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LOWER CRETACEOUS OF WESTERN OKLAHOMA

A study of
THE OUTLYING AREAS OF LOWER CRETACEOUS
in Oklahoma and adjacent states

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INTRODUCTION

The Lower Cretaceous of the southwest has been an area of more or less concentrated study since the date of its recognition in 1887 by R. T. Hill. So much progress has been made that at the present time the stratigraphic details, the paleontology of the various formations, and the general structural relations are well known. The marine beds of Lower Cretaceous age are not limited to southern Oklahoma and Texas, but are known from western Oklahoma, southern Kansas, southeastern Colorado, and eastern New Mexico. They consist of disconnected outcrops differing in the character of material and variable in size and extent. Their true relationship one with another and with the main outcrop in Texas has only been vaguely determined.

The Lower Cretaceous beds in southern Kansas and southeastern Colorado have been studied in considerable detail and are fairly well known. The area in western Oklahoma, which intervenes between these areas and the main Cretaceous outcrop of Texas, has received only scant attention. It has long been known that numerous outliers of lower Cretaceous are present in western Oklahoma, but until the investigations by the writer they had never been mapped or studied in detail. It would seem necessary that the gap in western Oklahoma should be thoroughly explored before any definite conclusions as to the former extent of the Lower Cretaceous sea, or the exact correlation of the "outlying areas" as they were termed by Hill, could be made.

The writer became interested in the "outlying areas" while working on the main Cretaceous outcrop of southern Oklahoma and Texas. Through the courtesy of Dr. Chas. N. Gould, Director of the Oklahoma Geological Survey, he was privileged to spend approximately 10 days in making a reconnaissance of the outliers of Lower Cretaceous of southern Kansas and western Oklahoma during the summer of 1925. The marked resemblance between the material constituting these outliers and certain formations in Texas is very striking. During the summer of 1927, as a member of the field staff of the Oklahoma Geological Survey, the writer mapped and studied in as much detail as possible the "outlying areas" of western Oklahoma and adjacent states. The results presented in this paper, with the exception of the information on southern Oklahoma and northern Texas, were secured during this field season. This portion represents information secured by the writer during the course of several field seasons from 1919 until 1927, and has been, for the most part, published.

The material presented in this paper may be grouped under the following headings:

(1) An accurate map of the "outlying areas" of Lower Cretaceous in western Oklahoma.

(2) Details regarding the stratigraphy of the "outlying areas" of western Oklahoma and adjacent states.

(3) The correlation of the "outlying areas" with one another and their correlation with the main Cretaceous section of Texas.

(4) The writer's interpretation of the geologic history revealed by the "outlying areas" with particular reference to Oklahoma.

ACKNOWLEDGMENTS

The writer is indebted to Dr. Chas. N. Gould, Director of the Oklahoma Geological Survey, for the opportunity to make this study. Dr. Gould has assisted in outlining the work and his extensive experience and knowledge of the region have been of the utmost value.

Professor E. C. Case of the University of Michigan spent several days in the field with the writer going over the area and outlining the work. The report has been prepared under the direction and supervision of Professor Case.

The writer was ably assisted throughout the field season of 1927 by Mr. John S. Redfield, Assistant Geologist with the Oklahoma Geological Survey.

Dr. T. W. Stanton of the United States Geological Survey identified the ammonites in a collection made by the writer and offered some valuable suggestions in regard to the work.

Dr. N. H. Darton of the United States Geological Survey furnished data on the New Mexico region.

Mr. W. S. Adkins of the Bureau of Economic Geology, University of Texas, furnished certain information regarding the range of various species of ammonites in the Texas region.

Free use has been made of the wealth of published material on this region, and, insofar as possible, credit is acknowledged in each case.

The maps and charts accompanying this report were drafted by Mrs. Bess Mills-Bullard.

DESCRIPTION OF THE AREAS

In the following discussion the various areas of Lower Cretaceous are considered separately. The southern Oklahoma and northern Texas section, typically exposed near Denison, Texas, is described first and may be taken as the standard section. This is followed by a description of the Lower Cretaceous beds of southern Kansas, western Oklahoma, Colorado, New Mexico, and the Texas Panhandle. The correlation of the various formations with the Texas section is given.

SOUTHERN OKLAHOMA AND NORTHERN TEXAS

Historical Summary

The first important work on the Cretaceous of the Texas region was by Dr. Ferdinand Roemer, a distinguished German geologist, who visited Texas from 1845 to 1847 studying the region with reference to its adaptation to German settlement. Several papers were published giving the results of his studies. They were published both in German and English as follows: Two papers[1] in the American Journal of Science and two volumes in German, the titles[2] of which may be translated as "Texas, with especial reference to German emigration and the physical condition of the county, based upon personal observations", Bonn, 1849, and "The Cretaceous formations of Texas and their organic remains, with a description of the Tertiary and Paleozoic strata appended", Bonn, 1852.

Although the geology of Texas had been alluded to previously by various writers, Roemer deserves credit for presenting the first orderly treatment of the geology of this region, for, as he said at the time of publication, he had been unable to find a "single European or American publication on the peculiar features or distribution of the geologic formations of Texas".

Roemer did not make stratigraphic sections, but mentions in sequence the "Beds at the foot of the Highlands" and the "Beds of the Highlands". In this sequence the geologic column is practically reversed from its normal order, for, due to the Balcones fault, the "Beds at the foot of the Highlands" are younger than the topographically higher "Beds of the Highlands". In later publications Roemer suggests that the topographically higher po-

1. Roemer, Ferdinand, A sketch of the geology of Texas: Am. Jour. Sci., 2nd ser. vol. 2, pp. 358-365, 1846, and Contributions to the geology of Texas: Am. Jour. Sci., 2nd ser. vol. 6, pp. 21-28, 1848.
2. Roemer, Ferdinand, Mit besonderer Ruckicht auf deutsche Auswanderung und die physichen Verhaltnisse des Landes nach eigener Beobachtung geschildert. Mit einem naturwissenschaftlichen Anhange und einer topographisch-geognostischen Karte von Texas: Bonn, bei Adolph Marcus, 1849; and, Die Kreidbildungen von Texas und ihre organischen Einschlusse. Mit einem die Beschreibung von Versteinerungen aus palaozoischen un tertiaren Schichten enthaltenden Anhage und mit 11 von C. Hohe nach der Natur auf Stein gezeicheten Tafeln: Bonn, bei Adolph Marcus, 1852.

sition of the latter may be due to a fault. He did not recognize the Lower Cretaceous, but in accordance with the general usage at that time, considered it all as Upper Cretaceous.

The next observation of importance on the Cretaceous of Texas was made by Dr. G. G. Shumard[3], geologist attached to the expedition for the Exploration of the Red River of Louisiana, along the northern border of the state. He used the term Fort Washita limestone for the beds which he traced from Fort Washita, Oklahoma, to Fort Belknap, Young County, Texas. A report on the fossils collected by the expedition was made by Dr. B. F. Shumard.

Two expeditions sent out by the Federal government to locate a suitable route for a railroad to the Pacific coast crossed portions of Texas and Oklahoma. The first of these, known as the "Thirty fifth parallel survey"[4] followed approximately the course of the South Canadian river across Oklahoma and the Panhandle of Texas. It was accompanied by Professor Jules Marcou as geologist. He made some very important observations, but due to a misunderstanding with Jefferson Davis, Secretary of War, his notes were turned over to Mr. W. P. Blake who prepared the geologic section of the report. Thus the full value of the observations made by Marcou were never realized. However, many of his conclusions were incorporated in a later publication[5].

The second expedition known as the "Thirty second parallel survey" crossed Texas from the vicinity of Denison to El Paso. The notes and collections made by the officers under the direction of Marcou, who did not accompany the party, were turned over to him and he wrote a brief general report[6].

Marcou was the first to recognize the Lower Cretaceous in North America. In 1855 he identified[7] a number of fossils from Texas and western Oklahoma as Neocomian, and asserted that rocks of that age cover considerable areas in Texas and Indian Territory. Marcou maintained the validity of his conclusions in subsequent papers but for several reasons American geologists did not accept his view, although it was essentially correct. This was due in a large measure to the fact that Marcou referred a

3. Expl. Red River of La. in the year 1852, by R. B. Marcy. Capt. 5th Inf., U. S. Army, assisted by Geo. B. McClellan, brevet Capt. U. S. Engineers; with report on the natural history of the country and numerous illustrations. Washington, 1854.
4. Reports of Explorations and Surveys to ascertain the most practicable and economical route for a railroad from the Mississippi River to the Pacific Ocean, made under the direction of the Secretary of War, 1853-'54-'55, vol. 3, Washington, 1856.
5. Marcou, Jules, Geology of North America: Zurich, 1858.
6. Pope, John, Bvt. Capt., Corps of Top. Eng.: Geological notes of a survey of the country comprised between Preston, Red River, and El Paso, Rio Grande del Norte, in report of Exploration of a route for the Pacific Railroad near the thirty second parallel of latitude, from Red River to the Rio Grande: Report of Sec. of War House Document 129, vol. 4, Chap. 13, pp. 125-128, 1855.
7. Pacific Railroad Expedition reports: vol. 4, pp. 40-48, 1855. Republished in the 4th edition of Marcou's "Geology of North America", 1858.

portion of the same series, at Tucumcari Mt., New Mexico, to the Jurassic, and carried on a bitter controversy with American geologists as to the age of this section for nearly 40 years. Further, Roemer's work as well as Shumard's work referred these beds to the Upper Cretaceous.

In 1858 the State of Texas provided for a State Geological Survey and in the same year Dr. B. F. Shumard was named to fill the office of State Geologist. The Shumard survey was of short duration, due to internal friction, and in 1860 Shumard was relieved of his duties as State Geologist. No publications of any import were issued by this survey, but Shumard[8] published elsewhere some very important observations on the Cretaceous strata of Texas which included his now famous "Shumard section". This section is given on page 14 and up to the year 1886 it was quite generally accepted. Shumard's section was a composite section, compiled from the work of his brother G. G. Shumard, whose work in connection with the Expedition for the Exploration of Red River has been mentioned, from that of W. P. Riddell, assistant state geologist under the Shumard survey, and from his own observations. It will be noted that, like Roemer's, the Shumard section is for the most part reversed from the normal order.

The year following the publication of the Shumard section Marcou[9] published a criticism and rearranged it in accordance with his own views. Although Marcou's rearrangement of the section was not accepted, it presented the most accurate interpretation of the succession of formations published to date.

The subject remained in this state until 1887 when the publication of papers by R. T. Hill and C. A. White, based on the field work of the former, established the true succession of beds and showed that there is in Texas a great series of Cretaceous rocks underlying the generally recognized Cretaceous (Upper) of other parts of the country. This is the Comanche series made so familiar through the numerous papers by Hill.

It will be impracticable to follow in every detail the development of the Cretaceous section of Texas by Hill. The various papers which contain the record of this monumental work will be found listed in order in the Bibliography. It will suffice here to state that in 1887 Hill[10] published the first correct section of the Cretaceous of this region. He subsequently made numerous changes, chiefly in nomenclature, and finally in 1901 published

8. Shumard, B. F., Observations on the Cretaceous strata of Texas: Trans. St. Louis Acad. Sci., vol. 4, pp. 582-590, 1860.
9. Marcou, Jules, Notes on the Cretaceous and Carboniferous rocks of Texas: Proc. Boston Sci., vol. 1, pp. 582-590, 1[illegible].
10. Hill, R. T., Texas section of the American Cretaceous: Am. Jour. Sci., 3rd. ser. vol. 34, pp. 287-318, 1887.

his monograph[11] which is today the standard reference on the Cretaceous of Texas. Numerous papers have appeared on this region since 1901, and while some minor changes have been made in the nomenclature, the foundation established by Hill has not been changed.

The pioneer work on the Lower Cretaceous of southern Oklahoma was by J. A. Taff[12] in 1902 and 1903. His classification of the Lower Cretaceous beds of southern Oklahoma is given on page 14. His work formed the basis for future geologic work in Oklahoma. In the earlier stages of the work separate names were used for the formations in Oklahoma and Texas. Recently a movement has been started to apply the same name to formations, regardless of State lines.

General Statement

The Cretaceous rocks of this region have been divided into two major divisions; the Comanche series constituting the lower portion and the Gulf series the upper portion. The lower series is commonly known as the Lower Cretaceous, but by some authors it is considered to be a separate system, which they call the Comanchean, limiting the Cretaceous to the upper division or Gulf series. There seems to be little justification for this usage and consequently the Lower Cretaceous or Comanche series will be here considered as the lower division of the Cretaceous and equal in rank to the Gulf series.

The separation of the Cretaceous into two series is based on both paleontologic evidence and depositional sequence. In 1889 Hill[13] made the following statement in regard to the separation of the two series:

> This separate identity of the two series is shown by (1) the absolute stratigraphic break between them, as can be seen in numerous contacts in the city of Austin and elsewhere; (2) the radical change in character of sediments, as seen along the partings of the Lower Cross Timbers and the Comanche series; (3) the absolute change in life in the two formations, not a single species, as far as known, passing from the Lower series into the Upper, thus indicating a lapse of time between them sufficiently long for an almost complete change of specific characters in the ocean's inhabitants.

The Comanche series is divided into three divisions; beginning with the oldest they are: Trinity, Fredericksburg, and Washita. Each division is divided into formations, which are in turn divided into members and beds. In general it may be said that in southern Oklahoma and northern Texas the Trinity is composed of sand and clay deposited in an encroaching sea on a subsiding land mass; the Fredericksburg is a 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 occillating and in the main, a retreating sea.

11. Hill, R. T., Geography and geology of the Black and Grand Prairies, Texas: U. S. Geol. Survey Twenty-first Ann. Rept. Pt. 7, 1901.
12. Taff, J. A., U. S. Geol. Survey Geol. Atlas Atoka folio (No. 79), 1902; and the Tishomingo folio (No. 98), 1903.
13. Hill R. T., Annotated check list of the Cretaceous invertebrate fossils of Texas: Geol. Survey of Texas, Bull. 4, p. 8, 1889.

The Comanche series has an average thickness of about 1,000 feet in this region.

Stratigraphic column for southern Oklahoma and northern Texas

CRETACEOUS	Gulf series		Navarro formation Taylor marl Austin chalk Eagle Ford shale 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
		Trinity division	Trinity sand

Distribution

The Comanche series has a wide distribution in this region. Its outcrop forms a belt from 25 to 50 miles in width extending from Arkansas westward along the southern boundary of Oklahoma to a point as far west as Ardmore, thence southward in the vicinity of Fort Worth to Austin and San Antonio, then it turns westward again and forms a broad plateau (Edwards) which covers a large area in western Texas and extends into Mexico.

The character of the formations varies from place to place, showing chiefly a change due to their position with respect to the shore line. The off shore phase is well developed in the vicinity of Austin, while the near shore phase is typically represented in southern Oklahoma and northern Texas. The correlation between these two areas is well established, so that in this paper attention is confined to the northern area and the correlation between the two is merely indicated.

*Table showing stages in the development of the Cretaceous section of Texas and Oklahoma.**

(Modified and expanded after Hill)

Dr. F. Roemer, 1846[1].

Made no section or nomenclature but mentions in the sequence given what are known to be the following beds:

Cretaceous of the Highlands

Chalk marls and limestones of
6. Fredericksburg (Edwards and
5. Comanche Peak)
4. Limestone flags with Exogyra texana (Walnut)
2 Chalks with Orbitulina texana and Natica praegrandis (Glen Rose)
10. Yellow clays with Exogyra arietina.
9. White limestone with O. carinata (Washita or Fort Worth)
6 Dolomitic limestone with Requienia texana (Edwards)
6. Yellow limestone with Caprina (Edwards)

Cretaceous at foot of Highlands

Yellow marl with E. ponderosa
15. (Taylor marl)
14. White limestone (Austin chalk)
13. Beds with fish teeth (Eagle Ford)

Dr. B. F. Shumard, 1860[2].

Upper Cretaceous (Mostly Lower)

6. Caprina limestone
4. Comanche Peak group
5.
14. Austin limestone
13. Fish bed.
10. Indurated blue marl (E. arietina)
9. Washita limestone
12. Blue marl
2. Caprotina limestone.

Lower Cretaceous (all Upper)

12. Arenaceous group
13. Fish bed
13. Marly clay or Red River group. To which may be added later discoveries of—
16. Ripley
12. Dakota

Professor Jules Marcou, 1861[3].

(Criticism and rearrangement of Shumard's section)

Senonian (Upper Cretaceous)

14. Austin limestone
13. Fish bed in sandstone
13. Blue marl with I. problematicus

Middle Cretaceous, or Greensand and Turonian.

13. Marley clay or Red River group.
6. Caprina limestone (Edwards)
4. & 5. Comanche Peak group
Superior part with E. texana
10. Exogyra arietina marl.

Lower Cretaceous, or Aptian and Neocomian

9. Washita limestone
2. Caprotina limestone (Glen Rose)

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1. Roemer, F., "A Sketch of the Geology of Texas": Am. Journ. Sci. 2nd ser. Vol. 2, pp. 358-385, 1846.
Also see:
Roemer, F., "Contributions to the Geology of Texas": Am. Jour. Sci., 2nd ser. vol. 2, pp. 21-28, 1848.
Roemer, F., "Die Kreidebildungen von Texas und ihre organischen Einschlusse. Mit einem die Beschreibung von Versteinerungen aus palaozoischen und tertiaren Schichten enthaltenden Anhange und mit 11 von C. Hohe nach der Natur auf Stein gezeichneten Taflen. Bonn, bie Adolph Marcus, 1852. 4°, 100 pp., with plates.
2. Shumard, B. F., Trans. Acad. Sci. St. Louis, vol. 1, pp. 582-589, 1856-1860.
3. Marcou, Jules, "Notes on the Cretaceous and Carboniferous rocks of Texas": Proc. Boston Soc. Nat. Hist., vol. 8, pp. 86-97, 1861.

*NOTE: Material in parenthesis added by the writer. The numbers show proper order of the beds and like numbers show correlation of the beds of the several sections.

Table showing stages in the development of the Cretaceous section. Cont'd.

R. T. Hill, 1886-'93[4].

Upper Cretaceous

Montana division:
18. Washington
17. Brownston
16. White Cliffs
15. Taylor marl (E. ponderosa)
Colorado division
14. Austin chalk
13. Eagle Ford shales
Dakota division
12. Lower Cross Timber sands

Lower Cretaceous

Washita division
Central Texas — North Texas
11. Shoal Creek limestone
10. E. arietina beds. { Main Street, Pawpaw, N. Denison, Marietta }
9. Fort Worth limestone
8., 7. } Preston beds { Duck Creek chalk, Kiamitia clays }
Fredericksburg division
6. Caprina limestone
5. Comanche peak chalk
4. Walnut clay (E. texana beds)
Trinity division
3. Paluxy sands
2. Glen rose beds
1. Trinity sands

NORTH TEXAS (DENISON) SECTION

R. T. HILL, 1901[5].

(with slight simplification of nomenclature by Stephensons, 1918; Ballard[7], 1927.)

Upper Cretaceous

Navarro formation
15. Taylor marl
14. Austin chalk
13. Eagle Ford clay
12. Woodbine sand

Lower Cretaceous

Washita division
11. Grayson marl
10. { Main street limestone, Pawpaw sand, Weno clay, Denton clay }
9. Fort Worth limestone
8. Duck Creek formation
7. Kiamichi clay
Fredericksburg division
6., 5. } Goodland limestone
4. Walnut clay
Trinity division
3., 2., 1. } Trinity sand

SOUTHERN OKLAHOMA SECTION

Joseph A. Taff 1903[8].

Upper Cretaceous

12. Silo sand

Lower Cretaceous

Washita division
11., 10. } Bennington limestone
10. Bokchito formation
9. Caddo limestone
8. Caddo limestone
7. Kiamichi clay
Fredericksburg division
6., 5., 4. } Goodland limestone
Trinity division
3., 2., 1. } Trinity sand

CENTRAL TEXAS SECTION

Hill, R. T., and Vaughn, T W., 1902[9].

Upper Cretaceous

Gulf series
16. Webberville formation
15. Taylor marl
14. Austin Chalk
13. Eagle Ford clay
12. ——missing——

Lower Cretaceous

Comanche series
Washita division
11. Buda limestone
10., 9., 8., 7. } Georgetown limestone
Fredericksburg division
6. Edwards limestone
5. Comanche Peak limestone
4. Walnut clay
Trinity division
3., 2. } Glen Rose formation
1. Travis Peak formation

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4. Hill, R. T., Bull. Geol. Soc. Am., vol. 5, pp. 297-314, 1893.
5. Hill, R. T., "Geography and Geology of the Black and Grand Prairies, Texas": U. S. Geol. Survey 21st Ann. Rept., pt. 7, 1901.
6. Stephenson, L. W., U. S. Geol. Survey Prof. Paper 120, pp. 129-163, 1918.
7. Bybee, H. P., and Bullard, Fred M., Geology of Cooke County, Texas. Uni. of Texas Bull. 2710, 1927.
8. Taff, J. A., U. S. Geol. Sur. Geol. Atlas, Tishomingo folio (No. 98), 1903.
9. Hill, R. T., and Vaughan, T. W., U. S. Geol. Sur. Geol. Atlas, Austin folio (No. 76) 1902.

Stratigraphy

A brief description of each of the formations in the Comanche series of this region is here given. For a more complete discussion the reader is referred to the following reports:

Hill, R. T., Geography and geology of the Black and Grand prairies, Texas: U. S. Geol. Survey Twenty-first Ann. Rept. pt. 7, 1901.

Stephenson, L. W., Contributions to the geology of northeastern Texas and southern Oklahoma: U. S. Geol. Survey Prof. Paper 120, 1918.

Bullard, Fred M., Geology of Love County, Oklahoma: Oklahoma Geol. Survey Bull. 33, 1925.

Bullard, Fred M., Geology of Marshall County, Oklahoma: Oklahoma Geol. Survey Bull. 39, 1926.

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

Bullard, Fred M., Geology of Grayson County, Texas, Mss. to be published as Univ. of Texas Bulletin, 1928.

Additional references will be found in the Bibliography.

COMANCHE SERIES

Trinity Division

The Trinity division is represented in this region by a single formation, the Trinity sand. Farther south, in central Texas, the Trinity is composed of several formations which are mentioned later in the discussion.

TRINITY SAND

The Trinity sand was named by Hill[14] from the Trinity River of central Texas, along which the formation is typically developed. The Trinity sand of southern Oklahoma and northern Texas 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[15], occurring in massive beds 25 to 40 feet in thickness. Clay lentils varying from a few inches to 20 and 30 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 usually contains a conglomerate composed of well rounded quartz grains and pebbles ranging in size from that of a pea up to 2 or 3 inches in diameter.

14. Hill, R. T., Trinity formation of Arkansas, Indian Territory, and Texas: Science, vol. 17, p. 21, 1888.

15. The term "pack sand" as used in this paper refers to a fine grained sandstone with practically no cementing material and so loosely consolidated that it can be readily broken with the hand.

This conglomerate is from 0 to 50 feet in thickness. Directly south of the Arbuckle Mountains it is very coarse and thick. However, throughout most of the extent it is a rather coarse sand which in many places is quartzitic. This phase is well developed in Montague County, Texas, where the basal quartzite forms hills and knolls. It may also be seen to an advantage south of Wilson, Oklahoma, where the resistant basal beds form distinct ridges. It is desired to emphasize the quartzitic character of the basal Trinity for it seems to be quite characteristic of the formation and there will be occasion to refer to this feature again.

Locally the Trinity has some indurated layers, above the basal conglomerate, which project as massive ledges and form hills and escarpments. These ledges are more prominent in the lower half of the formation. They are usually composed of white sandstone, which is a dull gray on weathered surfaces.

The Trinity weathers so easily, forming a mantle of loose debris covering its outcrop, that exposures permitting measurement of a detailed section are extremely rare. From a study of well records it is estimated that the Trinity has a thickness of from 500 to 700 feet in the Red River region.

In central Texas the middle portion of the Trinity becomes calcareous and south of the Brazos River is separable, according to Hill[16], (in ascending order) into the Basement sands, 127 feet; the Glen Rose formation, chiefly limestone, 315 feet; and the Paluxy sand, 190 feet. Still farther south, at Austin, Texas, the Paluxy sand is apparently represented by limestone in the upper part of the Glen Rose so that the Trinity is there divided into two formations; the Travis Peak consisting of conglomerate, grit, sand, clay, and calcareous beds with a thickness of about 100 feet; and the Glen Rose consisting chiefly of limestone with a thickness of about 450 feet.

In southeastern Oklahoma and Arkansas calcareous beds appear in the Trinity indicating that to the east as well as to the south limestone forming conditions prevailed during at least a part of Trinity time.

The Trinity sand weathers to form a rolling topography usually covered by a thick growth of scrub oak and blackjack timber. Where it outcrops with the Goodland limestone overlying steep escarpments and a very rugged topography are developed. Excellent examples of this type may be seen near St. Jo, Montague County, Texas.

16. U. S. Geol. Survey Twenty first Ann. Rept. pt. 7, pp. 153-154; p. 171, 1901.

The Trinity sand, as Hill maintained in his many publications, is, the deposit of a transgressive sea which progressively overlapped to the north, so that much of the Trinity of central Texas is in part at least, older than that of southern Oklahoma. Recently Miser[17] has shown that the same condition prevails in southwestern Arkansas where the upper part of the Trinity overlaps the lower part towards the west. He has described two limestone lentils occurring in the Trinity; the lowest, the Dierks limestone member attains a maximum thickness of 40 feet and in central-southern Arkansas occupies a position about 200 feet above the base of the Trinity but towards the west it occurs lower and lower in the formation and near Dierks, Arkansas, it is only 50 feet above the base. The DeQueen limestone member reaches a maximum thickness of 70 feet and in central-southern Arkansas it overlies the Dierks member, but to the west it occurs lower and lower in the section finally overlapping the Dierks and extending into Oklahoma. At Broken Bow, McCurtain County, Oklahoma, the DeQueen lies directly on the basal gravels of the Trinity.

Paleontology of the Trinity sand: The Trinity sand in southern Oklahoma and northern Texas rarely contains identifiable fossils. In places fossil wood is abundant, but invertebrate remains are seldom encountered. In central Texas a well developed flora[18] and fauna[19] have been described from the Glen Rose limestone. The limestone members of the Trinity, previously mentioned, contain a fauna which, according to Dr. Stanton who identified the fossils, resembles the Glen Rose fauna of central Texas.

The following fossils are listed:[20]

Fossils from the DeQueen limestone member of the Trinity formation of southwestern Arkansas

Serpula paluxiensis Hill
Membranipora sp.
Barbatia parva missouriensis Hill?
Ostrea franklini var camelina Cragin
Ostrea franklini Coquand
Anomia texana Hill
Mytilus tenuitesta Roemer?
Cyprina? sp.
Eriphyla pikensis Hill
Astarte? sp.
Glauconia branneri (Hill)
Glauconia ? sp.

17. Miser, H. D., Lower Cretaceous rocks of Oklahoma and Arkansas: Bull. Am. Assoc. Pet. Geol. vol. 11, no. 5, pp. 443-454, 1927.
18. Fontaine, W. M., Proc. U. S. Nat. Mus., vol. 16, pp. 261-282, 1893; reproduced by Hill in U. S. Geol. Survey Twenty-first Ann. Rept., pt. 7, pp. 165-166, 1901.
19. Hill, R. T., Idem.
20. Miser, H. D., Op. cit. p. 450.

Fossils from the Dierks limestone lentil of the Trinity formation of southwestern Arkansas

Serpula paluxiensis Hill
Nucula sp.
Cucullaea sp.
Barbatia parva missouriensis Hill?
Ostrea franklini Coquand
Exogyra sp.
Anomia texana Hill
Mediola branneri Hill
Astarte? sp.
Eriphyla pikensis Hill
Corbicula arkansaensis Hill
Cardium? sevierense Hill
Glauconia sp.

Fredericksburg Division

The Trinity sand is overlain by the Fredericksburg division, which is represented in southern Oklahoma and northern Texas by the Goodland linestone.

The outcrop of the Goodland limestone parallels in general that of the Trinity sand. It forms a narrow sinuous band, rarely exceeding a few hundred yards in width, extending in a general east-west direction from the southwestern portion of Arkansas across southern Oklahoma until it reaches a point near Ardmore, Oklahoma, where it takes a general southwesterly course for some 50 miles across Cooke County and into Montague County, Texas where its outcrop takes a general southerly direction.

In its southerly extension the Goodland limestone thickens materially and in central Texas is divisible into three rather well defined formations; the Walnut clay, and the Comanche Peak and Edwards limestones which at Austin have a total thickness of 300 feet.

Much confusion has resulted from attempts to recognize the units of the Fredericksburg of central Texas in the southern Oklahoma and northern Texas area, particularly in regard to the Walnut clay. The basal 2 to 4 feet of the Goodland limestone consists of a persistent, hard, thin bedded, nodular limestone containing thin marly layers of shale, and an abundance of *Exogyra texana* Roemer. This basal phase was not recognized by Hill[21] in the type section of the Goodland in Choctaw County, Oklahoma. In speaking of this layer, he says:

> Proceeding westward along the ancient Ouachita shore line from Arkansas into Texas, the *Exogyra texana* beds (Walnut clay) and *Gryphea* breccia are missing until the escarpment is reached north of Marietta, in Chickasaw Nation (Love County) where they first appear, thinly represented beneath the Goodland limestone.

21. Hill, R. T., The Comanche series of the Arkansas-Texas region: Bull. Geol. Soc. America, vol. 2, pp. 503-514, 1891.

In 1894[22] and again in 1901[23] Hill restricted the term Goodland to the massive limestone between the underlying Walnut clay, which he regarded as forming the upper part of the Antlers (Trinity) sand, and the overlying Kiamichi clay. In the Atoka folio and again in the Tishomingo folio, Taff[24] included the Walnut clay in the Goodland limestone, and this usage has since been adopted and followed by others, including the United States Geological Survey. Stephenson,[25] in 1918, although following the usage of Taff, advocates that the original definition of the Goodland, as given by Hill, be followed and that the Walnut clay, or the Walnut shaly member as it is sometimes called, be separated from the massive limestone in accordance with Hill's original usage.

In most exposures in the vicinity of Red River the Walnut clay, is scarcely recognizable. Careful search will usually reveal a few inches to as much as 3 or 4 feet of yellow, nodular, calcareous clay, but in many exposures it is apparently entirely absent. Farther south, however, in the vicinity of Dallas and Fort Worth the Walnut clay assumes the importance of a formation, reaching a maximum thickness of 150 feet. As it is traced still farther south it begins to thin out until at Austin, Texas, its thickness is only 15 feet. Following is the description of the Walnut clay as given in the Austin folio:[26]

> Walnut clay.—At the top of the Glen Rose formation a bed of yellow clacareous clay always occurs, which is extremely rich in two species of oysters: *Exogyra texana* Roemer and *Gryphea marcoui* Hill and Vaughan. Its thickness is from 10 to 15 feet. This is an extremely persistent bed both in its lithologic and paleontologic characters. To it the name Walnut clay has been given. Above these clays is a soft chalky limestone, the Comanche Peak.

Attention is directed to the fact that the Walnut clay is the only horizon in the entire Lower Cretaceous section of Texas in which the oyster, *Exogyra texana* Roemer occurs in abundance. Scattered individuals range both above and below this horizon, but a marked abundance is sufficient to indicate the Walnut clay.

GOODLAND LIMESTONE

The Goodland limestone consists of from 20 to 35 feet of hard, white, semi-crystalline limestone, which weathers to almost a pure white. It is massively bedded, there being as a rule about

22. Hill, R. T., Geology of parts of Texas, Indian Territory and Arkansas adjacent to Red River: Bull. Geol. Soc. America, vol. 5, pp. 303-304, 1894.
23. Hill, R. T., Geography and geology of the Black and Grand prairies, Texas: U. S. Geol. Survey Twenty-first Ann. Rept. Pt. 7, pp. 216-222, 1901.
24. Taff, J. A., U. S. Geol. Survey Geol. Atlas Atoka folio (No. 79), 1902; Tishomingo folio (No. 98), 1903.
25. Stephenson, L. W., Geology of northeastern Texas and southern Oklahoma: U. S. Geol. Survey Prof. Paper 120, p. 135, 1918.
26. Hill, R. T., and Vaughan, T. W., U. S. Geol. Survey Geol. Atlas, Austin folio (No. 76), 1902.

4 beds ranging from 4 to 6 feet in thickness. The lower portion is slightly chalky, while the upper part is a very pure, hard, white limestone. A peculiar 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 into a spongy mass due to the spots of calcite in the limestone which dissolve more readily than the main mass of the rock. This peculiar weathering often gives fragments of the limestone a strange shape, which has been described as that of "old dry bones" or "skull rock".

Section of the Goodland limestone below bridge on Elm Creek, two miles south of Myra, Cooke County, Texas.[27]

	Ft.	In.
KIAMICHI CLAY		
GOODLAND LIMESTONE:		
Limestone, hard massive, white to gray, contains *Turritella* sp., *Gryphea* sp., *Oxytropidoceras acutocainatum* (Shumard)	6	0
Alternating beds of blue shale and soft gray limestone, which form terraces near the top of the Goodland	2	6
Limestone, massive, bluish white, hard, very fossiliferous	2	6
Shale, blue	0	6
Limestone, massive, weathering into small angular fragments, many large *O. acutocarinatum*	4	6
Clay, soft yellow calcareous, having *Grypheas* and small *Exogyra* cf. *E. plexa*	0	1
Limestone, massive gray, weathering into angular fragments; some small *O. acutocarinatum*	4	0
Shale, blue, and brown clay	0	6
Limestone, light gray, containing numerous shell fragments including *Gryphea* sp., and *Neitheas*	2	4
Limestone, yellow arenaceous, irregularly bedded, few fossils	0	4
Limestone, hard massive, bluish gray, containing echinoids, *Grypheas*, *Pectens*, *Turritellas*	6	3
Gryphea agglomerate	0	1
Limestone, massive, weathering into large irregular fragments containing yellow spots on weathered surface. Many fossils	2	3
Shale, white to blue sandy, few *Grypheas*	0	10
Limestone, light yellow nodular, containing large *Pinna* sp., *Neithea* sp., *Gryphea* sp., *Tylostoma* sp., echinoids and gastropods	2	6
Limestone, yellow argillaceous, nodular, with *Gryphea* and *Turritellas* in great abundance, also contains *Artica*, echinoids, and a large *Ostrea* sp.	2	0
Limestone, nodular blue sand, resting directly upon blue yellow (Walnut) clay	0	10
TRINITY SAND	—	—
	38	0

27. Bybee, H. P., and Bullard, Fred M., Geology of Cooke County, Texas: University of Texas Bull. 2710, p. 16, 1927.

Fauna of the Goodland limestone[28]

(Forms marked with an asterisk (*) are index fossils or of such common occurrence as to warrant special mention).

Hemiaster whitei Clark
Hemiaster sp.
*Enallaster texanus Roemer
*Holectypus planatus Roemer
*Salenia mexicana Schlueter
Diplopodia taffi Cragin
Cyphosoma texana
Goniopygus sp.
Engonoceras sp.
Oxytropidoceras sp.
*Oxytropidoceras acutocarinatum (Shumard)
Turritella seriatim-granulosa Roemer
Turritella sp.
Cinulia tarrantensis Cragin
Trichotropis shumardi Cragin
Cylindrites formosus Cragin
Cerithium bosquense Shumard
Tylostoma chihuahuense Boese
Tylostoma tumidum Shumard
Lunatia pedernalis Roemer
Nerinea sp.
Neritina sp.
Rostellaria subfusiformis Conrad
Tubo sp.
Homomya sp. .
Pinna sp. aff. comancheanus (Cragin)
*Protocardia texana (Conrad)
Protocardia filosa (Conrad)
Isocardia sp.
*Cyprimeria texana Roemer
Pecten occidentalis ? (Conrad)
Pecten irregularis (Boese)
Pecten subalpina Boese
*Exogyra texana Roemer
*Exogyra plexa Cragin
*Gryphea marcoui Hill and Vaughan
Pholadomya sancti-sabae Roemer
Ostrea sp. aff. johannae Choffat
Lima wacoensis Roemer
Trigonia sp.
Tapes sp.
Corbula sp.
Trochosmilia texana Conrad
Parasmilia austinensis Roemer

Fauna of the Walnut clay

*Exogyra texana Roemer
*Exogyra weatherfordensis Cragin
*Enallaster texanus (Roemer)
Remondia sp.
*Gryphea marcoui Hill and Vaughan
Salenia sp. aff. mexicana
Turritella sp.
Pecten irregularis Boese
*Trigonia sp.
Oxytropidoceras acutocarinatum (Shumard)
*Holectypus sp. aff. planatus

Washita Division

GENERAL STATEMENT

Overlying the Fredericksburg conformably is the Washita, the highest division of the Comanche series. The term Washita was applied to this division by Hill[29] from old Fort Washita, Bryan County, Oklahoma, which has become famous in the history of Cretaceous stratigraphy through the observations made there by Marcou and Shumard.

28. After Winton, W. M., and Adkins, W. S., Geology of Tarrant County, Texas: University of Texas Bull. 1931, 1919.
29. Hill, R. T., Annotated check list of the Cretaceous invertebrate fossils of Texas: Geol. Survey of Texas Bull. 4, 1889.

The Washita division is composed of marine shaly clays, marls, and subordinate limestones, having a total thickness of approximately 400 feet in southern Oklahoma and northern Texas. Towards the top there is a sandy formation, the Pawpaw, which is the only marked exception to the non-sandy character of this division. The limestones, although subordinate to the clays in thickness, form several definite horizons that contain characteristic fossils and are readily traceable throughout the area, and for this reason are of the utmost importance in determining the stratigraphic sequence and structure of the region.

The Washita division has been subdivided by Hill[30] and also by Taff.[31] The classification used in this paper is essentially that established by Hill, except that several of the apparently unnecessary group terms have been omitted and the members of these groups described as formations.

The Washita represents the withdrawal of the Comanche sea which reached its maximum in the preceding epoch, the Fredericksburg, or during the early part of the Washita. This shallowing of the sea is recorded in the increase of clay and shaly material towards the top and the final deposition of sand. The sandy layers of the Washita division bear evidence of shallow water deposition in the form of ripple marks and cross-bedding. It is believed that at the end of Washita time the sea retreated entirely from the area and a short erosional interval, indicated by a slight disconformity, intervened between the Comanche series and the Gulf series. This disconformity is of minor importance near Denison, Texas, but it increases in magnitude to the east until in Arkansas it indicates the removal of all of the Washita and Fredericksburg sediments and the Upper Cretaceous beds rest directly upon the Trinity sand.

The following formations of the Washita division have been recognized in southern Oklahoma and northern Texas. The type section for this region may be seen near Denison, Texas.

Washita Division in southern Oklahoma and northern Texas.

Washita Division	Grayson marl
	Main Street limestone
	Pawpaw sand
	Weno clay
	Denton clay
	Fort Worth limestone
	Duck Creek formation
	Kiamichi clay

30. Hill, R. T., Geography and geology of the Black and Grand prairies, Texas: U. S. Geol. Survey Twenty-first Ann. Rept. pt. 7, pp. 240-292, 1901.
31. Taff, J. A., U. S. Geol. Survey Geol. Atlas, Atoka folio (No. 79), 1902, and the Tishomingo folio (No. 98), 1903.

KIAMICHI CLAY

The Kiamichi clay was named[32] for the Kiamichi River of southeastern Oklahoma. It was in the valley of this river that Dr. Pitcher collected the now famous *Gryphea pitcheri* of Morton in 1827, the first fossil of the Comanche series to be described. The Kiamichi clay, which includes all the sediments between the Goodland limestone and the Duck Creek formation is easily recognized due to its position between two relatively hard, resistant, limestone formations. It is composed of about 35 feet of dark yellow to olive green to black shaly clay with thin platy lenses of a yellow siliceous limestone in the basal portion; at the top the formation is marked by two or three ledges of a hard yellowish shell breccia made up of *Gryphea navia* Hall and *Gryphea corrugata* Say. This *Gryphea* conglomerate is always present at the top of the Kiamichi, the individual beds ranging from a few inches up to three feet in thickness. It is confined entirely to this one horizon and is probably the most characteristic horizon in the entire Comanche series.

There has been more or less uncertainty as to whether the Kiamichi clay should be placed at the top of the Fredericksburg or at the base of the Washita. Hill, in his earlier publications, drew the boundary between the Fredericksburg and Washita "above the zone of *Ammonites acutocarinatus* (now *Oxytropidoceras acutocarinatum*) Shumard, which has been referred to *A. peruvianus* von Buch". [33]

Such a division would place the Kiamichi in the Fredericksburg. Later Hill changed his opinion in regard to the boundary between these two divisions, drawing it on the occurrence of *Nerinea* and *Rudistes* forms, which places the Kiamichi in the Washita. This usage has been quite generally adopted and in the dominantly limestone area of central Texas it seems to be very satisfactory, but in the marginal areas it has given rise to much confusion.

Taff, in a statement quoted by Hill[34], recognized that the Kiamichi clay would not fit in the adopted classification.

> In considering some of its (Kiamichi) fossil remains, like *Exogyra texana* and *Schloenbachia belknapi*, Taff has expressed doubts as to whether this formation in the areas of its marginal extension could be separated sufficiently from the Fredericksburg to give it the status of a distinct formation.

Such difficulties as Taff suggests have been encountered in the marginal areas. Stanton and Vaughan[35] in their study of the section at El Paso, Texas, experienced difficulty in separating the Fredericksburg and Washita. The following sentence is quoted from their report:

> The evidence of the fossils taken altogether is in favor of the view that part of the Fredericksburg is represented here and that it grades into the basal Washita so imperceptibly that no paleontologic line can be drawn between them.

32. Hill, R. T., The Comanche series of the Arkansas-Texas region: Bull. Geol. Soc. Am., vol. 2, p. 503, 1891.
33. Hill, R. T., U. S. Geol. Survey Twenty-first Ann. Rept. pt. 7, p. 257, 1901.
34. U. S. Geol. Survey Twenty-first Ann. Rept. pt. 7, p. 257, 1901.
35. Stanton, T. W., and Vaughan, T. W., Section of the Cretaceous at El Paso, Texas, Am. Jour. Sci., 4th ser. vol. 1, pp. 21-27, 1896.

Attention is also called to the controversy in regard to the correlation of the Lower Cretaceous of southern Kansas which was started about 35 years ago. Some writers maintained that it should be placed in the Washita while others referred it to the Fredericksburg, and even to this day it is a question open to dispute.

Recently Adkins[36] has returned to Hill's original definition of the Fredericksburg, that is drawing its upper limit on the occurrence of *Oxytropidoceras* sp., which places the Kiamichi in the Fredericksburg rather than the Washita. The writer is not qualified to pass on the wisdom of this suggestion, but it is necessary to admit that the division finally adopted by Hill, based on the occurrence of *Rudistes*, has led to much confusion in correlation, particularly in the outlying sections.

The following section, measured near Red River, is typical of the formation:

Section of the Kiamichi clay on Shawnee Creek immediately below the City Lake Dam on the Public Highway, four miles northwest of Denison, Grayson County, Texas

	Ft.	in.
DUCK CREEK FORMATION		
KIAMICHI CAY		
Limestone, hard gray, filled with *Gryphea navia* Hall and *G. corrugata* Say	0	3
Shale, light chocolate colored	0	3
Limestone, hard gray, filled with *Gryphea navia* Hall and *G. corrugata* Say	1	0
Shale, bituminous, light gray color, containing thin bands of ferruginous material	2	6
Shell conglomerate, light blue, containing *Ostrea* sp., *Pecten* sp., and *Grypheas*, with the latter predominating	0	9
Shale, dark blue bituminous, thinly laminated with streaks of ferruginous clay containing flakes of gypsum. Contains some thin layers of a hard blue arenaceous limestone	3	5
Limestone, hard gray, with a considerable number of *Gryphea navia* Hall. The lower 5 inches is loosely consolidated and contains few shells	0	10
Shale, dark blue bituminous, thinly laminated, with streaks of ferruginous clay containing flakes of selenite. The bituminous clay also has flakes of selenite between the laminae. Rather abundant fauna of small pelecypods	4	6

(Continued on next page.)

36. Adkins, W. S., Geology and Mineral Resources of the Fort Stockton Quadrangle: Univ. of Texas Bull. 2738, 1927.

Section of Kiamichi Clay, Cont'd.

Limestone, hard bluish gray, slightly arenaceous; weathers to a yellowish brown	0	2
Shale, dark olive to drab colored, containing small veins of ferruginous material; grades upward into dark gray shale	22	9
GOODLAND LIMESTONE		
	36	5

Fauna of the Kiamichi clay

(Forms marked with an asterisk (*) are index fossils.)

Cyprimeria texana (Roemer)
*Gryphea navia Hall
*Gryphea corrugata Say
Gryphea washitaensis Hill
Homomya sp.
Isocardia sp.
Exogyra texana Roemer
Exogyra plexa Cragin
Avicula leveretti Cragin
Ostrea sp.
*Oxtropidoceras belknapi (Marcou)
Oxytropidoceras acutocarinatum (Shumard)
Pecten subalpina Boese
Protocardia texana (Conrad)
Pinna sp.
Plicatula sp.
Trigonia sp.

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, Texas. The Duck Creek consists of approximately 100 feet of limestone and gray to grayish blue calcareous shaly clay. In the lower 30 to 40 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 60 to 70 feet the clay greatly predominates, the limestone layers becoming thinner and separated by a greater thickness of clay.

The contact between the Duck Creek and the overlying Fort Worth limestone has been placed at different horizons by various writers, resulting in a great variation in the thickness assigned to these formations. There is no sharp break between these two formations but rather a gradation from clay or marl into a marly limestone. In the upper part of the Duck Creek thin beds of limestone, varying from one-half inch up to 2 or 3 inches in thickness, are separated by several feet of clay. These limestone beds gradually become thicker and more numerous and the clay beds become thinner until the formation becomes dominately limestone. With the shifting of the contact first one way and then another the thickness assigned to the Duck Creek and Fort Worth varies accordingly. However, the total thickness of the two formations is fairly constant, so that by comparing the figures given for each formation it is possible to account for the disagreement in thickness as recorded by different writers.

Taff[37] combined the Duck Creek and Fort Worth in southern Oklahoma to form the Caddo limestone. In some cases it is difficult to determine the exact contact between these two formations but in general they are easily identified as each carries an abundant and a characteristic fauna.

37. Taff, J. A., U. S. Geol. Survey Geol. Atlas, Atoka folio (No. 79), 1902; Tishomingo folio (No. 98), 1903.

The following section by Stephenson is typical of the formation:

Section on Duck Creek and in cut of the St. Louis and San Francisco Railroad two and three-quarter miles north of Denison, Grayson County, Texas[38]

	Feet
FORT WORTH LIMESTONE:	
Limestone, nodular, impure, argillaceous and fossiliferous, in four or five layers interbedded with gray shaly clay	8
DUCK CREEK FORMATION:	
Clay, gray shaly calcareous, with interbedded layers of impure non-ledge forming limestone at intervals of 2 or 3 feet	22
Concealed (probably shaly clay)	20
Clay, greenish-gray calcareous from which weather numerous specimens of *Plicatula* cf., *P. incongrua* Conrad, and small rusty ammonites, probably young of *Pachydiscus* and *Schloenbachia*, also a few specimens of *Gryphea washitaensis* Hill	15
Limestone, ledges with interbedded layers of gray shaly clay, poorly exposed; the limestone, especially one layer near top, contains numerous keeled and non-keeled ammonites, many of which are of large size (maximum 2 feet in diameter)	20
Limestone and gray shaly clay, in alternate beds, ammonite bearing, well exposed in bluff along creek	20
KIAMICHI CLAY	
	105

Fauna of the Duck Creek formation[39]

(Forms marked with an asterisk (*) are important index fossils.)

Ostrea subovata? Shumard
Gryphea corrugata Say (base only)
Pecten texanus Roemer
Pecten subalpina Boese
Pecten bellua Cragin
Lima wacoensis Roemer
*Inoceramus comancheanus Cragin
Inoceramus munsoni Cragin
Trigonia sp.
Pholadomya sp.
Turritella sp.
Pleurotomaria austinensis Shumard
Cerithium sp.
Crania sp.
Nerinea sp.
Lunatia sp.
Oxytropidoceras belknapi (Marcou) (base only)
*Hamites fremonti Marcou
*Hamites comancheansis Atkins and Winton
Scaphites sp.
Turrilites sp.
*Desmoceras brazoense (Shumard)
Kingena wacoensis (Roemer)
Diplopoda sp.
Hemiaster whitei Clark
Holaster simplex Shumard (top only)
Hemiaster elegans Shumard (top only)
Gryphea washitaensis Hill
*Pervinquieria trinodosa (Boese)
Plicatula cf. incongrua Conrad

38. Stephenson, L. W., Geology of northeastern Texas and southern Oklahoma: U. S. Geol. Survey Prof. Paper 120, p. 139, 1918.
39 After Winton, M. W., and Adkins, W. S., Geology of Tarrant County, Texas: University of Texas Bull. 1931, 1919.

The lower portion of the Duck Creek, which has been described previously, contains an abundance of fossils, while in the upper portion fossils are comparatively rare. Probably the most outstanding fossil of the entire Comanche series is a large non-keeled ammonite, *Desmoceras brazoense* (Shumard), which is found near the top of the lower portion of the Duck Creek, limited to a vertical range of less than 10 feet. The zone of *Hamites* and *Inoceramus* occurs below the "large ammonite" horizon.

FORT WORTH LIMESTONE

Overlying the Duck Creek formation is the Fort Worth limestone, named from the city of Fort Worth, Texas, where it may be seen typically exposed along the streets. The Fort Worth limestone is readily separated into three parts; the lower portion consists of from 10 to 15 feet of a yellowish white limestone and grayish to blue shaly clay; the middle portion is chiefly shale and also ranges from 10 to 15 feet in thickness; the upper portion is predominately a limestone with thin layers of shaly clay and ranges in thickness from 15 to 20 feet. The limestone of the Fort Worth is a hard, cream colored limestone, very similar to the more massive beds in the lower portion of the Duck Creek. The lithologic resemblance between the lower portion of the Duck Creek and the Fort Worth makes it difficult to distinguish between the two formations except by the fossils contained. However, characteristic fossils are abundant in each formation and a separation on this basis is easily made.

The thickness of the Fort Worth varies from 40 to 50 feet.

Fauna of the Fort Worth limestone[40]

(Forms marked with an asterisk (*) are index fossils, or of such common occurrence that special attention is called to them.)

*Gryphea washitaensis Hill
*Exogyra americana Marcou (top)
Ostrea subovata ? Shumard
Ostrea carinata Lamarck (rare, top)
Plicatula sp.
Pecten subalpina (Boese)
Pecten wrighti (Shumard)
Pecten bellula Cragin
Pinna sp.
Trigonia sp.
Pachymya sp.
Pteria sp.
Remondia robbinsi (White)
Tapes sp.
Protocardia texana (Conrad)
Lima wacoensis Roemer
Lima sp.
Pholadomya shuttuchi Boese
Turritella marnochi White
Turritella seriatim granulosa Shumard
Pleurotomaria austinensis Shumard
Cinulia sp. aff. tarrantensis
*Nautilus texanus Shumard (top)
Enallaster texanus (Roemer)
*Holaster simplex Shumard
*Hemiaster elegans Shumard
Epiaster aguilerae Boese
Ophioglypha texana Clark
Trochosmilia sp.
Serpula sp.
Lamma sp.
*Pervinquieria leonensis (Conrad)
Pervinquieria aff. inflata

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

Following is a typical section of the formation:

Section of the Fort Worth limestone on branch of Duck Creek one mile north of Denison, Texas. Base of section just below tank on Tobin's Stock Farm.

	Ft.	in.
DENTON CLAY		
FORT WORTH LIMESTONE:		
Alternating layers of massive white limestone and thin beds of clay. The limestone layers are much thicker than those lower in the section, and contain iron stains. There are numerous fossils including *Gryphea washitaensis* Hill, *Pervinquieria leonensis* (Conrad), *Holaster simplex* Shumard, *Hemiaster elegans* Shumard, *Exogyra americana* Marcou, and some *Sphenodiscus* like forms. At the top there is a thin bed of fossiliferous marl which grades into the Denton	19	0
Thick beds of clay shale with thin altenating beds of impure limestone containing the following fossils: *Pervinquieria leonensis* (Conrad), *Holaster simplex* Shumard, *Gryphea washitaensis* Hill, and *Pecten* sp.	19	0
White limestone containing *Pervinquieria* sp. and *Hemiaster* sp.	0	6
Light gray shaly clay containing iron stains; also some small specimens of *Gryphea washitaensis* Hill	3	9
Impure yellowish limestone containing fucoids	1	0
Clay shale, blue	2	6
Light blue shaly limestone	0	5
Blue clay shale	1	2
Impure chalky limestone	0	9
Blue clay shale	0	10
Hard blue impure limestone containing traces of ferruginous material which gives the ledge a rusty color. The bed contains many large fucoids on its under surface	1	0
Blue clay shale with several thin ferruginous bands; contains several specimens of a small *Gryphea washitaensis* Hill	1	4
White, impure, chalky limestone, slightly arenaceous	1	2
DUCK CREEK FORMATION		
	52	5

The top of the Fort Worth is usually characterized by a marked abundance of *Gryphea washitaensis* Hill. This is the lowest horizon where this particular *Gryphea* has been noted in abundance, although it ranges throughout the Washita division. *Exogyra americana* Marcou is easily identified due to its size and is a valuable marker for the top of the Fort Worth. The two echinoids, *Holaster simplex* Shumard and *Hemiaster elegans* Shumard, begin in the upper part of the Duck Creek, but their zone of abundance is in the Fort Worth usually near the middle of the formation.

DENISON FORMATION

The Fort Worth limestone passes upward into a group of sediments of various aspects laid down in shallower water and characterized by certain well marked paleontologic zones. They are for the most part, near shore, littoral deposits, some of which have no traceable representative farther south than north-central Texas, and arenaceous and argillaceous formations in southern Oklahoma grade into marls and limestones in central Texas. The effect of this gradation may be seen by comparing the thickness of the Washita division in southern Oklahoma and central Texas. In southern Oklahoma and northern Texas the Washita division, as previously stated, is composed chiefly of shaly clays, marls, and subordinate amounts of thin limestones, with an average thickness of about 400 feet; while in the vicinity of Austin, Texas it is represented by three formations; the Georgetown limestone, the Del Rio clay, and the Buda limestone, having a total combined thickness of approximately 160 feet.[41]

Hill's description of the beds which make up the Denison formation in the Denison area, which he states may be considered the type locality for north Texas and Indian Territory, is as follows:[42]

> In this region it consists of laminated ferruginous clays, sandy clays, impure limestones (littoral breccia) and sand. These beds are all characterized by strong ferruginous colors peculiar to near shore deposits, which appear only faintly, if at all, in the lower lying Comanche series, or the extension of the Denison beds south of the Brazos, while the white chalky element is entirely absent.
>
> In the Denison section the beds consist of about 300 feet of ferruginous dark colored clays and sands, free from the lighter colored calcareous (chalky) element of the underlying beds, with occasional conspicuous indurated layers of impure limestone, ferruginous sandstone, iron ore, and clays, which lie between the top of the Fort Worth limestone and the Grayson marl.

Hill applied the term Denison beds to a portion of this series and then divided it into a number of members. In this regard he says:[43]

> In a general manner the Denison beds may be subdivided into three conspicuous subgroups; the lower, middle, and upper.
>
> The lower subgroup of the Denison beds, including all that portion below the top of the *O. carinata* horizon, will be generally alluded to as the Denton beds.
>
> The medial or Weno subgroup of the Denison beds, including all that portion above the *O. carinata* horizon and beneath the Main Street limestone, for convenience will be divided into the Weno and Pawpaw formations. For the upper subgroup consisting of the Main Street limestone and the Grayson marl, the term Pottsboro may be used.

41. Hill, R. T., and Vaughan, T. W., U. S. Geol. Survey Geol. Atlas, Austin folio (No. 76) 1902.
42. Hill, R. T., U. S. Geol. Survey Twenty-first Ann. Rept. pt. 7, p. 266, 1901.
43. Hill, R. T., Idem. p. 267.

Stephenson[44] in his work accepted Hill's subdivision of the beds but simplified his nomenclature somewhat by discarding all the subgroup names, calling the whole series the Denison formation with the following members:

DENISON FORMATION

Grayson marl member
Main Street limestone member
Pawpaw sandy member
Weno clay member
Denton clay member

Taff[45] grouped all the beds in southern Oklahoma lying below the Main Street limestone (which he called Bennington) and above the Fort Worth limestone under the name Bokchito formation. In recent reports[46] the Bokchito has been separated into the three subdivisions recognized in Texas; namely, the Denton, Weno, and Pawpaw members respectively. The Main Street and Grayson are described as separate formations. In order to further simplify the already complicated nomenclature of these beds, all unnecessary terms have been dropped and the following formations described:

Grayson marl
Main Street limestone
Pawpaw sand
Weno clay
Denton clay

While it is recognized that these beds have a certain unity or similarity both in lithologic and paleontologic characteristics, it is believed that the dropping of all unessential terms is justified.

DENTON CLAY

In southern Oklahoma and northern Texas the Denton consists of from 40 to 60 feet of brownish yellow clay containing numerous sandstone beds and lenses, terminated at the top by a hard, brownish yellow, arenaceous limestone filled with fossils. This is the "*Ostrea carinata* horizon" of Hill.

The lower 5 to 10 feet is usually a decidedly calcareous clay grading upward into the typical brownish ferruginous clay of the Denton. The first horizon, and in fact the only horizon except the "*Ostrea carinata* bed", which can be recognized in the Denton is a sandstone bed near the middle of the formation. It is from one to two feet in thickness, thinly laminated, a yellowish brown on weathered surface and usually exhibiting well de-

44. Stephenson, L. W., U. S. Geol. Survey Prof. Paper 120. 1918.
45. Taff, J. A., U. S. Geol. Survey Geol. Atlas Atoka folio (No. 79), 1902; Tishomingo folio (No. 98). 1903.
46. Bullard, Fred M., Geology of Marshall County, Oklahoma: Oklahoma Geol. Survey Bull. 39, 1926.

veloped ripple marks. It is practically the only indurated layer in the Denton and can be used to advantage in mapping, as it is easy to locate by the large slabs of the sandstone frequently covering the slope of a small escarpment or bench which it forms. The top of the Denton, as has been stated, is marked by a very fossiliferous impure limestone, the "*Ostrea carinata*" horizon of Hill. However, in southern Oklahoma the principal fossil observed in this bed is *Gryphea washitaensis* Hill, and only a few, scattered individuals of *Ostrea carinata* Lamarck are observed. Farther south *Ostrea carinata* Lamarck becomes very abundant and in places makes up the principal mass of the rock.

Section of the Denton clay on the east bank of Red River one-half mile south of the mouth of the Washita River, Bryan County, Oklahoma[47]

WENO CLAY, exposed on slope of hill.

DENTON CLAY:

	Feet
Limestone, shaly, argillaceous, containing an abundance of *Gryphea washitaensis* Hill	1
Limestone, hard, brownish yellow, containing numerous *Gryphea washitaensis* Hill, plates and spines of a large echinoid, probably *Leiocidaris hemigranosus* (Shumard), and a few specimens of *Ostrea carinata* Lamarck	1
Clay, brownish yellow to greenish	17
Sandstone, hard, thinly laminated, brownish yellow, containing an abundance of well preserved ripple marks	1
Clay, brown to green, calcareous at base and with numerous thin beds and lenses of soft non-ledge forming sandstone in upper part	26
	46

FORT WORTH LIMESTONE

The Denton is somewhat variable in thickness, even over rather limited areas. It has been noted that practically all the variations occur in the interval between the "ripple marked" sandstone and the top of the formation. In some sections the sandstone bed lies within a few feet of the top and in others near the middle of the formation. The interval between the sandstone and the top of the Fort Worth is fairly constant. The Denton attains a thickness of 60 feet on Red River north of Gainesville, Texas, 56 feet in Marshall County, Oklahoma, and from 30 to 35 feet in Grayson County, Texas. It is reported to be 25 feet in thickness at Fort Worth, Texas.

47. Bullard, Fred M., Geology of Marshall County, Oklahoma: Oklahoma Geol. Survey Bull. 39, p. 37, 1926.

Fauna of the Denton Clay

(Forms marked with an asterisk (*) are index fossils or of such common occurrence as to deserve special mention.)

*Leiocidaris hemigranosus Shumard (chiefly plates and spines)
*Ostrea carinata Lamarck
*Gryphea washitaensis Hill
Ostrea quadriplicata Shumard
Ostrea marcoui Boese
Pecten subalpina Boese
Pecten texanus Roemer
Nautilus texanus Shumard
Lima wacoensis Roemer
Protocardia texana Conrad
Trigonia emoryi Conrad
Plicatula sp.
Gervilliopsis invaginata Conrad
Nucula sp.
Tapes sp.
Tapes dentonensis Cragin
Turritella sp.
Ostrea subovata Shumard

WENO CLAY

The Weno is very similar to the Denton in lithologic characteristics. It contains perhaps more soft sandy layers and also a greater abundance of clay ironstone concretions. The Weno, like the Denton, is quite variable in thickness, probably averaging about 100 feet for the Red River region. The greatest thickness noted for the Weno is in Marshall County, Oklahoma, where it is 135 feet. In Cooke and Grayson counties, Texas, it is about 90 feet in thickness, but as the formation is traced southward it thins rather rapidly being about 65 feet at Fort Worth.

The top of the Weno is marked by a very sandy, flaggy limestone, usually about 4 feet in thickness which Hill called the Quarry limestone, because it was widely quarried for building purposes. The term limestone is somewhat of a misnomer because in the Red River region the typical "Quarry" is more of a sandstone than a limestone. Hill's description of the "Quarry" is as follows:[48]

> Quarry Limestone.—This is a persistent band of siliceous limestone, which is notable in the series of otherwise unconsolidated beds and is the chief building stone in the country underlain by the Denison beds. Its interior portion is a steel blue in color, but it oxidizes for a depth of 2 or 3 inches from the surface into chrome yellow. Its thickness at Denison is about 1.7 feet. This is an especially conspicuous formation within the relatively limited area of its occurrence, although at no place over 2 or 3 feet in thickness. It is very arenaceous and might as well be considered a sandstone as a limestone. It is accompanied above by great quantities of the peculiar *Ostrea quadriplicata*.

The following section of the Weno, measured in Cooke County, Texas, will show the character of this formation.

48. U. S. Geol. Survey Twenty-first Ann. Rept. pt. 7, p. 275, 1901.

Section of the Weno clay at Hampton Hollow, about 2 miles from the toll bridge on Red River, north of Gainesville, Cooke County, Texas[49]

PAWPAW SAND
WENO CLAY:

	Ft.	in.
"Quarry limestone"—arenaceous, flaggy limestone, brownish yellow in color, containing an abundance of *Ostrea quadriplicata* Shumard and *Ostrea subovata Shumard*	4	0
Blue to yellowish brown clay marl, contains a bed of ferruginous material carrying an abundance of fossils, especially *Turritella* sp. 15 to 20 feet below the Quarry	38	0
Light yellow flaggy limestone	1	0
Blue to brown clay marl	30	0
Sandstone, soft, light yellow	0	6
	73	6

DENTON CLAY

It has been noted that the ferruginous layer, mentioned in the preceding section, which contains an abundance of *Turritella* sp., as well as other fossils, such as *Nucula* sp., *Protocardia texana* (Conrad), *Cyprimeria* sp., *Corbula* sp., *Cymbopora* sp., *Anchura mudgeana* White, *Engonoceras serpentinum* (Cragin), occurs below the "Quarry limestone". Similar beds occur in the Pawpaw; but unlike those of the Weno, they usually consist of a mass of small pelecypods, and contain only an occasional *Turritella* sp. This fact is sometimes of great assistance in recognizing the Quarry, and in so doing establishing the top of the Weno.

PAWPAW SAND

The Weno clay is overlain by about 50 feet of irregularly bedded sandy clays to which Hill gave the name Pawpaw. The Pawpaw is here restricted to those sediments lying between the "Quarry limestone" below and the Main Street limestone above. Stephenson[50] included the "Quarry" with the Pawpaw, but in this paper it is considered as the top of the Weno in accord with Hill's original usage.

Following is Hill's description of these beds in the Denison area[51]:

> *Pawpaw beds.*—These include the strata between the "Quarry" and the Main Street limestones. In the Denison section these are very impure laminated sandy clays and sands, dark blue and bituminous in places, oxidizing surficially into brown ferruginous colors, very much like the Woodbine (Dakota) formation. They are very sandy in the upper 5 feet at the crossing of Pawpaw Creek and the Texas Central Railway. This aspect is local, however. There are also small fragments of lignite in the sands and the character of the sediments seems to be favorable to the preservation of leaf impressions, but careful search up to date has failed to discover these.
>
> The Pawpaw is the most impure of all the Denison beds, and was apparently laid down near shore, being accompanied by beds of ferruginous sand, which are not elsewhere found in the Washita division. The total thickness at Denison is 45 feet.
>
> At the base of the Pawpaw, just above the Quarry limestone, are lead colored shales with sandy alternations containing innumerable well preserved calcareous shells, which in some places are replaced by pseudomorphs of iron ore. One band, just above the Quarry limestone, consists of one foot or more of impure, friable ferruginous material, containing beautifully preserved fossils. These fossils are especially abundant in the lower 12 feet and consist of littoral Mollusca of many species.
>
> In certain clay layers the calcareous shells are preserved with all their pearly luster. In sandy layers where ferruginous percolation has taken place the shell substance is dissolved and they are preserved as casts and moulds in an arenaceous matrix of limonitic iron-stone.

49. Bybee, H. P., and Bullard, Fred M., Geology of Cooke County, Texas: University of Texas Bull. 2710, p. 34, 1927.
50. U. S. Geol. Survey Prof. Paper 120, 1918.
51. U. S. Geol. Survey Twenty-first Ann. Rept. pt. 7, p. 276, 1901.

Section of Pawpaw sand on west bluff of Washita River, due east of Woodville, Marshall County, Oklahoma[52]

MAIN STREET LIMESTONE—caps bluff.
PAWPAW SAND:

	Feet
Sandstone, soft yellowish to brown, containing numerous veins of limonite. The limonite weathers out and covers the surface. The sandstone grades downward into a yellowish clay	38
Clay, blue to yellow, containing ironstone concretions similar to those in the lower part of the Weno. Thin beds of soft yellow sandstone occur throughout	22
	60

WENO CLAY

While the Pawpaw is called a sand it should be noted that it contains, especially in the lower part, many clay beds which may be easily confused with the Weno. The upper part of the Pawpaw is usually dominantly sand, highly ferruginous, and cross-bedded. The iron usually occurs as a thin sheet between the bedding planes, or filling fissures which cut the sand at every angle. This portion of the Pawpaw is very similar to the Woodbine, with which it is frequently confused.

The Pawpaw weathers to a very sandy soil containing many iron concretions and segregations. Sometimes small hills are capped by a residual mass of limonite which has accumulated from the weathering of the Pawpaw. This again is a feature very characteristic of the Woodbine sand.

52. Bullard, Fred M., Geology of Marshall County, Oklahoma: Oklahoma Geol. Survey Bull. 39, p. 43, 1926.

Section of the Pawpaw sand in roadside cut two and one-half miles southeast of Gainesville, Cooke County, Texas[53] *(Section by M. W. Winton)*

	Feet
MAIN STREET LIMESTONE	
Massive white limestone	6.0
PAWPAW SAND:	
Alternating red ironstone and ferruginous sandy clay layers. About 16 compact ironstone layers each 3 to 4 inches thick, alternating with clay layers about one foot thick. The ironstone layers are similar from top to bottom and the basal 10 feet is more fossiliferous than the upper portion. The ironstone layers contain: *Remondia* sp., *Trigonia* sp., *Arca* sp., *Engonoceras* sp., *Nucula* sp., *Corbula* sp., and other *nacreous* and ironstone fossils	21.5
Sandstone, brown flag layer	0.5
Ironstone, brown layer with *Nodosaria texana*	0.3
Clay, brown	5.0
Clay, red, with *Arca* sp., *Ostrea quadriplicata*	0.5
Clay, red sparsely fossiliferous; *Arca* sp., gastropods	15.0
Sandstone, red calcareous; *Ostrea quadriplicata*	2.0
WENO CLAY (Quarry limestone)	44.8

Fauna of the Weno and Pawpaw formations[54]

	Weno	Pawpaw
Trochosmilia sp.	*	*
Hemiaster calvini Clark	*	*
Hemiaster sp.	*	*
Enallaster bravoensis Boese	*	*
Enallaster texana ? Roemer	*	*
Holaster sp.	*	*
Cottaldia sp.	*	
Leiocidaris hemigranosus (Shumard)	*	*
Nodosaria texana Conrad	*	*
Pentagonaster sp.	*	
Turritella sp.	*	
Cinulia sp.	*	
Anchura mudgeana White	*	*
Turbo sp.	*	*
Trochus sp.	*	*
Schloenbachia sp.	*	*
Schloenbachia sp. aff. inflata	*	*
Hamites sp.	*	
Engonoceras serpentium (Cragin)	*	*
Nautilus texanus Shumard	*	
Homomya sp.	*	
Pecten subalpina Boese	*	*
Pecten texanus Roemer	*	
Plicatula sp.	*	

53. Adkins, W. S., The Weno and Pawpaw formations of the Texas Comanchean: Univ. of Texas Bull. 1856, 1920.
54. After Winton, M. W., and Adkins, W. S., Geology of Tarrant County, Texas: Univ. of Texas Bull. 1931, 1919.

Fauna of the Weno and Pawpaw formations, Cont'd.

	Weno	Pawpaw
Corbula sp.	*	*
Tapes sp.	*	
Nucula sp.	*	
Cymbopora sp.	*	*
Astarte acuminata	*	*
Protocardia texana (Conrad)	*	*
Ostrea quadriplicata Shumard	*	*
Ostrea carinata Lamarck	*	*
Gryphea washitaensis Hill	*	*
Trigonia sp.	*	*
Gervilliopsis invaginata (White)	*	
Ostrea sp. near marcoui	*	
Lima sp.	*	
Lamna sp.	*	
Oxyrhina sp.	*	
Cyprimeria sp.	*	
Sphenodiscus sp.	*	

MAIN STREET LIMESTONE

The Main Street limestone, so named by Hill because it outcrops on the main street of the city of Denison, Texas, immediately overlies the Pawpaw sand. It consists of from 10 to 20 feet of massive, hard, brown, semi-crystalline limestone, with thin subordinate layers of calcareous clay or marl. As a rule the limestone beds are more massive near the base and become thinner towards the top with the marly layers becoming more prominent. The Main Street is the only limestone of any consequence in a thick series of clay and sand, and for this reason is a very important marker for stratigraphic and structural work. It differs from the other limestones of the Washita division in that it contains more ferruginous material which gives it a distinctly brownish color. Taff[55] applied the name Bennington to this limestone in southern Oklahoma.

The Main Street is characterized by two easily recognized fossils, *Exogyra arietina* Roemer, which occurs throughout the formation but is more abundant in the upper part, and *Kingena wacoensis* Roemer, the only brachiopod of common occurrence in the Comanche series, which is found more abundantly in the lower portion.

The following section gives in some detail the character of this formation:

55. U. S. Geol. Survey Geol. Atlas Atoka folio (No. 79), 1902; Tishomingo folio (No. 98), 1903.

Section of Main Street limestone in railroad cut on Pottsboro cut-off of Missouri, Kansas and Texas Railroad, about 4 miles west of Denison, Grayson County, Texas.

	Ft.	in.
WOODBINE SAND.		
GRAYSON MARL		
MAIN STREET LIMESTONE:		
Marl, containing nodules of lime	2	9
Limestone, somewhat arenaceous, containing many fossils, including *Exogyra arietina* Roemer, *Exogyra plexa* Cragin, *Kingena wacoensis* Roemer	0	8
Marl, containing *Kingena wacoensis* Roemer	0	7
Limestone, turns yellow on exposure, contains *Kingena wacoensis* Roemer	1	6
Marl, yellowish white, containing *Kingena wacoensis* Roemer, *Exogyra plexa* Cragin	0	3
Limestone, ferruginous, arenaceous, white, coarse grained, turns yellow on weathered surface. Contains: *Exogyra plexa* Cragin, *Exogyra arietina* Roemer, *Ostrea quadriplicata* Shumard, and *Pecten* sp.	0	9
Marl, containing fossils similar to limestone above	0	2
Limestone, similar to above	0	8
Marl, sandy, ferruginous, contains *Exogyra plexa* Cragin	1	0
Limestone, ferruginous, coarse grained, white, yellow on weathered surface. Contains: *Kingena wacoensis* Roemer, *Exogyra arietina* Roemer, *Exogyra plexa* Cragin	1	4
Marl, containing *Exogyra plexa* Cragin and *Exogyra arietina* Roemer	0	6
Limestone, impure bluish semi-crystalline, containing irregular veins of calcite	1	1
PAWPAW SAND	11	3

Fauna of the Main Street limestone[56]

(Forms marked with an asterisk (*) are especially characteristic).

Ostrea sp. aff. marcoui Boese
Ostrea carinata Lamarck
Ostrea quadriplicata Shumard
Lopha sp.
Ostrea subovata Shumard
*Exogyra arietina Roemer
Exogyra sp.
Gryphea sp.
Pecten texanus Roemer
Pecten subalpina Boese
Pecten wrighti Shumard
Pecten roemeri Hill
Pecten sp.
Spondylus cragini Whitney
Lima wacoensis Roemer
Protocardia vaughani Shattuck
Pholadomya shuttucki Boese
Ptychomya sp. aff. austinensis Shumard.
Ptychomya ragsdalei Cragin
Homomya sp.
Barbatia simondsi Whitney
Trigonia sp.
Schloenbachia sp. aff. inflata
Turrilites brazoensis Shumard
Turrilites sp.
Nautilus texanus Shumard
Nautilus hilli Shattuck
*Kingena wacoensis Roemer
Cyhosoma volanum Cragin
*Holectupus limitis Boese
*Enallaster bravoensis Boese
Enallaster sp.
Hemiaster sp.
Leiocidaris sp. aff. hemigranosus Shumard
Exogyra plexa Cragin
Cyprimeria sp.
Plicatula sp.

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

GRAYSON MARL

The Grayson marl is the uppermost formation of the Comanche series in the Red River region. The type exposure of this formation is in an abandoned cut of an old unused railroad grade in the southwestern portion of Denison, Texas, discovered by Cragin[57], who named the formation. The Grayson marl consists of about 25 feet of light colored fossiliferous clays or marls with many small lumps and thin lenses of a soft limestone.

The contact between the Grayson and the Main Street is not a sharp line, but rather a gradation from the limestone into a calcareous clay. The upper contact of the Grayson, the Grayson-Woodbine, is usually covered by ferruginous sandstone and other debris from the overlying Woodbine, so that in very few places can a clear cut contact be seen and for this reason the conformity of the Grayson and Woodbine has long been uncertain. In northwestern Grayson County, Texas, near Cedar Mills, a clear cut contact of the Woodbine with the underlying formations was examined, and at this place the Grayson is entirely absent and the Main Street is only about 7 feet in thickness. A few miles to the north of the Cedar Mills locality another clear cut contact was observed in which there appeared to be a rather perfect gradation from the Grayson into the Woodbine. However, considering the entire north Texas area, which must be considered in taking up a problem of this nature, it is noted that to the east the break between the Comanche series and the Gulf series increases in magnitude, so that in southwestern Arkansas the Woodbine rests directly on the Trinity sand, erosion having removed all of the Fredericksburg and Washita formations.

Section of the Grayson marl on public highway, at crossing of a tributary of Little Mineral Creek, one mile south of Fink, Grayson County, Texas

	Ft.	In.
WOODBINE SAND		
GRAYSON MARL:		
Marl, light gray, grading into thinly laminated beds of gray clay and thin veins of red and yellow iron oxide. Very few fossils	8	2
Clay marl, blue gray, containing thin beds of nodular limestone and an abundance of *Gryphea mucronata* Gabb	7	0
Marl, containing thin beds of nodular limestone	5	5
Limestone, chalky, shaly, nodular, containing *Turrilites brazoensis* Roemer, *Pecten* sp.	1	0
Clay marl, gray	4	1
Clay marl grading into shaly limestone at the top	2	2
Clay marl, light yellow to White, containing *Turrilites brazoensis* and *Exogyra arietina*	1	3
MAIN STREET LIMESTONE	29	1

57. Cragin, F. W., The Choctaw and Grayson Terranes of the Arietina: Colorado College Studies, Fifth Ann. publication, p. 43, 1894, Colorado Springs, Colorado.

The Grayson is very fossiliferous and well preserved fossils are easily secured. The base of the formation contains a marked abundance of the Main Street form, *Exogyra arietina* Roemer, associated with *Turrilites brazoensis* Roemer. Near the middle of the formation there is an abundance of a very characteristic oyster, *Gryphea mucronata* Gabb.

Fauna of the Grayson marl[58]

(Forms marked with an asterisk (*) are especially characteristic).

Gryphea sp. like corrugata Say	Pecten subalpina Boese
*Gryphea mucronata Gabb	*Turrilites brazoensis Roemer
*Exogyra arietina Roemer	Arca sp.
Exogyra sp. like texana Roemer	Lima sp.
Cyphosoma volanum Cragin	Cinulia pelletti Whitney
Ostrea sp.	Turritella sp.
Anomia sp.	Hemiaster calvani Clark
Plicatula sp.	Enallaster bravoensis Boese
Protocardia sp.	Nautilus sp.
Tapes sp.	*Hoplites sp.
Pholadomya shattucki Boese	Cyprimeria sp.
Trigonia sp.	Acanthoceras sp.
Certhium sp.	*Holectypus limitis Boese

GULF SERIES (UPPER CRETACEOUS)

Overlying the Grayson marl, in the Red River region, is the Gulf series, consisting of the following formations:

Navarro formation
Taylor marl
Austin Chalk
Eagle Ford shale
Woodbine sand

Of these formations, only the Woodbine sand and Eagle Ford shale are found in southern Oklahoma. It is not within the scope of this paper to discuss the Upper Cretaceous, so it is passed over with this brief mention.

SOUTHERN KANSAS

Historica Summary

The first report which attempted to give a description of the geology of the entire state was by Mudge[59] in 1878. On a map accompanying the report the area south of the Arkansas River is indicated as belonging to the Upper Carboniferous and Cretaceous systems. The area west of Harper County is shown as belonging to the Fort Benton and Dakota groups (Upper Cretaceous). St.

58. After Winton, M. W., and Adkins, W. S., Geology of Tarrant County Texas: Univ. of Texas Bull. 1931, 1919.
59. Mudge, B. F., Kansas State Board of Agrl. First Biennial Rept., pp. 47—, 1878.

John, in 1883, followed Mudge but in his description of the Dakota formation of the Arkansas valley, he states[60] that near Brookville, (Saline County), some beds have been discovered, "which are characterized by a molluscan fauna, some of whose forms, at least, indicate more intimate affinities with the Texan Cretaceous than has heretofore been observed so far north in deposits of this age".

In the following pages the papers which contain the record of the development of knowledge of the Lower Cretaceous stratigraphy of southern Kansas are grouped under the names of the various authors in chronologic order.

Cragin, 1885-86.—In a general paper on southern Kansas Cragin gives a description of the "Red Beds" and Gypsum Hills and in the latter part of the report describes the overlying formations as follows:[61]

> The deposits above the gypsum I examined but little, and only in western Barber County and eastern Comanche County. They belong to the Benton (Upper Cretaceous) and later deposits. * * * A locality a few miles southwest of Sun City, locally known as the Black Hills affords an easily recognized horizon for reference. * * * The deposit from which the hill takes its name is a bed of carbonaceous and rapidly decomposing shale. In connection with the shale are found fragmentary seams of poor lignite. Immediately above and below this is a layer of shell conglomerate made up largely of *Ostrea* and *Gryphaea*.
>
> Below this is a formation quite unlike ánything I have seen or heard of in Kansas and well worth a visit to the place to see. It is a verigated sandstone, unfortunately too friable for utility but displaying a most beautiful variety of colors. Brown, purple, blue, crimson, scarlet, pink, orange, lemon yellow, and white; these and many intermediate shades may be seen, in the brightest contrast and most delicate blending. * * * In the upper portion of these hills remains of large turtles are reported. I succeeded in securing only some fragments; insufficient to determine whether they are to be referred to the Niobrara or the Tertiary, but sufficient to verify the truth of the reports. I have no positive evidence of the Niobrara here as yet, but I am inclined to think it here, and that it would be found to begin shortly above the horizon of the black shale.

In this paper is found the first reference to the historic section near Belvidere and Sun City which has been so well described in subsequent papers by Cragin. The various colored sandstones above the "Red Beds" referred to by Cragin is the formation now known as the Cheyenne sandstone; the black shales of the Black Hills belong to the Kiowa: and the Tertiary forms the top of the section. The following year Cragin modified the suggested correlation of his previous paper, concluding that;[62]

60. St. John, O. P., Kansas State Board of Agrl. Third Biennial Rept., p. 571, 1883.
61. Cragin, F. W., Notes on the geology of southern Kansas: Bull. Washburn Col. Lab. Nat. Hist., vol. 1, pp. 85-91, 1885.
62. Cragin, F. W., Further notes on the Dakota gypsum of Kansas: Bull. Washburn Col. Lab. Nat. Hist. vol. 1, pp. 166-169, 1886.

> * * * the variegated sandstone * * * probably marks the upper limit of the Dakota, and the overlying dark shale from which the "Black Hills" takes its name, the base of the Benton. The large turtles mentioned in the same article are probably Tertiary, occurring only on the very highest hills fifteen to forty miles north and west of Medicine Lodge.

St. John and Hay, 1887.—In a paper published in 1887 St. John[63] states that only "the Dakota and Niobrara members have been with certainty identified in this southwest region". He described the Dakota formation as consisting in the lower portion of:

> * * * soft yellow and white stained sandstone, in places obliquely laminated, with hard indurated layers, the weathering of which produces monumental forms, recalling those which the elements have fashioned in the Tertiary sandstones on Monument Creek in Colorado. This sandstone horizon is very variable in thickness and may indeed be absent locally. It is succeeded by dark blue, drab and buff shales 50 to 70 feet above a soft yellow, sometimes reddish, obliquely laminated sandrock, five feet, more or less, and below a stratum of drab sometimes sandy shale, two to five feet, containing streaks of lignite and fragments of bituminized wood * * *.
>
> Succeeding the shale horizon occur successive beds of shaly limestone, alternating with drab and buff, more or less arenaceous shales, which are charged with fossils, mostly belonging to a species of *Gryphea* resembling *G. Pitcheri*, and *Exogyra*, *Trigonia*, *Turritella*, etc. The latter also occur in the upper portion of the underlying shales. The association of species and abundance of individuals strongly recall occurrences in Texas. * * * Judging from data at present accessible, it would appear that the present region marks the limits of the northern extension of this peculiar southern fauna of the Cretaceous.

In a paper before the Kansas Academy of Science in 1885 Hay[64] stated that:

> The beautifully variegated sandstones referred to by Professor Cragin in a printed notice of a run through Barber County I am inclined to consider as undoubtedly Dakota, but in the only place where I got at their base they seemed to rest on the eroded surface of the Red Rock.

Cragin, 1889-90.— In a paper on the region south of the Arkansas River Cragin[65] states that he "wrongly assigned all the formations between the great gypsum horizon and the base of the Tertiary southwest of Sun City to the Benton epoch".

In this paper Cragin describes a section of these rocks in a ravine and higher on a hillside to the southwest of Belvidere, on the Medicine Lodge River. So far as known this is the first accurate section of the Cretaceous rocks of southwestern Kansas. In conclusion in this paper he says:

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63. St. John, O. P., Notes on the geology of southwestern Kansas: Kansas State Board of Agri., Fifth Bien. Rept., pp. 143-144, 1887.
64. Hay, Robert, Report on Geology: Kansas Acad. Sci., vol. 10, p. 22, 1887.
65. Cragin, F. W., Geological notes on the region south of the Great Bend of the Arkansas: Bull. Washburn Col. Lab. Nat. Hist., vol. 2, p. 33, February, 1889.

> The above partial study of the Medicine Lodge River Cretaceous suffices to show something very like the fauna of the recently discovered Comanche series of Texas, which is said to be lower than the Dakota, or the lowest hitherto known American Cretaceous.

In December of the same year Cragin[66] named the variegated sandstone at the base of the Cretaceous in the Médicine Lodge valley the Cheyenne sandstone, from Cheyenne Rock at Belvidere. The next year Cragin published[67] a paper in which he gave a description of the Cheyenne sandstone, its lithologic characteristics, thickness, and distribution. In regard to its age he says:

> While this sandstone seems to be closely related to the Potomac and Tuscaloosa divisions of the Atlantic states, to the Trinity division of Texas and Arkansas, and to the Atlantosaurus beds of Wyoming and Colorado, it would be premature to assert positively, at this time, the precise identity of any two of these. Incomplete geographic and stratigraphic data suggest a probability that the above described sandstone represents a portion of the Trinity division; but reference of it to the Trinity division in any way, until the Indian Territory interval has been explored, is of course merely a supposition, however probable.

The latter part of this paper describes quite fully the distribution and stratigraphic character of the shales (Kiowa) between the Cheyenne and the Tertiary. Detailed sections together with fossil lists from the various zones in the shale are given.

Hill, 1888.—In a report on southwestern Arkansas Hill[68] referred to the paper by Cragin, mentioned above, and states that the rocks "undoubtedly represent the Comanche series", correlating zone No. 5 of Cragin's section with the Fredericksburg division and zone No. 6 with the Trinity.

Hay, 1890.—During the summer of 1885 Hay studied that portion of Kansas south of the Arkansas River. In his report[69], which was not published for several years, Hay is inclined to refer the fossiliferous shales (Kiowa) of this region to the Fort Benton, but also calls attention to the suggested correlation with the Comanche series of Texas.

Cragin, 1891.—In an article published by Cragin[70] during this year he states that he has visited the Comanche area of north Texas in company with Hill and agrees with him in correlating

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66. Cragin, F. W., Contributions to the paleontology of the Plains: Bull. Washburn Col. Lab. Nat. Hist., vol. 2, pp. 65-69, 1889.
67. Cragin, F. W., On the Cheyenne sandstone and the Neocomian shales of Kansas: Bull. Washburn Col. Lab. Nat. Hist., vol. 2, pp. 69-81, 1890. (Republished in the Am. Geol. for Oct., 1890, and June, 1891; in vol. 6, pp. 233-238, and vol. 7, pp. 23-33.)
68. Hill, R. T., Neozoic geology of southwestern Arkansas: Geol. Survey of Arkansas Ann. Rept. for 1888, vol. 2, p. 115.
69. Hay, Robert, A geological reconnaissance of southwestern Kansas: U. S. Geol. Survey Bull. 57, 1890.
70. Cragin, F. W., Further notes on the Cheyenne sandstone and Neocomian shales: Am. Geol. vol. 7, pp. 179-181, March, 1891.

his zone No. 5 of the Belvidere section with the Fredericksburg shale and zone No. 6 of the Belvidere section with the Trinity sandstone. He further states:

> The paleontologic and lithologic identity of No. 5 of my Belvidere section with a certain shell conglomerate occurring at Weatherford, the lowest *Gryphea* bearing horizon of Texas, is such as to warrant me in asserting the essential chronologic equivalency of the two horizons.

Williston, 1892.—The small geologic map prepared by S. W. Williston was the first to represent approximately the geologic formations south of the Arkansas River as they are now defined. He indicated the Comanche-Cretaceous as beginning in the southwestern portion of Kingman County, extending in a narrow band across the northern part of Barber County into the southeastern corner of Kiowa County, and then southwest diagonally across Clark County into the southeastern corner of Meade County.

Hay, 1893.—In a general paper Hay[71] discusses the geologic formations of Kansas and in his description of the Cretaceous system the Trinity sand and Comanche Peak beds are described as the two lowest formations as follows:

> In the northwestern corner of Barber County, in a ravine on the south side of the Medicine River, is an outcrop of beds, the bottom of which rests on an eroded surface of Red Beds something over 100 feet above the great gypsum horizon. The whole is not more than 25 or 30 feet of vertical exposure, * * * when I first saw these beds, I was inclined to synchronize them with the Cretaceous beds (Dakota and Benton) which were known to exist on the south side of the Arkansas River farther west. Professor St. John, however, who saw the beds in the region farther south, pointed out the resemblance of the fauna of the shell bed to Texas Cretaceous forms, and afterwards others have worked out the stratigraphy of the beds up the valley of the Medicine and some of its tributaries and made collections of the paleontological remains. Professor R. T. Hill of Texas, has also seen fossils belonging to these beds, and there seems now no doubt that they belong to lower horizons than the Kansas Dakota. There is no reason why the Texan names given to the beds—Trinity for the lower, fine grained sandstone, and Comanche Peak for the upper strata—should not be made permanent, but some of the paleontologists still differ as to whether certain of the shells are lower Cretaceous or of the Jurassic type. In the table I have placed them as lower Cretaceous.

Cragin, 1894.—Some invertebrate fossils are described[72] from Clark and Kiowa counties. In connection with the description of the species are notes explanatory of the typical sections of the formations.

Cragin and Hill, 1895.—In this year Cragin published another paper dealing with the invertebrate remains[73], and soon afterwards

71. Hay, Robert, Geology and mineral resources of Kansas: Kansas State Board of Agrl. Eighth Bien. Rept., pp. 99-163. 1893.
72. Cragin, F. W., New and Little known Invertebrata from the Neocomian of Kansas: Am. Geol. vol. 14, pp. 1-12, 1894.
73. Cragin, F. W., Description of invertebrate fossils from the Comanche series in Texas, Kansas, and Indian Territory: Colorado College Studies vol. 5, pp. 49-69, April, 1895.

one on the vertebrates[74]. In the latter paper he names the fossiliferous shales overlying the Cheyenne sandstone in Kiowa County the Kiowa shales. His definition is as follows:

> The designation, Kiowa shales, is proposed for the inferiorly dark colored and superiorly light colored shales that outcrop in several of the counties of southwestern Kansas, resting upon the Cheyenne sandstone in their eastern and upon the "Red Beds" in their middle and western exposures, and being overlaid by brown sandstones of middle Cretaceous age, or Tertiary, or Pleistocene deposits according to the locality.
>
> The Kiowa shales are a locally modified northern extension of part of Hill's Comanche series, cut off from the main part by erosion. They are named from the place of their typical occurrence, Kiowa County, Kansas. The fossils of the shales are chiefly those which, in Texas, are common in the Fredericksburg division (Comanche series).

In June of the same year Hill[75] announced the discovery of a dicotyledonous flora from the Cheyenne sandstone. He says:

> This sandstone has heretofore been referred to the Trinity division of Texas by Professor Cragin, but the flora, as determined by Professor Knowlton of the U. S. Geological Survey, consists entirely of species hitherto supposed to be peculiar to the Dakota group, while the flora of the Trinity division of Texas, as has been reported by Professor Fontaine, is all of the non-dicotyledonous Potomac type. The Cheyenne sandstones are separated from the true Dakota sands of Kansas by nearly 200 feet of shale, containing a molluscan fauna composed of fifteen species characteristic of the Washita division of the Comanche series of Texas, and about twenty littoral species peculiar to the locality.

In September of the same year Hill published an extended paper on the "outlying areas", as he termed them, of the Comanche series in Kansas, Oklahoma, and New Mexico, in which he reviews carefully the flora of the Cheyenne sandstone, giving a list of the forms as determined by Knowlton. In regard to the age of the Cheyenne he says[76]:

> Professor Knowlton's determination of the dicotyledonous Dakota flora in the top of the Cheyenne sandstone shows that from a paleontologic standpoint these sandstones have no resemblance to the flora of the Trinity division at Glen Rose, Texas, beds which contain a flora of typical Potomac non-dicotyledonous species. The Cheyenne sandstones are of far later age than the Trinity, and occupy a stratigraphic position at the base of the Washita, midway between the Trinity and the Dakota.

Hill gives a number of detailed sections from the Belvidere region Fossil collections made by Hill were identified by T. W. Stanton of the U. S. Geological Survey. In regard to the age of the Belvidere shales (Kiowa shales of Cragin) Hill says:

74. Cragin, F. W., Vertebrata from the Neocomian of Kansas: Colorado College Studies, vol. 5, pp. 69-73, 1895.
75. Hill, R. T., Discovery of a typical dicotyledonous flora in the Cheyenne sandstone: Am. Jour. Sci., 3rd ser. vol. 49, p. 473, June, 1895.
76. Hill, R. T., On the outlying areas of the Comanche series in Kansas, Oklahoma, and New Mexico: Am. Jour. Sci. vol. 50, 3rd ser. pp. 205-235, 1895.

> Mr. Stanton's studies of the fossils of the Belvidere shales also demonstrate the opinion I have long entertained, that these fossils are largely of the age of the Washita division of my Texas section, and not solely the Fredericksburg and Trinity divisions, as maintained by Cragin. I am glad to have my own conclusions sustained by such an authority, and I fully agree with him that the Belvidere beds represent in general the Washita division and probably the attenuated Fredericksburg as seen in the north Texas section.

Included in this paper are notes on two areas of Lower Cretaceous in western Oklahoma, the Camp Supply locality and the Comet Creek area of Marcou. It also contains a brief mention of the section at Tucumcari Mountain, Tucumcari, New Mexico. The closing statement of this paper is as follows:

> These beds (speaking of all outlying areas in general) represent the modified attenuated northern extension of the Washita division and probably a portion of the Fredericksburg division of the Comanche series of Texas, which, as we have previously shown, far overlapped to the northward those of the Trinity division.

Cragin[77] followed three months later with a paper, which, like the previous one, is somewhat controversial in its nature, a part of it being devoted to a discussion of Hill's paper. A number of new terms are added to the literature by the subdivision of the Cheyenne sandstone and the separation of the first shell horizon from the Kiowa shale. His classification is as follows:

C. KIOWA SHALES
- 4. Tucumcari shales
- 3. Fullington shales
  - b. Blue Cut shales
  - a. Black Hills shales

B. CHAMPION SHELL BED

A. CHEYENNE SANDSTONE
- 2. Elk Creek beds
  - b. Stokes sandstone
  - a. Lanphier beds
- 1. Corral sandstone

Of these names, in addition to Kiowa and Cheyenne, previously applied by Cragin, the Champion shell bed is still in common use. The other members can rarely be separated. Following the description of the Champion shell bed is a list of its fauna, which contains 36 species, 22 of which are known to extend into the Kiowa shales, though it is stated that the number of species common to the Champion and the Kiowa will probably be increased by further explorations. Finally, under the heading of correlation, Cragin reviews the facts at hand and concludes as follows:

77. Cragin, F. W., A study of the Belvidere Beds: Am. Geol. vol. 16, pp. 357-386, December, 1895.

> The evidence taken altogether seems to point to the conclusion that the Kiowa shales of Kansas * * *represent a group of sediments intermediate between the Fredericksburg and Washita divisions (of the Comanche series), and one which, as a meeting ground of the faunas of these two divisions, can not satisfactorily (though it may arbitrarily) be referred to either.

Haworth, 1896.—On a geologic map of Kansas prepared by Haworth[78] the formations south of the Arkansas river are represented more accurately than on any previous map.

Prosser, 1896.—A very complete report on the Comanche series of Kansas, beginning with a thorough review of all previous work, was written by Prosser.[79] He considers the Comanche series of southwestern Kansas to be composed of two formations, "which may be readily distinguished by both their lithologic and paleontologic characters and may be easily followed in the field for purposes of areal representation". For these two formations he adopts Cragin's terms, the Cheyenne sandstone and the Kiowa shale. He does not consider the Champion shell bed of sufficient importance to deserve the rank of a formation. In regard to the correlation of the beds of southern Kansas with the Texas section Prosser quotes a statement by Cragin and also one by Hill, but does not take a definite stand on the question. The remainder of the report is given over to a discussion of detailed stratigraphic sections. This report is truly a store house of information on the stratigraphy of the Comanche series of Kansas, and remains today one of the most complete papers on this region.

Gould, 1900.—In a general paper on the Lower Cretaceous of Kansas, Gould[80] gives a brief review of previous work and accompanying the descriptions of the Cheyenne sandstone and the Kiowa shale are lists of both plant and animal fossils. Gould does not make any definite statement in regard to the correlation of these beds.

Twenhofel, 1924.—Several papers dealing with the Lower Cretaceous of Kansas have been published by Twenhofel.[81] His results and conclusions, so far as the area of southern Kansas is concerned, are contained in a recent report in which the problem is reviewed and the faunal lists are revised from new collections from the Belvidere region. Twenhofel's conclusions in regard to the correlation of the Lower Cretaceous of southern Kansas do not differ from those stated by Hill 30 years before.

78. Haworth, E., Reconnaissance geologic map of Kansas: Kansas Geol. Survey, vol. 1, pl. 31, 1896.
79. Prosser, C. S., Comanche series of Kansas: Kansas Geol. Survey vol. 2, pp. 96-181, 1896.
80. Gould, C. N., Lower Cretaceous of Kansas: Am. Geol. vol. 25, pp. 10-40, 1900.
81. Twenhofel, W. H., Geology and invertebrate paleontology of the Comanchean and Dakota formations of Kansas: State Geol. Survey of Kansas Bull. 9, 1924.

Distribution

The Lower Cretaceous of Kansas is found principally in two areas: (1) central Kansas, where it consists of red fossiliferous marine sandstone, generally known as the Mentor beds, and (2) southern Kansas, where it consists of sandstone, shales, and shell beds. The Mentor beds outcrop in more or less isolated areas in the western half of Saline and McPherson counties and along the eastern edge of Ellsworth and Rice counties. The best exposures are to be found in the southwestern portion of Saline County, near Smolan, and in the northwestern corner of McPherson County, near Marquette. This area lies outside the limits of this paper and will therefore be passed by with this brief mention.

In the southern Kansas area the strata of Lower Cretaceous age are found appearing beneath the Tertiary cover northwest of Medicine Lodge, in Barber County, and as an irregular, narrow band extending in a general westerly direction around the headwaters of the Medicine Lodge River, Bluff Creek canyon, and other streams in Barber, Kiowa, and Clark counties and into Meade County. In addition to this band there is a very prominent outlier in southern Comanche County, on the Oklahoma-Kansas boundary, known as Avilla Hill. The most prominent and best known section in this area is the Belvidere section, about one-half mile south of the little village of Belvidere in the southeastern corner of Kiowa County. A detailed description is given of the Belvidere and Avilla Hill sections.

STRATIGRAPHY

GENERAL STATEMENT

The history of the successive stages in the development of the stratigraphic column of the Lower Cretaceous of Kansas has been reviewed in previous pages. It will suffice to recall here that the rocks were first assigned to the Upper Cretaceous; then Cragin, recognizing their resemblance to the Comanche series of Texas, properly placed them in that series. The exact division or divisions within the Comanche series which are represented by the beds in southern Kansas has been a matter of dispute for many years. The opinion now generally held was first expressed by Hill in 1895 when he correlated the beds of this area with the Washita division, and stated that the Fredericksburg "may be represented".

The following classification, which is essentially that of Hill, is used by Twenhofel in the most recent paper on this area:

COMANCHE SERIES
Washita division
Belvidere formation { Greenleaf sandstone member; Spring Creek clay member; Kiowa shale member, including the Champion shell bed. }
Cheyenne sandstone

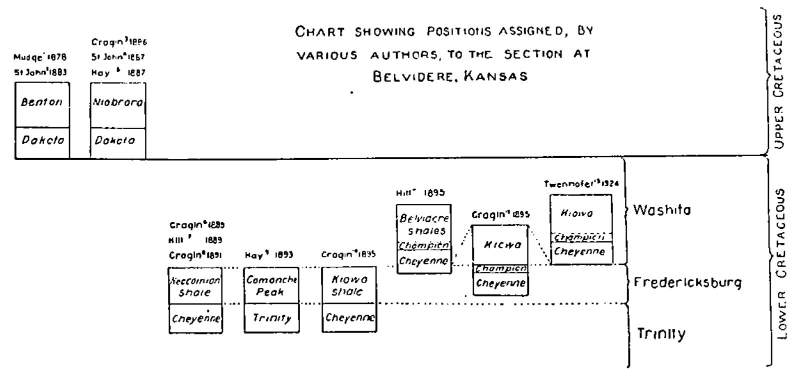

Figure 1.

1. First Biennial Rept. State Board of Agri. of Kansas: p. 53, 1878:
2. Third Biennial Rept. State Board of Agri. of Kansas: p. 571, 1883.
3. Cragin, F. W., Notes on the geology of southern Kansas: Bull. Washburn Col. Lab. Nat. Hist., vol. 1, pp. 85-91, 1885.
4. St. John, O. P., Notes on the geology of southwest Kansas: Kansas State Board of Agri., Fifth Biennial Rept. pp. 132-152, 1887.
5. Hay, Robert, Report on Geology: Trans. Kansas Acad. Sci. vol. 10, p. 22. 1887.
6. Cragin, F. W., Geological notes on the region south of the Great Bend of the Arkansas: Bull. Washburn Col. Lab. Nat. Hist., vol 2, p. 33, 1889.
7. Hill, R. T., Neozoic geology of southwestern Arkansas: Arkansas Geol. Survey Ann. Rept. for 1888 (a footnote p. 115) vol. 2, 1889.
8. Cragin, F. W., Further notes on the Cheyenne sandstone and the Neocomian shales: Am. Geol. vol. 7, pp. 171-181, 1891.
9. Hay, Robert, Geology and mineral resources of Kansas: Kansas State Board of Agri. Eighth Biennial Rept. pp. 108-109, 1893.
10. Cragin, F. W., Invertebrate fossils from the Comanche series in Texas, Kansas, and Indian Territory: Colorado College Studies, vol. 5. pp. 49-69; and Vertebrata from the Neocomian of Kansas: Ibid, pp. 69-73, 1895.
11. Hill, R. T., Outlying areas of the Comanche series in Kansas, Oklahoma, and New Mexico: Am. Jour. Sci. vol. 50, pp. 205-234, 1895.
12. Cragin, F. W., A Study of the Belvidere beds: Am. Geol. vol. 16, pp. 357-386, 1895.
13. Twenhofel, W. H., Geology and invertebrate paleontology of the Comanchean and Dakota formations of Kansas: Kansas Geol. Survey Bull. 9, 1924.

To the writer it seems unadvisable to retain Hill's term Belvidere and to place the various beds as members of this formation. They certainly do not contain enough common characteristics to justify placing them in a single formation and without doubt there are included in the Belvidere several formations of the Comanche series of Texas. The term Belvidere is therefore discarded and the members listed above described as formations. Some complications arise in the case of the Champion shell bed, which has been described both as a separate formation and as a member of the Kiowa shale. This is a matter which brings in the question of correlation of the Champion and Kiowa with the type section of Texas. Viewing the matter as a whole, it may seem advisable to separate the Champion shell bed from the Kiowa, especially if the Champion represents any part of the Fredericksburg. However, considered from the standpoint of the Kansas area alone, the Champion may well be included with the Kiowa. The problem of the correlation of these beds is discussed later. For convenience of description the Champion shell bed is here separated from the Kiowa shale.

BELVIDERE AREA

The Belvidere section, the most famous and the best exposed section of the Lower Cretaceous of southern Kansas, is located in Champion Draw, one-half mile south of the little village of Belvidere, Kiowa County, Kansas. This section is taken as the type section for southern Kansas.

CHEYENNE SANDSTONE

The basal formation of the Lower Cretaceous of southern Kansas was called the Cheyenne sandstone by Cragin, named from Cheyenne Rock, an indurated mass of this sandstone near Belvidere. Cheyenne Rock and Osage Rock are about three-fourths mile west of Belvidere and according to tradition were the site of an Indian battle between tribes from which the rocks were named.

The Cheyenne sandstone, considered as a whole, consists of a rather coarse-grained, friable sandstone, dominately light gray to yellow in color, but frequently spotted and striped with bright colors, as red and purple due to stains of iron oxide. In the upper portion are numerous lenses and pockets of black to brown carbonaceous sandy shale. The bedding in the sandstone is very irregular, cross lamination being the rule rather than the exception. The inclination of the cross-bedding is usually to the south at rather high angles. In some horizons, especially near the base, definite layers of conglomeratic material are found Frequently thin layers filled with an abundance of carbonized wood occur in the basal portion.

As a rule the sandstone is poorly cemented but locally indurated layers and masses occur, giving rise to very fantastic pillars and columns. Some very picturesque effects are produced in places known locally as "Hells Half Acre". 8 miles southeast of Belvidere, "Natural Corral", 5½ miles southeast of Belvidere, and Osage and Cheyenne rocks, previously mentioned.

A maximum thickness of 55 feet is attained by the Cheyenne sandstone in the Belvidere region. To the west and south the Cheyenne begins to pinch out; a section 5 miles southwest of Coldwater, Clark County, has a thickness of only 10 feet. In the Avilla Hill section, which is described later, the Cheyenne, if present, is represented by a thickness not greater than 5 feet. Still farther to the west, in Meade County, the Cheyenne is apparently entirely absent and the Kiowa shale rests directly on the Permian.

The following section, by Gould, shows in detail the character of the Cheyenne sandstone.

Section along the east branch of Champion Draw beginning one-half mile south of Belvidere and running up the draw nearly a quarter of a mile southeast[82]

		Feet
12.	KIOWA SHALES, well developed to top of hill	125
11.	CHAMPION SHELL BED	1
	CHEYENNE SANDSTONE:	
10.	Shale, sandy with plants	9
9.	Sandstone, soft with bands of shale and carbonaceous material	10
8.	Shale, sandy with much lignite and plant matter	12
7.	Sandstone, usually soft, yellow, cross-bedded with lignite in masses of shale. On the west bank near the top of the bluff is a hard ledge containing the best dicotyledenous leaves found in the Belvidere region	20
6.	Shale, yellow or brown, sandy with streaks of lignite, much cross-bedded, grading into No. 7	6
5.	Sandstone, soft variegated shaly in part, with plants and sandstone concretions	10
4.	Shale, yellow sandy with bands of black lignite and plant remains; distinctly stratified in all parts and often cross-bedded	8
3.	Sandstone, variegated, coarse, false bedded or massive with many pebbles and ferruginous concretions; containing several lenticular masses two feet thick of dark blue laminated clay, barren of fossils, upper part grades into No. 4	20
2.	Shale, yellowish gray (Permian)	3
1.	Red beds, from the river bed (Permian)	50

Gould states that the above section was measured where "the strata tilt at an angle of 15 to 20 degrees to the south; so that the total thickness of the Cheyenne would not exceed forty feet".

82. Gould, C. N., Lower Cretaceous of Kansas: Am. Geol. vol. 25, p. 20, 1900.

The fossils found in the Cheyenne sandstone are confined entirely to plant remains, unless the few imperfectly preserved pelecypods from the sand at the base of the Avilla Hill section be considered Cheyenne. Numerous collections of the plant remains have been made by Hill, Gould, Ward, and others. These collections were examined and described by Knowlton in 1895. Recently Berry[83] has studied this material as well as new collections made from the same area, and in his report the following list is given:

Fossils of the Cheyenne sandstone

Abietites ernestinae Lesquereux
Abietites longifolia (Fontaine) Berry
Aralia ploymorpha Newberry
Aralia ravniana Herr
Araliopsoides cretacea (Newberry) Berry
Arundo greenlandica Herr
Asplenium dicksonianum Herr
Carpolithus belviderensis (Lesquereux) Berry
Cladophlebis dakotensis (Lesquereux) Berry
Cupressinoxylon cheyennesnse(?) Penhallow
Cycadeoidea munita Cragin
Cycadeospermum lineatum Lesquereux
Feistmantelia oblonga Ward
Gleichenia bohemica (Corda) Berry
Gleichcenia nordonskioldi Herr
Sapindopsis belviderensis Berry
Sapindopsis brevifolia Berry
Sapindopsis magnifolia Fontaine
Sapindopsis variabilis Fontaine
Sassafras mudgii Lesquereux
Sterculia condita Lesquereux
Sterculia mucronata Lesquereux
Sterculia towneri (Lesquereux) Berry

These collections were made at various places in the vicinity of Belvidere, the Champion Draw section, previously described, being one of the best collecting localities. Gould[84] gives a list of other places where plant fossils were obtained.

Correlation of the Cheyenne.—Knowlton states that up to the present time (1895) the dicotyledonous flora identified from the Cheyenne sandstone are not known outside of the Dakota formation. However, he considered the possibility that the Cheyenne flora might be older than the Dakota and in his report says[85]:

> If more were known of the chronologic sequence of the Dakota flora it would possibly be found that the plants identified above belong to lower or older beds.

In 1896 Ward studied the Cheyenne sandstone in the field and made a collection of plant remains. He concluded that the Cheyenne belonged to the Comanche series and not to the Dakota. Ward presented a paper before the Philosophical Society of Washington which was reported by the secretary as follows:[86]

> Fossil plants were obtained at three different horizons showing corresponding changes in the flora. So far as they go they confirm Mr. Hill's conclusion that at least the upper part of the Cheyenne sandstone belongs to the Washita division of the Comanche series. It may be approximately correlated with the Raritan clays or the Albirupean series of the Potomac formation.

83. Berry, E. W., The flora of the Cheyenne sandstone of Kansas: U. S. Geol. Survey Prof. Paper 129, 1922.
84. Gould, C. N., Lower Cretaceous of Kansas: Am. Geol. vol. 25, p. 22, 1900.
85. Quoted by Hill, R. T., Am. Jour. Sci. vol. 50, 3rd ser. p. 214, 1895.
86. Ward, L. F., Science, new ser. vol. 4, p. 883, 1896.

In 1922 Berry studied the plant remains from the Cheyenne and placed them in the Upper Cretaceous. He says:[87]

> Its flora is lacking in the older elements that serve to distinguish the Patapsco from the Raritan and stamp its age as Albian. * * * The Cheyenne is unquestionably older than the flora of the Woodbine sand of Texas, for, although the latter also consists largely of so called Dakota forms, there is not a single species that is common to the Cheyenne and Woodbine, and the Dakota species are nearly all the common forms of Coastal Plains formations of known age.

From a stratigraphic standpoint the Cheyenne sandstone represents the basal or littoral deposit of an encroaching sea, the same conditions as obtained in southern Oklahoma and Texas during the deposition of the Trinity sand. However, as has been discussed in connection with the Texas area, the Lower Cretaceous overlapped to the north and west so that while the Cheyenne may represent conditions very similar to the Trinity, it does not follow that they are of the same age. In fact, according to evidence from plant remains, the Cheyenne is younger than the Trinity as would be expected. It has been shown that the Trinity of southern Oklahoma is younger than the Trinity of central Texas due to the northward overlap.

The fact that the Cheyenne is overlain by a formation containing a very characteristic basal Washita fauna would indicate that the Cheyenne is of pre-Washita age, perhaps Fredericksburg. Since a Fredericksburg flora is not known with which it can be compared, it is impossible to state that it should be referred to this division. The question of the exact correlation of the overlying formation, the Kiowa, will be discussed later and it will be shown that there are many elements of Fredericksburg aspect in it, so that until a more accurate correlation of the Kiowa is accomplished the best statement that can be made in regard to the age of the Cheyenne is that it is pre-Washita, or may represent a portion of the most basal Washita.

Berry's conclusion that the Cheyenne is younger than the Trinity and older than the Woodbine agrees fairly well with the evidence obtained from invertebrate fossils, but the real conflict which he raises is in placing it in the Upper Cretaceous. This is a question which is not peculiar to this region, but which involves the correlation of the American and European Cretaceous. It is interesting to note that while Berry would place the Cheyenne and Dakota both in the Upper Cretaceous, there are other investigators working on other lines of evidence who place the Dakota (Woodbine) in the Lower Cretaceous. The apparent contradiction between the plant and animal remains presents a problem which has been encountered wherever the two are found.

87. Berry, E. W., The flora of the Cheyenne sandstone of Kansas: U. S. Geol. Survey Prof. Paper 129, p. 206, 1922.

Origin of the Cheyenne sandstone.—The outstanding facts which must be explained in considering the origin of the Cheyenne sandstone are:

(1) Discontinuity of bedding.
(2) Cross-bedding—generally inclined to the south at high angles, up to 20 degrees, frequently truncated in a horizontal plane, but some have inclined truncation.
(3) Land plants—leaves curled and wrinkled.
(4) Absence of marine shells.
(5) Presence of gypsum.
(6) Character of sand grains (after Goldman)
  (a) size of grains
    5% fine sand
    90% very fine sand
    5% extra fine sand
  (b) grains in large measure angular
  (c) absence of secondary enlargement
  (d) no pitting or frosting.
(7) Distribution of the Cheyenne, its variable thickness and absence to the south and west.
(8) Conglomeratic and shaly lenses and layers.

Studies have been made on the origin of the Cheyenne by Twenhofel and Goldman.

Twenhofel's[88] conclusions are:

> This sand is considered to be of stream production and of wind deposition. The cross lamination, inclined truncation and degree of assortment are believed to harmonize better with wind deposition.

In a table showing the sequence of events in the formation of the Comanche series of southern Kansas Twenhofel makes the following statement in regard to the origin of the Cheyenne sandstone: "continental deposition by streams and wind on a Coastal Plain in a dry, semi-arid climate".

Goldman's studies were limited to the examination of one sample of the Cheyenne sandstone and for that reason may not be taken as conclusive for the whole formation. His conclusions are:[89]

> The portion of the Cheyenne represented by this sample is nothing like an eolian deposit in an arid region, nor even a part of a permanent dune area in a humid climate, but merely an accumulation of material blown by the wind out of a deposit of some other origin. Only an extensive field study could disclose the main facies and lead to a complete and satisfactory interpretation. From the roughness of the sand grains I would be inclined to assume rather a delta than a beach deposit as the dominant type. The very small, perfectly rounded grain noted appears entirely out of place as the product of the conditions under which the sandstone seems likely to have been formed and must therefore be assumed to be the product of an earlier cycle in the history of the grain, unless it is assumed that in a deposition of secondary silica the larger grains have been favored so that only the smallest grains retain their original form; but this seems to be incompatible with the uniform size of the larger grains.

88. Twenhofel, W. H., Geology and Invertebrate paleontology of the Comanchean and Dakota formations of Kansas: State Geol. Survey of Kansas, Bull. 9, p. 43, 1924.
89. Goldman, M. I., Quoted by Berry, E. W., The flora of the Cheyenne sandstone of Kansas: U. S. Geol. Survey Prof. Paper 129, p. 204, 1922.

Berry[90] in commenting on Goldman's observations says:

> The foreset bedding of which I have seen pictures suggests delta deposition * * *. The plants and their method of occurrence conclusively indicate a sparse vegetation, at least seasonal dryness, and accumulation by the wind. Whether these facts do or do not indicate beaches, interstream sand hills, or delta deposits can be determined only by future studies.

BEDS ABOVE CHEYENNE SANDSTONE

Overlying the Cheyenne sandstone is the Kiowa shale. Cragin originally defined the Kiowa to include all the sediments of Lower Cretaceous age lying above the Cheyenne sandstone. Later he separated the basal fossiliferous layer from the Kiowa and gave it the rank of a formation which he called the Champion shell bed. Crangin's[91] classification of these beds is as follows:

KIOWA SHALES
  Tucumcari shale
  Fullington shale
    Blue Cut shale
    Black Hill shale
CHAMPION SHELL BED.

The various members proposed by Cragin do not seem to be necessary and Hill, Prosser, Twenhofel, and others have considered the Kiowa as a single unit, including in it the Champion shell bed of Cragin. This usage is followed in this paper, but for convenience in describing the formation the Champion shell bed is treated separately. The inclusion of the Champion with the Kiowa seems logical in the light of the exposures in Kansas. However, Cragin, in correlating this horizon with the Texas section, advanced a careful argument in favor of its rank as a formation.

CHAMPION SHELL BED

The Champion shell bed, named for Mr. Champion of Belvidere on whose land the famous Champion Draw section is located, lies between the Cheyenne sandstone and the typical Kiowa shale. Its thickness varies from six inches up to about eighteen inches but in many places it seems to be entirely absent. It is best seen in Champion Draw, one-half mile south of Belvidere. It consists of a sandy, very fossiliferous, impure limestone, grayish white in color, and contains an abundance of gypsum and pyrite. The oxidation of the latter causes the decomposition of the rock and the destruction of the fossils.

90. Berry, E. W., Idem. p. 204.
91. Cragin, F. W., A study of the Belvidere beds: Am. Geol. vol. 16, p. 361, 1895.

In many places the Champion is a fossil coquina made up of fragments of a small, poorly preserved *Gryphea*. In other places it is only a matrix of sandy clay in which the fossils have been largely decomposed by the oxidation of the iron sulphide. The Champion is usually somewhat harder than the overlying Kiowa so that it outcrops as a bench or terrace. It seems to be very local in its distribution, as it has not been recognized in the Lower Cretaceous exposures to the west in Clark and Meade counties, or in the Avilla Hill section to the south.

Cragin[92] listed 36 species from this horizon, of which number he says that 14 are not known to extend into the Kiowa. Twenhofel[93] concludes that out of the 36 species listed by Cragin the following list, 27 in number, represent those concerning whose identity it is not likely he could have been mistaken.

Fauna of the Champion Shell Bed.

Anchura kiowana Cragin
Astrocoenia nidiformis Cragin
Cardita belviderensis Cragin
Cardium ? bisolaris Cragin
Cardium kansasensis Meek
Corbula crassirostrata Cragin
Cucullaea recedens Cragin
Engonoceras belviderei Cragin
Exogyra texana Roemer
Gryphea corrugata Say
Gryphea corrugata hilli Cragin
Limopsis subimbricatus Cragin
Margarita newberryi Cragin
Margarita marcouana Cragin
Neries ? incognita Cragin
Pecten fredericksburgensis Cragin
Pholadomya ? belviderensis Twenhofel
Pinna comancheana Cragin
Protocardia texana Conrad
Pteria belviderensis Cragin
Salenia kansasense Twenhofel
Schloenbachia kiowana Twenhofel (probably Oxytropidoceras cf. acutocarinatum)
Serpula championi Cragin
Turritella seriatim-granulata belviderii Cragin
Tylostoma elevata (Shumard)
Vanikora propinqua Cragin

KIOWA SHALE

The Kiowa shale consists typically of thinly laminated black shale grading into a yellowish clay in the upper part. The black shale of the lower portion of the Kiowa is especially characteristic consisting of very thinly laminated, paper like shale. It gives a black color to the hills and hence the name "Black Hills". The upper portion contains more lime and has a distinctly yellow color, standing out in marked contrast to the lower portion. There are numerous thin layers of a soft yellowish sandstone, particularly in the upper part. The formation contains throughout thin limestone layers, almost a fossil coquina, consisting of fragments of oyster shells. Fossils are exceptionally abundant, occurring in the limy and sandy layers throughout the formation. The black shale rarely contains fossils.

92. Cragin, F. W., A study of the Belvidere Beds: Am. Geol. vol. 16, p. 369, 1895.
93. Twenhofel, W. H., Geology and invertebrate paleontology of the Comanchean and Dakota formation of Kansas: State Geol. Survey of Kansas Bull. 9, p. 22, 1924.

The following section, given by Twenhofel, shows in detail the character of the Kiowa shale.

Section in Champion Draw, about one-half mile south of Belvidere, Kiowa County, Kansas. (After Twenhofel)[94]

KIOWA SHALE:

		Ft.	In.
19.	Not well exposed, appears to be largely gray shale and pink and gray *Gryphea* shell limestone	29	0
18.	Pinkish, poorly cemented limestone with a thin layer of satinspar on top. Contains many *Gryphea corrugata*, a few *Turritella seriatim-granulata belviderii* and *Cyprimeria kiowana*	0	8
17.	Shale, probably very dark blue, weathered yellow in exposure, with interbedded fine grained sandstone and gypsum. A few poorly preserved fossils in the sandstone; shale essentially without fossils	38	0
16.	Dark blue and yellow shale, no fossils	1	4
15.	Gray and blue shale, crowded with *Gryphea corrugata*	0	4
14.	Shell limestone, gray with pink patches. Contains *Gryphea corrugata* in great abundance (also *G. navia*)	1	6
13.	Black paper shale	7	0
12.	Gray shell limestone with patches of pink. Contains many small colored quartz pebbles, of which the diameter of the largest observed is about one-half inch. *Cyprimeria kiowana* very abundant	0	6
11.	Black paper shale	4	0
10.	Mottled gray and pink shell limestone. Contains some gypsum; many *Cyprimeria kiowana*	0	8
9.	Black paper shale	4	0
8.	Pink and gray shell limestone containing thin layers of satinspar. Contains an abundance of *Gryphea corrugata*, *Cyprimeria kiowana*, *Cardium kansasensis*, and *Turritella seriatum granulata belviderii*	0	6
7.	Black paper shale	11	0
6.	Fine grained gray quartz sandstone. Contains a few shell fragments and impressions	0	4
5.	Black paper shale	4	0
4.	Alternating thin bands of black and yellow shale, and thin, fine grained gray quartz sandstone. The shale contains small concretions and quartz pebbles, the former containing fossils	2	0
3.	Black paper shale	14	0
2.	Fine grained, friable gray sandstone, filled with needles of selenite. Contains poor impressions of pelecypods, among which *Tapes belviderensis* occur rarely	1 inch to 0	6
1.	Champion Shell Bed. A highly gypsiferous shell bed made up almost wholly of the shells of		

(Continued on page 58)

94. Twenhofel, W. H., Kansas State Geol. Survey Bull. 9, p. 23, 1924.

Section in Champion Draw, Cont'd.

Gryphea corrugata hilli. It is locally much iron stained and contains a great deal of iron pyrite and gypsum, each in a few places serving as a matrix for the shells. The iron oxide is known to have been partly derived from the oxidation of the pyrite. Where the pyrite and gypsum are most abundant the zone is thinnest and the shells mostly poorly preserved, largely because the oxidation of the pyrite has led to their decomposition. In many places the surface is covered with efflorescences of salt and gypsum, lime carbonate, and sulphur. The zone is splendidly exposed about the head of the draw, where it forms the floor of a well defined terrace with inclination in a southwesternly direction. Base of the Kiowa....4 inches to 1 6

CHEYENNE SANDSTONE (for section see page 5)

120 10

The thickness of the Kiowa is quite variable, decreasing both to the west and south. However, it has been recognized in all the outlying area of Lower Cretaceous in western Oklahoma, although its thickness rarely exceeds 10 feet.

Fauna of the Kiowa shale

Numerous fossil lists have been published for the Kiowa shale, the most recent being that given by Twenhofel. His list includes 40 species which have been identified from the Kiowa shale, exclusive of the Champion shell bed. It is as follows:[95]

Anchura kiowana Cragin
Anisomyon ? cragini Twenhofel
Carditia belviderensis Cragin
Cardium kansasense Meek
Cardium ? mudgeni Cragin
Cucullaea recedens Cragin
Cyprimeria kiowana Cragin
Dentalium sp.
Engonoceras belviderensis Cragin
Exogyra texana Roemer
Gervillia mudgeana White
Gryphea corrugata Say
Gryphea corrugata belviderensis Hill and Vaughan
Gryphea navia Hall
Leptosolen otterensis Cragin
Limopsis subimbricatus Cragin
Lingula sp.
Lithophagus interrogatum Cragin
Mactra antiqua Cragin
Margarita marcouana Cragin
Neritoma marcouana Cragin
Nucula catharina Cragin
Ostrea kiowana Twenhofel
Pecten texanus Roemer
Petersia medicinensis Cragin
Pholadomya ? belviderensis Twenhofel
Plicatula senescens Cragin
Protocardia texana Conrad
Pteria belviderensis Cragin
Remodia ferresi Cragin
Roudaria quadrans Cragin
Schloenbachia (Oxytropidoceras) belknapi Marcou
Schloenbachia kiowana Twenhofel (probably Oxytropidoceras cf. acutocarinatum)
Schloenbachia peruviana von Buch (O. acutocarinatum)
Tapes belviderensis Cragin
Trigonia emoryi Conrad
Trochus texanus Roemer
Turritella seriatim granulata belviderii Cragin
Tylostoma elevata Shumard
Yoldia microdonta Meek

95. Twenhofel, W. H., Kansas State Geol. Survey Bull. 9, p. 23, 1924.

Correlation of the Kiowa shale.—The problem of correlating the Lower Cretaceous of southern Kansas with that of Texas has been attempted by several investigators. Cragin, notably, maintained that the Champion shell bed should be referred to the Fredericksburg, and the Kiowa shales proper to the basal Washita. Cragin made a very careful analysis of the fauna and in a letter to Prosser he stated very clearly his position:[96]

> It is impossible to judge correctly of its (Champion shell bed) value by a study of Kansas alone. It can only be understood by first acquainting one's self with the formations of the Comanche series in Texas. Such comparative study shows clearly that the Champion bed is merely the extreme northern attenuated representative of the Comanche Peak limestone. The latter is the central member of Hill's Fredericksburg division, or the upper member of that division where, as in northern Texas and southern Indian Territory, the Barton Creek (Caprina) limestone is missing. Studies made since the publication of my article "A study of the Belvidere beds," make this clearer than ever. Indeed, with the exception of a few forms which are possibly peculiar to the northern shore region of the Comanche Peak sea, the Comanche Peak and Champion faunas are identical. The Kiowa shales represent the Kiamitia (Kiamichi) and the Tucumcari of Texas, Indian Territory, and New Mexico. In the typical Texas area the Comanche Peak is a great formation, while the Kiamitia and Tucumcari are limited. In Kansas, the Kiamitia and Tucumcari are amply developed and closely related, the lower formation shading into the upper, while the Comanche Peak (here called the Champion) is of little thickness and limited to the eastern part of the Comanche area, though rich, as everywhere, paleontologically. It is of course true that the Champion bed has many things in common with the Kiowa, and, where (as pardonably in this case) geology is to be bounded by state lines, may be viewed as part of it. But viewed in the light of the fuller knowledge available, the Champion belongs to the Fredericksburg division, while the Kiowa shales belong to a higher division which I call the Kiowa but which Hill includes in his Washita. The flora of the Cheyenne sandstone, as reported by Hill and Knowlton, shows conclusively that this sandstone belongs to a later time than the Glen Rose, and its affinity with the Dakota probably brings it up out of the Bosque (Trinity) division altogether. So the Cheyenne also probably belongs to the Fredericksburg. There are therefore good paleontological grounds for separting the Champion bed from the Kiowa shales and considering it as nearly related to the Cheyenne. Genetically, the Champion bed seems to be closely related to both the Cheyenne and the Kiowa and to be transitional between them; but the bed, whether thus transitional or not, was certainly deposited in Fredericksburg time, as no one intimately acquainted with its paleontology and that of the Comanche series of Texas could possibly question.

Hill[97] made a careful study of the area and together with Stanton, who identified the fossils, decided that:

> These beds (speaking of the Lower Cretaceous of southern Kansas) represent the modified attenuated northern extension of the Washita division and probably a portion of the Fredericksburg division of the Comanche series of Texas, which, as we have previously shown, far overlapped to the northward those of the Trinity division.

96. Cragin, F. W., Letter to Prosser, C. S., dated Dec. 14, 1896. Published in Geol. Survey of Kansas, vol. 2, p. 115, 1896.
97. Hill, R. T., Outlying areas of the Comanche series in Kansas, Oklahoma, and New Mexico: Am. Jour. Sci. 3rd ser. vol. 50, p. 234, 1895.

Cragin based his correlation of the Champion shell bed with the Comanche Peak almost entirely on his determination of the small *Gryphea*, so abundant in the Fredericksburg of Texas, (*Gryphea marcoui* Hill & Vaughan) as the same species which occurs equally abundantly in the Champion shell bed. Hill, however, concluded that the *Gryphea* of the Champion was a dwarf form of *Gryphea corrugata* Say, which was called *Gryphea corrugata hilli* Cragin, and not related to the small *Gryphea* of the Fredericksburg of Texas.

It seems to the writer that much of the confusion which has resulted from attempting to correlate these beds with the Texas section on the basis of paleontology is due to the fact that there is no clear cut, definite, paleontologic break between the Fredericksburg and Washita divisions. Hill originally drew the boundary between these two divisions on the basis of the ammonites. In this connection he says:

> In this preliminary classification, founded upon the Fort Worth section, the line between the Fredericksburg and Washita divisions was arbitrarily drawn above the zone of *Ammonites acutocarinatus* Shumard, which has been referred to *A. peruvianus* von Buch.

Later Hill modified his views drawing the dividing line between these two divisions on the basis of the occurrence of *Rudistes* and *Nerineas*. On this basis the boundary between the Fredericksburg and Washita in north Texas occurs at the Goodland-Kiamichi contact. While there is a very clear cut break in the character of the sediments at this horizon, a very pure limestone in one case and a bituminous clay in the other, the fauna of one has many forms in common with the other. Winton and Adkins[98] in their study of the Fort Worth section list 16 species in the Kiamichi, 10 of which also occur in the Goodland. It will be recalled that Cragin listed 36 species from the Champion, 22 of which he says range into the Kiowa.

Stanton and Vaughan[99] in their study of the section at El Paso, Texas, which is somewhat similar to that of north Texas in that it is also in the littoral zone of the Comanche sea, found it difficult to separate the Fredericksburg and Washita. The following is quoted from their report:

> The evidence of the fossils taken altogether is in favor of the view that part of the Fredericksburg is represented here and that it grades into the basal Washita so imperceptibly that no paleontologic line can be drawn between them.

The writer firmly believes that if the abrupt break in lithologic character did not occur between the Goodland and the

98. Winton, M. W., and Adkins, W. S., Geology of Tarrant Co., Texas: Univ. of Texas Bull. 1931, 1919.
99. Stanton, T. W., and Vaughan, T. W., Section of the Cretaceous at El Paso, Texas: Am. Jour. Sci. vol. 1, 4th ser., pp. 21-27, 1896.

Kiamichi in north Texas the same confusion would exist in the separation of the Fredericksburg and Washita divisions as now exists in southern Kansas. This situation has led Adkins[100] to return to Hill's original definition of the Fredericksburg, which places at least part of the Kiamichi in that division.

The Kiowa shale is correlated with the Kiamichi clay of southern Oklahoma and northern Texas. The fossils especially characteristic of the Kiamichi are: *Oxytropidoceras belknapi* (Marcou), occurring usually near the top of the formation, and *Gryphea corrugata* Say and *Gryphea navia* Hill, forming shell beds in the upper part of the formation. The Kiowa shale contains the same fossils and they are distributed in the same manner as in the Kiamichi. Moreover the Kiowa and the Kiamichi are very similar in lithologic characteristics, which combined with the paleontologic evidence seems to make their correlation conclusive.

The Champion shell bed occupies the stratigraphic position of the Goodland limestone. In addition it contains many fossils common to the Goodland. However, as has been pointed out the line between the Fredericksburg and the Washita is difficult to establish from paleontologic evidence which fact has resulted in the Champion shell bed being included with the Kiowa shale. The evidence at present is in support of Hill's statement made more than 30 years ago to the effect that, "probably a portion of the Fredericksburg" is represented in southern Kansas.

SPRING CREEK CLAY

Overlying the Kiowa shale, about 7 or 8 miles up the Medicine Lodge River from Belvidere, are found a series of beds which Gould[101] first recognized and described. The sequence given by Gould is as follows:

Reeder sandstone	"Dakota" flora
Kirby clay	"Dakota" flora
Greenleaf sandstone	Marine Comanche fauna
Spring Creek clay	Marine Comanche fauna

These beds do not occur in Oklahoma and for that reason only a very brief description of them is given here. Very little is known regarding these beds, practically the only work dealing with them being that by Gould. The following descriptions and fossil lists are from Gould's paper.

The Spring Creek clay, named from a creek west of Belvidere, consists of bluish, greenish, and yellowish clays and shales in

100. Adkins, W. S., Geology and mineral resources of the Fort Stockton quadrangle: Univ. of Tex. Bull. 2738, 1927.
101. Gould, C. N., Series of transition beds from the Comanche to the Dakota Cretaceous: Am. Jour. Sci. vol. 5, pp. 169-175, 1898.

which there are concretions of impure limonite. The contact with the underlying Kiowa is not sharply defined. The average thickness of this formation is around 50 feet. Stanton identified the following fossils from material collected by Gould:

Fossils from Spring Creek clay

Cardium kansasensis Meek
Corbula sp.
Cyprimeria cf. kiowana Cragin
Gryphea corrugata Say
Lingula sp.
Nucula sp., or Leda sp.
Mactra sp.
Ostrea quadriplicata Shumard
Pholadomya ? cf. belviderensis Twenhofel
Protocardia cf. texana Conrad
Tellina sp.
Sharks teeth and fish scales

GREENLEAF SANDSTONE

Overlying the Spring Creek clay occurs a light gray to brown, massively bedded, commonly cross-bedded sandstone, named for the Greenleaf ranch, about 8 miles up the Medicine Lodge River from Belvidere, where the formation is typically exposed. Nodules of clayey limonite and veins and stringers of limonitic material are very common. The following fossils have been identified:

Cyprimeria cf. kiowana Cragin
Lingula sp.
Pholadomya cf. belviderensis Twenhofel
Turritella sp.
Shark teeth

Section on Spring Creek, about 12 miles west of Belvidere
(after Gould)

	Ft.	in.
6. Covered slope underlain by plains Tertiary.		
DAKOTA FORMATION:		
5. Reeder sandstone. Dark brown, massive-bedded sandstone generally cross-laminated and containing many pebbles and nodular concretions, the latter up to 3 feet in diameter. No fossils observed....	20	0
4. Kirby clay. Yellowish to reddish clay, more or less sandy and containing beds of light yellow sandstone. Contains nodules of clay ironstone............	20	0
BELVIDERE FORMATION:		
3. Greenleaf sandstone. Light gray to yellow sandstone, generally much cross-laminated and containing nodules of dark brown to black ironstone	55	0
2. Spring Creek Clay.		
(a) Blue to yellow clay, containing bands and concretionary masses of impure limonite. Outcrop of reddish color........	20	0
(b) Dark brown clay ironstone, bedding undulatory and cross-laminated. Not everywhere present. Weathers into odd forms	5	0
(c) Green to yellow clay with one to eight inch beds of gray shaly sandstone. Contains numerous iron concretions; many of these are geodic, but contain clay	15	0
1. Kiowa shales. Black paper shale........	15	0

It is hardly possible to even attempt a closer correlation of the Spring Creek clay and the Greenleaf sandstone with the Texas formation, than to assert that they are of Comanche age and overlie the Kiowa shale which is lower Washita. To one familiar with the Texas formations the striking resemblance of the Spring Creek to the Weno and the Greenleaf to the Pawpaw in lithologic characteristics cannot be overlooked. Practically the only fossil of stratigraphic value listed from the two formations is *Ostrea quadriplicata* Shumard, which in Texas is limited to the upper part of the Washita division, its zone of abundance being in the Quarry limestone. However, it is very hazardous to even suggest a correlation based on such meager evidence.

AVILLA HILL

LOCATION

This prominent outlier is located on the Oklahoma-Kansas boundary, 16 miles due south of Coldwater, Kansas. A sketch map of this outlier is given in Figure 2, page 64. It is elongated in a northwesterly direction, its maximum length being about 4 miles and its average width about 1½ miles. It forms a very conspicuous topographic feature, standing 200 to 300 feet above the surrounding country. The top of the hill is capped by the Tertiary, the Cretaceous strata being exposed on the flanks.

HISTORY

The first reference to the Cretaceous strata on this hill was a brief statement by St. John[102] in 1887. Cragin[103] in crossing the area noted the presence of Kiowa fossils but did not describe the locality. Prosser[104] in 1896 gave the first section and detailed description of this exposure. The following year Vaughan[105] published an article in which he also gave a section and a description of this locality.

STRATIGRAPHY

The Lower Cretaceous rocks at Avilla Hill consist of about 138 feet of black paper like shales grading upward into yellow clay, containing throughout thin layers of a limestone shell breccia composed chiefly of oyster shells, thin beds of yellow sandstone, and numerous fossiliferous layers. The Cretaceous rests on Permian red beds, the contact being markedly irregular. It is overlain by Tertiary "mortar beds". The section on page 65, measured by the writer, shows in detail the nature of the material.

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102. St. John, O. P., Notes on the geology of southwestern Kansas: Fifth Bien. Rept. Kansas State Bd. of Agri., 1887.
103. Cragin, F. W., Bull. Washburn Col. Lab. Nat. Hist., vol. 2, No. 11, p. 74, 1890.
104. Prosser, C. S., Geol. Survey Kansas, vol. 2, p. 142, 1897.
105. Vaughan, T. W., Additional notes on the outlying areas of the Comanche series in Kansas and Oklahoma: Am. Jour. Sci. 4th ser. vol. 4, p. 46, 1897.

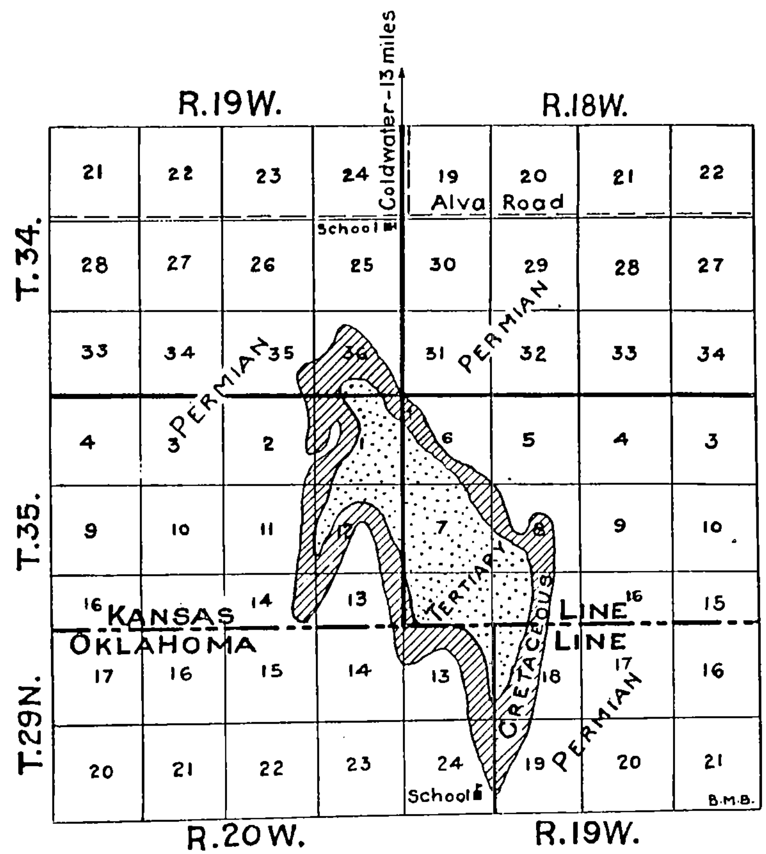


Figure 2. Map of Avilla Hill a Lower Creaceous outlier.

Discussion of the section.—The sandstone near the base is lenticular and locally becomes rather prominent. It may be seen on the east side of Avilla Hill and also near Lookout, Oklahoma, on the south side of the outlier. The first shell horizon, about 45 feet above the base in the measured section, is composed of a marked abundance of *Cyprimeria kiowana* Cragin, *Oxytropidoceras acutocarinatum* (Shumard), *Turritella seriatim granulata var. belviderensis* Cragin, and a few small *Grypheas.* This is the "Cyprimeria zone" in Pl. X. About 6 feet above the "Cyprimeria zone" is another shell horizon composed almost entirely of large, well preserved *Gryphea corrugata* Say and *Gryphea navia* Hall. Above this second shell horizon are several zones of black shale which grade upward into yellow clay and end in a sandstone layer.

This is repeated several times indicating an oscillating condition. There are two rather prominent shell horizons in the upper portion of the section; the lower one is composed of unidentifiable oyster fragments, but the top one is a typical Kiamichi shell bed made up of *Gyrphea corrugata* Say and *Gryphea navia* Hall. It marks the top of the section. Between these last two shell horizons are a number of layers of thin platy sandstones which carry an abundance of *Oxytropidoceras belknapi* (Marcou).

Section at Avilla Hill near the SE. cor. of the NW.¼ of the NW.¼ sec. 36, T. 34, R. 19 W., about 16 miles south of Coldwater, Kansas.

	Ft.	In.
TERTIARY—coarse conglomerate sandstone		
CRETACEOUS—Comanche series:		
Shell breccia, hard, composed of fragments of *Gryphea navia* Hall and *Gryphea corrugata* Say	0	4
Clay, yellow, sandy, containing several layers of sand from one to two inches in thickness	11	0
Shell breccia	0	4
Clay, yellow	24	8
Sandstone, grayish brown, fine grained, calcareous, separated by thin layers of yellow clay	0	6
Shell breccia, unidentifiable fragments of oysters	0	2
Shale, yellow, containing several one inch layers of sand	13	0
Sandstone, thinly laminated, weathers yellow	0	6
Shale, black, grading upward into yellow clay	26	6
Sandstone, thinly laminated, brown to gray	0	2
Shale, black, grading upward into yellow	6	6
Shell bed, composed of layers of impure shelly limestone, aragonite and shale; filled with large well preserved *Gryphea corrugata* Say, *Gryphea navia* Hall	1	0
Shale, black paper like	6	6
Shell bed, impure limestone, containing an abundance of *Cyprimeria kiowana* Cragin, *Oxytropidoceras acutocarinatum* (Shumard), *Trigonia emoryi* Conrad, *Gryphea navia* Hall, *Gryphea corrugata* Say, *Turritella seriatim granulata var, belviderensis* Cragin, *Anchura, kiowana* Cragin	0	6
Shale, black, containing many gypsum crystals. In lower portion are found thin layers and lenses of white sandstone coated with gypsum crystals and containing unidentifiable shell fragments	30	0
Sandstone, reddish brown, ferruginous, lenticular, absent in places, composed of coarse sand, gray and friable; locally contains concretions and indurated masses of iron	1	0
Shale, black, paper like, containing thin lenses of yellow clay at the base, grading upward into yellow clay containing thin layers of black shale. Much gypsum present	10	0
Clay, shale, gray to yellow containing iron stains in joints and between bedding planes	3	6
Clay, sandy, gray at base grading into yellow	2	0
PERMIAN—very irregular contact, dark red shales		
	138	2

One of the outstanding facts in regard to the Avilla Hill section is the apparent absence of the Cheyenne sandstone and the Champion shell bed. At Belvidere the Kiowa shale has a total thickness of about 115 feet, while in the Avilla Hill section it is over 135 feet in thickness. The various shell horizons, discussed above, are fairly distinct in the Belvidere section and the same gradation from black shale to yellow clay is observed. There can be no doubt as to the correlation of the Kiowa in the two areas, for even specific horizons can be recognized. The sandstone layers at the base of the section may represent the Cheyenne, as has been suggested by Prosser and others, but with the Kiowa so uniform in the two areas, and the Cheyenne reduced to a mere trace it would seem to require some special explanation.

STRUCTURE

No details regarding the structure of the Avilla Hill outlier are available. The observations made by the writer indicate that the outlier is situated in a basin like structure; this will be more fully discussed in the general chapter on structure.

WESTERN OKLAHOMA

Historical Summary

The first published note on the Cretaceous outliers of western Oklahoma was by Jules Marcou, who as geologist with the Pacific Railroad Expedition in 1853, 1854, and 1855 crossed western Oklahoma following approximately the course of the South Canadian River. The following extract is quoted from Marcou's[106] "Geology of North America".

> I have mentioned two points between Topofki Creek and Anton Chico, where the Triassic rocks are covered by more modern formations. The first of these points is upon one of the tributaries of the False Washita River, Comet Creek (latitude 35°32′ 21″, longitude 99°14′ 40″), near our camp No. 31, where, upon the heights are found the remains of beds of a limestone filled with shells which I connect with the Neocomian of Europe, or, in other words, with the lower division of the Cretaceous rocks. This limçstone is only 5 feet thick, it is of a whitish gray color, containing an immense quantity of Ostracea, which I consider as identical with *Exogyra (Gryphea) Pitcheri* Mort. * * * having the closest analogy with *Exogyra Couloni* of the Neocomian of the environs of Neufchatel (Switzerland). As it is the first time the Neocomian, where, until now, only the Greensands and Chalk Marl or Lower Chalk have been found, I will add that these strata are much more developed at Fort Washita, where Dr. G. G. Shumard has made a collection of fossils such as *Pecten quadricostatus, Gryphea Pitcheri, Cardium multistriatum, Ammonites acuto-carinatus, Holaster simplex,* all fossils or genera characteristic of the Neocomian of Europe. Further, at Fort Washita, the Neocomian is covered by the green sand containing very fine *Hemiaster*, large *Ammonites flacidicosta, Gryphea sinuata var. Americana, Exogyra Texana* and etc.
>
> The Neocomian has nearly been destroyed and carried away by denudations, for it is only found on the summits of the hills, where it appears like ruins of ancient buildings; it occupies actually only a width of three or four miles. Probably at the time of the deposit it covered more space, but as at Fort Washita, where it has been very little denuded, it is only twenty-five or thirty miles wide. This shows it to have been a narrow band in the immense basin of the prairies.

106. Marcou, Jules, Geology of North America: p. 17, 1858. The wording varies from that used in the resume printed as part of Lt. Whipple's report, House Doc. 129, p. 40, 1854, and makes locations more explicit.

The Comet Creek referred to above does not appear on any maps and the oldest inhabitants do not recall such a name. However, from the best information obtainable Marcou is referring to Barnitz Creek in the vicinity of Arapaho, Oklahoma. In addition to being the first observations on the Cretaceous of western Oklahoma, it is, as Marcou stated, the first time that the Lower Cretaceous had been recognized in North America.

In 1894 Cope visited a Cretaceous outlier near Supply, Oklahoma. No definite location is given but he states that it was on the divide north of Supply, between the Canadian and Cimarron rivers. He says:[107]

> We found that the formation which constitutes the higher levels at the heads of the canyons tributary to the Cimarron is an impure friable calcareous limestone of evidently Lower Cretaceous age.

In 1895 Hill[108] published an extended article in which he takes up chiefly the Belvidere, Kansas section, but also describes the Camp Supply area, the Comet Creek locality of Marcou, and the Tucumcari Mountain section of New Mexico. Detailed fossil lists are given for each region. Hill indicates that he is inclined to correlate these "outlying areas" in western Oklahoma with the Washita division of Texas.

In 1897 Vaughan[109] working under the direction of Hill visited a number of additional outliers of Lower Cretaceous in western Oklahoma. His conclusions do not differ from those stated by Hill two years earlier.

In 1905 Gould[110] showed on a map which accompanied his report on western Oklahoma over 40 separate outliers of Lower Cretaceous. This was the first attempt to map these outliers and was the only map available at the time of the writer's work (1927). In the discussion of these beds Gould says:

107. Cope, E. D., Observations on the geology of adjacent parts of Oklahoma and northwest Texas: Proc. Acad. Nat. Sci. Philadelphia, pp. 63-68, 1894.
108. Hill, R. T., Outlying areas of the Comanche series in Kansas, Oklahoma, and New Mexico: Am. Jour. Sci., 3rd ser. vol. 50, pp. 205-235, 1895.
109. Vaughan, T. W., Additional notes on the outlying areas of the Comanche series in Oklahoma and Kansas: Am. Jour. Sci., 4th ser. vol. 4, pp. 43-50, 1897.
110. Gould, C. N., Geology and water resources of Oklahoma: U. S. Geol. Survey Water Supply Paper 148, 1905.

In general the Comanche or Lower Cretaceous rocks in Oklahoma consist of limestones and shales. In many of the western counties these deposits are found on hillsides and are known locally as "shell rock," because they are composed largely of fossil shells belonging chiefly to some member of the oyster family.

The most eastern point to which the Comanche deposits formerly reached can not be ascertained, because these deposits have been largely eroded since they were laid down. It seems probable, however, that the same deposits are but the remnant of a much larger area of the Comanche beds.

The Oklahoma Cretaceous beds form a connecting link between larger areas of the Comanche series in Texas and Kansas. * * * It is not the intention of the writer to discuss the age of these beds further than to say that it seems probable that they belong to the Washita or upper member of the Lower Cretaceous.

Gould's work, cited above, was the last publication to deal with the outlying areas of the Lower Cretaceous in western Oklahoma. In fact on the geologic map of Oklahoma compiled by the U. S. Geological Survey in 1924 the mapping of these outliers was taken directly from Gould's map.

General Statenent

The Cretaceous outliers of western Oklahoma are distributed from the Kansas line (Avilla Hill) southward to within a few miles of the Wichita Mountains. The presence of these outliers of Lower Cretaceous rocks in western Oklahoma has been common knowledge for many years. A review of previous work has been given, but it may be well to recall here that Marcou, in 1854, was the first to note their presence, and at that time he correctly assigned them to the Lower Cretaceous. Others who have worked on these beds include Cope, Hill, Vaughan, and Gould. The first map which attempted to show the location of these outliers was made by Gould in 1905. The writer has mapped with some care all of the outliers of this area, several hundred in all, and found that many of them, as shown on the geologic map of Oklahoma, consist only of Tertiary gravels containing Cretaceous fossils.

It will be convenient for purposes of description to divide the outliers of this region into three groups: the Supply area, the Seiling-Cestos area, and the Butler-Foss area. It will be noted from the general map, Plate I, that while the outliers are distributed throughout western Oklahoma, they are concentrated in three areas near the villages mentioned above. The outliers of each area differ slightly in thickness and nature of material, yet horizons common to all of them are present so that a definite correlation can be made. The outliers in any given area are all similar and in the following discussion a typical exposure is described for each area and then the various outliers merely listed as to location.

SUPPLY AREA

LOCATION

This is the Camp Supply locality of Cope and Vaughan. It is near Supply, Oklahoma, formerly a Federal Army Camp, located about 20 miles northwest of Woodward, Oklahoma. The exposures in this area consist of two separate localities; one on the south side of the North Canadian River, west of Supply, and the other on the north side of the North Canadian River, north of Supply. The latter is the most extensive and best developed, extending in disconnected outcrops for a distance of about 10 miles. Details regarding the location of these outliers are given on Figure 3. It is the area west of Supply that Vaughan visited. Cope, while his location is very indefinite, apparently visited the area north of Supply.

STRATIGRAPHY

The outliers in this area rest on the Permian (Day Creek dolomite) and are capped, in places, by the Tertiary. The relation of the Cretaceous to the topography of the country is shown on the profile accompanying Figure 3.

Outliers north of Supply.—The outliers north of Supply extend in disconnected outcrops from sec. 17, T. 25 N., R. 22 W., which is about 4½ miles due north of Supply, in a general eastward direction for a distance of about 10 miles; the most easterly outcrop observed being in secs. 11 and 12, T. 25 N. R. 21 W. The outcrops follow the divide between the North Canadian River and the Cimarron River. Their southern extension is covered by wind blown sand from the North Canadian River. On the north the country breaks off very rapidly leaving the Cretaceous exposed on the crest of a rather prominent north facing escarpment, formed by the Day Creek dolomite overlying the soft, easily eroded Whitehorse sandstone.

In the section below there are three well marked fossiliferous horizons. The lowest, No. 7, "*Exgogyra texana* zone", contains the following fossils:

Exogyra texana Roemer, abundant.
Trigonia emoryi Conrad
Gryphea corrugata hilli (?) Cragin
Turritella seriatum granulata Roemer
Cucullaea recedens Cragin
Pecten sp.

The second fossiliferous horizon, No. 9, "*Cyprimeria* zone", contains the following fossils:

Cyprimeria kiowana Cragin, abundant
Oxytropidoceras sp. cf. O. acutocarinatum,[111] abundant
Trigonia emoryi Conrad
Turritella seriatum granulata Roemer
Turritella sp.

The third fossiliferous horizon, top of No. 10, "*Gryphea corrugata* zone", contains the following fossils:

Gryphea navia Hall, abundant
Gryphea corrugata Say, abundant
Oxytropidoceras belknapi (Marcou)

Section of the Lower Cretaceous in the SE.¼ sec. 11, T. 25 N., R. 22 W., north of Supply, Oklahoma.

LOWER CRETACEOUS:

	Ft.	In.
10. Clay, gray to yellow, terminating at the top with a shell horizon from 6 inches to one foot in thickness which contains large and well preserved *Gryphea corrugata* Say, *Gryphea navia* Hall, and *Oxytropidoceras belknapi* (Marcou)	9	0
9. Clay, yellow, sandy, containing many *Cyprimeria* sp., *Turritella* sp., and *Oxytropidoceras*, sp.	0	6
8. Shale, blue black paper like, grading upward into a gray to yellow clay	22	0
7. Clay, yellow arenaceous, grading into a yellow sandy lime, abundance of fossils including *Exogyra texana* Roemer, *Trigonia* sp., *Gryphea corrugata hilli* ? Cragin, *Pecten* sp., *Turritella* sp.	5	0
6. Sandstone, ferruginous, hard, yellow, breaks into large blocks	1	6
5. Sand, soft, yellow, ferruginous	1	6
4. Clay, lower 18 inches yellow grading upward rather rapidly into a decided coal black	6	0
3. Sand, coarse, conglomeratic, yellow, ferruginous, containing layers and lenses of quartz conglomerate with a maximum size of particles about that of a pea, and lenses of clean, white sand, locally indurated and attaining a thickness of two feet. The conglomeratic zone is about 3 feet thick and occurs at the base. It grades upward into soft yellow to gray pack sand	5	6
2. Clay, sandy, dove gray with ferruginous streaks grading upward into black shale	10	0
1. Clay, light green, sandy	0	8
PERMIAN RED BEDS		
	51	8

111. Identified by Dr. T. W. Stanton.

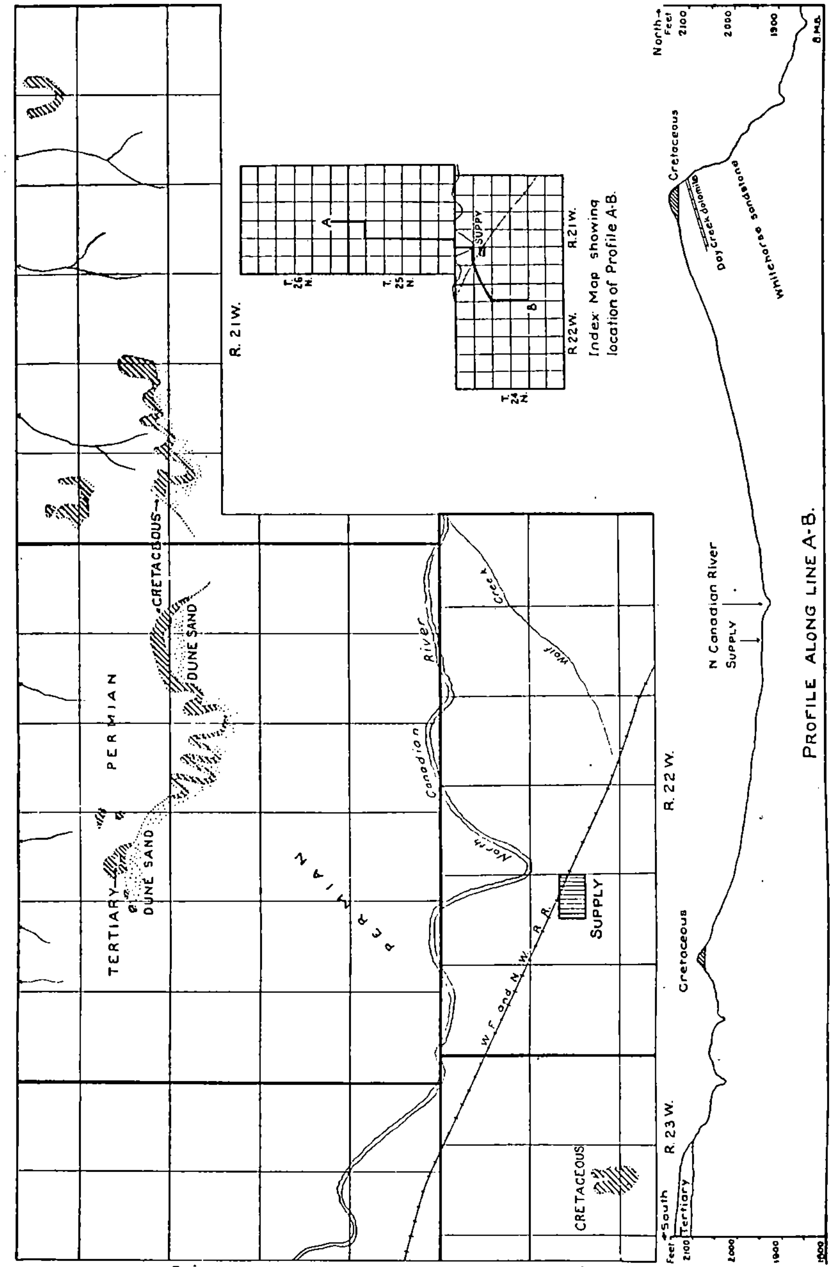


Figure 3. Map of the Supply area, showing location of the Lower Cretaceous outliers.

This section resembles the Avilla Hill section, except the upper part of the Avilla Hill section seems to be missing in the Supply section. (See Pl. X). This could be accounted for by a thinning of the sediments, or by erosion. The character of the material is essentially the same. The same gradation from black shale to yellow clay is observed and the same fossiliferous horizons can be recognized, occupying essentially the same relative position in the section. It would seem, therefore, that the difference in thickness of these two sections is due to erosion rather than any other factor.

The Cretaceous rests on the Permian, the contact surface being very irregular. The basal portion of the Cretaceous contains many fragments of the Permian red beds. This red material does not extend far up into the Cretaceous, so it would seem that the surrounding Permian area was covered by the Cretaceous sea, or at least was so low lying that it did not furnish sediments to the Cretaceous sea.

In the Supply area the Cretaceous decreases in thickness to the east, so that in the most easterly exposure noted, secs. 11 and 12, T. 25 N., R. 21 W., it has a thickness of from 10 to 15 feet. Beginning at the base this section consists of a thin zone of yellow clay which rests on the Permian. This is followed by an unconsolidated yellow sand, (Nos. 5 and 6 in the previous section), above which is the typical "*Exogyra texana* zone", (No. 7 in the previous section). The Tertiary caps the section and it is apparent that at this locality both the basal portion and the upper portion of the section previously given are missing.

Other good exposures of the Cretaceous in the area north of Supply may be found at the U-shaped outlier in secs. 7 and 18, T. 25 N., R. 21 W., and near the center of sec. 17, T. 25 N., R. 22 W. Both of these outcrops show only the lower portion of the typical section, the "*Exogyra texana* zone" forming in each case the top of the section. The U-shaped outlier mentioned above, exhibits the best exposure of the lower portion of the section observed in this area.

Outlier west of Supply.—This area consists of a single hill capped by Lower Cretaceous rocks, 3 miles west of Supply, in secs. 11 and 14, T. 24 N., R. 23 W., on the divide between the North Canadian River and Wolf Creek. The total area of the Cretaceous outliers does not exceed 60 acres. The character of the material and the sequence of beds, athough rather poorly exposed, is practically the same as for the area north of Supply.

Section of Lower Cretaceous outlier west of Supply, Oklahoma, in sec. 11, T. 24 N., R. 23 W.

	Ft.	In.
Shell horizon composed of yellowish brown shell breccia of oyster shell fragments, forms cap of hill	1	0
Clay, yellowish brown, ferruginous	11	0
Shell bed, containing an abundance of pink, large, well preserved *Gryphea corrugata* Say, *Gryphea navia* Hall, *Turritella* sp., *and Trigonia* sp.	0	6
Shale, black paper like, grading upward into gray clay which contains numerous lenses and fragments of iron and sulphur. A reoccurrence of black shale is found near the top. Lower contact is covered by stream alluvium	15 to 20	
PERMIAN—red shales containing beds of yellow ripple-marked sandstone.		

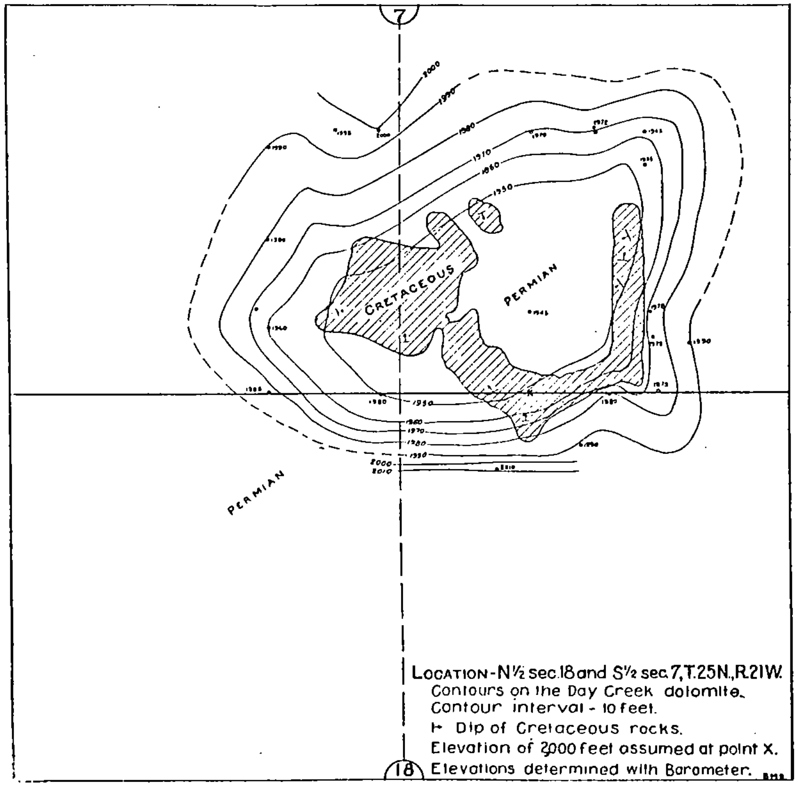
STRUCTURE

The dip of the Cretaceous beds is to the south. It is very difficult to determine the amount of dip, because practically all of the exposures are along the strike of the beds. A profile from the area north of Supply to the outlier west of Supply shows a difference of elevation of about 60 feet. The direction is south by west and the distance about 8 miles, which gives a dip of less than 10 feet per mile, but of course it is probably not in a direct line with the dip.

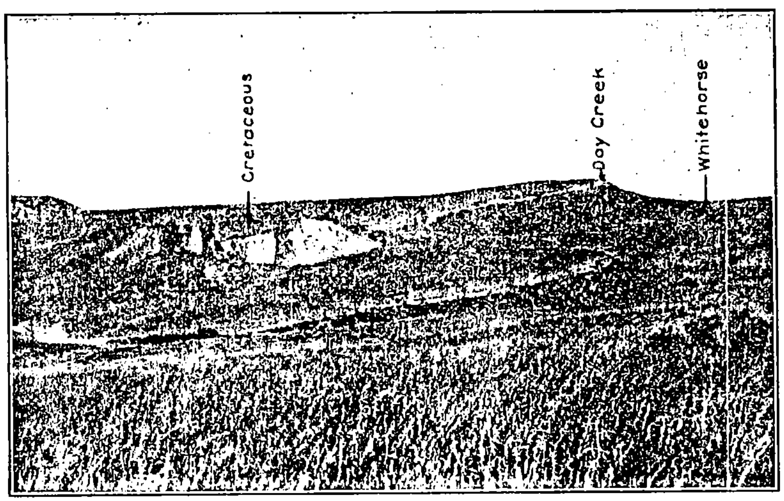
The *U*-shaped outlier in secs. 7 and 18, T. 25 N., R. 21 W., northeast of Supply, presents a very interesting feature in connection with the relation of the Cretaceous to the Permian. It may be noted from the map that this outcrop is separated from the main exposure. It is surrounded on all sides by the Permian (Day Creek dolomite), which dips at rather steep angles in towards the Cretaceous outlier on all sides. A structural contour map was made of this small area by taking elevations with a barometer on the Day Creek dolomite, (See fig. 4). It shows a basin-like structure covering about 160 acres and about 50 feet deep. The Cretaceous occupies the trough of the basin and conforms in structure to the basin in which it is situated. The development of a sink hole and the settling of the beds into the basin has protected that portion of the Cretaceous in the trough from erosion. Similar features were noted in other localities, notably in secs. 11 and 12, T. 25 N., R. 21 W.

CORRELATION

The rocks of the Supply section may be correlated directly with the Kiowa shale of Kansas, as indicated on the columnar section chart, Plate X. The two important fossiliferous hori-



A. MAP SHOWING A LOWER CRETACEOUS OUTLIER IN A "SINK HOLE"
(The photograph below is the small detached area on the north)



B. VIEW LOOKING WEST FROM THE NORTHEAST END OF THE OUTLIER SHOWN ABOVE.

zons common to both areas are: (1) the *Cyprimeria* zone, No. 9 in the Supply section, and (2) the *Gryphea corrugata* zone, No. 10 in the Supply section. The lower horizon, *Exogyra texana* zone, does not seem to be present as a definite unit in the Kansas area, unless it is represented by the Champion shell bed in the Belvidere section. The Supply section is almost a duplicate of the Avilla Hill section, as has been discussed before, except that the upper part of the former has been eroded. The Cheyenne sandstone may be represented in the Supply section by the sand and conglomerate layers near the base, but conclusive evidence in support of this assumption is lacking.

SEILING-CESTOS AREA

LOCATION

The outcrops of Lower Cretaceous rocks in this area are shown on Figure 4. They are located in the southeastern corner of Woodward County and in the northeastern corner of Dewey County, about 30 miles southeast of Woodward. This area is about 45 miles southeast of the Supply area.

STRATIGRAPHY

The outliers in this area consist usually of large slabs of a *Gryphea* agglomerate lying loose on the Permian (Cloud Chief). Sometimes a few feet of blue to yellow clay is observed intermixed with the shell bed. In the exposures to the northwest of Seiling the material usually consists of fragments of a sandy limestone.

The outcrops occur along the valley slopes, frequently well down in the bed of the streams, (see profile accompanying Fig. 4). The material has gradually slumped from higher levels into the valleys, and being more protected from erosion has been preserved, while all traces have been removed from the more exposed places. Careful search, however, has shown that remnants occur on the tops of the highest points in the area, so there can be no doubt that it once occurred at a much higher level and due to soil creep or some form of slumping has reached its present position. The fact that the material is usually found on the sides of Permian hills has led to the erroneous conclusion by some writers that the Cretaceous sea did not cover the tops of the Permian hills in western Oklahoma.

There are few good exposures in this area, but in most any locality fragments of the "shell bed" can be found in the fields and in many places they may be seen stacked up along the fence row where the farmers have piled them after plowing them up.

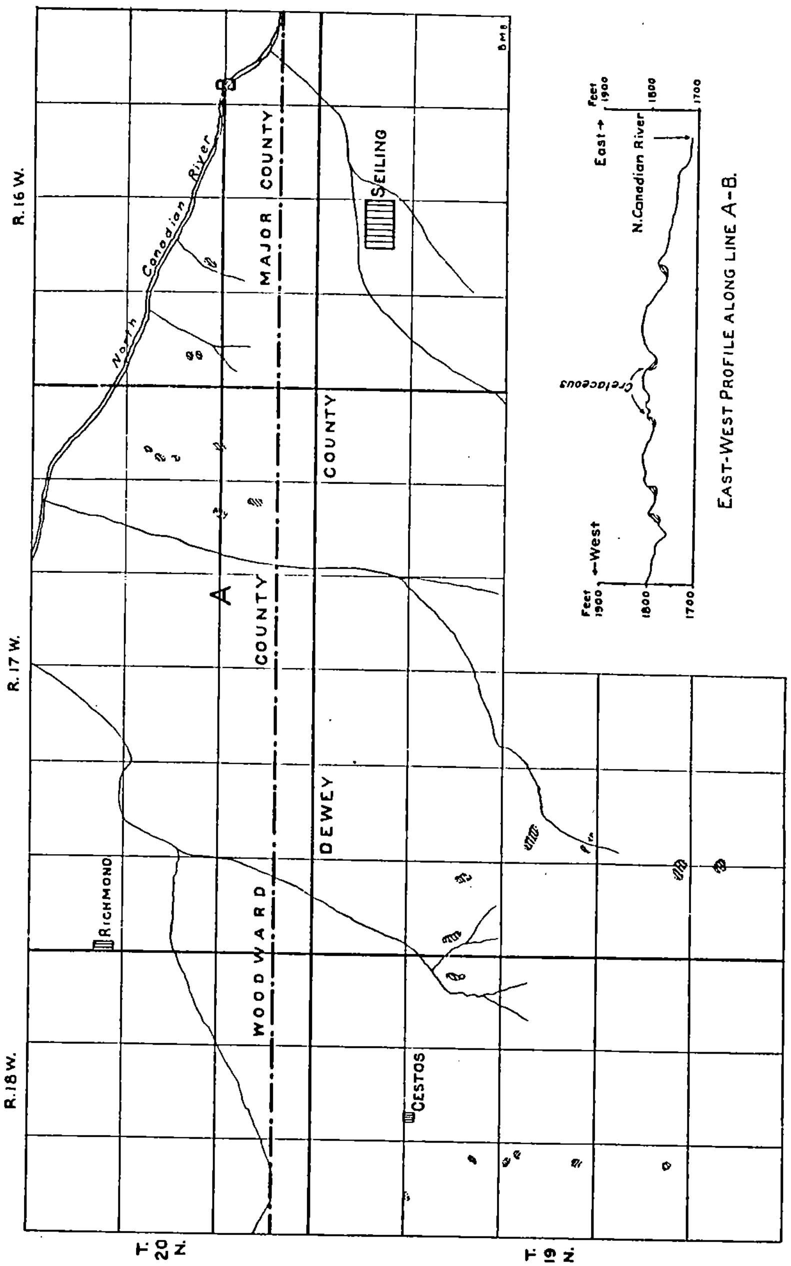


Figure 4. Map of the Ceiling-Cestos area showing location of Lower Cretaceous outliers.

Due to the lack of a better "hard rock" in this vicinity the shell bed has been rather widely used as a concrete filler. The best exposure observed by the writer is the one at which the following section was measured:

Section of the Lower Cretaceous outlier in the NE.¼ sec. 17, T. 19 N., R. 17 W., about 2 miles east of Cestos, Oklahoma.

(This exposure occurs along the north bank of a small creek where the material has slumped into the stream valley and the creek later cut through the slumped material. None of the material is *in situ*, but clean cut exposures are available and an estimated section based on this exposure is as follows:)

	Feet	Inches
3. Shell bed, yellowish shell limestone, composed of large and well preserved *Gryphea navia* Hall and *Gryphea corrugata hilli* Cragin, *Turritella* sp., and *Oxytropidoc-* (Marcou); occurs in large slabs and blocks up to 15 feet square	3	0
2. Light blue to gray limestone, hard, nodular, weathers white, contains *Cyprimeria* sp., a small *Gryphea cf. corrugata hilli* Cragin, *Turritella* sp., and *Oxytropidoceras cf. acutocarinatum* (Shumard)[112] 6 in. to	1	6
1. Blue clay grading into yellowish brown clay, impossible to estimate its thickness accurately, but appears to be rather prominent 5 to	10	0

PERMIAN (Cloud Chief gypsum)

The outstanding points in regard to the above section are the prominence and thickness of the *Gryphea* shell bed, the presence of the limestone horizon, and the absence of sand. It is to be noted that the top shell bed, No. 3, and the limestone horizon, No. 2, carry the same fossils and bear the same relation to each other as is observed in the two upper fossiliferous horizons in the Supply section.

In the exposures northwest of Seiling, along the North Canadian River, the limestone horizon seems to be more fully developed and many of the outliers consist only of blocks of this horizon. The exposures all occur well down along the valley walls, no outcrops being found in which the material was *in situ*.

NOTES ON THE OUTLIERS IN THE SEILING-CESTOS AREA.

SW¼ sec. 15, T. 19 N., R. 18 W., on the highest point in the area are found large slabs of the shell bed with some yellow and blue clay intermixed. This material is believed to be approximately in place. The elevation as determined with a barometer is 1,910 feet.

Cen. SW.¼ sec. 30, and SW. cor. sec. 29, T. 20 N., R. 16 W., are exposures consisting of large pieces of a sandy limestone ranging from 18 inches to 2 feet

112. Identified by Dr. T. W. Stanton.

in thickness. No material could be found in place, but some of the fragments are quite large, weighing several hundred pounds. They contain many polecypods, *Trigonia* sp., *etc.*

Quinlan outlier.—Sec. 24, T. 23 N., R. 17 W., on the main highway about 1½ miles west of Quinlan is a small "patch" of Lower Cretaceous. The material consists of the top shell bed, blue to yellow clay and a few fragments of the limestone horizon. It occurs along the roadside and is limited to a spot not more than 50 feet square. It obviously has slumped into its present position and is the only outcrop that could be found in the vicinity. It is outside the bounds of the Seiling-Cestos map.

Outliers near Taloga.—On the main highway about 3.8 miles north of the Taloga bridge over the South Canadian River is a small knoll containing a cap of the "shell bed." It occurs on the highest point in the vicinity at an elevation of 1,825 feet as determined with a barometer.

On the south side of the South Canadian River, 4½ miles south of Taloga, on the main highway to Clinton, is a small remnant of Lower Cretaceous. The material is a yellowish limestone about 6 inches in thickness and fragments of the shell bed. The exposure occurs along the roadside on the highest point in the vicinity, just before the country begins to slope rapidly into the valley of the South Canadian River. The elevation as determined with a barometer is 1,825.

The last two outcrops mentioned do not appear on the large scale maps of the separate areas.

BUTLER-FOSS AREA

LOCATION

This area lies in Custer and Washita counties, Oklahoma. Butler is located near the northern edge and Foss near the center of the area. Clinton is located on the eastern and Elk City on the western edge. The area is about 35 miles south of the Seiling-Cestos area. Details regarding the location of the outliers in this area are given on Plate II.

NATURE OF OCCURRENCE

The outliers in this area are probably more widely known than those previously described. Marcou's Comet Creek locality, to which reference has already been made was presumably Barnitz Creek west of Arapaho. The outliers occur as isolated patches, usually covering only a few acres and to the casual observer consist only of large slabs of an oyster shell conglomerate resting in a confused mass on the tops and sides of small knolls and hills and along the creek valleys. These outliers are readily seen, as the large slabs of yellow shell limestone stand out in marked contrast to the surrounding Permian red beds.

The relation of the outliers to the topography of the country is shown on the profiles accompanying Plate II. The fact that the outliers are more commonly found along the valleys and on the sides of Permian hills has led some writers to conclude that the Cretaceous sea did not cover the Permian in this area. However, as is shown on the profiles, the highest points in the area are frequently capped by the Cretaceous. Most of the outliers now occur at a much lower level than that at which they were originally deposited; for, due to some type of slumping or creep, large masses of the Lower Cretaceous beds have gradually settled into the valleys. Those masses that were more protected from erosion were preserved, while the remainder has been carried away.

STRATIGRAPHY

Due to the fact that slumping is so common, exposures which will permit a detailed section to be measured are somewhat rare. It is fairly common to find good exposures which will show the type of material, but it is seldom that accurate measurements can be made of the thickness of the beds. About 3 miles west of Foss the highway passes over a small hill which is capped by Cretaceous. The material is thought to be practically in place and the exposure along the roadside is one of the best to be found in this area.

Section of Lower Cretaceous outlier at the NW. cor. sec. 9, T. 11 N., R. 19 W., 3 miles west of Foss, Oklahoma. (Elevation with a barometer 1,825 feet).

	Ft.	In.
Shell bed, yellowish brown shell conglomerate composed of *Gryphea corrugata* Say, *Gryphea navia* Hall, and *Oxytropidoceras belknapi* (Marcou)	3	0
Yellowish clay, blue and yellow mottled	10	0
Coarse sand, conglomeratic and locally quartzitic........3 to	5	0

PERMIAN (Quartermaster formation)

Many times the basal sand is thicker and may be entirely conglomerate or quartzite. To the north of the Washita River, between Hammon and Butler, the sand is poorly developed and less conglomeratic. However, to the south, near Foss and Canute it becomes more prominent attaining a thickness of 10 feet and contains much conglomerate. It is usually cross-bedded and in one exposure, near the center of the east line of sec. 7, T. 11 N., R. 18 W., about 2 miles east of Foss, well developed current ripple marks were observed on this basal sandstone. The sandstone is quite characteristically quartzitic in spots, and layers and frequently large masses of this quartzitic sandstone, 10 to 15 feet square, are found standing alone in a field, sometimes miles from other Cretaceous rocks. In the vicinity of Canute, in sec. 29, T. 11 N., R. 19 W., and also north of Sayre in sec. 5, T. 11 N., R. 23 W., are numerous outliers of a quartzitic sandstone and conglomerate without either the clay or shell horizons. This makes it difficult to assign them to the Cretaceous, for they also resemble to some extent the Tertiary beds of this region. However, they are composed of the same type of material, show the same type of cross-bedding, and in every way resemble so closely the basal sand, conglomerate, and quartzite that has been observed in place beneath the shell bed that the writer feels fairly confident they belong to the same horizon. The outliers which show only this basal sand are separated from the other outliers on the map of the Butler-Foss area.

Another horizon frequently found in the outliers of this area is a limestone bed, usually only a few inches in thickness, which occurs between the basal sand and the shell bed. It is very similar to the limestone horizon of the Seiling-Cestos area, but is apparently lenticular as it has not been seen in all of the outliers. It contains *Cyprimeria* sp., *Turritella* sp., and a small *Gryphea*, and in that respect also resembles the limestone of the Seiling-Cestos area. The limestone horizon seems to be more common in the northern than in the southern portion of the area. A most interesting occurrence is along the road between secs. 24 and 35, T. 16 N., R. 19 W., about 0.3 mile from the west line, where the limestone is conglomeratic. It contains flint pebbles, somewhat rounded, and also the customary limestone horizon fossils. The various locations at which the limestone horizon is developed are given at the end of this chapter.

The top shell bed is the characteristic shell agglomerate made up of *Grypheas,* such as has been described from the Seiling-Cestos area. It is found usually in enormous slabs, 10 to 20 feet square, which rest at all angles due to slumping following the removal of the underlying clay. In many exposures the clay has been entirely removed and the large slabs rest directly on the Permian.

The most southerly exposure is near the little village of Dill City in T. 9 N., R. 18 W., about 25 miles north of the nearest granite outcrop of the Wichita Mountains.

NOTES ON THE OUTLIERS IN THE BUTLER-FOSS AREA

(It is not intended to list all of the outliers, but only those that give the best exposures or show some particular features.)

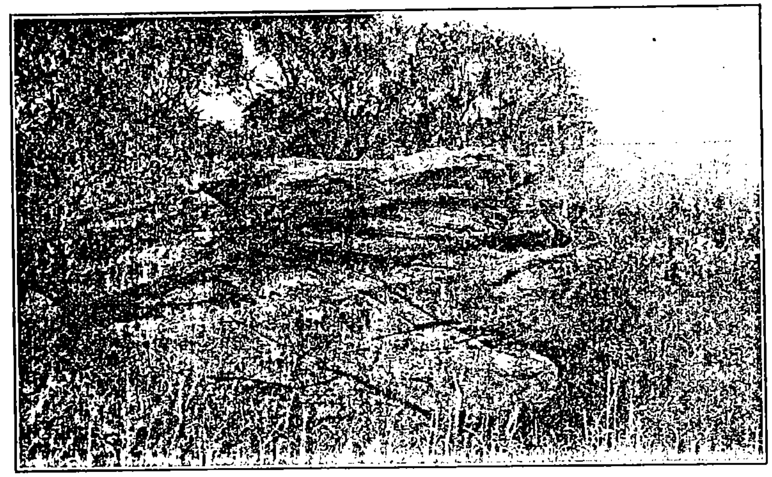
T. 15 N., R. 18 W.

On the road between sections 5 and 6, 2 miles southwest of Aledo, typical fragments of the shell bed cover the slope of the hill. A hard white sandstone, about 14 inches in thickness, occurs at the base. Some yellow and blue clay intermixed with the shell bed are visible along the roadside.

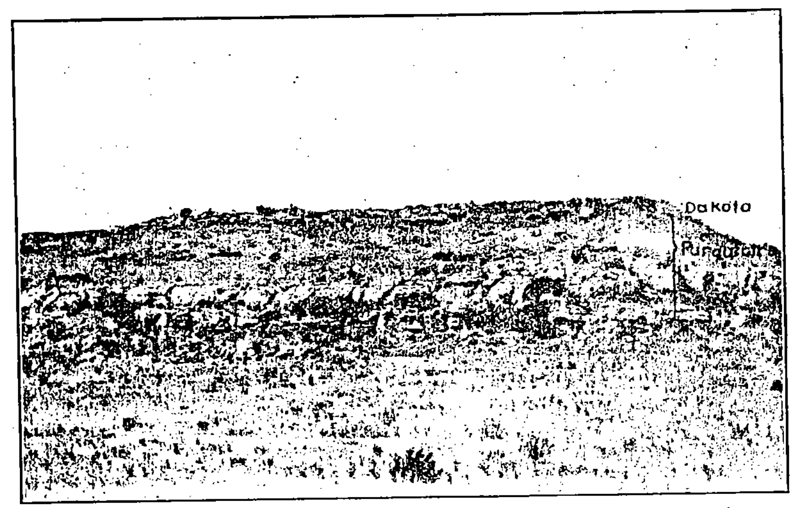
T. 16 N., R. 19 W.

On the road between sections 24 and 35, 0.3 miles from the west corner, is an outcrop consisting of a coarse conglomeratic sandstone at the base, then a finer sandstone overlain by the typical shell bed. Large fragments of a conglomeratic limestone with flint pebbles up to one inch in diameter and containing *Cyprimeria sp., and Turritella sp.,* apparently occurs between the sandstone and the shell bed. The thickness of the entire section is not more than 3 feet, the basal sand being from one foot to 18 inches in thickness.

PLATE IV.



A. LARGE BLOCK OF LOWER CRETACEOUS SANDSTONE NORTH OF CHANUTE, OKLAHOMA.
(Note cross-bedding)

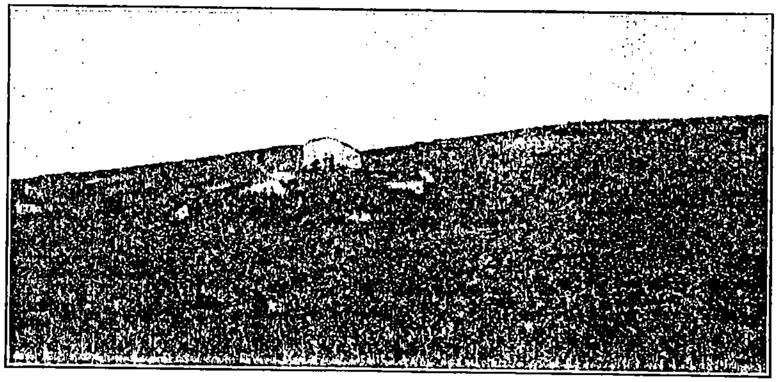


B. PURGATOIRE FORMATION AT 101 HILL.
About 5 miles east of Kenton, Cimarron County, Oklahoma.

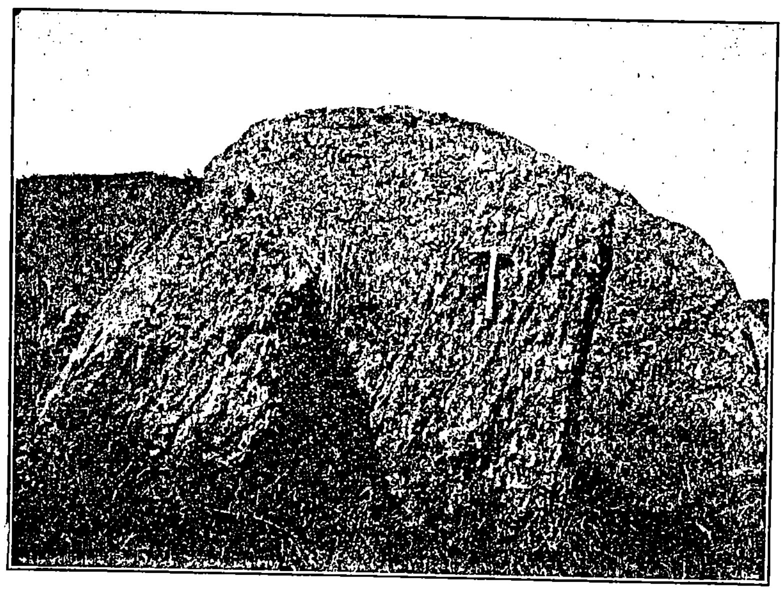
T. 14 N., R. 18 W.

Near the center of the SW.¼ section 31, one mile east of Butler, on the east side of a small draw, is an outlier consisting of a coarse sandstone at the base, followed by a hard white sandstone, and then the typical shell bed. The shell bed ranges from 12 to 18 inches in thickness. The outcrop is apparently not in place.

PLATE V.



A. OUTLIER OF LOWER CRETACEOUS.
Sec. 4, T. 11 N., R. 19 W., 2 miles west of Foss, Oklahoma.
For size compare with cow in right of picture.



B. NEAR VIEW OF "SHELL BED" AT LOCALITY SHOWN IN A

Near the center of the south line of section 31, along the roadside, is an outcrop consisting of a mass of blue and yellow clay and the shell bed. Some fairly large pieces of a hard bluish limestone, similar to the limestone of the Seiling-Cestos area, are present.

T. 14 N., R. 19 W.

In the SE.¼ section 29, about 20 feet below the top of the highest point in the vicinity, which is capped by the Tertiary, is a mass of the Lower Cretaceous shell bed. Other masses occur lower down on the hillside and just south of the section line near the center of the north line of section 32 a large mass of Lower Cretaceous occurs in the bed of a small creek.

T. 12 N., R. 19 W.

In section 28 there are a number of good exposures near the center of the section. They consist of about 5 feet of soft, clean white sand, locally quartzitic, and the shell bed. In one of the exposures a nodular sandy limestone is present between the sand and the shell bed. A very thin zone of blue and yellow clay is present.

In section 27, near the center of the north half, there are a number of exposures similar to those described in section 28.

In the SE. cor. section 35 there is an exposure consisting of a pure, white sandstone, locally quartzitic. Some fragments of the shell bed were noted but they were not in place.

T. 12 N., R. 20 W.

In the cen. SE.¼ and in the SE.¼ SW.¼ section 33, are some exposures consisting of a soft yellow sandstone, slightly quartzitic in spots. The sandstone occurs in enormous blocks, fully 10 to 12 feet square. The sandstone shows a very complicated type of cross-bedding. No indications of the shell bed could be found.

T. 13 N., R. 17 W.

On the road between sections 21 and 28, 0.3 mile from the west line, a mass of Cretaceous is found in a crevice in the Permian. It appears that at some previous time the Cretaceous has slumped into a Permian gulley and later erosion has reduced the level of the country leaving this former gulley on a hill side. The Cretaceous is a confused mass of yellowish clay with flakes and streaks of black paper-like shale, soft yellow sandstone, limestone nodules, and large slabs of the shell bed. One-half mile due south of this exposure is a hill, approximately the highest point in the vicinity, capped by the shell bed.

Near the NW. cor. section 30, along the roadside, is another exposure of the same type as described above except somewhat larger.

Near the center of the SW.¼ section 31, around the head of a small creek are found large blocks and slabs of the shell bed resting on the Permian. These slabs seem to be residual blocks, the softer material having been removed.

T. 13 N., R. 18 W.

In the SE.¼ NE.¼ section 20 there is an outcrop consisting of three separate knolls located around the head of a small ravine. A coarse conglomeratic sandstone about three feet in thickness forms the base. The shell bed is from 18 inches to two feet in thickness and contains large, well preserved *Grypheas*, usually pink on the upper surface.

T. 13 N., R. 19 W.

Near the center of the south line of section 12 is an excellent exposure which appears to be practically in place. The shell bed is 18 inches to 2 feet in thickness and occurs as large slabs, 8 to 10 feet square, standing on edge, (see Pl. VI). A clay zone, a yellowish green on weathered surface and a dark blue on unweathered surface, is fairly well exposed. Very little sandstone is present.

Near the center of the SE.¼ section 4 there are several good outcrops occurring on opposite sides of a small creek. In the bed of the creek is a mass of Cretaceous material intermixed with red beds which has evidently slumped into the creek valley and then the creek has cut through the slumped material.

The W.½ section 19 is covered in many places by large blocks and masses of a cross-bedded sandstone, conglomeratic and quartzitic, occurring in blocks 8 to 10 feet square. No remains of the shell bed could be found.

In the SE. cor. section 36 there is a mass of the shell bed covering the top of one of the highest points in the area.

In the SW.¼ section 3, and the NW.¼ section 10 there are some exposures consisting of the basal quartzitic sandstone and the shell bed.

T. 11 N., R. 20 W.

The outcrops in this township are located to the east and south of Canute, in sections 13, 24, 23, and 26. They consist entirely of sandstone, quartzite, and conglomerate.

T. 11 N., R. 23 W.

The outcrops in this township are found on each side of the west branch of Timber Creek, in sections 33, 34, 35, and 36. There is also a large area in sections 5 and 8, T. 11 N., R. 23 W. The material consists of a cross-bedded coarse sandstone with conglomeratic layers of red, yellow, and brown chert and flint. The conglomerate is more prominent between the beds. No traces of the shell bed could be found.

T. 11 N., R. 18 W.

In the E.½ section 7 and the W.½ section 8 there are a series of small knolls covered with blocks and slabs of a soft yellow sandstone. Some quartzite layers are present, but they are not conspicuous. The sandstone is cross-bedded: and well developed current ripple marks were observed on one of the sandstone blocks. In the southwest corner of section 8 there is a hill capped by large blocks of this sandstone which is the highest point for several miles around. Fragments of the shell bed are common, but no large slabs are present.

Near the center of the east line of section 15, along the creek valley, is an outcrop consisting of a mass of the shell bed and sandstone.

Near the center of the east line of section 20 there is a small knoll covered with slabs of the shell bed. This material is probably *in situ*.

In the SE.¼ SW.¼ section 30 is a small knoll capped by large slabs of the shell bed.

In the SE.¼ NW.¼ section 32 is an exposure consisting chiefly of sandstone with some shell fragments.

T. 11 N., R. 19 W.

In the SE.¼ section 17, the SW.¼ section 16, and the NE.¼ section 20, there is an excellent group of outliers consisting of soft yellow mottled sandstone ranging up to three feet in thickness, followed by a layer of greenish clay above which is a massive shell bed up to three feet in thickness. In some of the exposures the basal sand is quartzitic, usually quartzitic layers alternating with soft sandstone. In the SW.¼ section 16 the basal quartzite occurs with the shell bed overlying.

PLATE VI.

A. VIEW SHOWING CHARACTERISTIC POSITION OF THE "SHELL BED", *GRYPHEA CORRUGATA* ZONE.
Sec. 13, T. 13 N., R. 20 W.

B. CLOSE IEW OF THE "SHELL BED," *GRYPHEA CORRUGATA* ZONE.
Sec. 13, T. 13 N., R. 20 W.

In the NW.¼ section 8 the basal quartzite shows well developed cross-bedding and is overlain by the shell bed.

T. 10 N., R. 18 W.

The outliers in this township consist of both the typical shell bed and the basal sandstone, quartzite, or conglomerate. In sections 4 and 9, exposures consisting of the shell bed capping small hills are found. In section 23 there is an outlier consisting of a mass of quartzite and conglomerate.

T. 9 N., R. 18 W.

Only one exposure was located in this township. It is the most southerly outlier observed in western Oklahoma. It is in the NW. cor. section 3, and consists of the typical shell bed with some clay. It is a very poor exposure.

T. 9 N., R. 23 W.[113]

In the SW.¼ section 6, 2 miles west and one mile south of Sayre, on the bluffs along the north side of the North Fork of Red River are several hills capped by a hard quartzitic conglomerate and coarse sandstone. The conglomerate consists chiefly of flint and chert particles, mostly rounded, but some are angular; red and brown jasper seem most abundant. The pebbles are practically uniform in size, averaging about ½-inch in diameter, although some were observed two and three times as large. In places the material is a coarse sandstone with only thin layers of conglomerate, but in other places the conglomerate predominates. The maximum thickness of the conglomerate observed is 15 feet. The conglomerate and sandstone are cross-bedded and contain abundant fragments of Permian red beds in the basal portion. No fossils could be found. The material resembles very closely the basal quartzite as seen near Foss, in the SW.¼ section 16, T. 11 N., R. 19 W., although there is a possibility that it may be Tertiary.

About 7 miles north of Sayre on State Highway No. 24 (approximate location, sections 28 and 29, T. 11 N., R. 23 W.) there is a sandstone and conglomerate very similar to the one just described.

OKLAHOMA PANHANDLE

Cimarron County

HISTORICAL SUMMARY

In 1901 Lee[114] announced the discovery of the Morrison formation in southeastern Colorado along the Purgatoire River. The following year at the Washington meeting of the Geological Society of America he reported the discovery of *Gryphea corrugata* Say in the Morrison near the old postoffice of Garret, Cimarron County, Oklahoma. Lee correlated the Morrison with the Washita division of the Comanche series, concluding that the non-marine Morrison is traceable laterally into the marine Comanche series. Only very brief abstracts of Lee's paper have been published[115].

In 1905 Stanton joined Lee in the field and found that the true source of the invertebrate fossils found by Lee and others

113. The writer is indebted to Prof. A. J. Williams for this location.
114. Lee, W. T., Jour. of Geol. vol. 9, pp. 313-352, 1901.
115. Science, new ser. vol. 17, pp. 292-293, 1903, and Bull. Geol. Soc. America vol. 14, pp. 531-532, 1904.

was a black shale about 30 feet thick lying between two massive sandstone members, both of which had been previously classified as Dakota. Stanton[116] correctly assigned the shale to the Washita division and suggested also that the white sandstone underlying the black shale was probably related to the shales and should be classed with them. The sandstone overlying the black shales is the true Dakota.

In 1912 Stose[117] applied the name Purgatoire to the sandstone and shale members, after the Purgatoire River of southeastern Colorado.

In the Colorado Springs folio Finlay[118] named the upper shale member of the Purgatoire the Glencairn and the sand member below the Lytle. These two members, while fairly distinct in Cimarron County, Oklahoma, have not been separated and the Purgatoire has been mapped as a single unit.

The last important work on this area was by Rothrock[119] in 1925. The Purgatoire is mapped and a detailed description of the formation as exposed in Cimarron County is given.

DISTRIBUTION

The distribution of the Purgatoire in Cimarron County is limited to the extreme northwestern corner of the county. It is found also in the southeastern corner of Colorado, along the eastern boundary of New Mexico, and according to Reeside,[120] beds with the same fauna have been recognized as far north as southern Wyoming. The outcrop of the Purgatoire is shown on the general geologic map, Plate I.

STRATIGRAPHY

The Lower Cretaceous, represented in Cimarron County by the Purgatoire and the Morrison, is questionably referred to this period. The geologic section in Cimarron County as given by Rothrock[121] and modified by DeFord[122] is as follows:

116. Stanton, T. W., The Morrison formation and its relation with the Comanche series and the Dakota formation: Jour. of Geol. vol. 13, pp. 657-669, 1905.
117. Stose, G. W., U. S. Geol. Survey Geol. Atlas Apishapa folio (No. 186) 1912.
118. Finlay, G. I., U. S. Geol. Survey Geol. Atlas Colorado Springs folio (No. 203), 1916.
119. Rothrock, E. P., Geology of Cimarron County, Oklahoma: Oklahoma Geol. Survey Bull. 34, 1925.
120. Reeside, J. B. Jr., The fauna of the so-called Dakota formation of northern Colorado and its equivalent in southeastern Wyoming: U. S. Geol. Survey Prof. Paper 131, pp. 199-205, 1922.
121. Rothrock, E. P., Idem.
122. DeFord, R. K., Geological Note, Bull. Am. Assoc. Pet. Geol. vol. 11, No. 7, pp. 753-755, 1927.

Geologic Section, Cimarron County.

Tertiary sediments and lavas
~~~~~~ *angular unconformity* ~~~~~~
Dakota sandstone
Purgatoire formation
~~~~~~ *disconformity* ~~~~~~
Morrison formation
Exter sandstone
~~~~~~ *angular unconformity* ~~~~~~
Unnamed variegated shales (absent in places)
Triassic red beds, containing maroon shales, and red and gray conglomeratic standstones.

The age and correlation of the Morrison has been discussed by many writers and will not be further mentioned in this paper. The Purgatoire is typically represented in Cimarron County, where it consists of two members, a basal sandstone member and an upper shale member. According to DeFord the thickness of these two members is somewhat variable, the sand varying from 15 to 50 feet and the shale averaging about 30 feet.

The sandstone is white, rather massive, very much cross-bedded, and contains many lenses of conglomerate scattered at irregular intervals throughout the formation. As a whole it is poorly cemented and therefore yields readily to weathering, producing the fantastic pillar and mushroom forms so common in this region. According to Rothrock feldspar is rather abundant in this sandstone, as well as other minerals as zircon and apatite from igneous rocks. After examining a number of slides of the sandstone Rothrock records the average mineral composition as quartz 75%, orthoclase 2%, plagioclase 3%, cement and pore space 20%. He concludes that it should be called an arkosic sandstone rather than an arkose. The conglomerates found in the sandstone are rarely over 5 or 6 feet thick and occur in lenses from 10 to 30 feet in length. The material consists of subangular pieces of flint, chert, and vein quartz, ranging in size from ⅛ inch up to an inch and a half. Fossil wood is fairly abundant in the sandstone but no other fossils have ever been found. This sandstone resembles the Cheyenne sandstone of Kansas in type of cross bedding, character of material, stratigraphic position, and type of weathering. Its correlation with the Cheyenne seems well established.

The shale member of the Purgatoire is rarely well exposed, as it usually outcrops on a slope covered by debris from the Dakota. According to Rothrock a good section of this shale member may be seen at 101 Hill, near the center of sec. 18, T. 5 N., R. 2 E. (Cimarron meridian), where it is bluish black, weathering lighter in spots and has a thickness of 32 feet. Near the old townsite of Mineral the upper part of the Purgatoire shale is light gray to yellow and contains thin sandstone layers throughout the section.

This shale member carries a marine invertebrate fauna. The fossiliferous beds are, in most instances, lenses of yellow shaly sandstone. The best collecting localities, noted by Rothrock, are on Wolf Mountain in sec. 27, T. 5 N., R. 5 E., C. M. and at the southwest corner of sec. 31, T. 5 N., R. 6 E., C. M.

Stanton[123] gives the following generalized section as observed near the old postoffice of Garret, Cimarron County, Oklahoma, in sec. 25, T. 6 N., R. 4 E., C. M.

Section in Sec. 25, T. 6 N., R. 4 E., Cimarron County.

DAKOTA.	
Massive, coarse, cross-bedded gray and brown sandstone	150 feet
PURGATOIRE.	
Dark shales with layers of brown flaggy sandstone and bands of somewhat calcareous yellow sandstone with Comanche fauna	50 to 60 feet
Coarse, brown or gray cross-bedded sandstone with irregular bands of pebbles, apparently unconformable on the underlying stratum	4 to 15 feet
MORRISON.	
Variegated shales, gray sandstone and bands of siliceous limestone, not well exposed, thickness probably less than	100 feet
RED BEDS	

From collections made by Lee and Stanton at the above location Stanton[124] identified the following fossils:

Gryphea corrugata Say
Ostrea subovata Shumard
Ostrea quadriplicata Shumard
Plicatula incongrura Conrad
Inoceramus comancheanus Cragin
Gervilliopsis invaginata White
Trigonia emoryi Conrad
Protocardia multilineata Shumard
Pholodomya sancti-sabae Roemer ?
Anchura kiowana Cragin?
Turritella seriatim granulata Roemer
Hamites fremonti Marcou ?
Pachydiscus brazoensis (Shumard)

AGE AND CORRELATION

The fauna listed above is without doubt a Washita fauna and, as Stanton concludes, is similar to the Washita fauna that has long been known from northern Texas, Tucumcari Mountain in New Mexico, and the Kiowa shale of southern Kansas. This fauna differs however from that of the Kiowa shale in one important respect. The Kiowa shale is correlated with the Kiamichi formation of southern Oklahoma and northern Texas, but the Purgatoire shale carries in addition to the Kiamichi fauna species which are characteristic of the overlying formation, the Duck Creek. The characteristic Duck Creek species listed above are: *Pachydiscus brazoensis* (Shumard), *Hamites fremonti* Marcou, and *Inoceramus comancheanus* Cragin. It appears, therefore, that the Purgatoire represents the

123. Stanton, T. W., Jour. of Geol. vol. 13, p. 664, 1905.
124. Stanton, T. W., Idem.
~~~~~~

Kiowa shale of Kansas and in the Texas section is represented by the Kiamichi clay and at least the basal portion of the Duck Creek.

The sandstone member of the Purgatoire must be correlated largely on stratigraphic and lithologic evidence in the absence of fossils. Its position below a marine Washita fauna and its lithologic character place it in the same position as the Cheyenne sandstone of Kansas with which it is correlated.

Red Point, Texas County, Oklahoma

A small outlier of Lower Cretaceous material was discovered by R. L. Clifton, geologist with the Champlin Refining Company, near the old postoffice of Red Point on the North Canadian River (Beaver Creek), about 10 miles west of Guymon. Clifton reported the discovery in a letter to Dr. C. N. Gould, Director of the Oklahoma Geological Survey, during the summer of 1925. He gave a list of fossils which he had collected and properly referred the beds to the Washita division of the Comanche series. So far as the writer is aware this occurrence had not been previously noted and the following description is the first to appear in print.

The outlier is located in secs. 14 and 15, T. 3 N., R. 13 E., (Cimarron Meridian. (See fig. 5). The best exposures are along the highway where the road has cut through the principal outcrop. The Cretaceous rests on Triassic red beds and is capped by the Tertiary.

The exposure of Lower Cretaceous at this locality consists of a soft, white to yellowish brown sandstone which on weathered surfaces has a red color due to its ferruginous content. This red color is so like the underlying Triassic that the outlier, while very conspicuous topographically, escaped detection until the area was surveyed in detail by the oil companies. The sandstone is about 5 feet in thickness and breaks into large blocks which may be seen covering the slopes of the small ridges which it forms. The sandstone contains lenses and layers of quartzite very similar in occurrence to that noted in the Butler-Foss area. It also contains an abundance of fossils, although they are usually only casts in a very poor state of preservation. The following forms were recognized:

- Oxytropidoceras belknapi (Marcou), several good specimens.
- Trigonia sp.
- Turritella sp.
- Inoceramus sp.
- A great number of poorly preserved pelecypods similar to Cuculleaea sp., and Tapes sp.

A noticeable feature in the above list is the total absence of *Grypheas,* but in a purely sand environment it is not expected that

oysters would be found. The Tertiary gravels, overlying the Cretaceous, contain fragments and specimens of *Grypheas* in some abundance, but none were found in the Cretaceous.

The Cretaceous sandstone rests directly on the Triassic red beds and the abruptness of the contact, together with the large blocks in which it occurs, caused some doubt among geologists who visited the exposure as to whether the material was in place or whether it had been transported. However, there seems to be no doubt that the material, except for some slumping, is approximately *in situ.* The Tertiary covers the Cretaceous and Triassic alike, indicating that pre-Tertiary erosion had removed all the Cretaceous except this outlier, which was covered by the Tertiary and only recently (geologically) exposed.

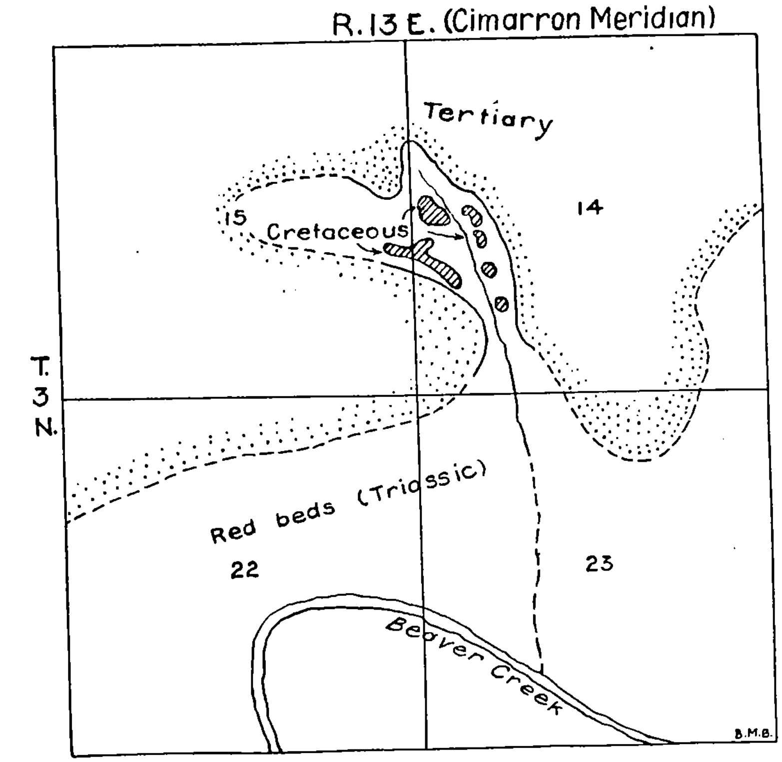


Figure 5. Sketch map of the Red Point area, Texas County, Oklahoma.

Due to the absence of beds which have not been affected by slumping it is very hazardous to make any statement in regard to the dip. However, the outcrops on the east side of the small creek are in general lower than those on the west side, indicating in a measure an eastward dip.

The fossils from the Red Point outlier indicate that it should be correlated with the Purgatoire of Cimarron County. It is considered to be the eastward extension of the Purgatoire and doubtless if the Tertiary covering were removed many such areas would be exposed.

TUCUMCARI MOUNTAIN, NEW MEXICO

Tucumcari Mountain is located 1½ miles southeast of Tucumcari, New Mexico. It is approximately due west of Amarillo, Texas, and is about 50 miles west of the Texas-New Mexico boundary on the south side of the South Canadian River. It is an erosional remnent; a cone shaped mass some 6 miles in circumference at the base and about 600 feet in height, reaching the level of a once extensive plateau. This mountain stands out very prominently, being visible for many miles from the east. There are several other similar remnents in the vicinity of Tucumcari and some confusion occurred as to which hill was the Cerro de Tucumcari. Cummins[125] reviews the nomenclature of the various hills near Tucumcari and shows that Marcou was in error in the names that he applied to certain of them.

Tucumcari Mountain is important from the standpoint of Lower Cretaceous stratigraphy in that it contains a section of marine sediments of Lower Cretaceous age. It is one of the most westernly exposures of the Lower Cretaceous, and as it is separated from the Texas and western Oklahoma outcrops by more than 250 miles its importance in interpreting the former extent of the Lower Cretaceous sea is readily appreciated.

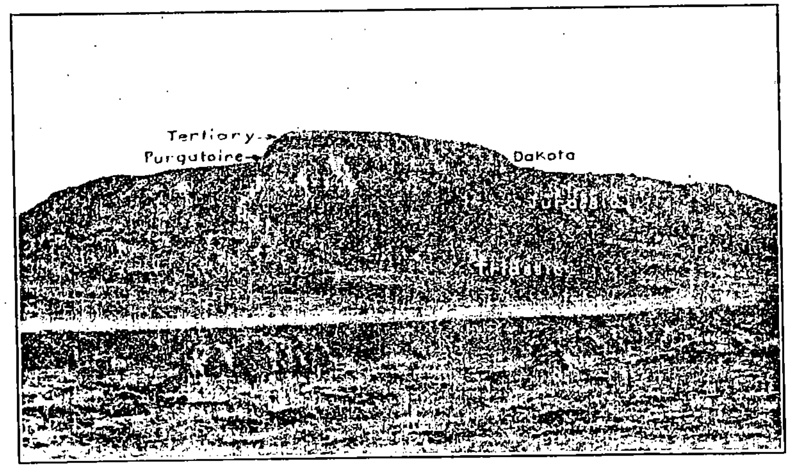
Historical Summary

The first mention of Tucumcari Mountain from a geologic standpoint was by Marcou,[126] who as geologist with the Pacific Railroad Expedition, made a section of the mountain and collected fossils which led him to place the beds in the Jurassic.

No other information was obtained on this locality until 1888, when Hill[127] visited Tucumcari Mountain and confirmed Marcou's conclusions. Hill[128] visited the area again in 1891 and while he maintained that the lower portion of the section was Jurassic, he correlated the upper portion with the Trinity sand of Texas.

125. Cummins, W. F., Tucumcari Mt., Am. Geol. vol. 11, p. 375, 1893.
126. Marcou, Jules, Geology of North America, p. 17, 1858.
127. Hill, R. T., Neozoic geology of southwestern Arkansas: Arkansas Geol. Survey Ann. Rept. for 1888, vol. 2, 1889.
128. Hill, R. T., Comanche series of the Arkansas-Texas region: Bull. Geol. Soc. America vol. 2, p. 506, 1891.

PLATE VII.



A. THE NORTH SIDE OF TUCUMCARI MOUNTAIN, NEW MEXICO, FROM A DISTANCE OF ABOUT TWO MILES.
(Photograph furnished by the Kiwanis Club of Tucumcari)

B. RESULT OF WAVE ACTION (?) ON THE TISHOMINGO GRANITE. Five miles north of Milburn, Oklahoma.

Cummins[129] made a careful study of the area and after comparing the fossils with specimens from Europe concluded that the beds should be correlated with the Washita division of the Comanche series. He placed the basal portion of the section in the Triassic and the upper portion in the Cretaceous as indicated above. He gives a very generalized section of Tucumcari Mountain.

Hill, soon after the publication of his paper in 1891, came to the conclusion that the Jurassic was not represented in the section at Tucumcari Mountain and placed the beds as indicated in the following quoted section:

Section of Tucumari Mesa[130]

	Feet*
6. Summit of Mesa (Neocene) White calcareous, siliceous, marly limestone of character peculiar to Tertiary formations of Great Plains....	25-30
5. Escarpment around summit of Mesa (Dakota) Consisting of massive brown-yellow sandstone..................	75
4. Crumbling yellow sandstone at base of above and: (4a) Gentler slope, forming bench around summit escarpment (Washita division of Comanche series). Decomposing sandstone at base of 4, and arenaceous clays and marls. Containing fauna of Denison beds, Washita division, at top and *G. dilatata* Marcou in debris, apparently weathered out	100
3. Shoulder at base of above: Impure yellow arenaceous stone	15
Pedestal or lower slope of Mesa.	
2. Upper part (Trinity). White and red unconsolidated sands (pack sands), with thin strata of dimension layers of hard quartzitic rock, and thin layers of blue clay, resembling in general character the Potomac sands of Maryland and the Trinity sands of Texas. This horizon contains a peculiar granular mineral resembling red coral, and outcrops in all the escarpments of the Las Vegas plateau on the north side of the Canadian, and is denominated the white band in that region to distinguish it from the brown band, (Dakota) and underlying red beds...........	150
1. Lower portion of slope, pre-Cretaceous. Bright vermillion, argillaceous clays of the red beds continuing to bed of Canadian..	250

*Thickness estimated on spot.

The above section by Hill agrees with present ideas except that horizon No. 2, which he calls Trinity, is now placed in the Jurassic and horizon No. 1 is placed in the Triassic.

Hill[131] published a brief statement in regard to the Tucumcari region in 1895.

129. Cummins, W. F., Texas Geol. Survey, Third Ann. Rept., pp. 201-211, 1891.
130. Hill, R. T., Science, p. 23, July 14, 1893.
131. Hill, R. T., Outlying areas of the Comanche series in Kansas, Oklahoma, and New Mexico: Am. Jour. Sci. vol. 50, p. 229, 1895.

Stratigraphy

The writer visited Tucumcari Mountain during the summer of 1927 for the purpose of comparing the section of Lower Cretaceous exposed there with that of southern Kansas, western Oklahoma, and elsewhere. Limited time permitted making only a very generalized section and noting only the most common fossils.

Section of Tucumcari Mountain. Section exposed on the north side of the mountain.[132]

	Feet*
TERTIARY	
White, marly limestone, typical Tertiary cap of the plains	25
DAKOTA	
Brownish, massive sandstone, forming a very precipitous scarp around the top of the mountain. Sandstone is typical Dakota as seen in Cimarron County, Okla.....	60
PURGATOIRE. (Lower Cretaceous)	
(a) Impure sandy, shaly zone containing gastropods and pelecypods	30
(b) Blue to gray yellow clay, sandy, containing an abundance of large *Grypheas* (*G. corrugata var. tucumcari*) at one horizon near the top. (This horizon is much better exposed on the south side of the mountain)	20
(c) White, coarse, cross-bedded sandstone very similar to basal Purgatoire of Cimarron County, Oklahoma, and the Cheyenne sandstone of Kansas..	20-30
WINGATE SANDSTONE. (Jurassic) Lower slope of mountain, Pack sand, white to red to yellow, forming vertical cliffs on north side of mountain......................................	100
DOCKUM beds. (Triassic)	
Bright red argillaceous, micaceous, sands and clays, typical red beds	250

*Thickness determined with barometer.

The fossiliferous horizons of the Purgatoire are contained in impure shaly clay layers which form the slope between the steep escarpment at the top of the mountain and the almost vertical cliffs of the lower portion of the mountain.

The following fossils have been recognized from the Tucumcari region. The list as given below has been slightly modified by the writer from Hill.[133]

Ostrea quadriplicata Shumard	Protocardia sp.
Gryphea corrugata var. tucumcari (Marcou)	Pinna comancheana Cragin
Gryphea corrugata Say	Cardita belviderensis Cragin
Exogyra texana Roemer	Tapes belviderensis Cragin
Plicatula sp.	Cyprimeria sp.
Neithea occidentalis Conrad	Turritella seriatum granulata Roemer
Trigonia emoryi Conrad	Pervinquieria leonensis (Conrad)
	Ostrea cf. subovata Shumard

132. Note.—The Wingate and Dockum formations of this section are classified according to recent advice from Dr. N. H. Darton. The above section differs from Dr. Darton's classification in that he considers the basal sandstone of the Purgatoire (c in section) as the Exter, a member of the Morrison formation.
133. Hill, R. T., Am. Jour. Sci., vol. 50, p. 230, 1895.

Of the twenty species which Hill listed, he says that 13 of them are common to the Belvidere beds (Kiowa shale) and 10 are also common to the Washita division of the Comanche series of Texas. The lithologic character, as well as the fossil content, shows that the Tucumcari section does not differ in any material respect from the Purgatoire as exposed in southeastern Colorado and Cimarron County, Oklahoma. One point which should be mentioned, however, is that in the Tucumcari section the presence of *Pervinquieria leonensis* (Conrad) and *Ostrea quadriplicata* Shumard indicates that beds at least as far up in the stratigraphic column as the Fort Worth limestone are included, while in Cimarron County the fossils from the Purgatoire do not indicate a horizon higher than the lower Duck Creek.

MONUMENT LAKE, BAILEY COUNTY, TEXAS

Monument Lake, one of the many lake beds found on the Plains, is about 26 miles southwest of Muleshoe, Bailey County, Texas. It is northwest of Lubbock and only a few miles from the Texas-New Mexico state line; Clovis, New Mexico, is 30 to 40 miles to the northwest. Monument Lake rarely contains water, but is a salt encrusted flat. Along the north end of this flat between the outcrop of Tertiary and the lake bed there are about 30 feet of Lower Cretaceous rocks exposed. The exposure extends for a few hundred yards and consists of a lense-shaped mass with the Tertiary extending to lower levels on either side. It is obviously a mass that for some reason was not removed by pre-Tertiary erosion and later was covered by the Tertiary and preserved.

Section of Lower Cretaceous at Monument Lake.

	Feet (Estimated)
TERTIARY.	
CRETACEOUS (Comanche series)	
Yellow clay containing layers of white limestone in beds 4 to 6 inches in thickness; an abundance of large and well preserved *Gryphea corrugata* Say, also *Exogyra texana* Roemer, a small *Gryphea*, *Pectens*, *Fucoids*, and Echinoid spines	10-15
Blue and yellowish clay, locally paper like, containing thin ferruginous layers	10-15
LAKE BED.	

The blue and yellow clay of the Lower Cretaceous stands out in marked contrast to the overlying snow white Tertiary and the white alkali crust on the lake bed. The material here belongs to a horizon similar to that at Tucumcari Mountain, but the absence of sand and the presence of limestone seem to link it more closely with the main Texas area than with the "outlying areas".

The Monument Lake "inlier" is about midway between Tucumcari Mountain and the nearest outcrop of the Lower Cretaceous of the main Texas area, south of Post, Texas. It seems probable that if a detailed study of the lakes of the Texas Plains were made that additional outcrops similar to the above would be found. If the Tertiary blanket were removed no doubt numerous outliers would connect the Lower Cretaceous of Texas with the northwestward extension in New Mexico and Colorado.

ESTALLINE, TEXAS

Professor E. C. Case, while passing through Estalline, a little village between Memphis and Childress in Hall County, Texas, saw a fragment of *Gryphea* limestone at the Ford garage. He sent the information to the writer who made a trip to that region and was informed that the rock in question was picked up west of town and that it occurred in large masses. A search was made but the writer was unable to find any large pieces of the material. Mr. J. L. Marcum, who lives 7 miles west of Estalline, stated that he had seen the material in place, but could not give the writer a definite location The fragment at the garage was sharply angular and did not show any signs of having been transported. It is believed that a thorough search would reveal some "outliers" of the typical *Gryphea corrugata* shell bed in this region. A careful search in the Tertiary gravels at this locality showed an abundance of worn oyster shells.

It is interesting to note that the Palo Duro Basin, a synclinal trough similar to the Anadarko Basin, but located to the south of the Amarillo uplift, passes through this region. If the writer's hypothesis that the Lower Cretaceous deposits are preserved in the synclinal basins is correct, it is to be expected that some outliers will be found in this region.

DOUBLE MOUNTAIN, TEXAS

The most northerly outlier which is clearly connected with the main Texas Cretaceous outcrop is Double Mountain, in the southeastern corner of Stonewall County, 15 miles north of Rotan and about the same distance southwest of Aspermont.

The writer visited Double Mountain in order to compare the beds exposed there with the outlying areas to the north and west. Double Mountain, consisting of two peaks with a saddle between them, is a very conspicuous feature, standing about 600 feet above an almost perfect plain. It is clearly visible for many miles in all directions.

Section at Double Mountain, southeastern Stonewall County, Texas.

	Feet*
CRETACEOUS (Comanche series)	
Edwards limestone:	
Massive, hard, white limestone containing *Oxytropidoceras acutocarinatum* (Shumard)	30-40
Comanche Peak limestone:	
Soft, chalky, white limestone, nodular	40
Walnut clay:	
Brown clayey limestone containing *Exogyra texana* Roemer and *Gryphea marcoui* Hill	25
Trinity sand:	
White sand	25
Conglomerate, consolidated in places, in others loose and intermixed with white sand	50
PERMIAN	
Red beds	50-75
Gypsum	3
Red beds to plain below	200

*Measured with a barometer.

It is to be noted from the above section that the material which caps the butte is the Comanche Peak and Edwards limestones, equivalent to the Goodland limestone of the Fredericksburg division in the north Texas section. The Washita division has been entirely removed by erosion, but here the hard, resistant Edwards limestone has protected the underlying beds and preserved the outlier, which represents a former extension of the Edwards Plateau of central Texas. The beds exposed at Double Mountain do not represent the shoreward facies of the Lower Cretaceous, as the southern Oklahoma and northern Texas sections, but rather a condition farther from shore and more closely related to the central Texas section.

WICHITA FALLS, TEXAS

A careful search, but without success, was made for remnants of the Lower Cretaceous beds in southern Oklahoma, south and west of the Wichita Mountains. Dr. C. W. Clark[134] informed the writer that southeast of Wichita Falls, in western Clay County, near the northwestern corner of Archer County, there is a small knoll covered with a quartzitic conglomerate. From the description of this material it seems to conform to the basal quartzitic conglomerate of the Trinity sand.

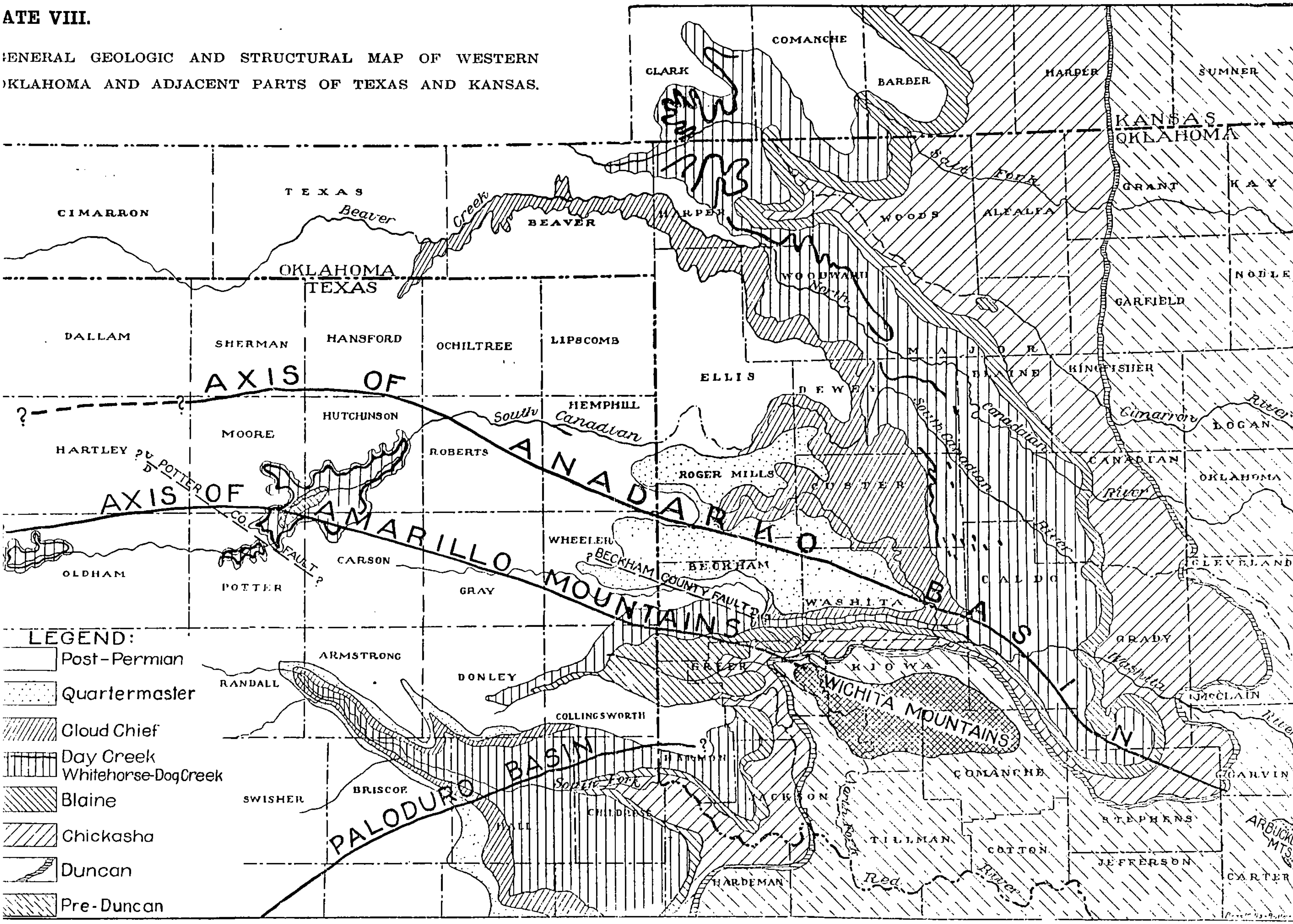
STRUCTURE

In this discussion only the major structural features of western Oklahoma and the Texas Panhandle are considered. The minor details regarding the structure of the various areas have already been given.

134. Consulting geologist, Wichita Falls, Texas.

ATE VIII.

ENERAL GEOLOGIC AND STRUCTURAL MAP OF WESTERN OKLAHOMA AND ADJACENT PARTS OF TEXAS AND KANSAS.



The controlling structural feature of western Oklahoma and the Texas Panhandle is the Arbuckle-Wichita mountain uplift, which trends in a general northwesterly direction. The extensive oil development in the Texas Panhandle during the past few years has shown that the Wichita Mountains are continued to the northwest beneath the covering of the Tertiary and Permian formations, extending through the Amarillo oil field to a point near the northwestern corner of the Texas Panhandle. This buried extension of the Wichita Mountains has been called the Amarillo Mountains.

ANADARKO BASIN

Paralleling the Wichita-Amarillo mountains on the north is a great structural trough, the Anadarko Basin. It extends practically the entire length of the mountain system, but the absence of well records makes it impossible to definitely outline the western limits of the basin. Some writers would continue the axis of the basin to the northwest into Dallam County, Texas, and perhaps into Cimarron County, Oklahoma. Others would swing it to the southwest probably ending it in Hartley County, Texas. The Anadarko Basin is an asymmetrical syncline with the steep slope adjacent to the mountains. Its maximum depth is reached in southern Custer and northern Washita counties, Oklahoma, near Foss and Clinton. Extending northward from the lowest part of the basin is a shallow trough which runs through eastern Custer, eastern Dewey, central Major, across Woods counties, Oklahoma, and into Comanche and Clark counties, Kansas. A map of the Anadarko Basin is shown in Figure 6.

PALO DURO BASIN

Studies carried on the past few years indicate that there is a great structural trough, similar to the Anadarko Basin, lying south of the Wichita-Amarillo mountain uplift. Neither the exact location nor the extent of this great syncline or basin are now definitely known. It appears to differ from the Anadarko Basin in that it is probably shallower and more nearly circular in outline. The dips from the axis of the Wichita-Amarillo mountains northward into the Anadarko Basin are relatively steep, while the dips southward from the mountains are more gentle. The approximate location of the Palo Duro Basin is indicated on Plate VIII.

RELATION OF THE LOWER CRETACEOUS

After mapping the "outliers" of Lower Cretaceous in western Oklahoma it was discovered that they were limited largely to the center of the Anadarko Basin and to the shallow trough extending northward into southern Kansas. The greatest number of outliers are in the Butler-Foss area in southern Custer and northern Washita counties, which is the lowest part of the basin. The other outliers, the Seiling-Cestos, the Supply, and the southern Kansas areas are all located in or near the trough that extends northward from the main axis of the Anadarko Basin. These relations are shown in Figure 6.

It has also been pointed out that the Lower Cretaceous material reported from near Estalline, Hall County, Texas, is near the axis of the Palo Duro Basin.

The relationship between the structural basins and the location of the "outliers" seems to be too constant to be accidental. The explanation offered by the writer is given under the heading of Summary and Conclusion.

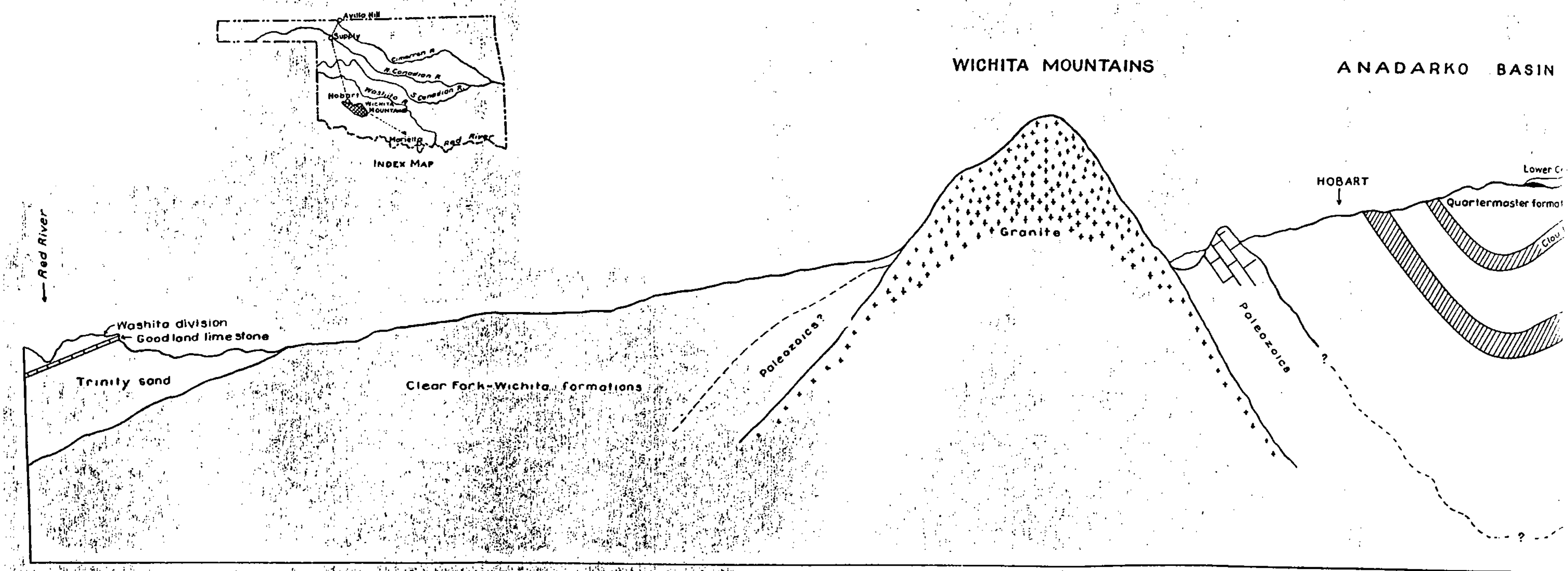
STRUCTURE OF THE LOWER CRETACEOUS OUTLIERS

The details regarding the structure of the various outliers have been pointed out in connection with the descriptions of the various areas, but the general structural relations of the outliers are very difficult to determine. The difficulties are readily realized when one recalls that most of the outliers are not *in situ*, but have slumped to lower levels. An attempt was made, however, to secure elevations on the most reliable outcrops and in this way to connect the various areas. The lack of United States Geological Survey topographic maps and in fact the total absence of government bench marks greatly complicated the work.

Elevations were secured from the various railroads and with the aid of a barometer, which was checked with all possible care, the elevations of a number of outliers in each area were determined.

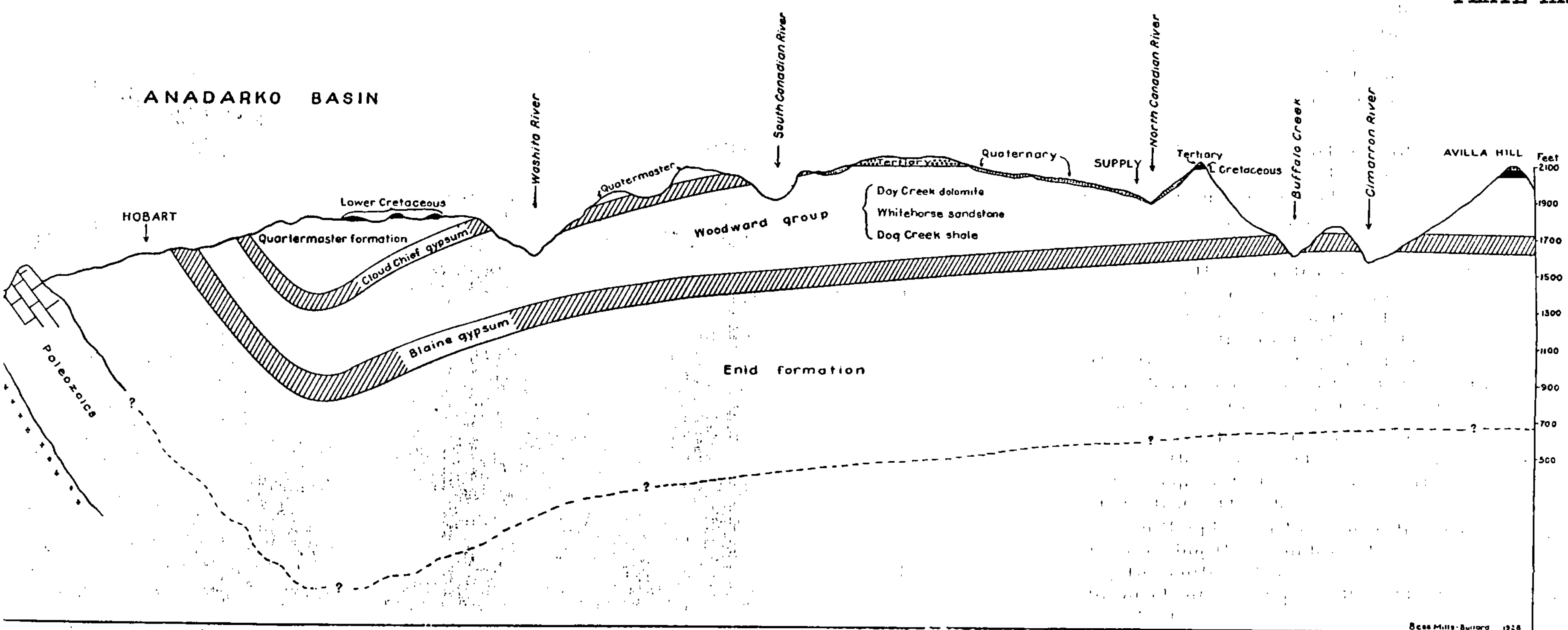
The Avilla Hill outlier, on the Oklahoma-Kansas line, has an elevation of 2,115 feet. The outliers in the Supply area have an elevation of about 2,100 feet. However, it must be remembered that erosion has removed fully 70 feet from the Supply section, which is present at Avilla Hill, so that reducing the elevation to a common datum it would show a gentle dip to the northeast. This conforms in general to the structure of the Permian in this area which, due to the shallow trough previously mentioned, has a dip to the northeast in the region between Supply and Avilla Hill.

From the Supply area southward the Lower Cretaceous beds show a very gentle dip to the south. The outliers in the Seiling-Cestos area have an elevation of 1,910 feet, and in the Butler-Foss area the elevation is 1,805 feet. This shows a difference in elevation of nearly 300 feet between Supply and Foss, or a dip of only about 4 feet per mile. After crossing the trough of the Anadarko Basin, that is south of Foss, the outliers begin to rise in elevation and show a northward dip of about 6 feet per mile. The lowest elevations observed were in the trough of the Anadarko Basin, and on



Structure section across western Oklahoma showing relation of the Lower Cretaceous outliers

PLATE IX.



g relation of the Lower Cretaceous outliers to the structure of the underlying rocks ta counties, which is the lowest part of the basin. The other outliers, the Seiling-Cestos, the Supply, and the southern Kansas areas are all located in or near the trough that extends northward from the main axis of the Anadarko Basin. These relations are shown in Figure 6.

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The relationship between the structural basins and the location of the "outliers" seems to be too constant to be accidental. The explanation offered by the writer is given under the heading of Summary and Conclusion.

STRUCTURE OF THE LOWER CRETACEOUS OUTLIERS

each side the outliers rise to higher levels. It is concluded therefore that the structure of the Anadarko Basin is reflected in the Lower Cretaceous outliers of western Oklahoma.

The following details are given in order to allow subsequent investigators to check the observations of the writer. The following elevations, furnished by the several railroads, were used as bench marks. The elevations given refer to the track in front of the stations.

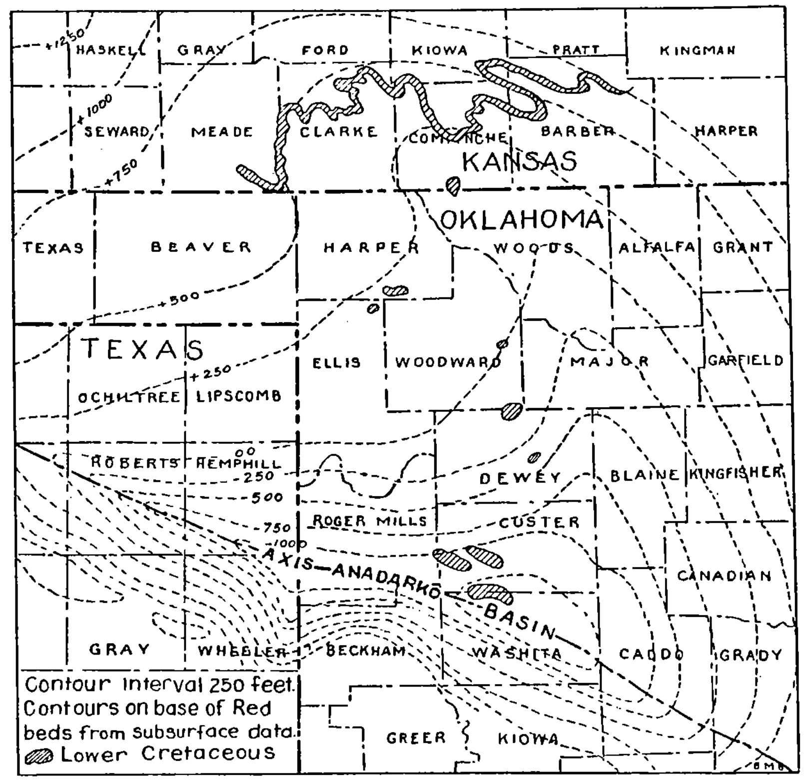


Figure 6. Map showing the relation of the lower Cretaceous outliers to the Anadarko basin. (Structure contours by Clifton.)

The elevation of the Avilla Hill outlier was taken from the U. S. Geological Survey Coldwater topographic sheet.

In the Supply area the elevation was determined by running a traverse with a barometer from the railroad station at Supply to the outcrop. The elevation thus determined checked with that given by the oil company for the top of the casing at the derrick in the NE.¼ sec. 14, T. 25 N., R. 22 W.

Elevations in western Oklahoma.

		Feet
Woodward	Sante Fe R. R.	1,893
Supply	W. F. & N. W. R. R.	1,937.52
Sharon	" "	2,006.11
Vici	" "	2,210.28
Moorewood	" "	1,694.5
Hammon	" "	1,691.57
Rocky	St. L. & S. F. R. R.	1,643
Bessie	" "	1,537
Clinton	" "	1,512*
Elk City	C. R. I. & P. R. R.	1,912
Foss	" "	1,622

*NOTE.—It was found that there is an error of about 50 feet in the elevation of Clinton as compared with Elk City. Numerous traverses were run between these two points and invariably Clinton was 50 feet low.

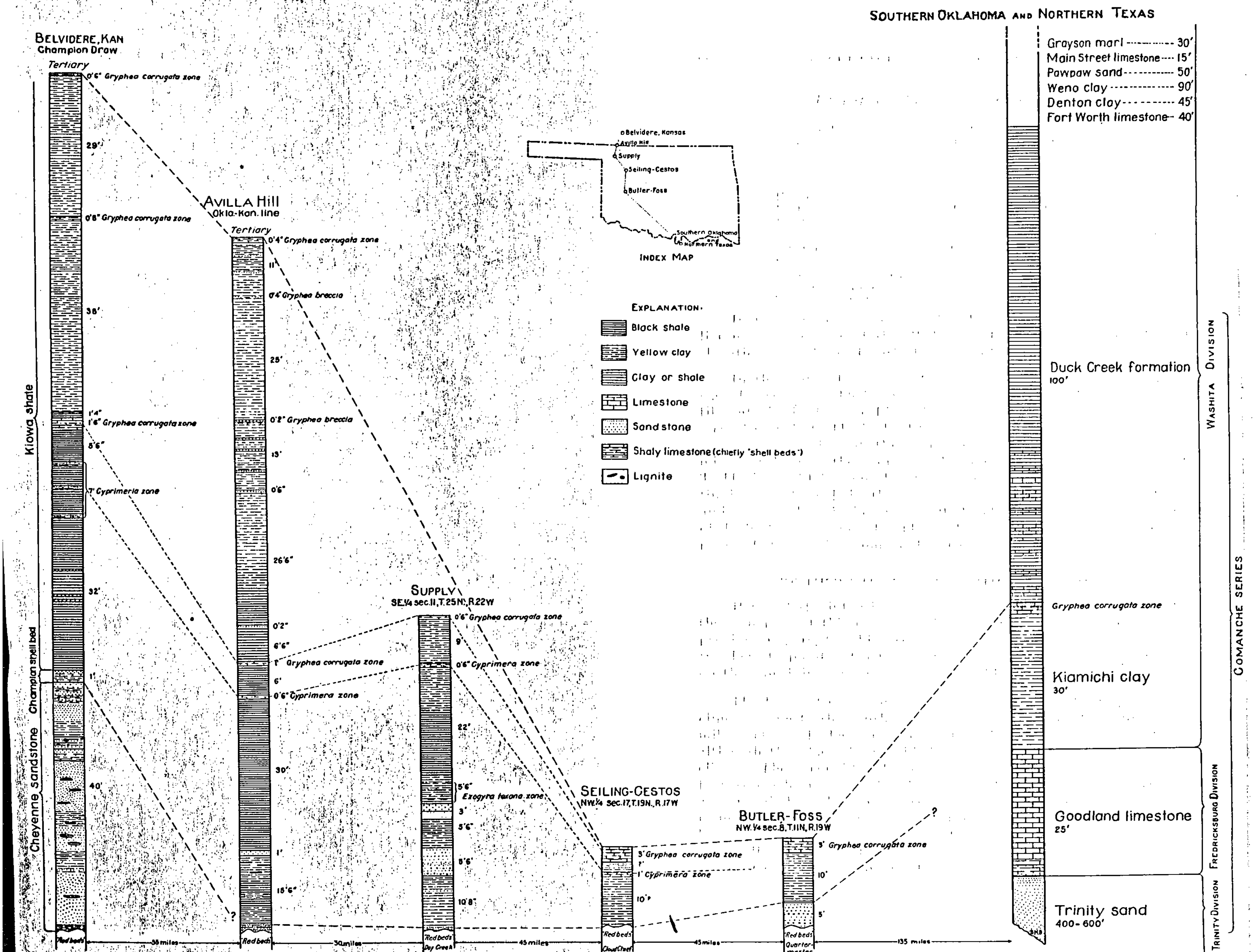
In the Seiling-Cestos area the elevation was taken on the outlier near the center of the SE.¼ sec. 15, T. 19 N., R. 18 W. The elevation was checked with the railroad station at Vici.

In the Butler-Foss area the elevation of many of the outliers was determined. Their approximate values are given on the profiles at the bottom of Plate II. An outlier on the road between secs. 8 and 9, T. 11 N., R. 19 W., gave an elevation of 1,825 feet. A detailed section of this exposure is given on page 79. Two miles south, near the center of the south line of the SW.¼ sec. 16, T. 11 N., R. 19 W., an elevation of 1,805 feet was recorded. Continuing southward, in the SE. cor. of sec. 36, T. 11 N., R. 19 W., and also in the SW.¼ of sec. 30, T. 11 N., R. 19 W., an elevation of 1,840 feet was noted. These elevations were checked with the railroad station elevations at Elk City and Foss.

NORTHERN TEXAS AND SOUTHERN OKLAHOMA

It is not the intention of the writer to go into detail regarding the structure of this region in this report. It has been discussed in previous papers, to which reference has been made, and it will suffice here to point out a few facts which have an important bearing on the "outlying areas" of western Oklahoma.

The Lower Cretaceous of this region is a gently dipping monocline, sloping to the southeast at a rate averaging about 40 feet per mile. The beds have not been disturbed to any marked degree, although they have been folded into a series of anticlines and synclines. The Arbuckle Mountain axis is the dominant structural feature of the region. All the minor folds are arranged with their axes parallel to the general trend of the Arbuckle Mountains, that is northwest-southeast. The most important of these minor folds known at the present time is the Preston anticline, extending from Marshall County, Oklahoma southeastward into Grayson County, Texas. On the south of the Preston anticline is a broad shallow



Geologic sections in southern Kansas, western Oklahoma, and northern Texas syncline, extending from Love County, Oklahoma, where it is called the Marietta syncline, southeastward into Grayson County, Texas, where it is known as the Sherman syncline. On the north of the Preston anticline there is a series of anticlines and synclines, which, in the order of their occurrence are: the Kingston syncline, the Madill anticline, and the Cumberland syncline.

A very important and significant feature in this region is the relation between the structure and topography. In every case noted the axis of the syncline is marked by a topographic high on which remnants of the youngest beds in the region are exposed. This relationship has a very important bearing on the explanation offered by the writer to account for the occurrence of the Lower Cretaceous outliers in the trough of the Anadarko Basin.

GENERAL SUMMARY AND CONCLUSIONS

The section of the Comanche series of southern Oklahoma and northern Texas is taken as the type section and the "outlying areas" of Kansas, western Oklahoma, and New Mexico are correlated with this section. In this section the beds have been divided into three divisions: the lowest, consisting of sands and shales, is the Trinity; the middle division, consisting principally of limestone, is known as the Fredericksburg; and the upper division, the Washita, is made up of clays and thin-bedded limestones with a subordinate amount of sand. The Comanche series attains a thickness of about 1,000 feet in this area.

Northwestward from the main outcrop of southern Oklahoma and Texas the Cretaceous beds have been eroded and no outliers are found until the area north of the Wichita Mountains is reached where they begin to appear and northward from that point they are more or less continuously present, finally connecting with the somewhat more extensive area in southern Kansas. The variations in thickness and character of material in the various areas are graphically shown on Plate X. It may be briefly reviewed at this time.

In the Butler-Foss area the outliers consist of a basal sand locally quartzitic and conglomeratic, followed by a layer of blue clay, and capped by a very conspicuous oyster shell breccia (*Gryphea corrugata* zone). The conglomerate is quite variable, even locally, but in general is more prominent in the southern portion of the area as the Wichita Mountains are approached. The outliers average about 15 feet in thickness in this area.

The Seiling-Cestos area differs from the Butler-Foss area in that the basal sand and conglomerate are practically absent; and separating the blue and yellow clay zone from the "oyster shell breccia" is a thin, hard, nodular, bluish limestone. The *Gryphea corrugata* zone reaches its maximum development in this area but the thickness of the section as a whole is the same as in the Butler-Foss area.

In the Supply and Avilla Hill areas, which are essentially the same in character, a marked increase in thickness is noted and the limestone bed of the Seiling-Cestos area is not present as such but the horizon can be recognized by the fossils.

From Avilla Hill northward to the Belvidere region the most outstanding change is the appearance of the Cheyenne sandstone beneath the Kiowa shale. This sandstone, if present in the Avilla Hill and Supply sections, is represented by only a few feet of shaly sand, while at Belvidere it is over 40 feet in thickness.

The points that the writer would like to emphasize are the following:

1. A rapid decrease in the thickness of the beds southward from Belvidere, Kansas.

2. The disappearance of the Cheyenne sandstone southward from Belvidere, but the appearance of a sand and conglomerate layer occupying the stratigraphic position of the Cheyenne as the Wichita Mountains are approached.

3. The total absence of sand in the Seiling-Cestos area and the presence of a thin limestone horizon and the maximum development of the *Gryphea corrugata* zone.

From the Avilla Hill and Supply areas it is over 250 miles to the Lower Cretaceous (Purgatoire) outcrop of Cimarron County, Oklahoma. The Purgatoire is composed of two members, a basal sandstone very similar to the Cheyenne and an upper black to gray shale containing a marine fauna which correlates directly with the Kiowa shale of Kansas.

Intermediate between Supply and Cimarron County, at Red Point, near Guymon, Texas County, Oklahoma, there is an isolated outlier consisting of a sandstone bed about 5 feet in thickness and carrying a fauna that connects it with the shale member of the Purgatoire.

At Tucumcari, New Mexico, there is a section of Purgatoire exposed which is essentially the same as that of Cimarron County, Oklahoma.

Intermediate between Tucumcari and the main Cretaceous outcrop of Texas, at Monument Lake, Bailey County, Texas, there is a small "inlier" of Lower Cretaceous carrying a fauna that indicates the same horizon as the Purgatoire of Tucumcari, but apparently different conditions of sedimentation.

The conclusions of the writer in regard to the correlation of the various areas are shown graphically on Plate X. They may be briefly summarized as follows:

1. The Kiowa shale of southern Kansas is basal Washita in age and is correlated with the Kiamichi clay of southern Oklahoma.

2. The Champion shell bed is either basal Washita or Fredericksburg in age. The absence of a sharp paleontologic break between these two division makes the determination of the exact position of this layer with respect to the Texas section very unsatisfactory.

3. The Cheyenne sandstone underlies a typical basal Washita fauna and must therefore be older, and it contains a flora younger than the Trinity sand of Texas. The absence of a Fredericksburg flora with which it could be compared makes its correlation with that division doubtful.

4. The outlying areas of western Oklahoma are correlated with the Kiowa shale of Kansas and the Kiamichi clay of southern Oklahoma and Texas.

5. The Purgatoire sandstone of Cimarron County, Oklahoma, is correlated with the Cheyenne sandstone of Kansas.

6. The Purgatoire shale of Cimarron County, Oklahoma, is correlated with the Kiowa shale of Kansas, but it also includes horizons of the lower Duck Creek of Texas.

7. The Purgatoire of Tucumcari Mountain, New Mexico, is very similar to that of Cimarron County, Oklahoma, except that it includes at least a portion of the Fort Worth limestone of Texas.

Finally it has been shown that the Lower Cretaceous outliers of western Oklahoma are: (1) Confined to the trough of the Anadarko Basin, and to the trough of the shallow extension to the north, and (2) that the "outliers" reflect the structure of the underlying Permian rocks. In the erosion of gently folded beds of the Lower Cretaceous in southern Oklahoma and northern Texas the trough of the synclines are marked by a line of hills capped by the youngest beds in the area. This is well illustrated by the Marietta syncline in Love County, Oklahoma, and has also been noted in Cooke and Grayson counties, Texas. As erosion continues there will of course come a time when all the Cretaceous beds will have been removed, except that portion in the trough of the synclines which would then become typical outliers, similar in origin to those found in western Oklahoma.

GEOLOGIC HISTORY

The geologic history of this region becomes very complicated when considered in its entirety. The main points have been summarized by Gould and Lewis,[135] so that in this paper attention will be confined to the events which are recorded by the Lower Cretaceous deposits. In order to form a background it will be appropriate to mention the outstanding events leading up to the deposition of the Lower Cretaceous beds.

Late in the Paleozoic, probably during late Pennsylvanian time, the Arbuckle-Wichita-Amarillo mountains were elevated and folded. The Anadarko Basin, to the north of the Wichita-Amarillo mountains, was probably first formed at this time. During Permian time this elevated area was being eroded and the sediments deposited in the basins on the flanks. The Amarillo Mountains were covered rather early in the Permian, but the Wichita Mountains persisted as a land mass. At the close of Paleozoic time renewed uplift and folding occurred along this axis. During the Triassic and Jurassic a part of this area, western Oklahoma at least, was being eroded and by the beginning of Cretaceous time it had been reduced to an area of low relief. With the beginning of the Cretaceous the last great flood of the interior of this continent was inaugurated. It is believed by some that a tilting of the continent seaward allowed the Gulf of Mexico to extend its shore line far to the northwest.

This transgression of the sea, beginning in Lower Cretaceous time, is recorded in the type of deposits in the various areas. At the base, as the beach moved farther and farther landward, a deposit of gravel and coarse sand was laid down on the eroded and beveled edges of the Paleozoic floor. This was followed by finer sands and shales, and in the areas farther from shore by limestone deposition. Thus, the Trinity division of central Texas is represented at the base by the Travis Peak, a formation consisting of conglomerate, sand, and shale and is followed by the Glen Rose, a predominately limestone formation. In the Red River region the Trinity is represented entirely by conglomerate, sand, and shale, indicating that throughout Trinity time this was a near shore, littoral area.

The shore line of the Trinity overlapped on the Ouachita and Arbuckle mountains, but its maximum extent northward is unknown. Some writers have maintained that the Cretaceous sea covered the Arbuckle Mountains, while others hold that it did not extend much beyond the present Trinity boundary. By projecting the normal dip of 40 feet per mile to the northward, the Cretaceous

135. Gould, C. N., and Lewis, F. E., The Permian of western Oklahoma and the Panhandle of Texas: Oklahoma Geol. Survey Cir. 13, 1926.

beds would cover the Arbuckle Mountains. It is doubtful whether such a procedure is justified, for the Arbuckle Mountains have been subjected to both diastrophic movements and erosion so that their present position in relation to the Lower Cretaceous is not necessarily the same as it was in Lower Cretaceous time. The Arbuckle Mountains are at the present time partly buried by the Cretaceous deposits, for drill holes to the south frequently pass from the Cretaceous into steeply dipping Paleozoics, showing that they extend far to the south beneath the Cretaceous cover.

No deposits of unquestioned Lower Cretaceous age have been recognized north of the Arbuckle Mountains. Some sandstones and shales have been described by Dott[136] from the southeastern corner of Garvin County, along the north side of Wildhorse Creek in T. 1 N., Rs. 1 E. and 1 W., which he questionably referred to the Trinity. However, he also suggests that they resemble the Gertie sand of Quarternary age. The deep erosion around the Arbuckle Mountains since Cretaceous time has effectually removed all traces of the Cretaceous deposits if they ever extended far to the northward.

North of Milburn, in eastern Johnston County, about 5 miles north of the present Cretaceous contact, some features suggestive of wave action were discovered. Preserved on large blocks and masses of the Tishomingo granite are some hollowed out surfaces which resemble wave erosion. (See Pl. XI). These concave surfaces are on the south side of the blocks and occur at the same level. They have been traced for several miles in a horizontal plane and no doubt detailed work would enable them to be traced throughout the extent of the Arbuckle Mountains. These marks are believed by the writer to have been formed by wave action along the shore of the Trinity sea and if such a conclusion is true they doubtless represent the northward limit of the Cretaceous sea, otherwise they would have been obliterated. However, their origin cannot be definitely stated until more detailed work is done.

The vigorous erosion during Trinity time reduced the adjacent land masses to low lying areas and the following epoch, the Fredericksburg, was marked by wide spread limestone deposition producing the Comanche Peak and Edwards limestones of central Texas and the Goodland limestone of southern Oklahoma and northern Texas.

Late in the Fredericksburg or at the beginning of Washita time, the sea expanded, extending a great bay around the western end of the Wichita Mountains into western Oklahoma and southern Kansas, across the Texas Panhandle, into eastern New Mexico,

136 Dott, Robert H., Geology of Garvin County, Oklahoma: Oklahoma Geol. Survey Bull 40-K, 1927.

PLATE XI.

A. EFFECT OF WAVE ACTION (?) ON GRANITE.
Five miles north of Milburn, Oklahoma.

B. MUSHROOM ROCK CARVED BY WAVE ACTION (?)
Same locality as in A.

Colorado, and as far north as central Wyoming. The Wichita Mountains stood out either as an archipelago or a peninsula in this shallow sea. The first sediments deposited in this great shallow bay were sands and gravels representing the beach deposit as the sea extended its shore line landward. This initial deposit is quite variable in thickness ranging from zero up to more than 100 feet. It also varies locally, probably due to currents and inflowing streams. This deposit is represented by the basal Purgatoire in Colorado and New Mexico and by the Cheyenne sandstone in Kansas. It is practically absent in most of the outliers of western Oklahoma, but appears as a coarse conglomeratic sandstone in the Butler-Foss area as the Wichita Mountains are approached, showing that they were high enough to provide coarse sands and gravels.

This sand is followed by a deposit of clay and shale, predominately black, representing the debris from the adjacent land masses which had been exposed to weathering for a long period of time. This deposit is known as the Kiamichi in northern Texas, the Kiowa in southern Kansas, and the upper Purgatoire in Colorado and New Mexico. In the shallow bay extending over this region oysters grew in abundance and their generous size indicates that life conditions were very favorable. Their shells accumulated on the sea floor forming "shell beds" which attain a maximum thickness of three feet in the Seiling-Cestos area of western Oklahoma. The waters must have been warm, shallow, and probably more or less brackish from inflowing streams. Some of the shell beds are composed of broken shells showing that the water was of such shallowness that the bottom was within the reach of current and wave action.

In the areas farthest removed from shore there is an absence of sand and usually a thin, nodular, limestone as in the Seiling-Cestos area of western Oklahoma. The limestone conglomerate in the Butler-Foss area probably represents some very unusual condition, such as a violent storm which carried conglomeratic material into a zone that ordinarily did not receive land debris. The alternation of fine sand and conglomerate observed in the same area may be explained in a similar manner.

The Lower Cretaceous sea completely covered the Permian in western Oklahoma and the position of the "outliers" on the sides of the hills is due to a slumping of the beds.

The land mass which furnished most of the sediments to this great interior sea was to the north and west as the beds are in general thicker in that direction and become thinner to the south and east.

Explanation of Figure 7

A. Uplift and folding of the Wichita-Amarillo mountains and the formation of the Anadarko Basin at the close of the Paleozoic. Prolonged erosion during Triassic, Jurassic, and the beginning of Lower Cretaceous time, reducing the area to a low plain. At the beginning of Washita time (upper Lower Cretaceous) a shallow sea covered the area depositing sands, clays, and shell beds on the beveled edges of the Permian.

B. Post-Comanchean pre-Tertiary uplift along the axis of previous folding, resulting in the warping of the Comanchean sediments into a broad syncline conforming to the structure of the underlying rocks.

C. Pre-Tertiary erosion resulting in the removal of the Lower Cretaceous rocks except the parts located in the trough of the Anadarko Basin and in the shallow trough extending to the north, which does not show on the diagram since it is parallel to its axis.

D. Post-Tertiary erosion resulting in the present land surface.

The great bay over western Oklahoma was of short duration for with the close of Kiamichi time the sea began to withdraw to the west, persisting during lower Duck Creek time in Cimarron County, Oklahoma, and then retreating to the south but remaining in the Tucumcari, New Mexico region until at least Fort Worth time. The numerous oscillations of the Washita sea in the Red River region are indicated by the rapid change in the character of the sediments. The broad, shallow bay extending to the northwest was so shallow that a very minor movement would suffice to cause it to withdraw or flood large areas.

In southern Oklahoma and northern Texas limestone forming conditions alternated with the deposition of calcareous shales and clays during Duck Creek and Fort Worth time. However, with the beginning of the Denton the sediments of this region become clays and sands and record the retreat of the sea from this area. In central Texas the various oscillations of the Washita sea did not affect the character of the deposits and limestone forming conditions prevailed throughout this epoch.

At the close of Washita time the sea withdrew entirely from this region and an erosional interval separates the Lower Cretaceous from the Upper Cretaceous. This disconformity is scarcely visible in the Denison, Texas section, but becomes more prominent to the east. In southwestern Arkansas the entire Washita and Fredericksburg divisions have been removed by erosion and the Upper Cretaceous rests directly on the Trinity.

In post-Cretaceous time, probably accompanying the Rocky Mountain Revolution, renewed uplift and folding occurred along the Wichita-Amarillo axis resulting in the warping of the Cretaceous beds into a series of gentle folds conforming to the structure of the underlying rocks. Erosion following this folding removed

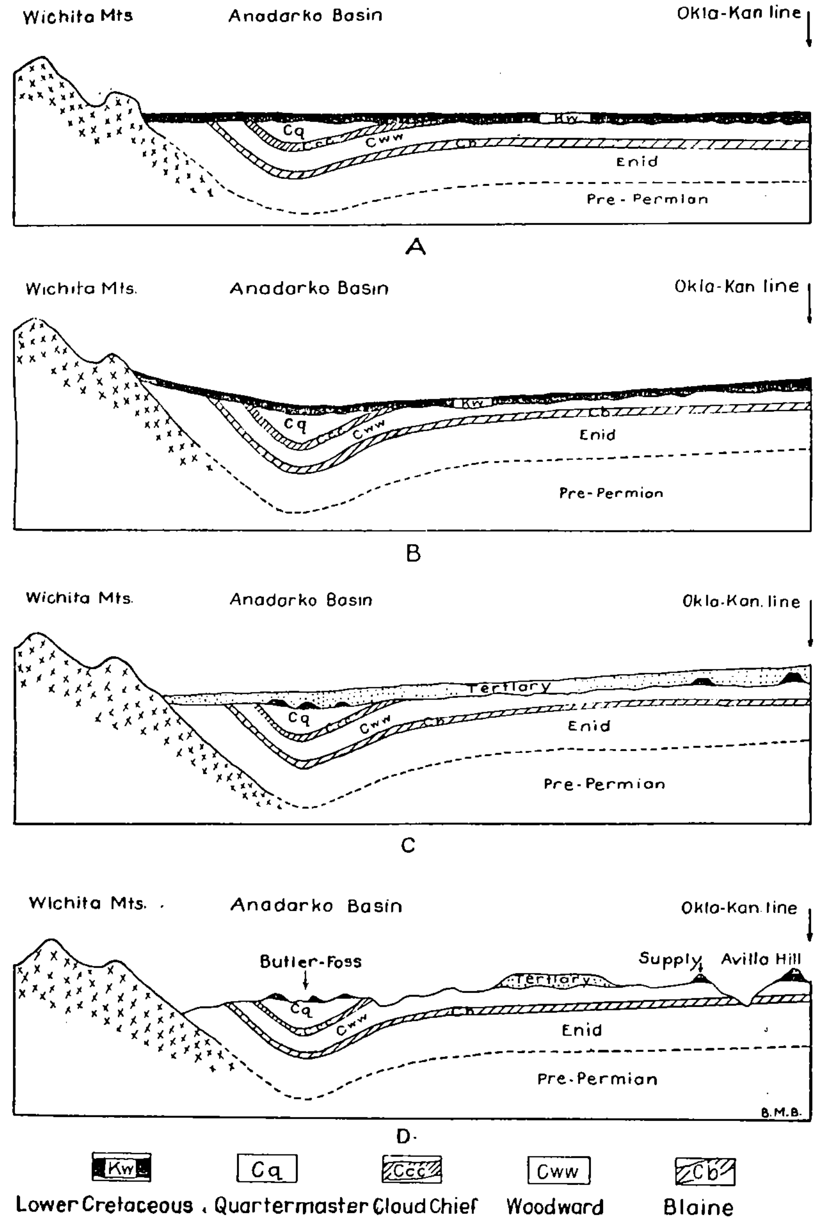


Figure 7. Diagrammatic representation of the stages in the geologic history of the Lower Creaceous of western Oklahoma. (See explanation on opposite page.)

the thin veneer of Cretaceous deposits in western Oklahoma with the exception of a few scattered outliers in the troughs of the synclines. The erosion was greatest along the axis of uplift which accounts for the absence of outliers near the Wichita Mountains. The Tertiary was then spread over the country in a great sheet-like deposit covering and preserving the "outliers". The Tertiary, as would be expected, contains an abundance of fragments of the Cretaceous. In practically any exposure oyster shells and even pieces of shell rock are found. Fenneman[137] has pointed out that the streams of western Oklahoma, the Cimarron, the North Canadian, and the South Canadian Rivers, have parallel channels. These, he says, could only have developed on a very flat plain, either the Permian peneplain or on the flat Tertiary surface when it extended far to the east.

Post-Tertiary erosion has stripped off the Tertiary cover from a portion of western Oklahoma exposing the remnants of the once wide spread Cretaceous beds.

The various stages in the geologic history of the Lower Cretaceous rocks, as outlined above, are graphically shown in Figure 7.

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