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THE UPPER PALEOZOIC ROCKS OF OKLAHOMA

STRATIGRAPHY AND AREAL GEOLOGY

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PALEOGEOGRAPHY

By

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INTRODUCTION

Rocks of upper Paleozoic age, including the Mississippian, Pennsylvanian and Permian, in Oklahoma are exposed on the surface over about 80 per cent of the area of the State. The total combined thickness of the outcropping formations as shown by surface outcrops approximates 40,000 feet.

With the exception of certain granites and porphyrys, and the earlier Paleozoic sedimentary rocks in the four mountain uplifts, a strip of Cretaceous rocks along the Red River, some Tertiary and Pleistocene deposits in the western counties, and strips of alluvium along the streams, practically all of the surface rocks in Oklahoma are of upper Paleozoic age. Few states show such a complete representation of rocks of each of the systems, Mississippian, Pennsylvanian, and Permian.

The literature on the subject is becoming quite voluminous. Beginning with the earlier work of Drake and Taff in the last decade of the nineteenth century, various men at different times have added to our knowledge. Only a few of the outstanding workers[2] who have contributed to our knowledge of the subject can be mentioned at this time. It is to the published reports of such men as Taff, Drake, Girty, Beede, Snider, Ohern, Morgan, and Honess, that we are chiefly indebted for the information we now have on the upper Paleozoic of Oklahoma.

A very large amount of information which has been secured during the past few years by geologists working for various oil companies throughout the State is not yet available for publication, being considered in the nature of confidential data. It is to be regretted that for various reasons much of this data will probably never be liberated, and will be lost to science. On the other hand much of it will some day be published and will add much to our knowledge of the subject. One is safe in making the statement that very few parts of the earth's surface have been subjected to such close geological scrutiny as has the area occupied by the upper Paleozoic rocks of Oklahoma during the past decade. Literally thousands of geologists have swarmed over the surface examining ledges, plotting outcrops and determining elevations,

1. It will be understood that in this paper the term, upper Paleozoic, is used to include the Mississippian, Pennsylvanian, and Permian.
2. See abridged bibliography, p. 45.

while others have examined the logs of deep wells throughout the State, so that the information is adequate, if and when it is ever released for publication.

The purpose of this report is not to make new contribution to either the areal geology or the stratigraphy of Oklahoma, but simply to present an outline of this information as it is now available in the literature, and to point out some of the more significant problems which have developed as the result of the studies carried on by various investigators during the past thirty years.

The earlier work of Taff and others in the coal fields in eastern Oklahoma revealed the presence of the vast beds of coal, estimated by the United States Geological Survey at 79,000,000,000 tons. Some of the most prolific fields of high-grade, refinable oil in the world are located in the upper Paleozoic of Oklahoma. The total amount of petroleum produced in this state to date approximates something over two billion barrels valued at above $4,000,000,000.

The amount of natural gas and casing head gasoline both of which are usually associated with petroleum is very great. In addition there are contained in the rocks of upper Paleozoic age vast deposits of stone, clay, gypsum, salt, and other valuable mineral products.

While we are yet far removed from a complete solution of all of the scientific and economic problems connected with the upper Paleozoic of Oklahoma, the writers believe the time has come when we may profitably set forth our present knowledge of the subject, particularly of the stratigraphy, and the source of the sediments, and discuss the bearing of these matters on some of the vital economic problems. The map, Plate I, redrawn from the Miser Geologic Map[3] of Oklahoma attempts to show the areal exposures of the rocks of the three systems as they occur in Oklahoma.

It will be noted from the map that the Mississippian rocks are exposed on the surface in the larger part of the Ozark Mountains. These rocks also occupy large areas in the Ouachita Mountains and occur as a fringe around the margin of the Arbuckle Mountains.

The Pennsylvanian rocks are exposed chiefly in the great structural trough known as the Arkansas Valley syncline lying between the Ozark Mountains and the Ouachita Mountains in eastern Oklahoma, and in the area lying north of the Ouachita and Arbuckle Mountains as far west as central Oklahoma.

3. The Colored Geologic Map of Oklahoma, prepared by H. D. Miser has been published by the U. S. Geological Survey, Washington, D. C.

The Permian formations occupy practically all of the western half of the State, except the Wichita Mountain area. In some of the western counties the Permian is covered by Tertiary deposits and by Quaternary sand hills. The latter deposits are not shown on the map.

In the following description of the three systems of the upper Paleozoic[4] only the major characteristics are considered.

MISSISSIPPIAN

Rocks of this system are exposed in the Ozark Mountains, the Ouachita Mountains, and the Arbuckle Mountains. In both the Ozark Mountains and the Ouachita Mountains rocks of Mississippian age make up the major part of the surface exposures. In the Arbuckle Mountains Mississippian strata are exposed only around the flanks of the uplift. In both lithologic character and stratigraphic succession, the rocks of the three areas differ widely *inter se.*

At the base of the Mississippian in all three mountain regions there occurrs a formation composed chiefly of shale (and chert) known in the Ozark Mountains as the Chattanooga shale, in the Arbuckle Mountains as the Woodford chert, in the Ouachita Mountains as the upper Talihina chert, and upper Arkansas novaculite. These formations, by whatever name described, have usually been regarded by geologists as upper Devonian in age, but Ulrich and others now believe the Chattanooga to be basal Mississippian. Luther H. White,[5] who has studied the subsurface rocks of the region, says, "subsurface studies convince the author that the Chattanooga shale cannot be correlated with the Woodford formation." It is not our purpose at this time to attempt to settle the exact age of these beds.

Assuming, then, the Chattanooga-Woodford-Talihina-novaculite base for the Mississippian of the State, let us examine briefly the sequence of the Mississippian formations, and immediately superjacent strata as exposed in the three mountain uplifts.

MISSISSIPPIAN ROCKS IN THE ARBUCKLE MOUNTAINS

The Arbuckle Mountains of southern Oklahoma consist of an elevated, truncated dome, composed of a granite core flanked with sedimentaries of Cambrian, Ordovician, Silurian, and Devonian

4. Brief descriptions of the various upper Paleozoic formations will be found in "Index to the Stratigraphy of Oklahoma", Bull. 35, Oklahoma Geological Survey, prepared by the senior author.
5. White, Luther H., Subsurface distribution and correlation of the pre-Chattanooga ("Wilcox" sand) series of northeastern Oklahoma: Oklahoma Geol. Survey, Bull. 40-B, 1926.

age. Lying above the Devonian, and exposed around the periphery of the mountains, are the Mississippian strata. These formations named in ascending order, are as follows:

Woodford chert; composed of limy chert and shales averaging 650 feet in thickness.

Sycamore limestone; hard, tough-slaty, blue, arenaceous limestone, weathering yellow, often separated into thin beds usually 1 to 2 feet thick, averaging 150 feet in thickness.

Caney shale; lower part black shales and slates with limestone lentils; upper part blue and light-colored shales, with sandy members. Thickness 800 to 1,600 feet. There has been considerable controversy regarding the age of the Caney. The basal part of the formation is now thought by most geologists to be Mississippian, while the upper part is assigned to the Pennsylvanian. Succeeding the Caney on the south side of the Arbuckle Mountains occurs the Glenn formation of Pennsylvanian age.

MISSISSIPPIAN ROCKS IN THE OUACHITA MOUNTAINS

Succeeding the upper Talihina chert, and the upper Arkansas novaculite, as these rocks are exposed in different parts of the Ouachita Mountains of southeastern Oklahoma, there occurs a very thick formation known as the Stanley shale. This formation is described by Honess as "thin-bedded, ripple-marked, fine-grained, dark-colored, hard sandstone, and blue clay shales and slates, irregularly inter-bedded in one vast series." On account of meager fossil evidence, there has been much controversy regarding the age of the Stanley, but the present consensus of opinion is that this vast series of rocks. 10,000 feet in thickness, is of upper Mississippian age.

The Stanley is succeeded by the Jackfork sandstone which is composed of heavy-bedded, massive, medium to fine-grained sandstones. The thickness is usually given as 6,000 to 6,600 feet but Honess would include in addition several thousand feet more of superjacent sandstones and shales on the grounds that the entire series is lithologically a unit and should be considered as a single formation. A Morrow (lower Pennsylvanian) fauna has recently been discovered by Honess near the middle of his Jackfork, and the formation has been divided by him into a lower Jackfork and an upper Jackfork. The lower Jackfork (Jackfork as originally defined) is supposed to lie beneath the Caney shale and therefore would be Mississippian in age, but the Caney shale does not occur in northern McCurtain County where Honess measured his Jackfork succession, or, at least, it has not been recognized there, and he has not therefore come to a final conclusion

regarding the age of his lower Jackfork in McCurtain County, but on faunal evidence the upper Jackfork is correlated with the Atoka (lower Pennsylvanian).

The Wapanucka limestone, containing approximately the same lower Pennsylvanian fauna as the Morrow and middle Jackfork, is exposed along the north slopes of the Arbuckle and Ouachita Mountains. The Wapanucka is a massive white to light-brown limestone, with white, cherty, sandy and shaly beds, sometimes oolitic, becoming sandy eastward. The thickness averages 300 feet. This ledge usually forms a long narrow ridge, dipping steeply northward away from the mountains. The Wapanucka is now believed by Honess to represent the deep sea phase of the middle Jackfork.

MISSISSIPPIAN ROCKS IN THE OZARK MOUNTAINS

In the Ozark Mountains of northeastern Oklahoma, stratigraphic conditions of the Mississippian are quite different from those in either the Arbuckle or Ouachita Mountains. Instead of a single series of clastic sediments comprising a thick formation as in the Ouachita Mountains, one finds in the Ozark Mountains a succession of several rather thin formations which have been named, in ascending order, as follows:

Chattanooga shale; is a black, slaty bituminous shale of uniform texture, 25 to 50 feet thick, usually non-calcareous, containing a lenticular sandstone member, the Sylamore at the base. Luther White[6] considers the Sylamore to represent pre-Chattanooga dune sands, the material of which was derived from the underlying formation.

Boone limestone; interstratified cherty limestone and chert, with St. Joe limestone member at the base, average total thickness, 300 feet.

Mayes limestone; dark gray to black limestone, lying unconformably on the Boone, becoming shaly and composed of beds that are assigned to the Moorefield shale and Batesville sandstone of Arkansas. The average thickness of the Mayes is 40 feet. The name Mayes proposed by Snider[7] has not been accepted by the U. S. Geological Survey, and therefore neither the name nor the outcrop of the beds appear on the geological map of Oklahoma.

Fayetteville shale; dark bituminous shale, with sandstones and thin limestones, 150 feet thick; a lenticular sandstone, the

6. White, Luther H., Op. cit.
7. Snider, L. C., Geology of Northeastern Oklahoma: Okla. Geol. Survey, Bull. 24, p. 27, 1915.

Wedington sandstone member sometimes occurs in the middle portion.

The Pitkin limestone which is the highest of the Mississippian formations in the Ozark Mountains, varies in thickness up to 80 feet and is of Chester age. It is succeeded by the Morrow limestone and Cherokee shales, both of which are Pennsylvanian in age.

CORRELATION

The present interpretation of the correlation of the various sediments including both those of Mississippian and basal Pennsylvanian age in the three mountain regions of the State, as the same is now understood by geologists most familiar with the situation, is shown on the following table:

Tentative Correlation of the upper Paleozoic Rocks of Oklahoma.

(approximate thicknesses given)

Arbuckle Mts.	Ouachita Mts.	Ozark Mts.
Glenn (18,000)	upper Jackfork-Atoka (6,000)	Cherokee-Winslow (1100)
Wapanucka (300)		
upper Caney (800-1,600)	lower Jackfork-upper Caney (6,000)	Morrow (100)
Mississippian-Pennsylvanian Contact		
		Pitkin (80)
		Fayetteville (150)
Lower Caney	Stanley-lower Caney (10,000)	Batesville, Moorefield } Mayes (40)
Sycamore (200)		
Woodford (600)	Upper Talihina-Arkansas Novaculite	Chattanooga (50)

CONDITIONS OF DEPOSITION OF THE MISSISSIPPIAN

From the time of the first studies in the region, the problem of the age and inter-relations of the various Mississippian and lower Pennsylvanian formations in the three mountain regions of eastern and southern Oklahoma has been a matter of much friendly controversy among geologists. This controversy has been due to a lack of information on the subject rather than to definite opinions based on complete data. The problems are by no means easy and adequate data have been very difficult to secure. As new facts have been slowly accumulated new interpretations have constantly become necessary. We are indebted to Taff, Ulrich, Girty, Roundy, David White, Miser, Snider, Morgan, Mather, and especially to Honess, for our present understanding of this extremely complicated problem.

The present interpretation of the origin of these sediments as derived from a study of the exposures in the three mountain uplifts, is as follows: The land mass usually known as Llanoris[8] (sometimes spelled Llanoria), which was evidently the source of the greater part of these sediments lay somewhere to the south of the present Ouachita Mountains, probably occupying much of eastern Texas and adjacent parts of Louisiana. During Mississippian times the region occupied by the present Ouachita Mountains was an area of deposition known to students of paleogeography as the Ouachitaic embayment in which the clastic sediments were accumulating from the above described eroding land mass. In this area of deposition, perhaps a gradually subsiding trough, the 10,000 feet of Stanley shale and sandstone with the overlying 10,000 to 12,000 feet of Jackfork sandstone and shale were laid down. The great thickness of the deposits and the predominance of clastic materials in this Mississippian section is explained by the nearness of the area to the source of the sediments, the land mass Llanoris, to the south.

As would naturally be expected, all of these sediments appear to thin northward. The Caney is not known to occur in the southern part of the Ouachita Mountains, and it is Honess' present belief that the Stanley represents the Caney in that region. He also suspects that wedges of sandstone projecting northward from the Jackfork sandstone mass proper "might interdigitate with shales of typical Caney sedimentation to make it appear as if the Caney lay on top of the Jackfork, as has been thought by various geologists."

Regarding the origin of the Stanley-Jackfork series, Honess[9] has very concisely stated:

"the.................succession is thought to be a delta deposit, washed down from an ancient continental mass which lay to the south. It is presumed that this old land (Llanoris) lay fairly near at hand in southern McCurtain County, but in northern McCurtain and southern LeFlore counties one should expect to find incursions of more typically marine conditions. In the Stanley, fossils are very scarce indeed, but in the Jackfork several horizons of marine invertebrates occur. The depauperate condition of all the faunules thus far discovered is an indication unhealthful living conditions of the times, and these conditions may have maintained because of the presence of delta sediments and river waters. At any rate the marked and sudden thickness of the Stanley shale toward the south, the passing of the Atoka formation in a southerly direction

8. Miser, H. D., Llanoria, the Paleozoic land area in Louisiana and Eastern Texas: Am. Jour. Sci., 5th ser. Vol. 2, pp. 61-84, 1921.
9. Honess, C. W., Geology of Southern LeFlore and northwestern McCurtain counties, Oklahoma, Bureau of Geology, Cir. No. 3, p. 22, Jan. 1924.

into brown sandstones which are indistinguishable from typical lower Jackfork sandstone, and the occurrence of depauperate faunas in the Jackfork, are certainly in accord with the delta theory for the origin of these formations and bear out the evidence presented formerly."

The authors of this paper are in substantial agreement with these conclusions.

On passing northward from Llanoris, the source of the sediments, the Mississippian formations gradually become thinner and the clastic materials become non-clastic. The Mississippian beds pass beneath the Arkansas Valley syncline, north of the Ouachita Mountains and do not again appear until the Ozark Mountains are reached. Here the Mississippian is composed, not of a single thick clastic formation like the Stanley, but, as has already been shown, of a succession of relatively thin beds, largely non-clastic. This would seem to indicate that the Ozark Mountain region, which had emerged during Ordovician time, had been base-leveled and had ceased to be a positive element before Mississippian time.

This condition would also be interpreted to mean that during Mississippian time the Ozark region was not stable, but was subjected to frequent periods of oscillations, during the occurrence of which, several thin veneers of various kinds of sediments were deposited. As corroborative evidence it may be stated that deep drilling in certain parts of the Mid-Continent oil field of east-central Oklahoma, has shown that the Boone chert, the "Mississippi lime" of the driller, gradually loses its calcareous character and becomes more shaly as one leaves the Ozark Mountains and approaches either the Arbuckle Mountains or the Ouachita Mountains, and in the vicinity of the Arbuckle Mountains it appears to grade into the lower Caney.

The interpretation of the conditions of sedimentation during Mississippian times in the Arbuckle Mountains, as shown by the succession of strata, would indicate, first a relatively deep sea in which the Sycamore limestone was deposited, succeeded by gradually shoaling waters characterized by thick beds of shale and thin limestones during lower Caney time, and by still shallower waters during upper Caney, when many sandy beds, interstratified with shale, were deposited. The absence of massive sandstones and conglomerates and the presence of limestones and clays in the Arbuckle section may well be construed to mean that the source of these sediments, probably Llanoris, lay at some distance from the present mountains.

PENNSYLVANIAN

It has already been stated that the work of Honess has shown that the upper Jackfork as exposed in the Ouachita Mountains is correlative with the lower part of the Atoka. The Wapanucka which underlies the Atoka is now believed to represent the middle Jackfork. The Wapanucka and superjacent Atoka have heretofore always been considered to be the base of the Pennsylvanian coal measures as the latter formations occur in the Arkansas Valley syncline north of the Ouachita Mountains. Following the Atoka in regular sequence there occurs a series of sandstones and shales, with interbedded coal, totaling about 4,000 feet in thickness. To these formations, the following names (in ascending order) have been applied by Taff: Hartshorne sandstone, McAlester shale, Savanna sandstone, and Boggy shale. These beds have been folded into a great series of anticlines and synclines throughout the greater part of the area of their surface exposure in eastern Oklahoma. To the north these formations grade into the Winslow formation which lies along the south flank of the Ozark Mountains in western Arkansas and eastern Oklahoma. They are also the time equivalent of part of the Cherokee shales which formation demarks the Ozark Mountains on the west.

Lying unconformably above the Pitkin limestone, which is the highest Mississippian formation, as the latter is exposed around the western margin of the Ozark Mountains in northeastern Oklahoma, occurs the Morrow formation of Pennsylvanian age, 100 feet thick, consisting typically of three members, a lower sandstone, a middle limestone, and an upper shale member. As has already been said the fauna of the Morrow formation indicates that it is of the same age as the Wapanucka limestone and middle Jackfork sandstone of the Ouachita Mountain region.

Next in succession, and lying unconformably above the Morrow occurs the Cherokee shale, which formation also outcrops in areas in southeastern Kansas and western Missouri. At the Oklahoma-Kansas line the thickness of the Cherokee is approximately 450 feet, the formation consisting of shales with several beds of coal and interbedded sandstones. The most conspicuous of these sandstones, the Bluejacket, is shown on the Miser Geologic Map of Oklahoma. Farther west, where buried by superimposed Pennsylvanian strata, this bed with associated sandstones constitutes the very prolific Bartlesville oil sand. To the south the Bluejacket is provisionally correlated with the Savanna sandstone. On passing southward the Cherokee formation thickens. At Pryor it is 960 feet thick, and the thickness increases gradually but persistently toward the south. In the region of the Arkansas River in

Wagoner and Muskogee counties, the lower part of the Cherokee grades into the Winslow formation. To the south the Cherokee is believed to be correlative with the series of beds including the Atoka, Hartshorne, McAlester, Savanna, Boggy, Thurman, Stuart. Senora, Calvin, and Wetumka formations. However, at the present time there are several details connected with the correlation of the Cherokee-Winslow-Atoka to Wetumka beds not clearly understood.

The Pennsylvanian of southeastern Kansas and northeastern Oklahoma has suffered through an overabundance of names. These formations were first studied in southern Kansas by the fathers of Kansas geology, and by these men certain names were applied to the different beds. Later, other geologists studied the same formations and in many cases made different groupings and often applied other names. Geological formations are no respectors of state lines, and consequently many of the Kansas names were used by the first men working in northeastern Oklahoma. As early as 1910 Ohern, Hutchison, and the writer[10] attempted to classify the Pennsylvanian rocks of northern Oklahoma. Unfortunately some of the very excellent work of Dr. Ohern in the region, accomplished from 1909 to 1912 still remains unpublished.

At the time of the compilation of the data included in the colored geologic map of Oklahoma by Miser in 1924-25, a revision of the former classification was made, using some of the names in current use, and other names first employed in the Ohern manuscripts. The names now used for the Pennsylvanian formations in northern Oklahoma on the Miser map and described in the Index to the Stratigraphy of Oklahoma compiled by the senior author, follow in ascending order: Morrow formation, Cherokee shale, Fort Scott limestone, Labette shale, Pawnee limestone, Bandera shale, Altamont limestone, Nowata shale, Oologah limestone, Lenapah limestone, Coffeyville formation, Hogshooter limestone, Nelly Bly formation, Dewey limestone, Ochelata formation, Nelagony formation, Elgin sandstone, Pawhuska formation, Buck Creek formation, Sand Creek formation, and Elmdale formation.

In east-central Oklahoma, the various Pennsylvanian formations received entirely different names from those in the northern part of the state. Taff, in his descriptions of the rocks exposed in the Coalgate quadrangle, Folio No. 74, U. S. Geological Survey, has given us the names for the following thirteen Pennsylvanian formations, named in ascending order: Atoka formation, Hartshorne sandstone, McAlester shale, Savanna sandstone, Boggy shale. Thurman sandstone, Stuart shale, Senora formation, Calvin sandstone, Wetumka shale, Wewoka formation, Holdenville shale, and Seminole conglomerate. Morgan, in his description of the formations in the Stonewall quadrangle has added six names, as follows: Francis formation, Belle City limestone, Vamoosa formation, Ada formation, Vanoss formation, and Stratford formation.

10. Gould, Chas. N., Ohern, D. W., and Hutchison, L. L., Proposed Geology of Pennsylvanian Rocks of Eastern Oklahoma. University of Oklahoma. Research Bulletin No. 3, March 1910.

Now the formations described by Taff and Morgan in southern Oklahoma consist almost entirely of sandstones and shales, while the formations of the Kansas geologists, Ohern and others in the northern counties are chiefly shales and limestones. Almost no formations have been carried across the State from north to south, connecting the rocks as exposed in northern and in south-central Oklahoma. While the general correlation of the beds in the two regions has been worked out, the stratigraphy is so different that it has rarely been found possible to trace any single formation or member from the vicinty of the Arbuckle Mountains north to the Kansas line. A possible exception to this statement is the Belle City limestone of south-central Oklahoma which Miser believes to be correlative with the Dewey limestone in the northern region.

CONDITIONS OF DEPOSITION OF THE PENNSYLVANIAN

In studying the Pennsylvanian formations of Oklahoma as a whole two essential facts should be kept constantly in mind. First, the materials composing the various beds are more clastic toward the south, and more calcareous and less clastic as one approaches the Kansas line. Relatively few limestones are found south of the Arkansas River, while sandstones are generally rare north of that stream. Shales are present in both regions, but the shales of the southern region are more likely to be arenaceous and those north of the Arkansas River are more calcareous. Second, it should be noted that the combined thickness of the Pennsylvanian beds decrease from approximately 13,500 feet in the region north of the Ouachita and Arbuckle mountains in southeastern Oklahoma to a thickness of approximately 3,500 feet along the Kansas line.

Taking into account all observed phenomena, including the gradual thinning of the formations to the north as well as the transition from clastic to non-clastic materials in the same direction, it would appear that the most logical interpretation of these facts indicates that the chief source of the Pennsylvanian sediments of eastern Oklahoma lay to the south. Whether the ultimate source of these deposits was from the land mass Llanoris or from the Stanley-Jackfork beds is not now definitely known. While it is not possible at this time to write the final word on the subject it would seem most reasonable in the light of our present knowledge to assign the origin of the beds partly to Llanoris, and partly to the truncated Stanley-Jackfork beds, the deposition taking place in a retreating sea.

From a study of the map (Plate I) it will be noted that after leaving the vicinity of the Ozark Mountains and the intensely folded area in the great intra-mountain syncline in eastern Oklahoma, usually spoken of as the Arkansas Valley Trough, all the formations lying above and west of the thick Cherokee-Boggy shale beds, are exposed on the surface in long, ribbon-like zones, striking northeast-southwest. The dip of these beds is to the northwest away from the mountains, averaging from 1 to 3 degrees. It naturally follows that the formations dipping northwest are concealed by successive younger or higher beds. Throughout this part of the State erosion has cut away the various formations until today the whole series of westward-dipping Pennsylvanian rocks exhibit a stair-step arrangement, with the harder sandstones and limestones forming the summit of the east-facing scarps, as well as the long western dip slopes, while shales between these harder beds outcrop along the lower part of the scarp slopes and in the valleys.

What has just preceded applies only to the main body of the Pennsylvanian as exposed in eastern and northeastern Oklahoma, in the region lying between the Ouachita and Arbuckle Mountains on the south, and the Kansas line on the north. Another exposure of Pennsylvanian rocks of smaller areal extent, but of great thickness, occurs in southern Oklahoma in the region south of the Arbuckle Mountains chiefly in Carter County.

This is the Glenn formation, first named by Taff, and since studied in more detail by Goldston and others. According to Goldston[11] the Glenn consists of a thickness of 15,000 to 18,000 feet of sediments composed chiefly of blue shales, with beds of massive sandstones and some limestones. Goldston has divided the Glenn into five following members, named in ascending order: Springer, Otterville, Cup Coral, Deese, and Hoxbar.

The upper Pennsylvanian of central and northern Oklahoma is generally believed to grade conformably into the Permian. The line of Pennsylvanian-Permian contact in the central part of the State is still a matter of controversy, Beede placing it at the Neva limestone, the United States Geological Survey placing it at the base of the Cottonwood limestone, while other capable geologists would place the line of contact as high as the Herrington limestone. The senior author prefers to follow Beede, our best authority on the Permian, who places the contact at the base of the Neva which is about 50 feet below the Cottonwood.

11. Goldston, W. L. Jr., The Differentiation and structure of the Glenn Formation: Bull. Am. Assn. Pet. Geol. Vol. 6, No. 1, pp. 5-23, 1922.

PERMIAN

With the exception of the granites and certain lower Paleozoics in the Wichita Mountains, beds of Permian age occupy all of western Oklahoma, extending westward from the line of the Pennsylvanian-Permian contact to the western border of the State. In some of the western counties the Permian has been covered by Tertiary and Pleistocene deposits.

In general, the Permian of the State consists of a great mass of red clay shales, reaching a thickness of 3,500 feet in certain parts of western Oklahoma. Inter-stratified with these red shales are certain heavy beds of sandstone with several ledges of gypsum, dolomite, and rock salt.

However, not all the Permian rocks are red, nor are all the Pennsylvanian rocks non-red. The line of color change between the red and the non-red rocks does not coincide with the strike of the rocks, as the line of the Pennsylvanian-Permian contact, but cuts this contact at an acute angle. Entering Oklahoma from Kansas in northeastern Grant County, this color-change line passes in a southeast direction across Kay, Noble, and Payne counties about as far as the Cimarron River, and thence trends south across eastern Lincoln and western Seminole, across northwestern Pontotoc and eastern Garvin counties to the region of the Arbuckle Mountains. The approximate location of this line is shown on the map (Plate I). However, it should not be imagined that this change of color is abrupt. Rather it is a gradation from non-red below to red above, through several hundred feet of strata exposed on the surface along a zone 5 to 10 miles in width.

It will be noted that in northern Oklahoma there is a triangular area of non-red Permian rocks occupying parts of Kay, Osage, and Pawnee counties. In this region the rocks are chiefly limestones and gray shales, which are the southern extension of the Kansas formations which make up the Flint Hills. In Kansas these non-red Permian rocks include the following formations, named in ascending order: Neva limestone, Eskridge shales, Cottonwood limestone, Garrison formation, Wreford limestone; Matfield shale, Florence flint, Fort Riley limestone, Doyle shale, Winfield limestone, Luta limestone, Enterprise shale, Herrington limestone, and Pearl shale. On coming south these various limestones begin to thin out in the region of the Arkansas River, and along the color-change line the color of the shales changes from gray to red. Some of the limestone ledges persist for a number of miles into the area of red rocks but all of them finally thin out and disappear and their place is usually taken by a ledge of sandstone, so that in east-central Oklahoma the facies of the rocks is entirely different. The name Stillwater[12] formation has recently been proposed for the Oklahoma red beds equivalents of the rocks from the Cottonwood to the Herrington inclusive.

The Wellington, with which for purposes of mapping is included the subjacent Pearl shale, has been traced south across the color-change line and tentatively mapped as far as the region of the Arbuckle Mountains.

On the map also may be noted an area averaging 10 to 15 miles wide and about 100 miles long, extending from the Arbuckle Mountains north to the Cimarron River in eastern Payne County, where the rocks, although of upper Pennsylvanian age, are red in color.

The Permian beds of central and western Oklahoma have been named and described as follows, beginning with the oldest: Stillwater formation, red shales and sandstones, 800 feet thick; Wellington shales, red shales and sandstones, 600 feet thick; Garber sandstone, red sandstones and shales, 600 feet thick; Hennessey shale, red and banded shale, 400 feet thick; Duncan sandstone, red to gray sandstone and shales, 100 feet thick; Chickasha formation, red shales with gypsum, 200-400 feet thick; Blaine gypsum, massive gypsum and interbedded shales, 75-100 feet thick; Dog Creek shales, red clay shales, 150 feet thick; Whitehorse sandstone, massive to shaly sandstone, 400 feet thick; Day Creek dolomite, massive white dolomite, 4 feet thick; Cloud Chief gypsum, massive gypsum, with interbedded clay shales, 100 feet thick; Quartermaster formation, red shaly sandstone, 300 feet thick. The thicknesses as indicated above are not constant, but represent the general average throughout the region.

For many years, on account of lack of data, it was not found possible to trace any single formation of the Permian red beds from Kansas across Oklahoma into Texas. Several attempts were made at the correlation of these beds, but all were in error. The difficulty has always been that until recently no one had ever recognized the presence of a great structural trough, now known as the Anadarko Basin, which lies north of the Wichita Mountains in southwestern Oklahoma and the Panhandle of Texas. The presence of this syncline was established during a field conference[13] held in December 1924. Since this syncline has been recognized many extremely baffling problems of stratigraphy and correlation have become plain and the various parts of the problem now fit together like a puzzle picture.

12. Aurin, F. L., Officer, H. G., and Gould, Chas. N., The Subdivision of the Enid Formation: Bull. Amer. Assn. Pet. Geologists. Vol. 10, No. 8, p. 786, et. seq., August, 1926.
13. Gould, Chas. N., A new classification of the Permian red beds of southwestern Oklahoma: Bull. Amer. Assoc. Pet. Geol., vol. 8, No. 3, p. 340, 1924.

As the result of investigations carried on during the past few months, it has been found possible to trace several formations in the three states mentioned. The Blaine gypsum usually serves as a key ledge but the Duncan-San Angelo sandstone, below the Blaine and the Whitehorse-Lake Trammel sandstone above it, may also be followed across the region. It has been shown that all the Permian formations of Oklahoma from the base of the Duncan to the Quartermaster sandstone are correlative with the Double Mountain formation of Texas. It has also been shown that the so-called "beds of uncertain relations" in the region of the Wichita Mountains and between those mountains and Red River are in reality the Wichita-Clear Fork beds of Texas and are of approximately the same age as the sub-Duncan part of the Enid[14].

The source of the Permian sediments is not at this time thoroughly understood. For many years certain geologists looked for the source in the Arbuckle and Wichita mountains, but since the presence of the buried granite range known as the Amarillo Mountains has been discovered, many geologists believe that the material derived from the erosion of these mountains contributed to the formation of the red beds. Others would go partly to the Ancestral Rocky Mountains or to the Ozark Mountains for the source of a part of the red beds material. It is altogether possible that all these regions, and even others not now suspected, were drawn upon for source material for the Permian sediments.

Another of the unsolved problems connected with the Permian is the matter of the change of color. By studying a map showing the Permian of Kansas, Oklahoma, and Texas, it will be seen that the color-change line which transgresses the strike of the beds is located about the same distance north and south of the region of the great structural features, namely the Anadarko Basin, the Arbuckle Mountains, the Wichita Mountains, and the probable northwestern extension of the Wichita Mountains, the Amarillo Mountains. It is the location of this line of change of color that furnishes one argument to those who look to the Arbuckle Mountains, the Wichita Mountains, and the Amarillo Mountains, as the source of the Permian sediments. This is a problem for the paleogeographer and one which probably awaits the acquisition of new data for its final solution.

One of the most vexing problems concerning the matter of the Permian red beds of Oklahoma and adjacent states, has been the matter of the origin of the red color of the rocks. Every geologist from the time of Jules Marcou to the present has remarked

14. Gould, Chas. N., The correlation of the Permian of Kansas, Oklahoma, and northern Texas: Bull. Amer. Assn. Pet. Geol. vol. 10, No. 2, pp. 144-155, 1926.

the red color of these formations, and many papers have been written on the subject.

The best summary with which the writers are acquainted is by Dr. W. H. Twenhofel of the University of Wisconsin. In his admirable "Treatise on Sedimentation" Dr. Twenhofel says on pages 176-179:—

"Wide diversity of opinion has existed and, no doubt, still exists with respect to the origin of the Red Beds, particularly with respect to the conditions which permitted the development of the color. Some have held that the color developed subsequent to deposition, but the weight of opinion has supported the view that the sediments had the red colors when they were deposited.

"**Environments and Agents of Deposition.** The Red Beds have been assigned to a marine origin by a few students, and to a continental origin by the majority[15]. The conclusions of marine origin have been based very largely on the occurrence of the gypsum and the carbonate beds and the occasional presence of marine fossils. That beds of red color develop under marine conditions is shown by the red muds and red clays of parts of the present sea bottom, but these sediments bear little, if any, resemblance to the Red Beds. Furthermore, there are sediments deposited in marine environments which are physically like the Red Beds, except they are not red and do carry marine fossils. Various horizons of the geologic column carry red sandstones and shales which contain marine fossils, but these strata are of limited extent and never reach such wide distribution as the Red Beds. Where Red Beds carry marine fossils in some abundance, the marine origin for those portions may be conceded; but where they are so notably absent as they are in the Permian of Kansas and Oklahoma, this environment of origin may with difficulty be postulated.

"It is probable that the Red Beds developed in a continental environment. Certain continental environments, as the glacial, humid-fluvial, humid-lacustrine, rigorous-arid, and paludal are precluded by both the negative and positive characteristics. The wide extent of the gypsum and carbonate beds proves a nearly flat land subject to occasional flooding, prolonged evaporation, and the presence of an agent with ability to produce wide and fairly uniform distribution. These conditions are best found on the flat, alluvial fans and deltas of regions which are somewhat semi-arid to arid. This environment would permit the development of lakes with lacustrine deposits, and at the same time conditions would be favorable for the occasional development of eolian deposition.

15. Tomlinson, C. W., The Origin of the Red Beds: Jour. Geol. Vol. 24, p. 161, 1916, and Tieje, A. J., The Red Beds of the Front Range in Colorado; Jour. Geol., Vol. 31, pp. 192-207, 1923.

If such environments were near the sea, there might also be deposited with the continental sediments some of marine production. * * * Tomlinson's general conclusion, with which most students are probably in accord, is that the Red Beds were deposited in a subaerial environment in which fluvial deposition was most important, the deposition taking place under climatic conditions which were semi-arid or at least less humid than the places where the sediments originated[16].

"**Sources and Origin of the Sediments Composing the Red Beds.** Three hypostheses have been advanced: namely, the sediments are (1) arkoses produced through the disintegration and partial decomposition of red granitic rocks, (2) they were derived from preexisting Red Beds, and (3) they were derived from red residual soils.

"The first hypothesis has application only in those cases where it can be shown that the constituents are those which could have been derived from granitic rocks, * * * However, as most of the Red Beds do not appear to contain a great deal of feldspar, the hypothesis has little application.

"The hypothesis that the sediments were derived from preexisting Red Beds does not yield a solution of the problem.

"The third hypothesis appears to give a satisfactory source for the sediments. Red soils are common in upland regions with good underground drainage. The quartz particles in these soils are coated with ferric oxide in the same manner as they are in the Red Beds. If these quartz particles were carried to environments where continued oxidation was favored and where there was not enough abrasion to remove the films from the grains, the redness of the sediments would persist. The environments which favor continued oxidation and little abrasion are found on the flood plains of semi-arid lands. The conditions of arid lands are not favorable, as the drifting of the particles leads to the abrasion of the ferric oxide films. Beede[17] has suggested that the sediments which formed the Red Beds of western Oklahoma were derived from red residual soils of the Arbuckle and Wichita Mountains of southern Oklahoma where such soils are now forming, while Tomlinson[18] concluded that the 'development of ferruginous soils is the first prerequisite to the deposition of Red Beds of the western type', a conclusion with which most sedimentationists will probably agree."

16. Tomlinson, C. W., op. cit., pp. 250-253.
17. Beede, J. W., Origin of the sediments and coloring matter of the western Oklahoma Red Beds: Bull. Geol. Soc. Am., Vol. 23, pp. 723-724, 1912.
18. Tomlinson, C. W., op. cit., p. 252.

PALEOGEOGRAPHY

By

Roy A. Wilson

INTRODUCTION

The problem of the correlation and origin of the upper Paleozoic sediments of Oklahoma has been a matter of deep interest to many geologists for several decades, but little attempt has been made to bring together the scattered threads of information and weave them into a general statement. Much work remains to be done before the last word can be said on this matter, if ever.

The following preliminary discussion of the paleogeography[19] of Oklahoma is an attempt to correlate the information from all available sources into a generalized statement for the purpose of presenting the problems involved in the studies that have thus far been made on the past geologic history of this region. This discussion in no sense of the word presents any final conclusions, or even provisional ones, but is put forth with the hope that it will lead to a more active consideration of the paleogeographic viewpoint in studies of stratigraphy and correlation. To many geologists the term "paleogeography" is a name only and the practical significance of this phase of geology is but poorly understood.

It is with these facts in mind that the appended series of maps and associated discussions have been prepared with the idea of presenting the most established generalized paleogeographic knowledge in a practical manner. None of this information is original. It represents a compilation of the most established data based on **known** field evidence and contains no special or personal viewpoint. The information has been assembled and viewed from many angles. In preparing this material one idea has been kept foremost—an idea which should form the basis for all true scientific research—every conclusion or generalization must be based upon **established field evidence.** Too often geologists, like other scientists, try to make the actual evidence fit their own ideas rather than adjust their ideas to the evidence. Science, least of all lines of study, has no room for dogmatism or biased personal opinion.

However, it is possible to correlate, in a general way at least, the information which has been obtained in the detailed studies

19. Paleogeography is that part of geology which treats of the physical features of the earth during past geologic periods, more especially those features of its surface which include the atmosphere, the distribution and flow of water, the distribution and forms of organic life; and the form and character of the surface as a result of the operation of existing physical agencies in those periods.

of various areas and districts. From the sifting out of the large amount of information already available on the upper Paleozoic of the State, certain generalized conceptions relative to the correlation and origin of this system of rocks stand out. In the following paragraphs is a tentative presentation of these conceptions, which are not presented as conclusions, but with the hope that they will aid in clarifying the problems of the upper Paleozoic of Oklahoma and open up new avenues of approach in the study of these formations.

The very nature of this subject makes it highly imperative that the reader understand where facts end, and where probabilities and possibilities begin. In working out the paleogeographic history of the region only the broadest generalizations can, as yet, be made, because the factors which determine deductions as to the geography of the past at any given geologic time are so varied, numerous and incomplete. Much of the information is based upon subsurface data which with the rapid addition of new well log information is subject to almost daily revision and correction. The accumulated mass of evidence from field studies now begins to point towards certain preliminary generalizations which are herewith given.

The Mississippian, Pennsylvanian and Permian rocks of Oklahoma show a great variety of depositional history and hence a lack of stratigraphic uniformity. The heterogeneity of the sections measured in different areas over the State and more especially the rapid horizontal variation in the sections developed in the critical Arbuckle-Ouachita region has led to a confusion in correlation which does not open itself to ready solution by attempting to "pair up" the various sections on the basis of lithologic characteristics. The paleontologic evidence, which in places is very abundant, and in other regions extremely scarce, has been helpful, but even with the use of good index faunas, the problems of correlation remain.

While it is perhaps speaking tritely to state that the character of any sedimentary section has been determined by the conditions of deposition, yet this factor is too often given little consideration by the geologist who is more interested in detailed measurement, lithologic and faunal descriptions. The matter of origin of the sediments, the geography and environmental conditions at the time of deposition, is often considered as too much in the realm of speculation and theory to merit serious attention. The character of an environment determines the character of the deposits. Hence, the determination of the origin of sedimentary deposits necessitates detailed consideration of environmental conditions (paleogeography). Too often the field geologist is interested in the matter of description rather than the origin of the formations he is studying.

The importance of paleogeography in bringing out the relationships between formations which differ widely in their characteristics over different areas of exposure is becoming increasingly significant. And in many cases where it seems impossible to tie up various sections on the basis of lithologic characteristics an interpretation, insofar as it is possible, of the regional conditions at the time of deposition may clear up in a surprising manner the resulting problems of correlation.

This is especially true of deposits formed at critical moments in earth history just preceding great continental emergencies or revolutions. The late Paleozoic of Oklahoma, especially the Pennsylvanian and Permian systems, belong to this category.

In the following discussion of the paleogeographic conditions of the Mississippian, Pennsylvanian, and Permian systems in Oklahoma, no attempt is made to explain in detail the depositional history of these strata. Much more field evidence will be necessary before this can be done. It is hoped that a very generalized statement of the known facts of paleogeography and their bearing upon the problems of correlation and origin of the Carboniferous rocks will, as previously stated, give up new avenues of approach to those who are interested in the late Paleozoic formations.

Finally, it must be understood that interpretations of the geography of the past at any given time cannot be based upon investigations in one area. The geographic conditions of one locality represents but a part of a much larger physiographic province, and conditions over this province as a whole must be understood before any definite conclusions can be drawn as to the more local physical history. Therefore, field evidence from a relatively large area, an entire state, several states, or even the major part of a continent, is necessary before permanent conclusions can be arrived at relative to the paleogeography of a specific region. The interpretation of field evidence from studies in one locality without extending the problem and not relating it to broader and more regional conditions, has often led geologists into serious and embarrassing blunders.

SOURCES OF INFORMATION

The accompanying series of paleogeographic maps of Oklahoma are based upon the most recent available maps of North America prepared by Schuchert[20]. Although these maps are provisional and subject to even radical revisions in certain areas, yet they show some approach to the probable facts and bring out in a very generalized way the changing physical conditions of Oklahoma during recorded geologic time. The immediate value of these maps is to show the relationships existing between the formations deposited in the State and the environmental conditions under which they were formed. The fact that these maps only indicate approximate geographic conditions and may have wide departures from accuracy as to detail does not detract from their value. All of the varied characteristics of sedimentary deposits are intimately related to the conditions under which they are deposited and therefore even an approximate knowledge of such conditions may throw great light upon the correlation of stratified deposits. It is hoped that the maps and explanations will aid in emphasizing these relationships between physical environment and sediments—a relationship which is frequently not well understood or which is underestimated as to its practical value and in many cases is completely ignored. In subsurface studies especially, a knowledge and an application of paleogeography offer much practical aid in correlating horizons. In this connection it is important to state that the correlation of strata cannot be logically based upon any single method. The very fact that stratified deposits were formed under a complex set of environmental conditions indicates that these complex factors must be considered in tracing the deposits from place to place. In doing this, each method, the stratigraphic, the lithologic, the paleontologic, etc., has its place and importance. No one method can be used to the exclusion of the others without arriving at erroneous conclusions.

Another feature which it is hoped the maps will emphasize is the fact that considerable information, even of a more or less final nature, is already available relative to matters which some geologists think are new or unsettled problems. A study of the maps shows very readily certain facts, namely; why the Ouachita Paleozoic section is mainly a thick group of clastic sediments with siliceous limestones; why this section grades westward into the more typically calcareous sections of the Arbuckle Mountains; why much of the middle Paleozoic section is missing from the Wichita region; why the middle and lower Paleozoic section is probably largely absent from the Panhandle region; why the upper Paleozoic section of southeastern Oklahoma is so thick; why, in the late Paleozoic orogeny of Oklahoma, the Ouachita Mountains, developed first with a progressive rise of the mountains westward, while the Arbuckle Mountains and Wichita Mountains

20. Schuchert, Charles, Textbook of Geology; revised edition, John Wiley & Sons, Inc., 1924.

appeared next in order; why the Pennsylvanian deposits become more thin and shaly northward; why the Permian red beds are largely non-red in Kansas, becoming more red and terrestial in Oklahoma, and more calcareous and typically marine towards southwestern Texas; why the Paleozoic section in general thins towards the Kansas line when traced from the Arbuckle-Ouachita region; and why the upper Paleozoic formations tend to overlap and lens-out upon the Archean granite landmass (Siouis) of the Panhandle region. The significance of transitional formations[21] such as the Chattanooga, and others, are also indicated.

Among active field geologists there is a too frequent lack of contact with available information, which material is often highly practical and useful; it is embalmed in technical publications that reach the eyes of only a few, or else the reader fails to grasp the significance or value of the publication, or discounts practical information which is buried in a mass of theories and personal views.

In order to establish a better contact with the more important sources of information which bear upon the Mid-Continent paleogeography the reader is especially urged to study the publications and articles referred to on page 45. This list, while by no means complete, attempts to cite the most important publications on the late Paleozoic rocks of Oklahoma.

GENERAL STATEMENT

During the late Paleozoic Oklahoma was bordered on the south by a land mass which was evidently of considerable development and an important source of the Carboniferous sediments of the State. The general position and character of this land mass, Llanoris[22] is shown on the map. (Figure 1).

This land was bordered on the north by an area of active sedimentation, the present Arbuckle-Ouachita uplifts. This area of active and long continued sedimentation had existed from early Paleozoic times as indicated by the Arbuckle and Ouachita sections, the Ouachitaic embayment.

In the northeast portion of the State, the Ozark Mountains was an area which tended to be positive, except during the Mississippian period.

21. Transitional formations:—Formations which are transitional from one geologic time division into another and contain characteristics of both divisions and hence do not typically belong to either but lie in between. The attempt of stratigraphers to place such formations entirely in one group, system, series, or stage has led to an endless amount of discussion and difference of opinion.

22. Miser, Hugh D., Op. cit.

The remainder of the State was neither well under or well above sea level during the Carboniferous, but tended to be a neutral region on which slight elevation or depression would produce marked changes in sedimentation.

With the above generalized geographic features in mind the following types of sedimentation would be expected. Immediately north of the land mass Llanoris the sediments should tend to be thick, more coarse, with more clastic materials and the least amount of calcareous material. In the bordering areas where the land mass to the south was lowest or the seas deepest, the sediments should show the greatest vertical uniformity and fineness. Conversely, in those areas where the adjacent land mass was higher or rising, or where the seas were shallow, the sediments should be more coarse and show less uniformity in their sections. Calcareous sediments would tend to accumulate in those waters most free of suspended clastic material or in areas where sedimentation from land was the least active.

In the Ozark region which was moderately positive during much of the Paleozoic but completely submerged during Mississippian times, the deposits should be quite calcareous in the Mississippian since there were no known adjacent land masses to furnish clastic material. During the remainder of the Paleozoic the sediments of this area should be more locally developed or absent as the area tended to be more above sea level than below. The deposits as a result should be dominately finer clastic with more or less associated calcareous material since the areas furnishing the sediments were generally low and featureless.

Over the remainder of the State which was relatively flat and featureless during late Paleozoic times the sediments should form more widespread deposits of less thickness and greater horizontal uniformity. Calcareous deposits should be more common due to remoteness from areas of active erosion and resulting clearness of waters. Vertically, the sediments should show abrupt and wide spread alternation, as only slight uplift or depression of these areas was needed to bring about wide spread invasion or retreat of the seas. As the previously described land masses are approached the sediments should be growing coarser, more clastic and less calcareous. In the eastern part of the State between the Ozark positive area on the north and the Llanois land mass on the south, the sediments in the interior neutral region should be thicker and the more clastic. Due to the distance from the source of the sediments the resulting clastics should tend toward fineness rather than coarseness.

With this generalized analysis of the types of sediments which would normally result from the broad geographic features previously described, let us next turn to a consideration of the Carboniferous section in more detail.

In southern Oklahoma during Mississippian times the bordering land mass Llanoris was, from all present evidence, the most conspicuous positive area adjacent to the State. This general area, including the Ouachitaic trough immediately to the north of Llanoris was having active signs of uplift, the birth of the Ouachita-Arbuckle-Wichita Mountain group. The Ouachitaic trough was thus beginning to emerge first at its eastern end and this emergence was to gradually extend westward, first developing the Ouachita, next the Arbuckle, and finally the Wichita Mountains.

From the above physical events the resulting Mississippian sediments would show a domination of clastic material of considerable thickness. Since the rising lands were working from east to west the Ouachita region would show the thickest sections with clastics throughout (Stanley, Jackfork). Westward in the Arbuckle region, the earlier Mississippian sediments would be associated with some more quiet water deposits (calcareous) material in the lower part, (Sycamore and lower Caney) and with the westward progress of the Ouachita disturbance this area could be subjected to intensive sedimentation with the upper deposits approaching terrestrial conditions (late Caney and Glenn).

In early Pennsylvanian times a part of this area was apparently subjected to temporary cessation of mountain building as the waters cleared up sufficiently to permit the deposition of a fairly extensive limestone (Wapanucka). During this time the Ouachita region was sufficiently elevated to cause a continuation of clastic sedimentation in this area, as the Wapanucka becomes clastic eastward.

Northward through central Oklahoma and into the Ozark region the seas during Mississippian times were widespread, shallow and, as previously indicated, remote from sources of sedimentation other than the agitation of bottom materials. Hence the Mississippian deposits in east-central and northern Oklahoma are dominantly calcareous (Boone formation). Since this general area was relatively featureless only a slight oscillation of level was necessary to bring about rapid and widespread changes of sedimentation. This explains the frequent vertical alternation of limestone, sandstone, and shale in the late Mississippian and following Pennsylvanian sections. Furthermore, as the land areas to the south were rising to form the future Ouachita-Arbuckle Mountain chain, the shallow seas in central and northern Oklahoma would become increasingly filled up with sediments and thus the section when traced upward becomes characterized by a greater development of clastic material with coal deposits present when the sea ways were temporarily filled in (Cherokee and later formations).

By middle Pennsylvanian times (Allegheny) the Arbuckle Mountains were well developed and subject to rapid erosion (Seminole conglomerate). The Wichita Mountains at the western end of the Ouachita trough were also rising. Hence the former area of sedimentation on the north border of the land mass Llanoris was now entirely an uplifted region undergoing erosion and furnishing sediments to the middle and late Pennsylvanian seas of central and northern Oklahoma.

The Ouachita Mountains had been an area of active erosion since early Pennsylvanian (Boggy shale, early Allegheny) time and the section above this shale is missing up to the lower Cretaceous (Trinity sand). The Arbuckle Mountains were in general an area of erosion after the Glenn time (late Allegheny).

Over much of the remainder of the State, especially the central, eastern and northeastern part, the late Pennsylvanian seas were characterized by frequent changes in depth and position due to the widespread diastrophic movement associated with the Appalachian revolution. As a result the upper Pennsylvanian deposits of these areas are characterized by alternations of marine and brackish water deposits, resulting in alternating layers of limestone, sandstone, and shale with frequent horizontal variations

Finally the late Pennsylvanian seas began a permanent retreat to the southwest by way of northern Texas. The retreat was not abrupt but oscillatory, the waters reinvading the region from which they were retreating several times.

From the above analysis of the upper Pennsylvanian geographic conditions north of the new mountain uplifts the following types of sediment would result. The vertical section would show the alternations already described and would become increasingly clastic upward with a final preponderance of terrestial sediments (Permian red beds). The frequent oscillations of the late Carboniferous seas would produce horizontal variations in types of sediments. Due to the southwesterly direction of sea retreat, the sediments would show marine conditions more persistently in this direction. The occasional temporary reinvasions of the sea which was well to the southwest of this general region by Permian time would produce the interstratified marine deposits which are found in the Permian section.

ANALYSIS OF PALEOGEOGRAPHIC MAPS

In the following analysis of the paleogeographic maps of Oklahoma the relationships between the paleogeographic features indicated on each map and the character and distribution of the sediments that would logically result from such a relationship are brought out.

The reader must bear in mind the fact that these maps are only approximations. The positions of the shorelines and land masses, represent only a mean average condition for each time division. In some places the position of the shorelines oscillated back and forth from the lines indicated and the maps are accurate only insofar as they indicate the more permanent positions of the strand. Naturally, the greater the number of maps for a period, the more accurately each map would indicate the physical features of the time represented. Two or three maps for a period cover a tremendous length of geologic time, in which all the minor and detailed physical changes must of necessity be omitted. In spite of these limitations, however, the maps bring out the broader relationships of the formations and indicate what should be expected in the way of changes in the character of groups, systems, and formations from place to place.

PRE-CAMBRIAN ERAS

ARCHEOZOIC

The history of Oklahoma during Archean times is practically unknown. The granites and other igneous rocks exposed in the mountain uplifts and in drilled wells suggest that the physical conditions of this region were much the same as for the rest of North America at that time.

PROTEROZOIC

Oklahoma has no known Proterozoic deposits. Certain rocks in the Wichita Mountains, thought by some to be of this age, probably represent a differentiation phase of the Archean intrusives. The Llano-Burnett, Van Horn, and El Paso regions of Texas contain deposits which probably represent late Proterozoic sedimentation. The apparent restriction of these deposits to the Llano-Burnett uplift and regions to the south and west indicates that the sea invasion was from the west. By late Proterozoic time the major paleogeographic features which so largely governed the movements of Paleozoic seas were developed. The above described Proterozoic sediments could have conceivably been deposited by the sea invading Texas as an embayment from the west (see Sonoran embayment, Fig. 1). This would explain the absence of Proterozoic sediments from other parts of Texas and from Oklahoma and adjoining areas. Thus Oklahoma was most probably a region of erosion during all of the Proterozoic times, the sediments being carried entirely out of this region. Therefore, the Archean land surface of the State should have been well leveled with low, rounded, elevated points here and there as remnants of former highlands.

THE PALEOZOIC ERA

Figure 1.

INTRODUCTION

In the accompanying map, Figure 1, modified after Schuchert, are shown the major paleogeographic features which existed throughout much of the Paleozoic Era and largely influenced the formation and distribution of sediments during this time in North America. In the Oklahoma region note the following: The neutral, area, Siouis[23], covering in general the Panhandle of Oklahoma and the northern part of the Texas Panhandle; the Ouachitaic embayment extending into eastern Oklahoma from the great Appalachian geosyncline and mainly developed in southern Oklahoma although it frequently included all of the eastern and central part of the State; the land mass Colombis developed over Mexico and Texas and with the highland Llanoris forming its northeastern part and abutting against southeastern Oklahoma; the more local land mass Ozarkis appeared toward the close of the lower Paleozoic and had an important effect upon Paleozoic sedimentation in northeastern Oklahoma after that time. The influence of all the above paleogeographic features upon sedimentation in Oklahoma will be indicated in the following map analyses.

A summary of the Paleozoic history of each of the above named physical features shows the following general facts:

Siouis, called a neutral area by Schuchert, because it was never very conspicuously above or below water (more often above in the Paleozoic) was not invaded by seas until the upper Paleozoic (Mississippian) and hence the lower and middle Paleozoic deposits should be largely absent in the Panhandle region, and should overlap upon its then irregular granite surface from the east. The so-called granite ridge of the Amarillo region is possibly but a part of this larger land mass which had a general northerly trend into eastern Montana and the adjoining Dakotas. The Ancestral

23. Siouis, Llanoris and all other ancient land masses are written by Schuchert with the "is" ending. The ancient epicontinental seas have the "ic" ending. These forms have not been consistently followed in the literature.

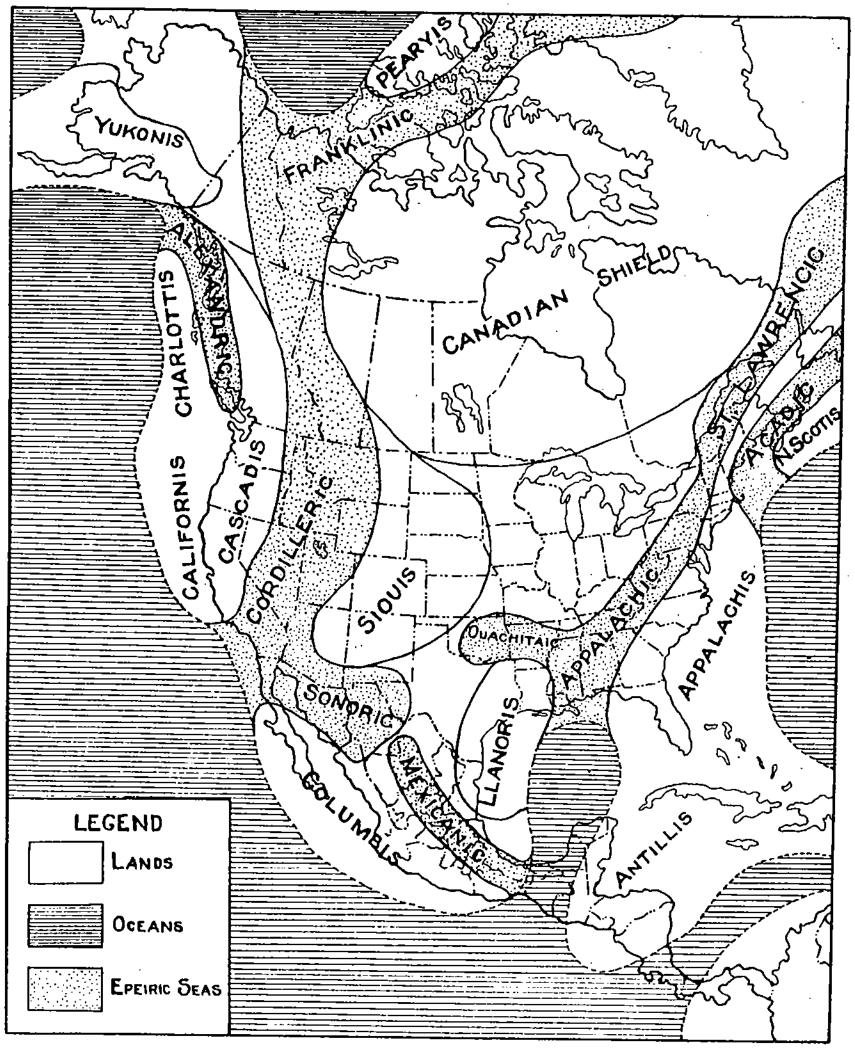

Figure 1. MAJOR PALEOGEOGRAPHIC FEATURES OF THE EARLY PALEOZOIC

(Map by Roy A. Wilson, modified after Schuchert)

The paleogeographic features which largely influenced the formation and deposition of sediments in the Oklahoma region are: the neutral area, Siouis; the Ouachitaic embayment, an arm of the Appalachian geosyncline; Columbis, with its subdivision, Llanoris, furnishing the sediments for the Ouachita Mountains; and Ozarkis (not shown), which developed at the close of the lower Paleozoic, and which influenced Paleozoic sedimentation in northeastern Oklahoma after that time.

Rocky Mountains described by Lee[24] represent a special phase of the history of a part of this more positive[25] area in the latest Paleozoic. The relation of the Amarillo Mountains is brought out in a later part of this discussion.

Columbis, especially its northeastern highland area, Llanoris[26], was the most conspicuously positive area bordering Oklahoma during the Paleozoic, and made very important contributions of sediments throughout this time. The Llanoris highland bordering the southeast corner of the State formed an especially prolific source of sediments and hence the Paleozoic section of the Ouachita Mountains is thicker and more clastic than that of the Arbuckle Mountains to the west.

The Ouachitaic embayment, extending into Oklahoma through Arkansas from the Appalachic geosyncline. represents an area which was inclined to be conspicuously negative throughout much of the Paleozoic; hence a more or less complete Paleozoic section is developed over the areas where this embayment was present. The southern portion of the embayment bordering Columbis was the most active area of sedimentation and therefore the most complete sections are found in this area. The northern portion tended to oscillate near sea level and so the Paleozoic strata in this area are more widespread and thin with more frequent stratigraphic breaks. Since the embayment was bordered on the southeast by the Llanoris highlands of the land mass Columbis, the sediments in this direction should be the thickest and the most clastic as in the Ouachita Mountains. The abundant amount of chert in the strata of the Ouachita region is also possibly explained by this fact. Over the remaining land areas bordering this embayment, the Arbuckle Mountains and other areas, the lands were so low during lower and middle Paleozoic times that calcareous sediments were formed almost up to the shorelines—the appearance of clastic materials in these areas indicating emergences of land or shoaling of waters rather than proximity of highlands.

The Ozark land mass or island of southern Missouri and northern Arkansas developed in middle Ordovician times and influenced more or less the future deposition of sediments in adjacent parts of Oklahoma. In Mississippian times this positively inclined feature was probably completely submerged by the widespread Boone-Osage seas, becoming distinctly emergent after that time.

24. Lee, Willis T., Early Mesozoic physiography of the southern Rocky Mountains; Smithsonian Miscel. Coll., Vol. 69, No. 4, 1918.

25. The terms positive, neutral, and negative are used respectively for areas which were dominantly above, not conspicuously above or below, and dominantly under the waters of invading epecontinental seas.

26. Miser, H. D., Llanoria, The Paleozoic land area in Louisiana and Eastern Texas; Am. Jour. Sci. 5th ser., Vol. II, No. 8, pp. 61-89, 1921.

ANALYSIS OF UPPER CAMBRIAN AND BASAL ORDOVICIAN (Beekmantown).

(Figure 3)

Oklahoma was not invaded by epicontinental seas until the upper Cambrian epoch. Previous to this time the region was undergoing erosion and must have been generally reduced to a low, rather featureless area covered with deposits of arkosic residual material from the granitic and gneissic bedrock. The absence of land plants in Cambrian time was especially conducive to disintegration and the production of arkose. As the upper Cambrian seas invaded the State, they came in primarily by way of the Sonoric embayment from the southwest across Texas. This embayment joined the Ouachitaic embayment from the east and the sea at its maximum probably covered the State as indicated. The clastic sediments of the Reagan sandstone were deposited first as the invading sea worked over the residual deposits from the eroding Archean rocks.

The seas gradually cleared and the calcareous deposits of the latest Cambrian and earliest Ordovician, Arbuckle and related limestones, were laid down.

The map, Figure 1, indicates an emergence of Oklahoma just before Beekmantown times. If so, evidence of this break should be found somewhere in the upper part of the Arbuckle limestone.

Note on the map showing the North American borderlands and geosynclines of early Paleozoic time (figure 1), that northwestern Oklahoma and the Panhandle were emergent. This area is therefore probably free of these deposits, or at best, they are local and poorly developed.

MIDDLE ORDOVICIAN (Mohawkian-Trenton-Chazy)

(Figure 4)

At the close of Arbuckle (Beekmantown) time there was a complete emergence and the seas next invaded from the east through the Ouachitaic embayment.

Note the presence now of Ozark Island which should effect the deposits in that area. Much of western Oklahoma was above water during this time (Siouis).

Note the more conspicuous development of the southern part of the Ouachitaic embayment.

EARLY-UPPER ORDOVICIAN (Early Richmond).

(Figure 5)

At this time the seas retreated to the east and therefore the early Richmond deposits are probably largely confined to southeastern Oklahoma.

Note the tendency for the seas to persist longest and invade first in the eastern part of the Ouachitaic embayment. For some time Texas and western Oklahoma had been free of sea invasions (Columbis and Siouis).

LATE UPPER ORDOVICIAN (Late Richmond)

(Figure 6)

The seas of late upper Ordovician were more extensively developed than shown on Figure 5. This is the time for the maximum Richmond invasion of North America.

LOWER SILURIAN

(Figure 7)

Note the restriction of the seas to the northeastern Ouachita region at this time.

LATE-LOWER SILURIAN

(Figure 8)

This map shows the Alexandrian submergences of North America which covered the eastern half of Oklahoma.

MIDDLE SILURIAN

(Figure 9)

This map shows the retreating Niagaran sea. Note that the Ouachita region was positive, the seas leaving from the northeast corner of the State. Oklahoma was above water during late Silurian times. The tendency for the Ouachita region to rise is now noticeable.

EARLY DEVONIAN

(Figure 10)

As usual, the Ouachita embayment is the invaded area. Note that the embayment in the southeast corner of the State is now beginning to rise. This feature was first indicated in the previous map and will become more important from now on.

The abundance of chert in the deposits of the Ouachita region and the siliceous novaculites indicate that much of the silica was carried from the land to the southeast in the usual colloidal form and deposited with the fine-grained clastic sediments and calcareous material in the areas where the fresh and salt waters were intermingling[27].

27. Twenhofel, W. H., Treatise on Sedimentation: Williams & Wilkins, pp. 378-394, 1926.

LATE DEVONIAN

(Figure 11)

Again note retreat of sea to the northeast due to the tendency of the Ouachita region to become emergent. (See map and explanation).

MISSISSIPPIAN

(Figures 12, 13, 14, 15, and 16)

See maps and detailed explanations. Note especially the growing tendency for the southern part of the Ouachita embayment to become emergent.

PENNSYLVANIAN

(Figures 17, 18, 19, and 20)

These maps show the gradual retreat of the seas westward with the rising of the Ouachita trough and the Ouachita-Arbuckle-Wichita Mountains. The progressive westward movement of mountain building is also indicated.

PERMIAN

(Figure 2.)

The Permian of North America is probably correlative with the lower Permian of Europe. The middle and upper Permian may not be represented on this continent.

This map especially brings out the development of the north-south trending Ancestral Rocky Mountains, the widespread development of Permian seas over the western interior region, and the Kansas-Oklahoma embayment opening out into more typical marine conditions in southwestern Texas. Note also the important development of the Mexican geosyncline which first appeared in early Pennsylvanian (Pottsville) times.

The retreat of the Permian seas was southwest into southwestern Texas, northern Mexico and adjacent areas, and hence there should be a general gradation south and west into more typical marine conditions. Contrast the thick Permian limestone section of southwestern Texas with the Oklahoma red beds. This transition is also well illustrated in northwestern Texas by the gradation of the Wichita red beds southwestward into the calcareous "Albany" formation.

The constriction of the Kansas-Oklahoma embayment in southwestern Oklahoma and adjacent part of the Panhandle region by the newly elevated Ancestral Rocky Mountains on the west and the Wichita-Arbuckle Mountains on the east, is a physical feature which probably had an important effect on Permian sedimentation. It is suggested that the important development of salt and gypsum deposits in western Oklahoma and the non-red Permian of Kansas, may be explained by this factor. These problems will be considered later.

THE PERMIAN DEPOSITS

The Permian of Oklahoma and adjacent areas is characterized by all the features of irregularity and lack of uniformity which would be expected of deposits formed during a critical time in geologic history when the geographic environment was changing gradually but irregularly from marine (negative) conditions to terrestial (positive) conditions.

In order to obtain a generalized view of the Permian section of Oklahoma in its relation to the known changes of geographic environment, it is necessary to first outline briefly the probable general topography of the State at the opening of the Permian times (Figure 2).

The Ouachita-Arbuckle Mountain group had its greatest development during the Permian and was an area of active erosion and an important source of sediments for adjacent areas.

The eastern and northeastern portions of the State were probably not far above sea level, but sufficiently positive to undergo moderate erosion rather than deposition.

Over the remainder of the State, especially the southwestern, central and northern part, the Permian lands were oscillating above and below sea level with positive conditions becoming more dominant as the period drew to a close and the sea retreated to the south and west.

At the close of Permian times in Oklahoma the seas had retreated to the extreme southwestern part of the State and finally this embayment was filled in and terrestrial conditions prevailed everywhere in Oklahoma (latest Permian formations). But even well toward the close of the Permian (latest Blaine) the seas temporarily invaded southwestern and western Oklahoma and left dolomitic deposits with a well developed marine ammonite fauna.

During Permian times and through much of the earlier Paleozoic there is good evidence that a positive land area of pre-Cambrian granite existed on the western border of New Mexico and adjacent parts of Colorado. This land mass was possibly of sufficient magnitude during Permian times to be an active source of sediments.

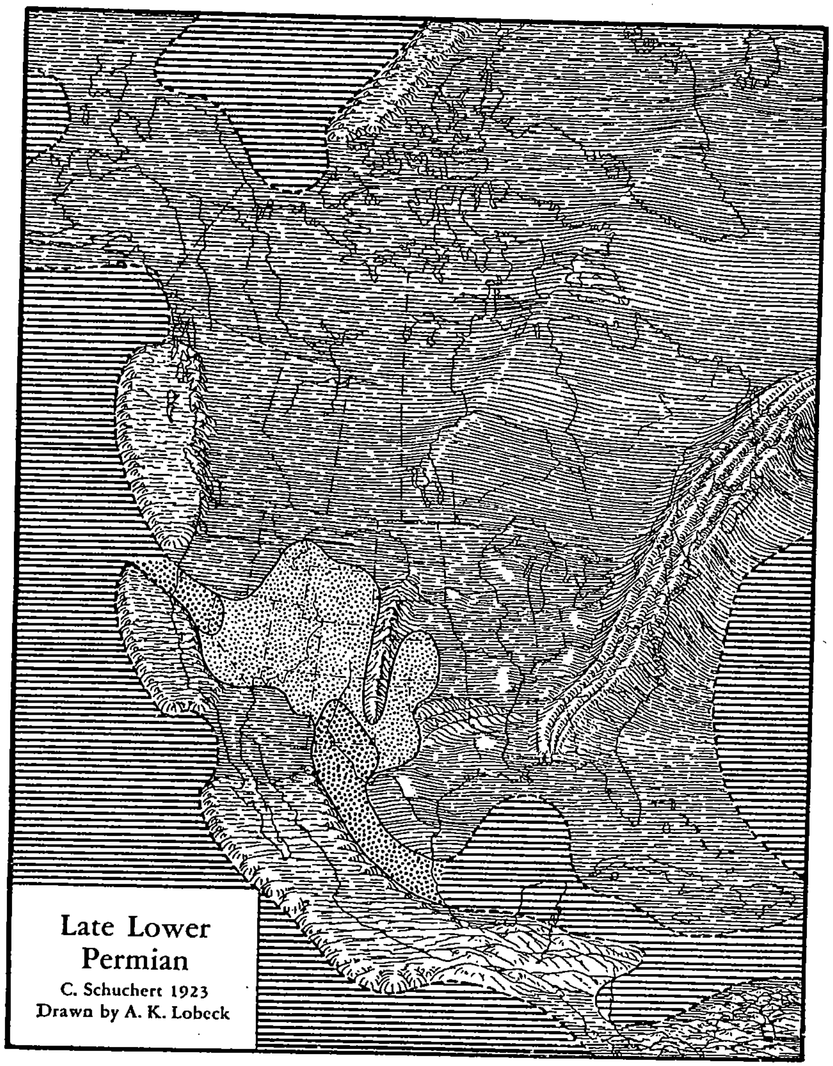

Figure 2. LATE-LOWER PERMIAN PALEOPHYSIOGRAPHY.

(Reprinted by permission, from "Textbook of Geology", Vol. II, by Charles Schuchert, published by John Wiley & Sons, Inc.)

The time of the seas shown on this map (the earlier invasions are in darker shading) is late-lower Permian, but the rising mountains came later. Eastern North America, in the Appalachian area, stood higher then than at any subsequent time. Note also the Ancestral Rocky Mountains of Colorado, and the several domal areas in the central United States. The medial ridge through the Canadian Shield is drawn too prominently, and the broken-lined area in California-Sonora means that epeiric seas may also have extended there.

The climate was warm, arid and the seas of the Great Plains area left much salt and gypsum in their withdrawal. The Permian ice age came just after the time of this map and probably before the Appalachian Mountains had been completed.

From the above general analysis of Permian paleogeography the following types of sedimentation would be expected.

In eastern and northeastern Oklahoma the lands were areas of erosion rather than deposition and hence the Permian is absent.

In the areas immediately bordering the mountain uplifts the sediments should be dominantly clastic and the formations relatively thick.

In the central part of the State the deposits could be more widespread with terrestrial material becoming more dominant upward.

In the western, southwestern and northern parts of the State, where the Permian seas persisted the longest and tended to reinvade, the deposits would show marine horizons well toward the top of the system. The oscillatory character of the seas would show as alternating deposits of marine and brackish or terrestrial material. Dolomites with marine faunas would alternate with clastics of brackish water or terrestrial origin.

In the extreme southwestern part of the State the marine conditions would be more persistent.

As the marine embayments from the southwest began to fill in with sediments towards the close of Permian time, saline and gypsiferous deposits would become common in the isolated marine lagoons and embayments (relic seas), and these deposits would alternate with calcareous materials and clastics. The salt and gypsum layers would be most important at the top of the resulting deposits.

In general the Permian section shows marine conditions most persistent in the western, northern and southwestern part of the State, and least persistent eastward and northward. The sediments should thicken and become increasingly clastic and less calcareous toward the positive areas or uplifts.

In concluding the discussion of the Permian of Oklahoma there are several phases of the problem of sedimentation which deserve special mention. These are as follows: (a) the origin of the red color and the stratigraphic and areal distribution of the red beds contact; (b) the source of the Permian sediments; (c) the Pennsylvanian-Permian boundary; (d) and significance and origin of the Anadarko Basin.

SPECIAL PROBLEMS OF THE UPPER PALEOZOIC FROM A PALEOGEOGRAPHIC VIEWPOINT

THE ANCESTRAL ROCKY MOUNTAINS

A study of the appended paleogeographic maps shows that throughout the entire Paleozoic the Great Plains region was positive over a large part of its area; the seas flooding across its southern end (western Texas) in the late Cambrian and early Ordovician and again in the upper Paleozoic during the Mississippian (Chester time). During the early-middle Mississippian (Burlington-Boone stage) and late Mississippian (Chester stage) a relatively narrow strait extended across Siouis through the Panhandle region of Oklahoma and adjacent parts of Kansas and Colorado connecting the Cordilleran trough sea with that of the Mississippi Valley.

Aside from these early and late Paleozoic invasions which only covered a small part of Siouis; this more positive region, now roughly marked by the Great Plains, was above water. Therefore, the general Paleozoic section should be expected to be largely absent or poorly developed under the Great Plains with the exception of the above described sea invasions.

The Ancestral Rocky Mountains which have been described and studied by Willis T. Lee[28] arose out of the east-central part of this north-south trending land area during the latest Pennsylvanian. These mountains were not composed of folded sediments except locally, but represented an upwarped mass of pre-Cambrian crystalline rocks, perhaps formed by underlying igneous intrusions.

Therefore the Ancestral Rocky Mountains which extended as a crystalline backbone from western South Dakota well into the Panhandle of Texas. were probably rather low, haphazardly distributed and rounded granite hills which did not supply an abundant amount of sediment but had an important influence upon the development and distribution of Permian and late Paleozoic seas.

The width of this late Paleozoic ridge is a matter which can only be determined by a study of many well logs, probably the ridge was relatively narrow (a few miles wide). In the Panhandle region of Texas, the uplift is probably wider and extends into New Mexico due to a northwestward trending fold representing the continuation of the Arbuckle-Wichita uplift.

In general, the upper Paleozoic sedimentary deposits should overlap both from the Cordilleric geosyncline and the Ouachitaic embayment upon this land area. The Permian sediments would be best developed over this ancestral ridge, being thin over the top of the ridge and thick in both directions away from it.

28. Op. Cit.

It is to be noted that the main axis of the Ancestral Rocky Mountains trends north-south and not northwest-southeast as some geologists believe. Subsurface evidence of this buried landmass is already known for western Kansas, Nebraska, and South Dakota as well as the eastern areas of Colorado, Wyoming, and New Mexico.

The relationship of the pre-Cambrian landmass to the Panhandle oil production is already a matter of great interest, and this relationship should be considered in prospecting for oil in the line of trend to the north.

The probable minor importance of this uplift as a source of sediments for the late Pennsylvanian and Permian deposits has already been noted. In seeking a source for sediments making up a group of formations, too much emphasis must not be given to any one area of erosion. The sediments represent material coming from a number of different localities, every bit of land bordering the inland seas made its contributions, some areas to a much greater degree than others, depending upon the rate of erosion and transportation.

THE RED BEDS PROBLEM

A large amount of literature has accumulated relative to the origin of the source of the material of the so-called red beds. This discussion does not attempt to offer any new theories, but presents the problem from the paleogeographic viewpoint.

A general analysis of Twenhoefel[29] on the red beds, shows that they are composed of sand, silt, and sandy clay deposits with interstratified beds of gypsum, salt, limestone, and dolomite (often very pure). The color is due to ferric oxide and the quartz grains are generally coated with a film of this material.

The quantity of iron oxides is not large, no greater than in non-red sediments. The weight of opinion and the paleogeographic evidence indicates that the sediments had the red color when deposited. They were deposited in a continental environment in a semi-arid but not rigorously arid climate. This is shown by the fact that the deserts of today very often contain no red sediments.

29. Twenhofel, William H., Treatise on Sedimentation: The Williams Wilkins Co., p. 176, 1926.

Red soils are common today in upland regions where drainage is good, thus allowing much oxidation due to rapid underground water circulation. The iron is oxidized to the insoluble oxide and remains with the soil, coloring it yellow, brown, or red. This is well known in parts of the southern Appalachian Mountains and also in the tropics. If the streams carry this colored material into a dryer region the material retains its iron oxide without further reduction and red beds deposits are formed. In other words, the red beds sediments were formed during a period of more humid climate and were deposited in a period of less humid climate. The associated salt and gypsum beds also indicate arid conditions of deposition.

The red beds of Oklahoma were probably formed on a nearly flat land surface (wide extent of gypsum and lime beds) composed of flat alluvial fans and deltas and river flood plains. River deposition was probably very important.

The intercalated dolomite and limestone beds indicate intermittent flooding of the adjacent seas over these flat land areas.

Twenhoefel[30] states that in tropical and subtropical regions where effective downward drainage of ground water causes oxidation of the iron compounds, the red colors are common, but this feature is largely confined to hillsides which are not places of stable deposition. Hence stable red sediments seldom accumulate in the rain belt of the tropics or other warm and steadily moist climates.

Where wet seasons alternate with dry seasons each year, or where red soils are carried out into more arid regions the red colors are preserved and become a part of the final deposits.

Hence red sediments, if finally coming to rest at or near the point of origin, are developed in a climate involving alternating arid and moist conditions. If deposited elsewhere they represent material carried from a more moist to a less moist area, a condition which limits reduction and encourages further oxidation.

Another phase of the red beds problem involves the changing horizon at which the change to the red color appears. In central Oklahoma the latest Pennsylvanian is red, while northward into Kansas the base of the red beds rises higher and higher in the section, much of the Permian in Kansas having a non-red color. This condition indicates that the conditions necessary for red beds deposition occurred at an earlier time in the central Oklahoma region and progressively later northward.

30. Op. cit., p. 547.

A study of the Permian paleogeographic map (Figure 2) shows the following features: a constriction of the Oklahoma-Kansas embayment between the Wichita and Ancestral Rocky Mountain uplift with a spreading out of the embayment in northern Oklahoma and Kansas.

At the very close of the Pennsylvanian the conditions favorable for red beds deposits appeared in the central Oklahoma region. This paper cannot offer a possible mode of development in the light of present meagre field evidence. The non-red Permian of Kansas is probably explained by the fact that this region was a large interior embayment, as already stated, and that more typical marine conditions prevailed. This is indicated not only by the non-red color of the Permian, but also by the greater development of limestone horizons.

The fact that the Permian limestones of Kansas lens out southward into the Oklahoma region and that the Permian limestones of Texas also lens out northward toward Oklahoma (Wichita-"Albany" transition) indicates that conditions for red beds deposition were confined to the western half of Oklahoma and areas to the north and southwest. This suggests a broad, flat region of deltaic character over which wandered streams and rivers carrying material from the more humid slopes of the maturely eroded Wichita-Arbuckle Mountains and the low Ancestral Rocky Mountains. Sediments were entering this great basin from all sides except where it opened out southwest into the Texas area (Gaudalupe limestones). Just how important each of the various sources of sedimentation was can only be determined by much more detailed field work.

The basic conditions, however, as indicated on Figure 2, should be considered in carrying on detailed investigations. The open interior Kansas sea restricted in western Oklahoma by bordering uplifts and the previously described deltaic conditions, opening out again into typical marine conditions in western Texas, are the factors which largely governed the distribution and character of Permian sedimentations in the Mid-Continent region.

The extensive development of salt and gypsum beds in western Oklahoma is possibly explained by the deltaic conditions in this region with the cutting off of large areas of marine waters from the outer sea. The occassional flooding of these relic bodies of water by the outer sea explains the thin interstratified layers of dolomite and the source of the additional saline water necessary to form such extensive deposits.

PENNSYLVANIAN DELTAS

The Permian of Oklahoma largely represents extensive deltaic deposits formed from sediments coming from the rising lands to the north, east, and south. The Pennsylvanian maps (Figures 17, 18, 19 and 20) show the progressive westward movement of the shore line as the above land areas were developed. Naturally the high Ouachita and Arbuckle Mountains to the south and southeast were the most active sources of sediments; this is indicated by the rapid increase in thickness and increasing clastic character of the sediments in this general direction. The Pennsylvanian section with its alternating series of clastics and limestones and coal beds shows a typical deltaic physiography, long maintained, and over which the seas frequently oscillated in their attempt to maintain themselves against the rising lands.

CONCLUSIONS

With the progressive westward movement of the shore line it is suggested that the conditions most ideal for the development and later preservation of oil deposits also migrated westward and thus progressively into higher horizons. If there is a relationship between shore lines and oil deposits does this offer an explanation for the rough parallelism of the Pennsylvanian oil pools in east-central Oklahoma and the late Pennsylvanian and early Permian oil pools in west-central Oklahoma? Is it not logical to assume that there is a definite relationship between physiographic conditions and the development and the preservation of oil forming organisms? If so, we have a practical application of paleogeography. This has already been well stated by McCoy[31].

31. McCoy, Alex W., A short sketch of the paleogeography and historical geology of the Mid-Continent oil district and its importance of petroleum geology: Bull. Am. Assoc. Pet. Geol. Vol. 5, No. 5, pp. 541-584, 1921.

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Figure 3. UPPER CAMBRIAN AND EARLY ORDOVICIAN.

No Proterozoic sediments, from all known evidence; a time of erosion. First Paleozoic invasion in upper Cambrian. Sea on this map of upper Cambrian and basal Ordovician age-Beekmantown (lowest Ordovician). A transition with only slight tendency towards emergence between upper Cambrian and Beekmantown time.

Land area in northwestern Oklahoma a peneplained granite surface, with much disintegrated arkosic material, and no soil, plant or land life. Southwest Oklahoma a highland (exposed in eroded uplifts).

Sea in the State a moderately wide strait, opening out in Kansas and extending as a strait through Texas and westward (Sonoran Embayment).

FORMATIONS

Texas		Oklahoma
Ellenberger Wilberns Cape Mountain	Arbuckle Mts.	Arbuckle limestone Reagan sandstone
Hickory sandstone	Ouachita Mts.	Mazarn shale Crystal Mountain sandstone Collier shale

Lower Ordovician dolomite or Siliceous lime of northern areas.

Figure 4. MIDDLE ORDOVICIAN. MOHAWKIAN-TRENTON-CHAZY.

Land mass Columbia (Llanoris covered Texas until Mississippian).

FORMATIONS

Arbuckle Mts.

Trenton-Viola
Chazy-Simpson
Unconformity
Emergence at close of Arbuckle time

Ouachita Mts.

(Transitional)
Big Fork chert
Womble schistose sandstone
Blakely sandstone
Unconformity

Northeastern Oklahoma

St. Peter-basal Tyner dolomite, sandstone and shale of Kansas border.

Figure 5. UPPER ORDOVICIAN, EARLY RICHMOND.

After Ellenberger time Texas was a land area until the Mississippian. Probably erosion on Kansas border.

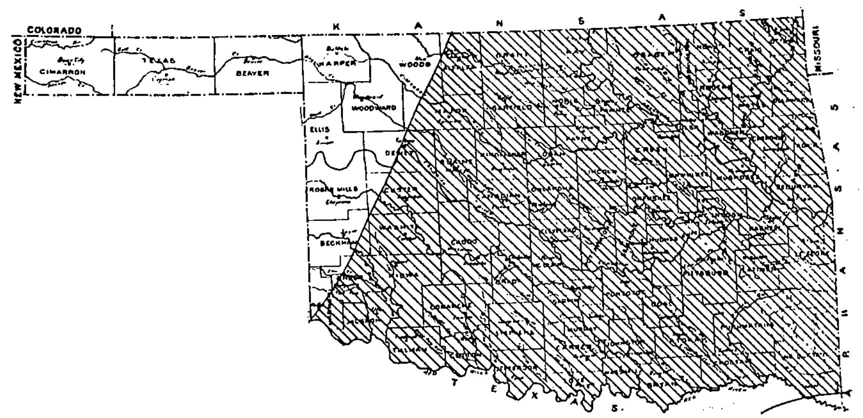
FORMATIONS

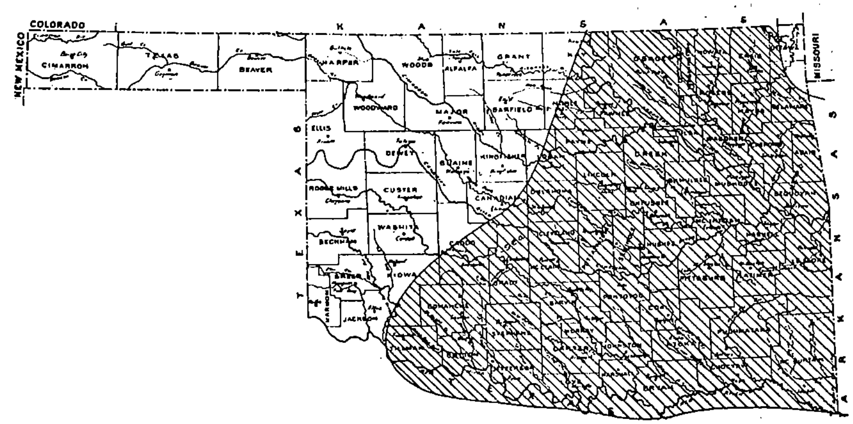
Arbuckle Mts.

Basal Sylvan

Ouachita Mts.

Polk Creek Shale
Probably some of basal Tyner.
Upper part of lower Tallhina.





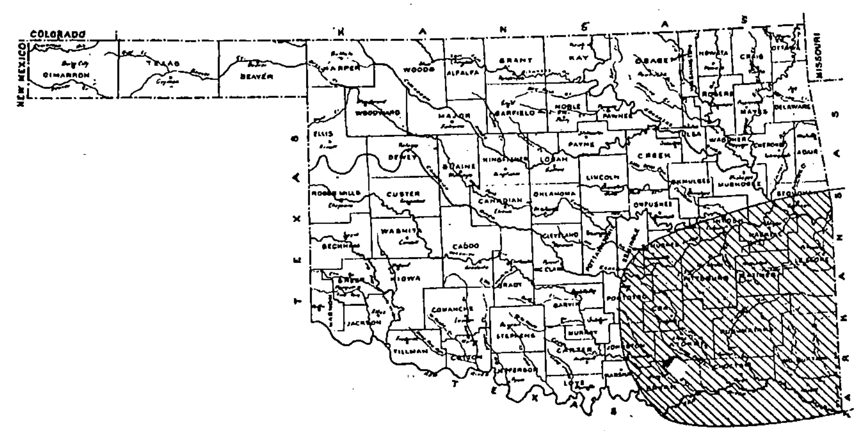


Figure 6. UPPER ORDOVICIAN, LATE RICHMOND.

FORMATIONS

Arbuckle Mts.—Probably most of Sylvan.

Ouachita Mts.—Probably most of Polk Creek shale (except base), and probably most of Tyner (except base).

Clastics of Kansas border.

Figure 7. LOWER SILURIAN.

Map shows sea in early Alexandrian (Edgewood) time.

FORMATIONS

Probably northeastern development of Blaylock sandstone and probably some portion of middle Talihina in the Ouachita Mts.

Figure 8. EARLY SILURIAN, ALEXANDRIAN-BRASSFIELD-CLINTON-EARLY NIAGARAN.

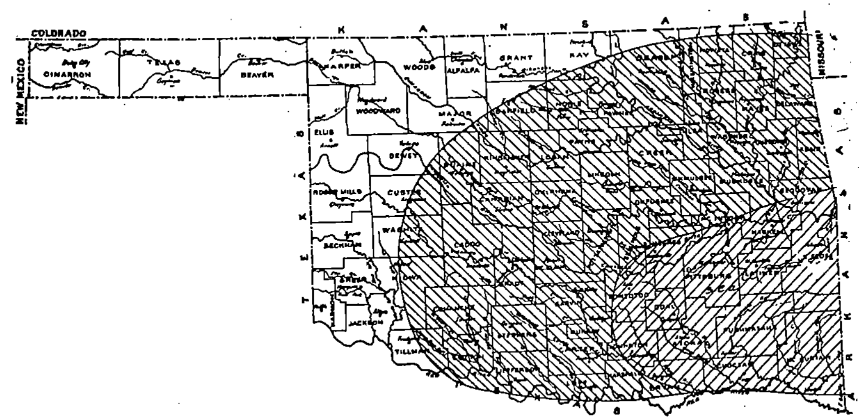
FORMATIONS

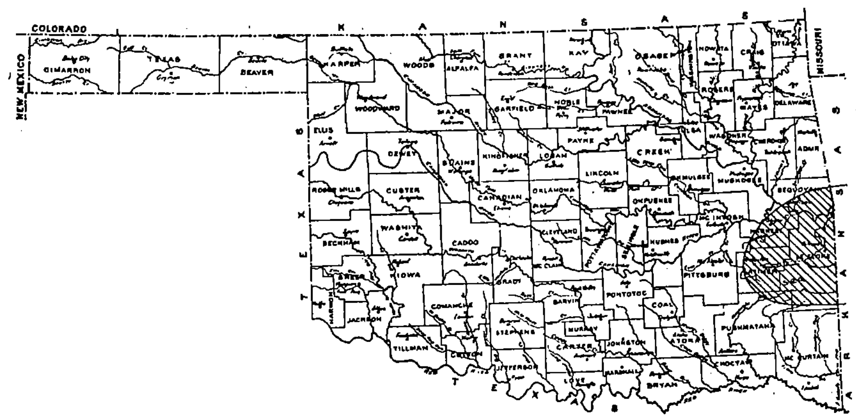
Arbuckle Mts.—Unconformity, Chimneyhill limestone (transitional) and Henryhouse limestone with a sea oscillation not indicated.

Ouachita Mts.—Missouri Mountain slate and upper and middle Talihina.

Kansas border.—Dolomite, sandstone and shale.

Northeastern Oklahoma.—Probably most of St. Clair marble.





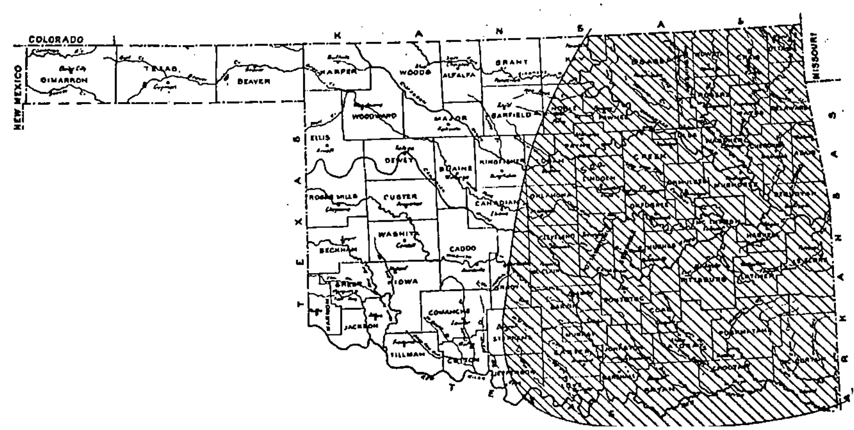


Figure 9. MIDDLE SILURIAN, LOCKPORT (LATE NIAGARAN).

Oklahoma, eroding during upper Silurian. Map shows retreat of Niagaran sea in this region.

FORMATIONS

Ouachita Mts.—Probably upper part of St. Clair marble, possibly some of the Talihina chert (upper-middle), also possible upper part of the Missouri Mountain slate.

Figure 10. EARLY DEVONIAN, ONANDAGIAN-ORISKANY-HELDER-BERGIAN.

FORMATIONS

Arbuckle Mts.—Bois 'd Arc limestone, Haragan shale (marl).

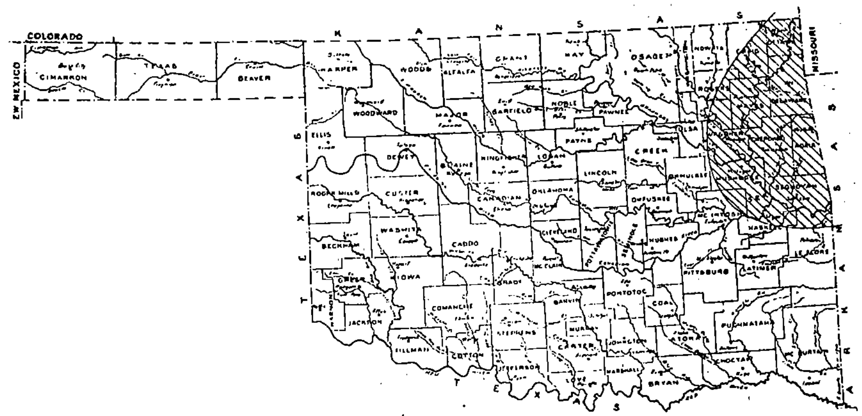
Ouachita Mts.—Probably basal part of Arkansas novaculite, and lower-upper Talihina chert, followed by the retreat of the sea to the northeastern corner of the State and out, probably preceeded by an unconformity of small extent. Middle Devonian sandstone of northeastern Oklahoma may represent the retreating phase of this sea, which is indicated in part on the next map.

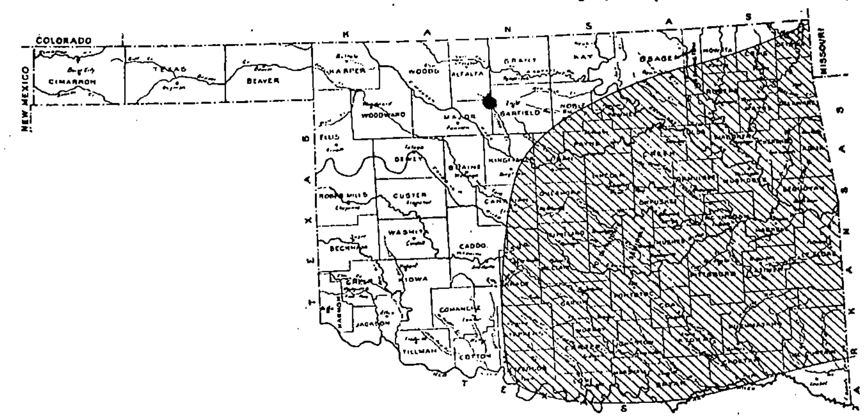
Figure 11. LATE DEVONIAN.

A general retreat of the sea from Oklahoma after early Devonian and no further invasion until the period of transition from the Devonian into the Mississippian.

This map shows this middle Devonian retreat and may represent the deposition, in part, of the middle Devonian sandstone of the northeastern part of the State, and possibly the opening phases of the Chattanooga shale time.

A break may show for the above hiatus in the middle of the Arkansas novaculite and in the upper part of the Talihina chert. Note the break at the base of the Chattanooga.





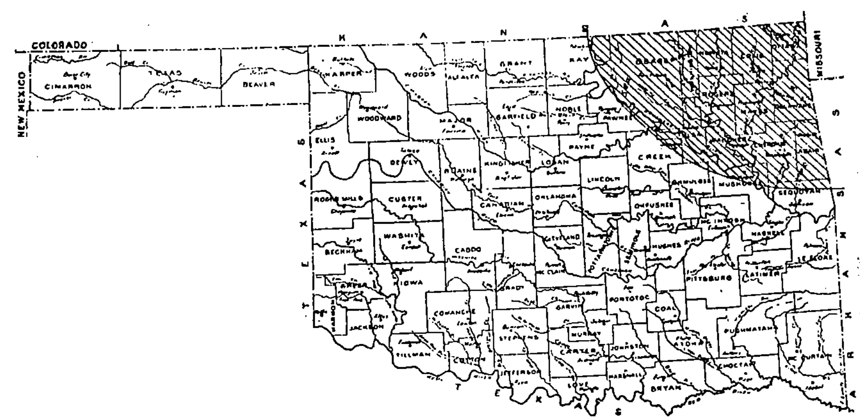


Figure 12. EARLIEST MISSISSIPPIAN-KINDERHOOK.

At this time the Arbuckle region may have been partially isolated by barriers more or less from the other areas of the adjoining seas, due to the initial phases of diastrophism attendant upon the rise of the Ouachita Mountains. Hence the latest Devonian and early Mississippian deposits of the Arbuckles might show provincial and localized features as to faunas and sediments.

FORMATIONS

Arbuckle Mts.—Possibly the deposition of the Woodford chert and the opening phases of the Sycamore took place at the time indicated in this map.

Ouachita Mts.—The closing phases of the Arkansas novaculite, Tallhina chert and possibly the opening phases of the Stanley shale.

Note: The Chattanooga of northeastern Oklahoma which has unconformities above and below may represent deposition in the northeastern basin of Figure 11 (latest Devonian).

Figure 13. EARLY-MIDDLE MISSISSIPPIAN, BURLINGTON-OSAGE-BOONE.

Texas.—For the first time since the close of the lower Ordovician the Paleozoic seas invaded Texas from the west (Sonoran Embayment) and laid down the Boone limestone in western and central Texas. During the intervening time the landmass Columbis (Llanoris) had covered the Texas region.

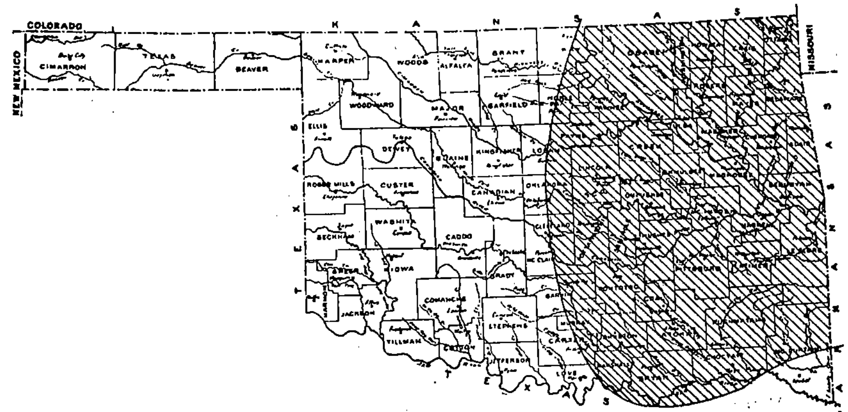
Kansas.—The portion of Kansas bordering Oklahoma had probably been eroding since the late Silurian, or at least the middle Devonian and the seas again covered the region in Boone times.

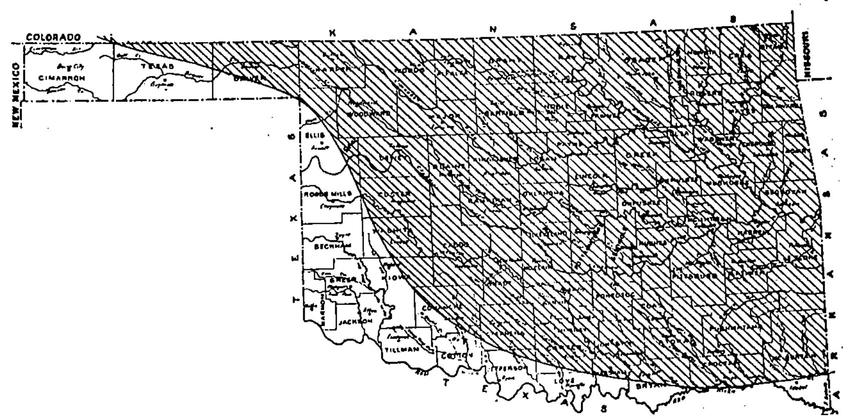
Oklahoma.—Probably much of the Sycamore limestone (especially the upper part) and perhaps some of the lowest Caney shale were deposited at this time. The Arbuckle region was perhaps a continuous area of deposition from Woodford into Caney times. In the Ouachita Mts. much or all the Stanley shale is represented. The Boone limestone of northeastern Oklahoma—a retreat of the seas toward the close of Boone time, for which see next map (Fig. 14). This explains the break at the top of the Boone, and there should be a break somewhere near the top of the Caney shale.

Figure 14. LATE-MIDDLE MISSISSIPPIAN.

Emergence at the close of Boone-Burlington-Madison-Osage time. This map shows the retreat of the seas to northeastern Oklahoma. This break shows at the top of the Boone and should show somewhere towards the bottom of the Caney. (See Boone of Oklahoma and Texas). Youngest Boone should be in northeastern Oklahoma and adjoining areas.

The Arbuckle region remained as a low delta subject to partial reinvasion by late Mississippian (Chester) seas—next map, Fig. 15. The latest phases of the Stanley may be represented, and the break at the top and bottom of Moorefield shale, etc., of Kansas may represent this retreat.





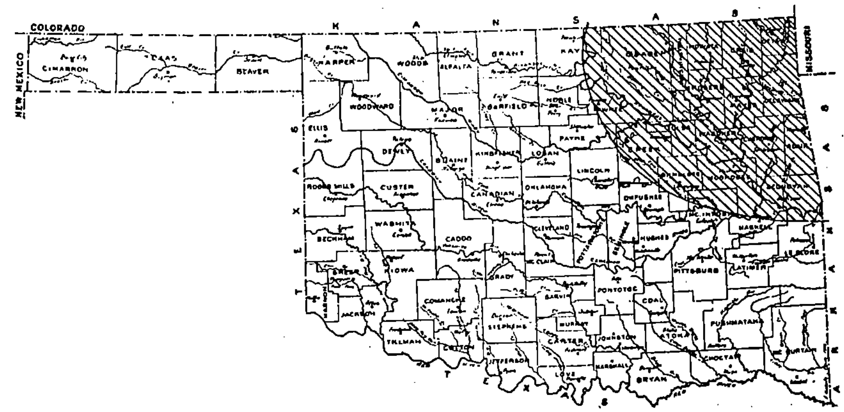


Figure 15. LATE MISSISSIPPIAN, CHESTER.

A reinvasion after the retreat at the close of Boone-Burlington-Osage times. This retreat was shown by the break at the top of Boone—lower Jackfork, etc.

FORMATIONS

Texas.—Barnett shale with unconformities above and below due to Boone and Chester retreats.

Oklahoma.—Much of the lower part of the Caney.

Kansas.—Pitkin, Fayetteville, and Batesville. Break at the top of the Pitkin limestone and top of Barnett shale indicates the Chester retreat; also lower Jackfork may be here.

Figure 16. LATE (close) MISSISSIPPIAN.

Break at top of Barnett shale (Chester of Texas) and Pitkin (top of Chester in Kansas) shows this retreat. Probably break at top of Caney somewhere (relationship to Glenn formation?)

This map shows opening phases of Pottsville invasion and close of Mississippian-basal Morrow. Perhaps much of lower Jackfork and top of Caney represented.

Figure 17. EARLY PENNSYLVANIAN, POTTSVILLE.

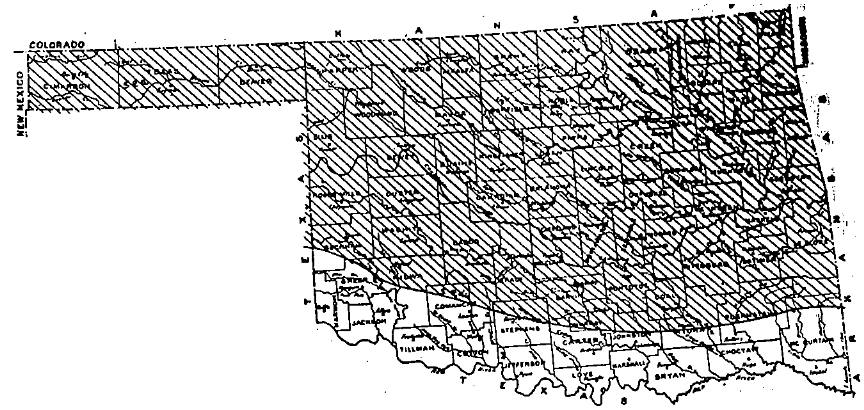
FORMATIONS

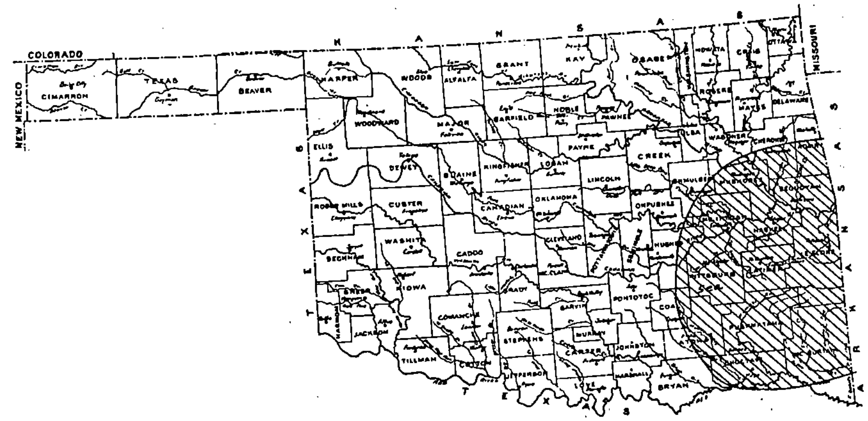
Texas.—Smithwick shale and marble Falls limestone.

Oklahoma.—Basal Glenn and Hartshorne sandstone, Atoka formation and Wapanucka limestone.

Morrow—lower Winslow and lower Cherokee.

Perhaps more or less of upper Jackfork of Ouachita Mountains.





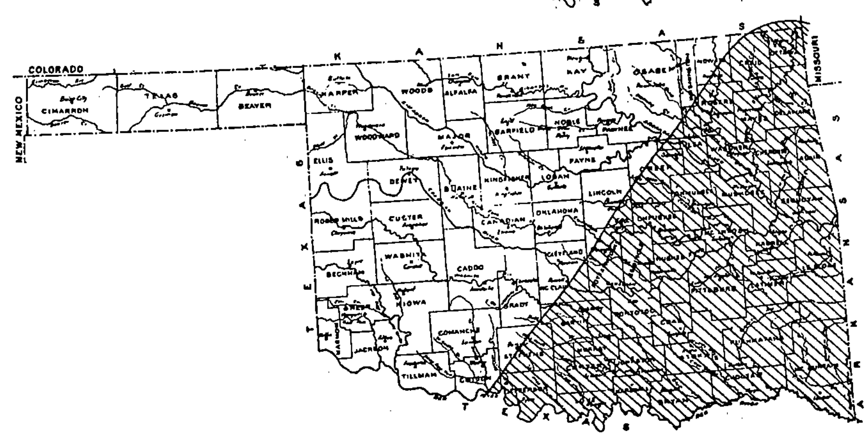


Figure 18. LATE-LOWER PENNSYLVANIAN, ALLEGHENY.

FORMATIONS.

Texas.—Strawn-Canyon, Brad, Caddo Creek, and Grayford.

Oklahoma.—Most of Glenn, except probably the basal part; Seminole, Holdenville, Wewoka, Wetumka, Calvin, Sonora, Stuart, Thurman, Boggy, Savanna, and McAlester. Top formations show westward retreat of the shore.

Northwestern Oklahoma.—Altamont, Bandera, Pawnee, Labette, Fort Scott, and Cherokee (middle and upper).

Figure 19. EARLY-UPPER PENNSYLVANIAN, CONEMAUGH.

Arbuckles and Ouachitas now well elevated. Ouachitas elevated about the end of Boggy time and the Arbuckles about the end of Seminole time. Shore line pushed west.

FORMATIONS.

Texas.—Cisco, lower and middle.

E-C Okahoma.—Vamoosa, Ada, and Francis.

Oklahoma

Pawhuska
Elgin
Nelagony
Ochelata (Bristow
Drum { Dewey
Nellie Bly
Hogshooter
Coffeyville
Lenapah
Nowata

Kansas

Shawnee
Douglass
Lansing
Iola-Chanute
Drum
Cherryvale
Winterset
Galesburg
Bethany Falls
Ladore
Hertha
Dudley

Figure 20. LATE PENNSYLVANIAN, MONONGAHELA.

FORMATIONS.

Texas

Upper Cisco
Putnam
Moran
Pueblo
Harpersville
Thrifty

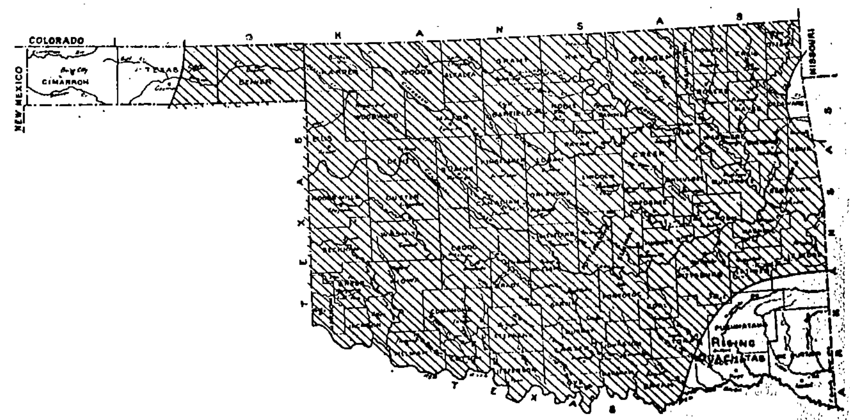
Oklahoma

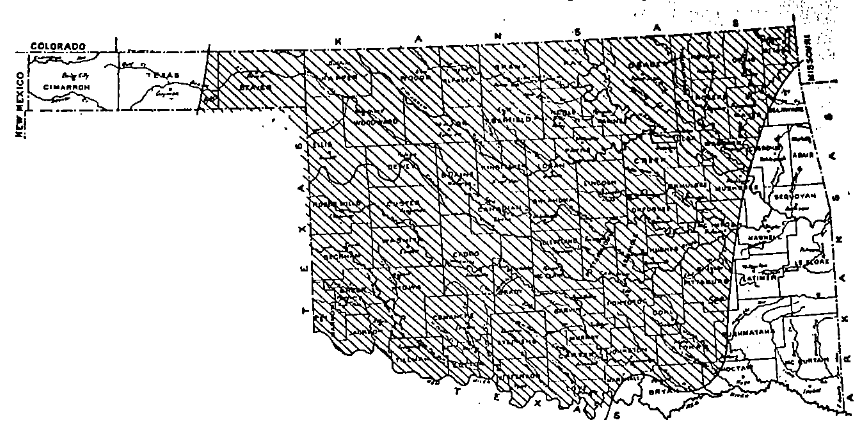
Pontotoc group

Oklahoma and Kansas

Neva and Eskridge

Elmdale
Sand Creek-Waubansee
Buck Creek





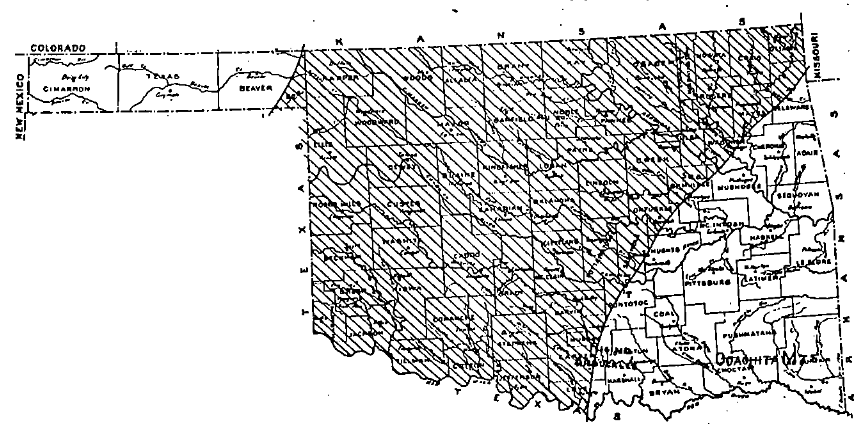


Figure 21. PERMIAN (Lower Permian of Europe).

FORMATIONS

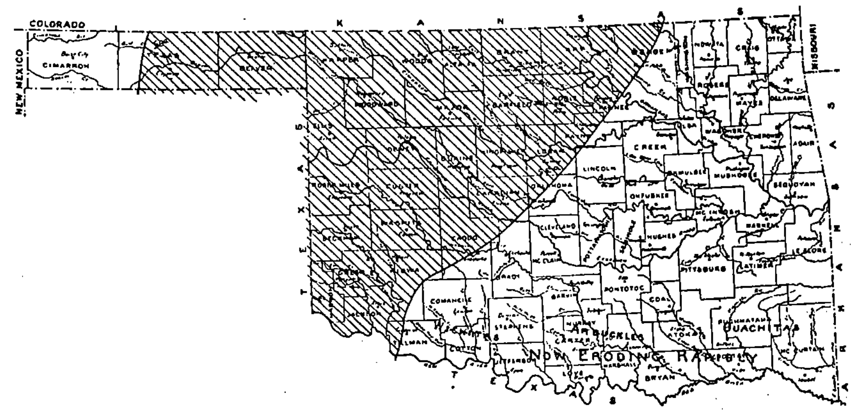
Texas	Oklahoma	Kansas
Double Mountain	Asher-Quartermaster	Sumner
Clearfork	Cloud Chief	Chase
Wichita-Albany	Woodward	Council Grove
	Blaine	
	Enid	
	Wichita	

Figure 22. TRIASSIC (very latest).

Oklahoma undergoing erosion. Some terrestial Triassic in the Panhandle. Dokum of Texas and red beds of Panhandle.

Figure 23. JURASSIC.

Terrestial and perhaps marine of Logan Sea (upper). Developed in New Mexico, and in possible area in the Panhandle. See maps of North America.



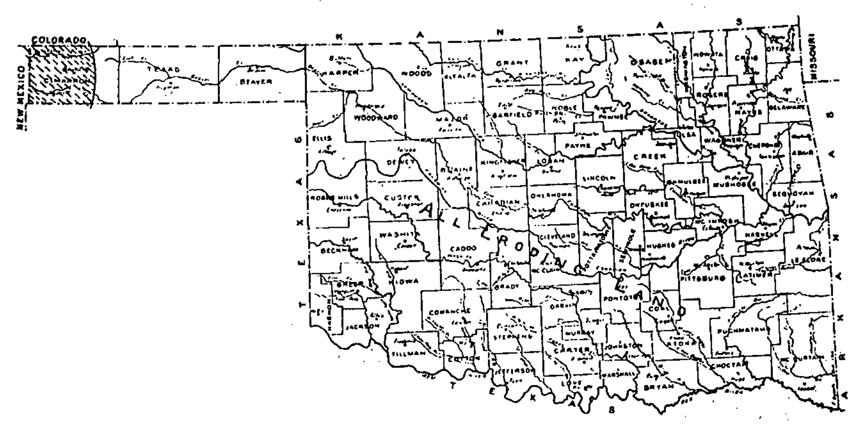


Figure 24. COMANCHEAN (early). TRINITY TIME.

FORMATIONS.

Texas	
Paluxy-Trinity	Kootenai of northwest
Glen Rose	
Travis Peak	

Figure 25. COMANCHEAN (middle). FREDRICKSBURG.

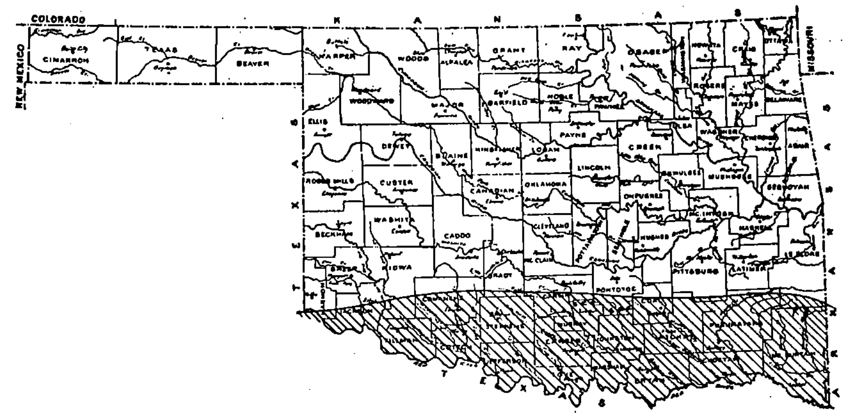
FORMATIONS.

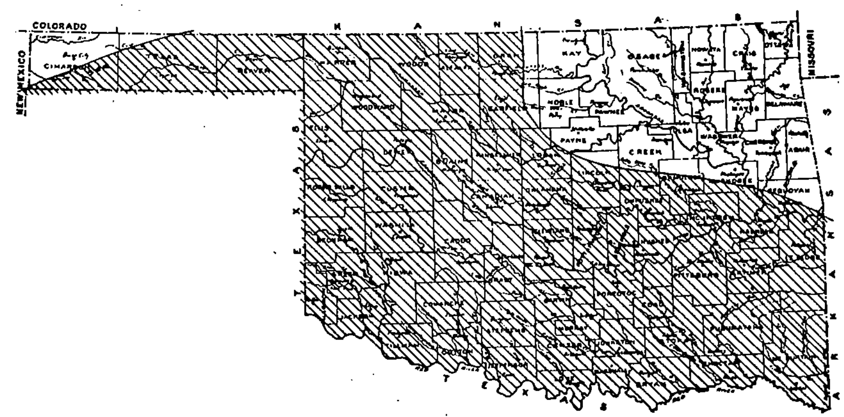
Texas	
Edwards	Lakota of northwest
Comanche Peak	Knoxville of California
Walnut	

Figure 26. COMANCHEAN (late). WASHITA GROUP.

FORMATIONS.

Texas	Oklahoma	
Denison-Preston	Bennington	Fusion of Black Hills
Fort Worth	Bokchito	Horsetown of California
Duck Creek	Caddo	(upper Shastan)
Kiamichia	Kiamichia	Purgatoire of Colorado





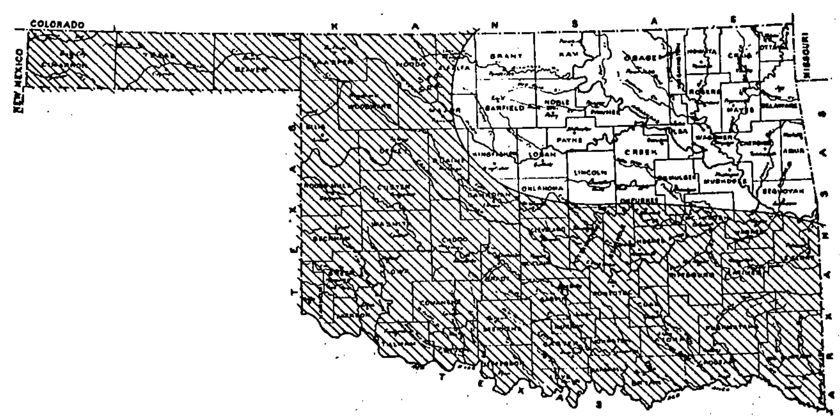


Figure 27. CRETACEOUS (lower), BASAL GULF SERIES.

FORMATIONS.

Texas

Brownstone marl

Blossom sand

Eagle Ford

Woodbine-Dakota

Figure 28. CRETACEOUS (middle).

FORMATIONS.

Texas

Taylor

Marlbrook

Austin Annona

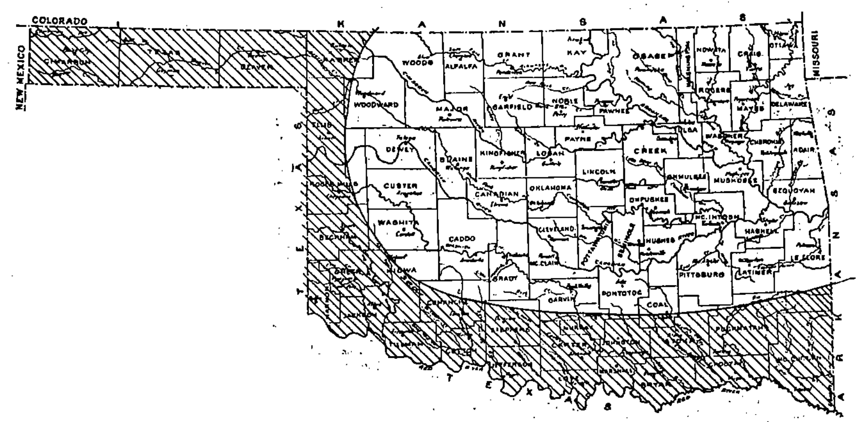
Figure 29. CRETACEOUS (late).

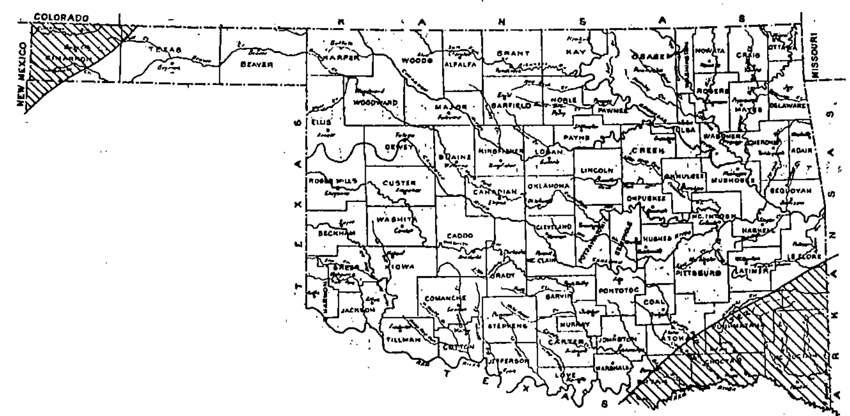
FORMATIONS

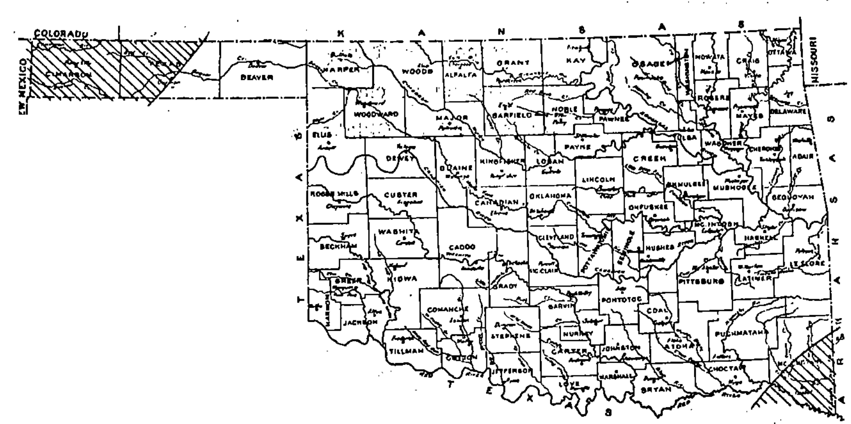
Texas

Arkadelphia

Navarro Nacatoch







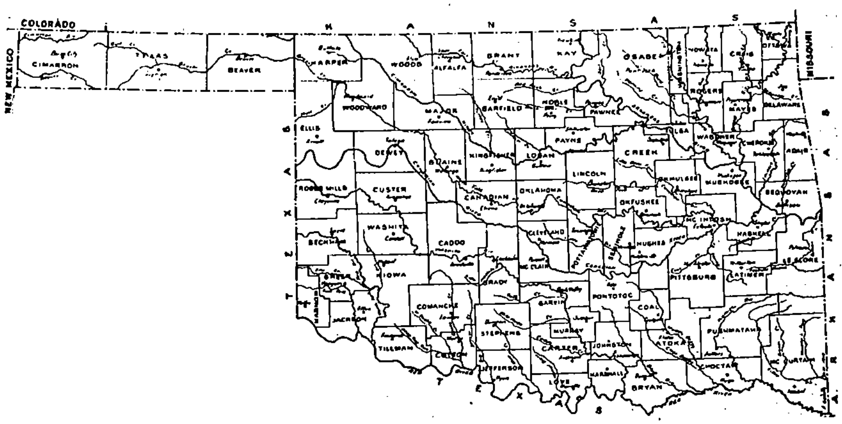


Figure 30. TERTIARY.

Rising of ancestral Rockies through eastern New Mexico. A north-south elevation of the region in late Tertiary.

FORMATIONS

Eocene of Texas
Jackson
Yega
Cook Mountain
Mount Selman
Wilcox formation
Midway

Oklahoma
Pliocene-basalt of Black Mesa
Grandfield conglomerate
of central and southern
Oklahoma (Ouachitas).

Pleistocene

Seymour of Texas

Beaumont clay

Gertie sand of Oklahoma