pays, Pennsylvanian and Ordovician, to July 31, 1930, was: oil, 2,260,996 barrels, and gas 21,508,554,795 cubic feet. Total production of oil from the field from discovery in 1923 to July 31, 1930 was 47,274,207 barrels. This amount is approximate only since there is necessarily some small unrecorded production.*

DISTRIBUTION OF ORDOVICIAN IN TEXAS

The recognition of rocks of Ordovician age in deep wells in the Permian Basin invites consideration of the known and probable distribution of the Ordovician in Texas. Rocks of this age appear in the state under two facies which may be referred to as the Llano and the Marathon facies respectively. Of the Llano facies only early Ordovician appears in surface exposures consisting of dolomitic limestones. The Marathon facies includes a much larger series of shale and sandstones with some limestones. (See fig. 23.)

The Llano facies found in the Llano uplift of Central Texas is of wide distribution. It is drilled into over an extensive area in North Central Texas, and is present under-

*For production from Texon and more shallow pay, see table following page 192; for details on deep pay production, Pennsylvanian and Ordovician, see the several deep wells (pp. 168–186).

lying the eastern part of the Red River uplift. In West Texas Ordovician rocks of similar character are found on the surface in the Van Horn and El Paso regions. The Llano facies resembles the Arbuckle facies of Oklahoma.

The rocks of this facies at all known localities are separated from the overlying formations by an erosional unconformity. Below they pass without evident unconformity into formations of upper Cambrian age.

In the Marathon region a much more complete Ordovician section is found, several formations being present. The most extended account that has been published on the Ordovician of the Marathon region is found in The University of Texas Bulletin No. 1753 issued in 1917.[14] This bulletin being now out of print the discussion of the Ordovician is herewith reprinted.

ORDOVICIAN ROCKS OF THE MARATHON BASIN
BY C. L. BAKER AND W. F. BOWMAN

Reprinted from Univ. Texas Bull. 1753, pp. 81–93.

ORDOVICIAN-MARATHON SERIES

The name Marathon series is given to a little-known group of rocks of lower and middle Ordovician age. These may not constitute a natural group, for there may be one or more unconformities within the series. Important paleontological gaps are indicated by the collections, but in some cases there are strata lying between these gaps which have yet yielded no fossils. No continuous or complete section of the series has yet been found, hence the apparent gaps may be accounted for by lack of knowledge of the real succession.

The series, so far as now known, comprises in ascending order the following members:

1. Flaggy and thin-bedded sandstones, mostly brownish in color, but some dark gray, interbedded with dark green sandy shale, the whole having a thickness of 300 to 500 feet. Grains of glauconite occur in the series. On exposed surfaces the sandstones often have lavender color. At the top is a dark-colored grayish and blackish shale interbedded with thin shaly and flaggy light brown sandstones, sometimes very fine-grained but generally coarse-grained, gritty, or conglomeratic. Near the top are layers of a white and brown spotted, soft, flaxseed-like, fossiliferous, phosphatic limestone, originally oolitic.

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[14]Geological Explorations of the Southeast Front Range of Trans-Pecos, Texas, by Charles L. Baker and W. F. Bowman, Univ. Texas Bull. 1753, pp. 61–172, Sept. 20, 1917.

Twenty to thirty feet below the top are thin-bedded light brown sandstones, containing *Lingula* and other brachiopods, and flaggy arenaceous shales of the same color as the sandstones. About 100 feet below the top is a conglomerate carrying seams of calcite, both rhombohedral and fibrous in form, small pebbles of quartz, bryozoans and brachiopods, and specks of glauconite. The matrix appears to be limestone. In this conglomerate are angular fragments up to an inch in diameter of light brown or green, very fine-grained sandstone or decomposed chert, very firmly welded to the light brown matrix so that the rock breaks across the conglomerate fragments. The following fossils were determined by E. O. Ulrich:

Obolus rotundatus Walcott
Lingulella pogonipensis Walcott
Schizambon typicalis Walcott
Eoorthis desmopleura Meek (Orthis hamburgensis Walcott)
Symphysurina mesleri Ulrich
Symphysurina spicata angusta Ulrich
Symphysurina brevifrons n. sp. Ulrich
Conokephalina inexpectans (Walcott)
Apatokephalus finalis (Walcott)
Hungaia ? sp. (pygidium only)

Of these he says: "This faunule represents unquestionably a well-marked zone in the lower part of the Pogonip limestone of Nevada. All save the last species of the list are found also in this zone in Nevada; and the last also is there represented by a closely allied species. In Nevada it underlies beds with Canadian faunas. In Quebec similar species are contained in boulders included in slates of the Levis shale containing myriads of early to middle Canadian graptolites. No similar types are known in any Canadian fauna. Evidently, then, this Symphysurina zone is older than the base of the known Canadian. As it is obviously younger than any true upper Cambrian fauna, it must belong to some intermediate Ozarkian stage. Now, because the genus Symphysurina—recently established by me with 26 species—occurs outside of Nevada, Texas, and Quebec only in the Oneota dolomite, an Upper Ozarkian formation in the Mississippi Valley containing 3 species of this genus, the present state of the evidence permits of only one conclusion respecting the age of this lower Pogonip fauna, namely, that it is Ozarkian, and most probably Upper Ozarkian."

Ulrich correlates the fauna of the Symphysurina zone of the Marathon series with the Upper Ozarkian of the Mississippi Valley, the Chepultepec chert of the southern Appalachian Valley, and with erratics in the Levis shale of Quebec.

The above described lowermost beds of the Marathon series were noted only in the axis of an anticline 1½ miles northeast of the junction of Peña Colorado and Maravillas creeks, where they overlie the Upper Cambrian Brewster formation and are unconformably overlain by the Maravillas chert.

The next locality showing a younger sequence of the Marathon series is at the north base of a hill 3⅓ miles in a straight line northeast of Maravillas Gap:

2. At least 300 feet of beds with fine quartz conglomerate on top, grading down through conglomerate to coarse-grained to fine-grained sandstone with much muscovitic or sericitic mica, interbedded with green or light bluish-gray arenaceous shale, much crumpled, much discolored by seams of red and brown oxide and traversed by thin seams of platy, transparent selenite. The base of the member was not exposed.

3. Dark gray thin-bedded limestone, both crystalline and very fine-grained, at the base of which is 2½ feet of rather uniform-sized pebble conglomerate, scarcely one of the pebbles of which is over one-fourth inch in size, composed of clear quartz and fine-grained limestone in a limestone matrix. There are a few thin beds of black chert near the top of the limestone. A species of the Obolidae is found above and graptolites near the base of the limestone. The member is 130 feet thick and has the following fossils, as determined by Ulrich:

Didymograptus cf. extensus
Tetragraptus aff. fruticosus
Phyllograptus cf. ilicifolius and angustifolius
Paterula sp.
Acrotreta sp.

Ulrich states that: "Even though the preservation of the fossils in this lot is not so good as one might wish, it is yet amply good enough to establish the age of the bed beyond any reasonable question. In other words, it is a small but unmistakable representation of the Phyllograptus fauna which marks the median zones of the Canadian system."

Ulrich correlates the Phyllograptus zone of the Marathon series with the middle to upper part of the Ouachita shale of Arkansas, the middle part of the Levis shale of Quebec and New York, and the Skiddaw (Arenig) shale of Scotland.

4. Rotten, soft, very dark dirty green, gray or black shales, interbedded with layers of sandstone from one-fourth inch to one foot in thickness, generally friable but sometimes hard, and dark greenish-brown, grayish, or russet in color. The thickness exposed is about 500 feet and the member is unconformably overlain by the Maravillas chert.

PRODUCTION CHART OF BIG LAKE OIL FIELD

(Deep Production Not Included)

	1923				1924				1925			
	Big Lake Oil Co.		Texon O. & L. Co.*		Big Lake Oil Co.		Texon O. & L. Co.		Big Lake Oil Co.		Texon O. & L. Co.	
	No. of Wells		No. of Wells		No. of Wells		No. of Wells		No. of Wells		No. of Wells	
January					1	1,832			11	179,318	3	115,652.42
February					3	3,432			11	186,154	3	101,248.48
March					3	1,986			12	209,747	4	174,397.33
April					3	4,003			14	317,365	7	212,166.96
May					4	8,191			17	491,139	9	401,108.88
June					7	20,236			18	427,174	12	437,508.93
July					8	64,437	1	110.00	20	456,603	14	453,249.55
August					9	132,701	1	12,751.53	28	462,005	18	490,633.17
September					9	117,620	1	32,315.45	33	530,114	22	434,610.50
October					8	121,413	1	42,990.09	37	506,505	25	441,570.45
November	1	1,796			9	174,966	1	45,333.14	41	511,380	29	435,181.87
December	1	1,908			9	193,264	2	84,781.54	43	537,734	32	473,246.08
		3,704				844,081		218,282.75		4,815,238		4,170,574.62
			3,704 Bbls.		11	1,062,363.75 Bbls.			75	8,985,812.62 Bbls.		

	1926				1927			
	Big Lake Oil Co.		Texon O. & L. Co.		Big Lake Oil Co.		Texon O. & L. Co.	
	No. of Wells		No. of Wells		No. of Wells		No. of Wells	
January	44	592,686	35	434,758.89	92	592,049	71	276,661.14
February	46	486,799	37	358,213.19	97	534,577	71	230,597.73
March	54	620,932	38	380,926.29	100	570,003	75	247,691.28
April	55	688,954	39	336,932.20	103	572,785	76	235,386.16
May	61	652,057	41	327,766.83	110	586,649	78	218,520.57
June	60	594,530	45	313,462.35	113	543,341	78	200,305.20
July	68	590,122	46	303,651.15	115	549,758	78	203,641.22
August	74	587,558	46	281,823.55	119	565,723	78	190,962.28
September	76	554,776	53	293,479.64	119	540,590	78	171,743.69
October	78	582,930	60	294,775.61	119	526,932	78	164,534.97
November	87	600,925	62	277,314.95	121	498,996	77	183,367.53
December	91	596,741	67	277,396.80	120	491,976	77	203,196.62
		7,149,010		3,880,501.45		6,573,379		2,526,608.39
		11,029,511.45 Bbls.				9,099,987.39 Bbls.		

	1928				1929				1930			
	Big Lake Oil Co.		Texon O. & L. Co.		Big Lake Oil Co.		Texon O. & L. Co.		Big Lake Oil Co.		Texon O. & L. Co.	
	No. of Wells		No. of Wells		No. of Wells		No. of Wells		No. of Wells		No. of Wells	
January	124	495,095	78	188,226.73	150	429,816	77	102,610.67	163	340,480	76	69,860.66
February	119	436,555	77	143,450.11	148	361,604	77	87,323.08	168	293,088	76	61,907.34
March	121	467,589	78	136,867.79	151	397,628	77	95,467.46	168	325,251	76	67,994.08
April	124	437,934	78	130,918.98	151	380,526	78	92,550.56	175	317,256	79	61,945.20
May	123	418,623	78	131,245.26	156	404,593	77	93,691.26	175	315,116	81	63,619.08
June	125	396,483	77	119,827.48	156	371,252	77	87,216.98	168	287,429	82	61,548.22
July	132	433,157	77	122,386.28	156	370,101	78	89,205.11		299,384		60,630.30
August	139	431,048	77	119,646.06	156	363,556	77	85,874.17				
September	140	420,188	77	116,794.16	162	353,245	76	79,165.83				
October	143	428,139	76	117,851.77	161	343,903	76	78,550.31				
November	146	386,934	76	108,811.00	166	343,478	76	73,135.64				
December	144	402,525	76	106,156.87	165	351,176	76	74,380.38				
		5,154,270		1,542,182.49		4,470,879		1,039,171.45		2,178,004.00		447,324.88
		6,696,452.49 Bbls.				5,510,050.45 Bbls.				2,625,328.88 Bbls.		

*The Big Lake oil field was brought in by the Texon Oil and Land Company which sold a part of its holdings to the Big Lake Oil Company in 1923 or 1924 and later a controlling interest to the Continental Oil Company. Total production Texon and shallow pay to July 31, 1930, 45,013,211 barrels.

5. About 5 miles southwest of the town of Marathon Dr. Böse found, in the cores of steeply-dipping anticlines, still higher strata below the horizon of the Maravillas chert. These consist of thin layers of grayish-white generally sandy limestone passing into fine-grained conglomerate or coarse calcareous quartz sandstone, varying from 4 inches to 2½ feet in thickness; interbedded with very thinly-laminated dark yellowish-brown, gray and yellow arenaceous and calcareous shales in beds from 5 to 50 feet in thickness; and some very thinly-laminated yellowish sandstones. The upper and middle parts are principally shales. The exposed thickness is about 375 feet, the base not being exposed.

About 8 layers of limestone can be distinguished. There are thin layers of limestone in the lower part which frequently contain grains of quartz, sometimes almost conglomeratic. The thickest limestones are unfossiliferous. Fossils were found in the 2 lowest layers of limestone, stratigraphically about 100 feet below the base of the Maravillas chert, about 2 miles southwest of the Lockhausen ranch. The following were determined by Ulrich:

Crinoidal fragments
Anolotichia aff. A. revalensis
Nicholsonella sp. (ramose, branches slender)
Phaenopora cf. incipiens
Stictoporella cf. exigua
Rhinidictya sp.
Plectambonites aff. P. quinquecostata
Eurychilina sp.
Aparehites sp.

Ulrich notes that: "This zone reminds mostly of early Trenton types of northeastern New York and latest Black River species in Pennsylvania and Minnesota. It does not seem to be quite as old as the lowest of the Viola faunas in central Oklahoma."

About one to 1½ miles to the east of the above fossil locality there are about 200 feet of shales with hardened layers, dark brown to yellowish, sometimes olive in color, overlain by the Maravillas chert.

At the southeast base of the series of chert ridges in which are the Garden Springs, at a point about 5 miles south 55 degrees east, of Marathon, north 20 degrees west from the summit of Caballos Mountain and north 35 degrees east from the summit of Santiago Peak, the upper strata of the Marathon series are rotten, dirty green shales with thin, rusty, greenish-brown, flaggy sandstone layers passing down into alternating beds of thin layers of rusty brown or blue-gray fossiliferous phosphatic limestone which alternate with layers several feet thick of a greenish-blue or dirty green, brittle shale. There may here be a gradation upward from the Marathon series into the lower or Trenton portion of the overlying Maravillas formation, since the strata at the contact are thin-bedded limestone with banded, nodular or lenticular chert, interbedded with a dirty-green to bluish-green, brittle, siliceous shale. The limestone and shale portion of the Marathon series here exposed has an estimated thickness of 300 feet and is underlain by shale. A layer near the top about one foot in thickness is full of small fossils. In the anticlinorium in the low country extending south from here to the next high ridge, the limestone and shale member of the Marathon series is repeated a number of times in the lower areas separated from each other by low ridges of the Maravillas formation.

Part of the Marathon series is exposed on the south slope of Caballos Mountain and probably in places between the ridges to the southwest of that mountain.

On the northeast slope of the ridge east of the wagon bridge on the Peña Colorado Creek, southeast of old Fort Peña, the following section of the Marathon series is exposed:

		Thickness in feet
Top	Maravillas Formation	
1.	Very finely laminated, dark green shale with local hardened and discontinuous thin blocks of finely crystalline brown limestone, for the upper 15 feet. These blocks are from ¼ to 1 inch thick and carry fossils	50
2.	Thin-bedded, nodular, greenish-brown limestone carrying fossils, interbedded with dark green shale	2
3.	Thin-bedded, dark green shales, more sandy than above, with local irregular, soft, brownish-green sandstones, about	65
4.	Greenish, thin-bedded limestone and shales with fossils in the limestones	2
5.	Like No. 3, to base of ridge, about	50

A part of the higher portion of the Marathon series is exposed in the axis of a normal anticline located partly on the Granger, and partly on the Gage ranch at a locality some 5 miles southeast of the town of Marathon. Here a thickness of about 500 feet of beds is exposed beneath the overlying Maravillas formation. The upper two-thirds of this thickness may be designated as dark green shale, al though it has frequent interbeds of peaty sandstone, rusty or greenish-brown in color, and of laminated brown limestones in beds up to one foot in thickness. Some of this limestone is phosphatic. There are also phosphatic limestone nodules in the shales which contain fossils, are oolitic, and when unweathered, are very dark brownish-black, or blue-black in color; but generally have a surface-weathered shell of a rich brownish-yellow color. Limestones increase in thickness and number toward the base of the section. They are, in the lower portion, mostly phosphatic; range in thickness from an inch or less up to three feet or more; weather either brownish or dove-colored; and are separated by intervals of shale and thin, flaggy sandstones which probably average 10 feet in thickness. The shales are also often phosphatic. The limestones sometimes give off a fetid odor upon being struck with a hard instrument. They are often oolitic. Small rounded pebbles of black chert are found in the limestones about 100 feet above the base of the exposure. The unweathered limestone is very dark brown, or blue-gray. Fossils are abundant in the lower limestones, especially in some beds about a hundred feet above the base of the exposure.

Ordovician—Maravillas Formation

The Maravillas formation consists of dark gray, thin-bedded, alternating chert and limestone with some beds of rather fine conglomerate of chert and quartz in a limestone matrix. There is generally a basal conglomerate from 1 to 3 feet in thickness, made up of boulders and pebbles of dark-colored chert, sandstone, limestone, and clay ironstone. Some angular chert boulders are as large as one foot in diameter, but in general the conglomeratic material ranges from one-eighth inch up to 6 inches in size.

The type locality of the Maravillas formation is Maravillas Gap on the Marathon-Terlingua road, about 14 miles in a straight line southwest from Marathon. There the Maravillas Creek cuts across the strike ridges of chert at a point near their southwestern end. The following description is of a section between 100 and 200 yards east of the Gap.

The base of the formation here, as elsewhere, is marked by either an erosional unconformity or a plane of shearing. At the base is a layer of conglomeratic and finely arenaceous limestone carrying angular and rounded dark chert fragments, ranging up to 6 inches in diameter. The limestone is finely crystalline and traversed by thin seams of crystalline calcite. Crystals and stalactitic forms of calcite coat exposed surfaces of both limestone and chert. The basal conglomerate averages about one foot in thickness and is mainly made up of rather large, often flattened, angular, and subangular fragments of black chert which range from one-eighth inch up to 6 inches in size. Subordinately, are fragments of chert of other colors, fragments of the underlying Marathon series sandstones, and clay iron-stone, the latter alone generally rounded. Locally the basal conglomerate may be 2 feet or more in thickness and carry angular chert boulders of one foot in size.

Near the base is some fine-grained light gray material with a pinkish cast, thinly and imperfectly laminated, aggregated in relatively thin beds a few inches in thickness and interbedded with the cherts. This somewhat resembles the Monterey Miocene shale of

California. Above are layers of dark-colored brownish or blackish chert, banded in layers ranging from 18 inches to less than one inch in thickness. The bedding is rather irregular and sometimes slightly contorted. The chert is greatly fractured and traversed by thin seams of crystalline calcite, often no thicker than fine pencil lines. Some of it is stained reddish or pinkish, apparently with iron oxide. There are many layers of fine-grained light gray limestone, often showing fine laminae on weathered surfaces. Thin layers of chert are either plastered on this limestone or firmly welded in interbeds with it. On the whole the member is chert.

The limestones contain fossil bryozoans, corals, and brachiopods, generally arranged in thin layers. The Bryozoa form thin reefs. The limestones are literally packed with fossils, mostly of Bryozoa and small corals. Another characteristic of the limestones is thin seams and lentils of blackish chert which weathers brown. Some of the limestone layers are only a few inches in thickness.

In the upper half are layers of fine-grained dark gray quartzite, ranging up to 2 inches in thickness, interbedded with chert, a large portion of which is of lighter color than lower down, being of a rather light blue-gray or mouse color. Some layers are of a rather coarse-grained light gray sandstone which has been metamorphosed to a quartzite. Both the quartzite and sandstone possess lentils, irregularly shaped masses and thin bands of chert, which weathers brownish. The sandstone is composed of clear-grained angular particles of quartz. Bedded black cherts continue to the top of the formation. The measured thickness of the Maravillas formation at Maravillas Gap is 325 feet.

At a locality about 8 miles northeast of the junction of the Peña Colorado and Maravillas creeks, there is at the top of the Maravillas formation, just under the Caballos novaculite, a small amount of light brown arenaceous shale, weathering pinkish, which may possibly be the equivalent of the Sylvan shale in the Arbuckle Mountains of Oklahoma. Fine conglomerate appears to be sparsely distributed more or less throughout the entire Maravillas chert. This conglomerate is gray in color and composed of fine angular to subangular quartz grains, averaging about one-sixteenth inch and less in size, in a matrix of finely crystalline limestone. This conglomerate also contains small pebbles of chert. On the south side of the Peña Colorado Creek a stadia measurement gave the Maravillas formation a thickness of 270 feet. At the site of old Fort Peña, 5 miles south of Marathon, it is less than 150 feet thick. The greatest thickness was observed by Dr. Böse in a normal, steeply-folded anticline about 5 miles southeast of Marathon, where there is between 700 and 800 feet with the base not exposed. Here the lower beds are mainly limestone and the upper beds mainly chert. The horizon of later Trenton fossils here is fully 300 feet above the base and the lower 300 feet of strata do not occur in the sections farther southwest. In a neighboring locality Dr. Böse found the total thickness of the Maravillas to be only about 100 feet.

Fossils and Age.—The following fossils, determined by Mr. E. O. Ulrich, were found at the type locality 200 yards northeast of the north end of Maravillas Gap:

Hallopora aff. H. elegantula
Anaphragma mirable?
Hemiphragma imperfectum
Bythopora cf. delicatula
Crepipora hemispherica?
Rhombotrypa subquadrata
Lioclema wilmingtonense
Constellaria maculata
Constellaria sp.
Favositella cf. epidermata
Pachydictya sp.
Rhinidictya sp.
Eurpdictya cf. sterlingensis
Phaenopora wilmingtonensis
Helopora sp.
Arthroclema angulare
Screptopora facula
Dalmanella aff. testudinaria
Dinorthis cf. subquadrata
Hebertella insculpta
Platystrophia sp.
Plectambonites transversalis elegantula?
Plectambonites cf. saxeus
Rhynchotrema capax manniense
Rhynchotrema cf. anticostiense

Ulrich says: "This is a typical Fernvale-Richmond fauna. The Bryozoa are particularly characteristic. Their abundance in this collection suggests very shallow, reef-like conditions."

Other collections made, add to the above list the following:

Leptaena rhomboidalis var.
Platystrophia
Hebertella insculpta
Crinoids
Zaphrentis and Streptelasma, 3 or 4 species
Columnaria aff. C. alveolata

Streptelasma sp. with angular dorsum
Cyathophylloides thomi (Hall)

The coral zone of the Richmond occurs in lenticular masses of conglomerate about 50 feet above the graptolite horizon of the later Trenton at the localities about 6 miles southeast of Marathon.

Ulrich discusses the stratigraphic position of the Fernvale-Richmond zone as follows: "In the Tishomingo, Oklahoma, folio, the Fernvale-Richmond zone holds precisely similar relations to the typical Viola limestone of Oklahoma as does this zone in the Maravillas chert to the underlying Trenton portion of that chert. Though seldom, if ever, exceeding 20 to 50 feet in thickness, and often less, the Fernvale zone is recognizable in many places from Texas to Alaska and Missouri. As it rests on various preceding formations and thus marks a great transgression following a more or less long period of emergence, I have placed it at the base of the Silurian."

A lower horizon in the Maravillas formation contains Trenton fossils. Ulrich determined the following from a locality one-half mile north of Payne's ranch on the east side of Maravillas (Dugout) Creek, 300 yards from the creek:

Diplograptus cf. amplexicaulis Hall
Fragment of a unicellular graptolite stipe suggesting a Didymograptus like D. sagitticaulis
Lingula sp.
Probably new genus of discinoid brachiopod
Leptobolus sp.
Probably two other undetermined species of inarticulate brachiopods
Scenidium cf. anthonense
Leptaenoid shell of undetermined genus
Leptaenoid shell of undetermined genus (a second species)
Strophomena ? n. sp.
Strophomena ? n. sp. 2
Plectambonites aff. sericeus
Parastrophia aff. hemiplicata
Bythocypris
Krausella arcuata
Aparchites aff. labellosa
Eurychilina aff. ventricosa
Eurychilina sp. 2
Dicranella cf. spinosa and simplex
Cryptolithus sp. fragments of shield
Fragments of 3 undetermined sp. of trilobites

Referring to these determinations, Ulrich says: "Most of the 25 species of the above list are recognized as forms belonging to the as yet undescribed fauna of the Viola limestone of Oklahoma. The general aspect of the fauna is that of the Atlantic facies of the Trenton; and as it contains some identical species it is assigned to that age.

"The Viola contains four or five distinguishable faunal zones. Most probably the equivalent beds in the Marathon Basin are similarly marked by slightly different faunal associations. Furthermore, some of the layers contain a little besides Diplograptidae, others chiefly fragments of the trilobite *Cryptolithus,* where others have a more varied fauna. The various collections here indicate like variations in fossil contents in the Marathon Basin region."

Two and a half miles north of Woodhollow tank, 6 miles southeast of Marathon, was found a species of graptolite of the genus *Climacograptus,* which is remarkable in that the lower side of the mouths of the cells of the lower half of its stipes is drawn out into a long spine. This species seems to be new.

At the east base of the Mount Ord Range, near its southern end, were collected the following:

Fragments of diplograptids
Lingulops cf. norwoodi
Dalmanella cf. testudinaria
Zygospira cf. modesta
Plectambonites cf. sericeus
Fragments of cryptostomatous Bryozoa
Fragments of trepostomatous Bryozoa
Cryptolithus intermedius ? (fragment only)
Cryptolithus explanatus
Fragment of free cheek of Ceraurus?

Ulrich states: "This faunule is regarded as of Trenton age. One of the trilobites is identical with a characteristic species of the Viola limestone of Oklahoma."

One mile northeast of the junction of Peña Colorado and Maravillas creeks were collected the following:

Leptobolus cf. walcotti
Acrothele ? sp.
Probably new genus of discinoid shells.
Reminds also of Acrothele.

Ulrich correlates the lower portion of the Maravillas formation with the middle and upper Viola limestone of the Arbuckle Mountains of Oklahoma and the Trenton of New York.

Stratigraphic Relation.—The lower or Trenton portion of the Maravillas formation marked a transgression of the sea over a number of older formations. In the normal anticline about 8 miles northeast of the junction of Peña Colorado and Maravillas creeks and one mile southwest of the Peña Colorado at its nearest point the unconformity at the base of the Maravillas lies only a few feet above the horizon of the Upper Cambrian fossils. In the anticline 1½ miles northeast of the junction of the Peña Colorado and Maravillas creeks the Upper Ozarkian crystalline limestone is succeeded by about 100 feet of beds of unknown age before the horizon of the unconformity at the base of the Maravillas is reached. Three and one-third miles northeast of Maravillas Gap 500 feet of sandstones and shales of unknown age overlie Middle Canadian limestones and are overlain unconformably by the Maravillas chert. Finally, near the northeast end of the earlier Paleozoic area about 5 miles southeast of the town of Marathon, Dr. Böse found a section with Lower Trenton at the base and above 300 feet of dark-gray limestone, on top of which lay the Maravillas chert. Since the lower part of the Maravillas chert carried later Trenton fossils everywhere noted, there may be no unconformity in the region 5 miles southeast of Marathon.

Since the deformation of the earliest Paleozoic strata is everywhere intense, there a possibility that some of the relationships interpreted as unconformities may have been produced by shearing between the beds.

As the Maravillas is of quite variable thickness, it is probable that it is separated everywhere by an unconformity from the overlying Caballos novaculite. But such unconformity between the two was actually observed only in the vicinity of old Fort Peña.

Whether the Ordovician section at Big Lake resembles more closely the Llano or the Marathon facies is at present unknown, that part of the Ordovician drilled into in the deep wells, the Chazyan or Simpson, not being represented in the exposed formations of the Llano series. Recent observations made by C. L. Baker lead him to believe that the Chazyan or Simpson, not previously recognized, is probably represented in the exposed section of the Marathon series. (Personal statement, July, 1930.)

EARLY INVESTIGATIONS ON PETROLEUM IN WEST TEXAS

In 1917 Dr. J. A. Udden after investigating the Glass Mountain area of Texas made the following comments on structural conditions in West Texas in relation to petroleum production.[15]

[15]Notes on the Geology of the Glass Mountains, Univ. Texas Bull. 1753, pp. 56–58, 1917.

Looking at the ancient Marathon mountain structure as a whole, it does not appear unreasonable to regard it as suggesting the possibility of the existence of buried structures in which oil may have accumulated, farther to the northeast. If we take into consideration all that is known concerning the trend of this structure, of the ancient Marathon mountains, all the way from the Solitario uplift on the Brewster-Presidio county line to the northeast, the general trend of this structure, as near as it can be made out, is north 40° east. At the last exposure of the Pennsylvanian to the northeast, at a point near the Purington ranch, where the Dimple formation occurs, it has a trend in the direction north 60° east. There can be no doubt that this structure extends a considerable distance northeast under the overlying Comanchean limestones. The last exposure seen shows the Carboniferous strata in an almost vertical position. There is no intimation in this or in any other exposures that the mountain structure developed in these old formations has undergone any modification except that it may have been cut down to a lower level in this direction. The same, we may say, is suggested also by the isolated uplift coming up through the Comanchean in the Madera Mountains, which suggests also that there is no narrowing of the folded region in this direction. From my observations on all parts of the Glass Mountains it appears that the formations from the Vidrio up, are much less tilted and folded than the Gaptank and the other formations of probable Pennsylvanian age. It would seem, therefore, that most of the folding of the Marathon mountains antedated the deposition of the latest Permo-carboniferous sediments. I believe that the redbeds exposed in the Pecos Valley overlie the Tessey formation. These and the overlying Comanchean have therefore probably been very little disturbed by the Marathon uplift. So that there should exist, under the Comanchean and under the redbeds, some places northeast of the Marathon uplift where the Pennsylvanian and probably some of the Permo-carboniferous lie folded under the relatively undisturbed redbeds and the Comanchean limestones. The redbeds are entirely impervious and would make an excellent cover for an oil pool. How far such covered places of tilted petroliferous formations of the Pennsylvanian may be found away from the exposures in the Marathon country no one can say, but it would be no surprise to find them at a distance of at least 50 or 100 miles beyond the Brewster-Pecos county boundary. The trend of the Marathon mountains would run through the southeast part of Pecos county into Upton and Reagan counties, or even farther east than this.

It will be remembered that on the west flank of the Glass Mountains, the Comanchean limestones have been slightly tilted and that outliers of this formation occupy some of the highest points on the mountains. This cannot be altogether due to an overlap. It certainly represents a slight uplift in post-Comanchean times. From what is generally known of the geologic history of the mountain-building forces, it is quite reasonable to suppose that post-Comanchean disturbances should have taken place over more than one part of a buried mountain system, such as that of the Marathon uplift. It ought for this reason to be practicable to find out how far in a northeast direction this uplift probably extends, for it can be expected to be marked by at least some slight elevation in the later Comanchean sediments. We have here a geologic problem, the solution of which may be of decided economic significance. In the distribution of the Comanchean along the North Concho and the Colorado rivers, there is nothing to especially suggest such an uplift. The conditions in the country to the northeast of the Glass Mountains, along the Pecos River, are singularly favorable for the testing of such a theory. The Comanchean limestones contain several sharply marked horizons that can be followed for long distances in the southwest part of Pecos County, and in most of Upton, Reagan, and Crockett counties. Quite accurate measurements of any structure present can certainly be made. It is, however, a region where very little work has yet been done, and in the absence of any accurate knowledge of the conditions involved, further speculations seem unprofitable. We can only see that in the buried unconformity which certainly must exist between the lower folded series and the overlying merely gently folded or quite undisturbed sediments, there are natural chances for finding accumulations of gas as well as oil. Drilling should not be undertaken, however, before a thorough geological examination has been made whereby the exceedingly small chance of making the right location for a test may be materially increased.

These observations on the probable extension of the Marathon uplift made in 1917, are known to have been influential in the location of exploratory drilling which led to the discovery of the Big Lake oil field in 1923.

PROBABLE MAXIMUM PRODUCING DEPTH

As already shown, production in this field has been obtained from successive horizons in Permian, Pennsylvanian, and Ordovician. Under these conditions the question very naturally arises as to the maximum depth at which production may be expected in this field. At present it is not known whether the early Paleozoic of this region is of the Llano or the Marathon facies. If the Llano facies of lower

Ordovician and Cambrian underlies this region it is not unreasonable to expect production from Cambrian shales and sands, and possibly likewise from Ordovician of Ellenburger or Beekmantown age. Likewise, if the facies of deposition is that of the Marathon region deeper drilling may be expected to encounter extensive series of bituminous shales, sands, and some limestones, in which are several probable producing zones. Drilling below the present producing zones in this field is therefore believed to be justified.

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Map of Sour Lake salt dome by E. H. Sellards and Ivan Fenn. Surface topography shown by contours at one-foot intervals. The sink shown by dotted contour lines at ten-foot intervals. Structural map on the dome shown by contour lines in red on the cap rock at 100-foot intervals.

GEOLOGIC MAP OF MONTAGUE COUNTY, TEXAS

BY

FRED M. BULLARD AND ROBERT H. CUYLER

Assisted by the students of the University of Texas Geology Camp, summer of 1928.