THE

AMERICAN JOURNAL OF SCIENCE

[FIFTH SERIES.]

ART. V.—*Llanoria, the Paleozoic Land Area in Louisiana and Eastern Texas**; by HUGH D. MISER.

CONTENTS.

INTRODUCTION.

Evidence for a Paleozoic land area that occupied at least a part of Louisiana and eastern Texas has been published from time to time within the last 30 years by different geologists. The most important paper on the subject is one by J. C. Branner,[1] published in 1897. In

* Published by permission of the Director of the U. S. Geological Survey.

[1] Branner, J. C., The former extension of the Appalachians across Mississippi, Louisiana, and Texas, this Journal, (4), vol. 4, pp. 357-371, 1897. Abstract, Brit. Assoc. Adv. Sci., Rept. 1897, pp. 643-644, 1898. Abstract Annales de Géographie, 7-me Année, No. 35, pp. 345-346, Sept. 15, 1898. Abstract, Nature, vol. 56, p. 70, Nov. 18, 1897. Review by A. H. Purdue, Jour. Geology, vol. 5, pp. 759-760, 1897.

this paper he brought together and presented many facts in support of his hypothesis that the Appalachians formerly extended across the lower Mississippi Valley to central Texas. Considerable information on the subject was obtained by the late Dr. A. H. Purdue and the writer during several years of study of the rock formations in the Ouachita Mountains and Arkansas Valley, in Arkansas, beginning in 1907. Not only is this presented here by the writer, but an attempt is made to bring together and state briefly all the data that have been published by other geologists. The writer is indebted to E. O. Ulrich, G. H. Girty, C. E. Siebenthal, Chas. Schuchert, and L. W. Stephenson, who have kindly read this paper and offered valuable suggestions.

This paper consists largely of the presentation of evidence for the existence of the old land area; it does not discuss more than the most striking events in its history. Discussion of the complete history, which would be based on the character and distribution of the rocks of the Gulf Coastal Plain and the adjoining regions and on the stratigraphic breaks presented by them, would be largely hypothetical.

The name Llano was applied to this old land area by Bailey Willis[2] and has been used by Charles Schuchert[3] and E. O. Ulrich,[4] but the name Llanoria has been used by E. T. Dumble[5] and Sidney Powers.[6] Of these two names Llanoria is the more appropriate because Llano is very frequently applied to the Central Mineral, or Llano-Burnett, region of Texas, which was an outlier of the main land area to the east, or which formed only a small part of it if the two were connected.

Since most of the present paper is a discussion of numerous features found in the Ouachita Mountains and Arkansas Valley, a brief summary of the geology of these regions is given.

[2] Willis, Bailey, A theory of continental structure applied to North America: Geol. Soc. America, Bull., vol. 18, pp. 394-395, 398, 1907. Discoidal structure of the lithosphere, Geol. Soc. America, Bull., vol. 31, Plate 11 opposite p. 301, 1920.

[3] Schuchert, Charles, Paleogeography of North America, Geol. Soc. America, Bull., vol. 20, pp. 448, 457, 458, 470, pl. 49, 1910.

The nature of Paleozoic crustal instability in eastern North America, this Journal, (4), vol. 50, pp. 403, 404, 407, 413, 1920.

[4] Ulrich, E. O., Revision of the Paleozoic systems, Geol. Soc. America, Bull., vol. 22, pp. 435, 476, 1911.

[5] Dumble, E. T., The geology of east Texas, Univ. of Texas Bull., No. 1869, pp. 11-13, Feb., 1920.

[6] Powers, Sidney, The Sabine Uplift, Louisiana, Amer. Assoc. Petroleum Geologists, Bull., vol. 4, no. 2, p. 125, 1920.

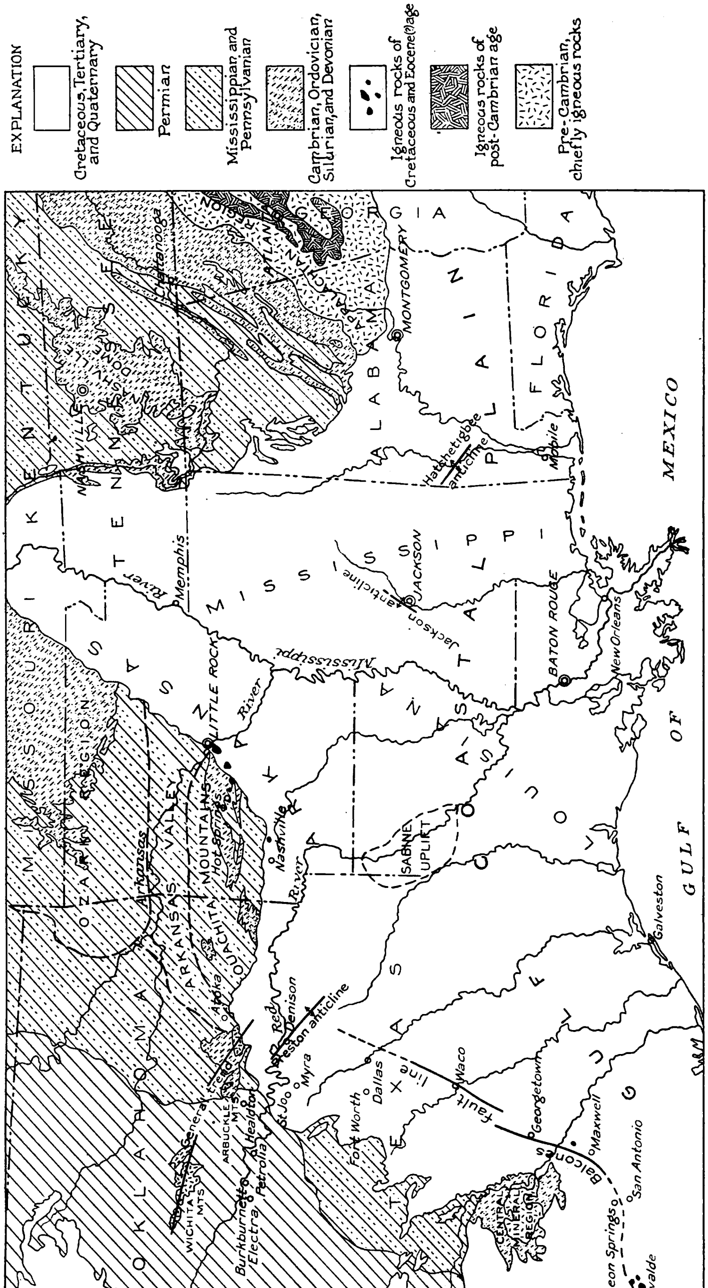

FIG. 1.—Geologic map of the Gulf Coastal Plain and adjoining areas. Geology taken largely from geologic map of North America, U. S. Geol. Survey, 1912.

General Geology of the Ouachita Mountains and Arkansas Valley.

The Ouachita Mountains are 50 to 60 miles wide and extend from Little Rock, Ark., to Atoka, Okla., a distance of 200 miles. They are joined on the south and east by the Gulf Coastal Plain. (See figure 1.) The Arkansas Valley just north of the Ouachita Mountains is 30 to 40 miles wide and extends westward from near Little Rock, Ark., to near Lehigh, Okla., a distance of about 220 miles. The rocks exposed in these regions are all of sedimentary origin except two small areas of igneous rocks and their related dikes, of Cretaceous age, in Arkansas. They range in age from Cambrian to Pennsylvanian and present the accompanying composite section. They were formed in a geosyncline to which the name "Ouachita" has been appropriately applied by E. O. Ulrich,[7] and they were compressed into numerous nearly east-west folds late in the Pennsylvanian epoch. The maximum thicknesses of the formations, as given in the section, aggregate 37,000 feet, but as the formations vary considerably in thickness from place to place the total thickness in any particular part of these regions would be less than the total just given, though, as pointed out on a later page, it would be great.

Composite section of exposed rocks of Paleozoic age in the Ouachita Mountains and Arkansas Valley.

	Thickness in feet	*Remarks on occurrence*
Carboniferous:		
Pennsylvanian		
Boggy shale	2,000[a]-3,000[b]	
Savanna sandstone	750[c]-1,500[d]	Present in Arkansas Valley in Arkansas and Oklahoma.
McAlester shale	1,150[c]-2,500[e]	
Hartshorne sandstone	100[f,g]-300[g]	
Atoka formation	3,000[h]-7,800[i]	Present in Arkansas Valley and Ouachita region in Arkansas and Oklahoma.
Wapanucka limestone	0[l]-800[j]	Exposed near boundary between Arkansas Valley and Ouachita region in Oklahoma; absent in Arkansas.

[7] Ulrich, E. O., Revision of the Paleozoic systems, Geol. Soc. America, Bull., vol. 22, pp. 293, 358, 435, 469, 476, 1911.

[a] Taff, J. A., U. S. Geol. Survey Geol. Atlas, Coalgate folio (No. 74), columnar section sheet, 1901. [b] Taff, J. A., and Adams, G. I., Geology of the eastern Choctaw coal field, Indian Territory: U. S. Geol. Survey Twenty-first Ann. Rept., pt. 2, 278, 1900. [c] Taff, J. A., U. S. Geol. Survey Geol. Atlas, Atoka folio (No. 79), columnar section sheet 1, 1902. [d] Taff, J. A., and Adams, G. I., op. cit., p. 277. [e] Taff, J. A., and Adams, G. I., op. cit., p.

Mississippian		
Caney shale	0[k]-1,500[c]	Exposed in Ouachita region in Oklahoma; absent in Arkansas.
Jackfork sandstone	0[l]-6,600[m]	Exposed in Ouachita region in Oklahoma and in Arkansas Valley and Ouachita region in Arkansas; absent at one locality in Oklahoma.
Stanley shale	0[l]-6,100[n]	Exposed in Ouachita region in Oklahoma and Arkansas; absent at one locality in Oklahoma.
Hot Springs sandstone	0[o]-200[o]	Exposed in places at and near Hot Springs, Ark., but absent at most places in Arkansas; not present in Oklahoma.
Devonian:		
Arkansas novaculite (upper part may possibly be Carboniferous)	0[o]-950[o]	Exposed in Ouachita region in Oklahoma and Arkansas; absent at few places in Arkansas.
Silurian:		
Missouri Mountain slate	0[o]-300[o]	Exposed in Ouachita region in Oklahoma and Arkansas.
Blaylock sandstone	0[o]-1,500[o]	Exposed in southern part of the Ouachita region in Oklahoma and Arkansas; absent in northern part of this region in both States.
Ordovician:		
Polk Creek shale	0[o]-400[p]	Exposed in Ouachita region in Oklahoma and Arkansas; absent at few localities.
Bigfork chert	700[o]	Exposed in Ouachita region in Oklahoma and Arkansas.
Womble shale	250[o]-1,000[o]	Exposed in Ouachita region in Arkansas; also present in Ouachita region in Oklahoma.[q]
Blakely sandstone	0[o]-500[o]	Exposed in Ouachita region in Arkansas; present in Ouachita region in McCurtain Co., Okla.[q]

275. [f] Taff, J A., and Adams, G. I., op. cit., p. 274. [g] Collier, A. J., The Arkansas coal field, U. S. Geol. Survey, Bull. 326, p. 12, 1907. [h] Taff, J. A., Grahamite deposits of southeastern Oklahoma, U. S. Geol. Survey, Bull. 380, p. 289, 1909. [i] Measured by writer in Yell County, Arkansas. [j] Wallis, B. F., The geology and economic value of the Wapanucka limestone of Oklahoma, Oklahoma Geol. Survey, Bull. 23, pp. 30, 42, 67, 1915. [k] Wallis, B. F., op. cit., p. 67. [l] Girty, G. H., The fauna of the Caney shale of Oklahoma, U. S. Geol. Survey, Bull. 377, p. 6, 1909; Wallis, B. F., op. cit., p. 27. [m] Purdue, A. H., The slates of Arkansas, Arkansas Geol. Survey, p. 48, 1909. [n] Taff, J. A., U. S. Geol. Survey, Geol. Atlas, Atoka folio (No. 79), columnar section sheet 2, 1902. [o] Measured by A. H. Purdue and writer in Arkansas. [p] Ulrich, E. O., Revision of the Paleozoic systems, Geol. Soc. Amer. Bull., vol. 22, p. 677, 1911. [q] C. W. Honess, structural features of the southern Ouachita Mountains, Oklahoma (abstract): Geol. Soc. America, Bull., vol. 31, No. 1, p. 121, March, 1920.

Mazarn shale	1,000[o]	Exposed in Ouachita region in Arkansas; also present in this region in Oklahoma.[q]
Ordovician (?):		
Crystal Mountain sandstone	850[o]	Exposed in Ouachita region in Arkansas; also present in this region in McCurtain Co., Okla.[q]
Cambrian:		
Collier shale (observed thickness)	200[o]	

The Caney shale and the underlying formations—the Jackfork sandstone, Stanley shale and Hot Springs sandstone of the Ouachita Mountains—have been placed in the Pennsylvanian series by some geologists but other geologists and the accepted usage of the U. S. Geological Survey place them in the Mississippian series. As the proper correlation of these formations has an important bearing on several features to be discussed below, brief summaries of E. O. Ulrich's opinion and of the evidence supplied by their fossils are presented. The Stanley and the Jackfork have yielded a few plants and the Jackfork has yielded a few indeterminable invertebrate fossils, but the Caney shale has yielded a rather large invertebrate fauna and a few fish remains. No fossils have been found in the Hot Springs sandstone.

In summarizing the evidence furnished by the plant collections obtained prior to 1915 by the writer and others from the Stanley shale and Jackfork sandstone David White[8] says:

> "The discovery of better material will doubtless necessitate revision of some of the tentative [specific] identifications. Possibly they will show that the beds are Pennsylvanian, but the aspect of the plant fragments and the apparent relations of the beds strongly suggest that they are Mississippian. Accordingly, I am inclined to regard them as Mississippian, and to suggest that they are of Chester age, but the paleobotanical data available is insufficient to justify their conclusive reference to the Mississippian."

C. S. Prosser, who collected some fragments of fossil plants from the Stanley shale in the city of Hot Springs, Ark., made the following statement concerning them:[9] "On one of the olive pieces of shale is a fern pinnule, which is similar to those of *Sphenopteris*. It resembles

[8] Statement for use in the Hot Springs and DeQueen-Caddo Gap folios (in preparation).

[9] Prosser, C. S., Notes on Lower Carboniferous plants from the Ouachita uplift, Arkansas Geol. Survey Ann. Rept. for 1890, vol. 3, pp. 423-424, 1892.

somewhat the pinnules of *Sphenopteris decomposita* Kidston, from the Calciferous sandstone (Lower Carboniferous) of Scotland; but nothing could be stated positively of such a fragment. Other fragments resemble *Cordaites.*''

C. R. Eastman,[10] who studied fish remains from the Caney shale, stated that their character tends to support the upper Mississippian age of the Caney.

A part of a recent summary by George H. Girty[11] on the invertebrate fauna of the Caney shale follows:

''When the formation [Caney] was first mapped and when its fauna was first described the Caney shale was referred, as it is now, to the upper part of the Mississippian series. * * *

''Since this conclusion was formed much evidence has accumulated, and it tends strongly to corroborate the opinion that the Caney shale is of Mississippian age. Hundreds of collections of invertebrate fossils have been made in Oklahoma and Arkansas in areas adjacent to those in which the Caney shale occurs. In these collections a pronounced faunal change is shown between the Morrow group, which is of Pottsville age, and the formations that underlie it, whose faunas, though differing more or less profoundly from the typical Mississippian faunas farther north, are nevertheless undoubtedly Mississippian. Wherever faunas of the Mississippian type occur they occur below faunas of the Morrow type, and the strata that contain them can be traced to other sections in which the same relation of rocks and faunas is maintained. The same relations are shown by the Caney shale and the formation that lies next above it, the Wapanucka limestone. The Caney fauna has conspicuously the facies of the Mississippian faunas of the adjacent areas in Oklahoma and Arkansas. This fact admits of no doubt. Furthermore, the fauna of the Wapanucka limestone is closely allied to that of the Morrow, which overlies the Mississippian rocks in nearby areas and without much doubt represents the same geologic epoch.

''It is true that as the Morrow is believed to be of upper Pottsville age other rocks may occur below it and still be Pottsville, but in that case their faunas might justly be expected to have the Pottsville rather than the Mississippian facies. It may be well to recall that the Caney fauna, so far as it is known, comes from the lower half of the formation, but so long as collections continue to show the facies of the Mississippian faunas that occur below the Morrow the Caney shale can logically be placed only in the Mississippian.''

[10] Eastman, C. R., Brain structures of fossil fishes from the Caney shales; Geol. Soc. America, Bull., vol. 24, pp. 119-120, 1913.

[11] Statement for use in the Hot Springs folio (in preparation).

E. O. Ulrich,[12] who has made field studies of the formations under discussion, holds: (1) that the Hot Springs sandstone and Stanley shale are equivalent to the Chester group and to beds that bridge the Chester-Pottsville interval, (2) that the Jackfork sandstone is of lower Pottsville age, and (3) that the Caney shale is of upper Pottsville age. The reasons for these opinions can not be discussed here for lack of space.

Evidence for a Paleozoic land area in Louisiana and eastern Texas, and its features.

Any land area that may have existed in Louisiana and eastern Texas during the Paleozoic era is now largely if not entirely concealed by Cretaceous and younger sediments of the Gulf Coastal Plain. Evidence regarding it must therefore be obtained from (1) the Paleozoic and older rocks that are exposed in the regions bordering the Gulf Plain, (2) the structure of the sediments of the Gulf Plain, and (3) wells that have passed through the Cretaceous and younger rocks of the Gulf Plain and penetrated the underlying Paleozoic and pre-Cambrian rocks. This evidence follows.

General character of Ordovician and Silurian rocks in Ouachita Mountains.

The rocks of Ordovician and Silurian age exposed in the Ouachita Mountains consist mainly of shale and sandstone, whereas the rocks of these ages in the Arbuckle Mountains, in the Ozark region, and in the Nashville dome in middle Tennessee consist predominantly of limestones. This strongly suggests that the present Ouachita region was near an old land area undergoing vigorous erosion during these two periods, and if this is true it is necessary to assume that the old land area existed south of the present Ouachita Mountains.

Blakely sandstone of Ouachita Mountains.

The Blakely sandstone, of Ordovician age, thins out to the north in Montgomery County, Ark. This formation is 500 feet or less thick and is composed largely of shale but partly of sandstone, though the sandstone is

[12] Oral communication.

the more prominent surface feature of the two. The sandstone beds are lenticular and thin out to the north, whereas the intervening beds of shale do not appear to thin out in this direction. The absence of the sandstone to the north therefore can not be explained by the hypothesis that it extended farther north and that it was subsequently eroded.

Blaylock sandstone of Ouachita Mountains.

Although the Blaylock sandstone, which at places reaches a thickness of 1,500 feet and is of Silurian age, is of wide extent from east to west, its outcrops stretching from a point near Malvern, Ark., nearly to Bismarck, Okla., it is present in the Ouachita Mountains only on their south side. The northward thinning of the sandstone may be due partly to erosion, as is indicated by the local occurrence of a conglomerate at the base of the overlapping Missouri Mountain slate. If the thinning out of the sandstone is due entirely to erosion this would mean that at least 1,500 feet of material has been removed from the northern part of the present Ouachita region, and it would be expected that the underlying Polk Creek shale would also have been removed from large areas at the same time the Blaylock was being removed. But the Polk Creek shale is generally present in the region north of that in which the Blaylock sandstone occurs, and its thickness there is much the same as it is in places where it underlies the Blaylock. The conclusions regarding the Blaylock are that it was deposited in a minor east-west trough on the south side of the Ouachita geosyncline, that the northward thinning of the formation can be attributed in only a very small part to erosion, and that the land-derived sediments for it came from the south.

Stanley shale and Jackfork sandstone of Ouachita Mountains.

The Stanley shale, 5,000 to 6,000 feet thick, and the Jackfork sandstone, 5,000 to 6,600 feet thick, both of Mississippian age, are exposed through the entire length of the Ouachita region, and the Jackfork sandstone is exposed at places in the Arkansas Valley in Arkansas but both formations thin out to the north and west. They are absent in the Arbuckle Mountains, and at a locality on the north border of the Ouachita region near McAlester, Okla.,[13] and also in the Ozark region, though in that region they may be represented by comparatively thin limestones, sandstones, and shales of Mississippian age. It may be suggested that these two formations formerly extended much farther west and north and that their absence is due to erosion, but there is no evidence to indicate that any considerable thickness of strata was removed by erosion from the Arbuckle and Ozark regions during the Mississippian epoch. Not only do the formations themselves become thinner toward the north, but sandstone beds that form about one-fourth of the Stanley shale along the southern border of the Ouachita region become thinner or thin out completely before they reach the north side of the region, and the Jackfork sandstone changes toward the north from a formation composed almost entirely of sandstone with very little shale to a formation composed largely of shale. This northward thinning of the sandstone beds of the Stanley shale and the dovetailing of thick beds of shale in the Jackfork sandstone to the north imply a southern source for the sand and mud that later formed these formations. Many small quartz pebbles, one-fourth of an inch or less in diameter, occur in the Jackfork sandstone, particularly in its lower part, on the southern border of the Ouachita Mountains. They become less abundant toward the north. The enormous thickness and comparatively large areal extent of the Stanley and Jackfork indicate that the land mass to the south suffered great erosion. From the evidence now at hand the Arbuckle and Ozark regions could not have supplied so vast a quantity of sediment during the Mississippian epoch.

The northward thinning of the sandstones in the formation to which the name Stanley shale is applied was noted by L. S. Griswold,[14] who says, "The existence of sandstone beds overlying the novaculites on the south side of

[13] Girty, G. H., The fauna of the Caney shale of Oklahoma, U. S. Geol. Survey, Bull. 377, p. 6, 1909. Wallis, B. F., The geology and economic value of the Wapanucka limestone of Oklahoma, Oklahoma Geol. Survey, Bull. 23, p. 27, 1915.

[14] Griswold, L. S., Whetstones and the novaculites of Arkansas, Arkansas Geol. Survey, Ann. Rept. for 1890, vol. 3, pp. 193, 213, 1892.

the Ouachita uplift, with shale beds occupying the corresponding position on the north side, indicates that the land whence these sediments were derived lay to the south, just as in the case of the Appalachians it lay to the east.'' G. H. Ashley,[15] who studied a large area of Carboniferous rocks underlain by the Stanley, Jackfork, and Atoka formations south of the area examined by Griswold, says that they apparently confirm Griswold's conclusion regarding the southern source of the Carboniferous sediments.

Concerning the source of the clastic sediments of not only the Stanley and Jackfork but of the Caney and Atoka formations, David White[16] says:

''Toward the northeast [of north-central Texas], somewhere in the region of the Red River Valley, a Mississippian-Pennsylvanian land barrier existed which is now bridged by later Pennsylvanian ''Red Beds'' or Cretaceous strata. The existence of such a land mass is predicated by the sediments (clastics) of the Jackfork, Stanley, Caney, and Atoka formations as well as by the fossils. The sediments of these formations could hardly have been derived from the Ozark uplift, nor does it seem probable that they could have originated in the areas now marked by the Arbuckle-Wichita uplift.''

Tuffs of Mississippian age in the Ouachita Mountains.

Tuffs occur near the base of the Stanley shale in Polk County, Ark., and McCurtain County, Okal., in three and possibly four or five beds, which range in thickness from 6 to 85 feet, the lowest bed being the thickest and the most widely distributed. According to E. S. Larsen, who has studied them in thin sections, these tuffs are composed in large part of devitrified and silicified volcanic glass and of feldspar and other minerals. A study of the tuffs in Arkansas has been begun by the writer but has not yet been completed. However, as they occur only on the south side of the Ouachita Mountains, and thin out toward the north, and as the size of grains of their component materials apparently decreases toward the north, it would seem that the volcanic materials they contain were ejected

[15] Ashley, G. H., Geology of the Paleozoic area of Arkansas south of the novaculite region, Am. Philos. Soc., Proc. vol. 36, p. 248, 1897.

[16] White, David, Discussion of paper by F. B. Plummer on the stratigraphy of the Pennsylvanian formations of north-central Texas, Assoc. Amer. Petroleum Geologists, Bull., vol. 3, p. 149, 1919.

from some vent or vents on or near the old land area to the south.

The Stanley shale, near whose base the tuffs occur, is underlain, where the tuffs are found, by the Arkansas novaculite and is overlain by the Jackfork sandstone and other Carboniferous rocks. The novaculite is of Devonian age with the exception of its upper part, which may be of early Mississippian age. The facts that this formation is generally free from coarse-grained sediments and that it consists mainly of novaculite, a fine-grained rock which is generally regarded as being a variety of chert, indicate that while it was being deposited the sea in the Ouachita geosyncline was comparatively clear. If so, any land area that may have existed at this time in Louisiana and eastern Texas had a low relief and was subject to little erosion. On the other hand, in Mississippian rocks that overlie the Arkansas novaculite, except the tuffs, are all shales and sandstones, and occur in very thick formations in most parts of the Ouachita Mountains, the thickest being the Stanley shale, 5,000 to 6,000 feet thick and the Jackfork sandstone, 5,000 to 6,600 feet thick. Any old land area to the south that could have supplied so much sediment in so short a time must have been extensive and must have been rapidly eroded and therefore probably included mountains. As the southern land area was low, and was eroded very little during Devonian and possibly during early Mississippian time, the diastrophic movements that produced the mountains must have taken place in late Devonian or early Mississippian time. The occurrence of the tuffs near the base of the Mississippian beds and the probability that the fragmental materials composing the tuffs had a southern source strongly suggest that the mountain-making movements were accompanied by volcanic activity during which the fragmental materials for the tuffs were ejected.

Pennsylvanian rocks in Arkansas and Oklahoma.

The Pennsylvanian rock, mainly shales and sandstones, become thinner to the north, particularly the Atoka formation which is 7,800 feet thick in the Arkansas Valley in Arkansas, 6,000 to 7,000 feet thick in this valley in Oklahoma, and 6,000 feet thick in Pike County, Ark., on the south border of the Ouachita region. In Pike County it was originally more than 6,000 feet thick; its upper part has been removed by erosion. The rocks that are equivalent to the Atoka along the southern border of the Boston Mountains which adjoin the north side of the Arkansas Valley, probably comprise the lower 1,500 feet or more of the Winslow formation in the Winslow quadrangle,[17] the lower 600 to 800 feet of the Winslow formation in the Tahlequah quadrangle,[18] and 200 to 400 feet of the Winslow in the Muskogee quadrangle.[18]

N. F. Drake,[19] in a discussion of the origin of the sediments of the "Coal Measures" of Oklahoma, which, as defined by him, include not only the Pennsylvanian but also the Mississippian rocks of the Ouachita Mountains, says:

"Throughout the Coal Measures the thickness of the sediments gradually decreases northward and westward. The most rapid decrease is toward the north, and the lower beds decrease more rapidly than the higher ones. * * * The relative proportion * * * of shales and limestones to sandstones and conglomerates gradually increases westward and especially northward. Because of these conditions the sediments are considered to have come from a land area lying to the southeast."

A recent study of the Pennsylvanian sandstones and shales in the Bristow quadrangle, in Creek County, Okla., by A. E. Fath[20] has led him to believe that the sediments for them come from a land area to the south-southwest.

Ice-borne bowlders in Caney shale in Oklahoma.

J. A. Taff[21] has described the occurrence of erratic ice-borne bowlders, up to 60 feet in length, in the Caney shale (Mississippian) in the Ouachita Mountains in southeastern Oklahoma. They have also been described

[17] Purdue, A. H., and Miser, H. D., U. S. Geol. Survey Geol. Atlas, Eureka Springs-Harrison folio (No. 202), p. 16, 1916.

[18] Taff, J. A., U. S. Geol. Survey Geol. Atlas, Tahlequah folio (No. 122), p. 5, 1905; Muskogee folio (No. 132), p. 4, 1906.

[19] Drake, N. F., A geological reconnaissance of the coal fields of the Indian Territory, Am. Philos. Soc. Proc., vol. 36, p. 380, 1898.

[20] Oral communication.

[21] Taff, J. A., Some erratic bowlders in middle Carboniferous shale in Indian Territory (abstract), Science, new ser., vol. 21, p. 225, 1905. Ice-borne bowlder deposits in mid-Carboniferous marine shales: Geol. Soc. America, Bull., vol. 20, pp. 701-702, 1910.

by E. O. Ulrich[22] and J. B. Woodworth.[23] The area of bowlder-bearing beds in the Caney shale, according to Taff, who carefully studied their character and distribution, extends from the vicinity of Atoka to within a few miles of the Oklahoma-Arkansas line. The identity, lithological and paleontological, of the bowlders with a large part of the Ordovician and Silurian strata in the Arbuckle Mountains, and the local relations of the Arbuckle and Ouachita mountains, according to Mr. Taff, "press toward the conclusion that the erratics had their sources in a range or group of mountains in the region now occupied by southern Indian Territory and northern Texas."[24] These mountains he considered a part of a supposed southeastward extension of the present Arbuckle uplift.

Veatch on source of Paleozoic sediments in Ouachita Mountains.

A. C. Veatch,[25] in a brief discussion of the Paleozoic rocks of the Ouachita Mountains, expresses the opinion that the land area that furnished the material for these immensely thick series of rocks lay to the south and southeast. He continues, "The relative position of the continental and oceanic areas was therefore at this time [Paleozoic era] somewhat reversed—the ocean occupying the greater part of what is now the central and western United States and the land the Coastal Plain of the eastern and southern United States and portions of the Atlantic Ocean and Gulf of Mexico."

Pennsylvanian rocks of north-central Texas.

According to N. F. Drake[26] most of the clastic material that forms the Pennsylvanian rocks of the Colorado coal field in north-central Texas appears to have been derived from an extensive old land area to the east and northeast,

[22] Ulrich, E. O., Revision of the Paleozoic systems, Geol. Soc. America, Bull., vol. 22, p. 352 footnote, 1911.

[23] Woodworth, J. B., Bowlder beds of the Caney shale at Talihina, Oklahoma, Geol. Soc. America, Bull., vol. 23, pp. 457-462, 1912. Abstract, Science, new ser., vol. 35, p. 319, 1912.

[24] Taff, J. A., op. cit., Science, new ser., vol. 21, p. 225.

[25] Veatch, A. C., Geology and underground water resources of northern Louisiana and southern Arkansas, U. S. Geol. Survey Prof. Paper 46, p. 17, 1906.

[26] Drake, N. F., Report on the Colorado coal field of Texas, Texas Geol. Survey, Fourth Ann. Rept., pp. 373-374, 1893. (Reprint), University of Texas, Bull. No. 1755, pp. 15-16, 1917.

now covered by later formations, and only a very small part of it from the older rocks of the Central Mineral region. His reasons for this conclusion may be briefly summarized as follows:

1. The outcrop or strike of the beds is almost at right angles to the northern border of the Central Mineral region.
2. The beds indicate deeper water and slower deposition near the Central Mineral region than farther north.
3. Each bed at or near the border of the Central Mineral region dips westward and overlaps in this direction the underlying beds, in much the same way that the younger foreset beds of delta deposits overlap the older beds.
4. Conglomerates extend almost to Red River, and the pebbles composing them remain remarkably uniform in character; they include no pebbles of limestone and marble such as would be derived from the rocks in the Central Mineral region.
5. The beds indicate that the sea was deeper to the west than to the east.

The same view regarding the source of the land-derived sediments of the Pennsylvanian rocks of north-central Texas has been expressed by C. L. Baker,[27] R. T. Hill,[28] E. T. Dumble,[29] and F. B. Plummer,[30] but Hill at the same time expressed the view that an old land mass in eastern Texas also supplied the sediments for the Carboniferous rocks in southeastern Oklahoma and western Arkansas.

Carbon ratios of Pennsylvanian coals in northern Texas.

M. L. Fuller in a recent paper on the relation of oil to

[27] Udden, J. A., Baker, C. L., Böse, Emil, Review of the geology of Texas, Texas Univ., Bull. No. 44, pp. 106-107, 1916.

[28] Hill, R. T., Geography and geology of the Black and Grand prairies, Texas: U. S. Geol. Survey, Twenty-first Ann. Rept., pt. 7, pp. 91-92, 103-104, 1901.

[29] Dumble, E. T., The individuality of Texas geology, The Rice Institute pamphlet, vol. 3, No. 2, pp. 155-156, April, 1916. Origin of the Texas domes, Am. Inst. Min. Eng., Bull. 142, p. 1634, Oct., 1918. The Geology of East Texas, Univ. of Texas Bull. No. 1869, pp. 11-13, 1920. Discussion of paper by E. DeGolyer on the theory of the volcanic origin of salt domes, Am. Inst. Min. and Met. Eng., Trans., vol. 61, p. 476, 1920.

[30] Plummer, F. B., Preliminary paper on the stratigraphy of the Pennsylvanian formations of north-central Texas (unpublished manuscript).

carbon ratios of Pennsylvanian coals in northern Texas[31] says:

"The high carbon ratio east of the Carboniferous area, apparently higher than that around the Wichita Mountains on the north or the Central Texas Uplift on the south, is very suggestive and apparently points to an area of high disturbance beneath the Cretaceous immediately east of the margin of the latter. Whether there is an old land mass of pre-Pennsylvanian rocks, an arch of older Pennsylvanian (Bend, etc.) or a series of troughs of the latter between arches of older rocks, is not yet established."

Similar conclusions have also been expressed by Fuller in the references cited below.[32]

Thickness and extent of sediments derived from Llanoria.

Llanoria was greatly croded and was of vast size, as shown by the large areal extent and enormous aggregate thickness of the Paleozoic rocks in the Arkansas Valley and Ouachita Mountains and of the Pennsylvanian rocks of north-central Texas.

The maximum thicknesses of the rock formations in the Ouachita Mountains and Arkansas Valley as given on page 64 aggregate 37,000 feet, but as their thicknesses differ considerably from place to place the total thickness in any particular part of these regions would be less than the aggregate given. Nevertheless the following estimates by several geologists of the aggregate thicknesses in different parts of the regions indicate that between 20,000 and 25,000 feet of rocks, of which fully 90 per cent are clastic, were laid down in the greater part of the Ouachita geosyncline comprising the present Ouachita Mountains and Arkansas Valley.

The total of the minimum and maximum thicknesses of the rocks in the Atoka and Coalgate quadrangles of Oklahoma, as given by J. A. Taff,[33] are 21,400 and 22,400

[31] Fuller, M. L., Relation of oil to carbon ratios of Pennsylvanian coals in north Texas, Econ. Geol., vol. **14**, no. 7, p. 541, Nov. 1919.

[32] Fuller, M. L., Carbon ratios in Carboniferous coals of Oklahoma, and their relation to petroleum, Econ. Geol., vol. **15**, No. 3, p. 234, April-May, 1920. Discussion of paper by F. B. Plummer on the stratigraphy of the Pennsylvanian formations of North-Central Texas, Assoc. Amer. Petroleum Geologists, Bull., vol. **3**, pp. 149-150, 1919.

[33] Taff, J. A., U. S. Geol. Survey Geol. Atlas, Coalgate folio (No. 74), 1901, and Atoka folio (No. **79**), 1902.

feet, respectively. J. C. Branner[34] has estimated that the Carboniferous rocks in the Arkansas Valley in Arkansas are 23,780 feet thick; N. F. Drake[35] has estimated that the "Coal Measures deposits" in Oklahoma are 24,500 feet thick; and the thickness of the rock formations of Cambrian to Carboniferous age in the Ouachita Mountains in west-central Arkansas, as given by A. H. Purdue,[36] aggregate 24,000 feet.

The combined width of the two regions here mentioned is 80 to 100 miles, and their length is about 200 miles. As the rocks were compressed into east-west folds and considerably faulted about the close of the Pennsylvanian epoch, they now occupy a smaller area than they did when they were horizontal or nearly so. The compression, as calculated for a large part of the Ouachita Mountains in Arkansas, has reduced this horizontal extent almost one-half. Furthermore, the rock formations of the Arkansas Valley and Ouachita Mountains extend an unknown though probably considerable distance both eastward and southward beneath the Gulf Coastal Plain.

The Pennsylvanian rocks of north-central Texas extend from the Central Mineral region northward to the State line and aggregate more than 5,000 feet in thickness, but only part of the Pennsylvanian sediments were laid down over all the area in which these rocks are now exposed, as is shown by the thinning of the strata to the west and their overlapping in this direction upon the Bend series of the Texas Geological Survey.[37]

Age and thickness of the exposed rocks of the Gulf Coastal Plain.

The exposed rocks of the Coastal Plain are of Lower Cretaceous, Upper Cretaceous, Eocene, Oligocene, Miocene, Pliocene and Quaternary ages. E. W. Shaw[38] has

[34] Branner, J. C., Thickness of Paleozoic sediments in Arkansas, this Journal, (4), vol. 2, pp. 229-236, 1896.

[35] Drake, N. F., A geological reconnaissance of the coal fields of the Indian Territory, Am. Phil. Soc. Proc., vol. 36, p. 388, 1898.

[36] Purdee, A. H., The slates of Arkansas, Arkansas Geol. Survey, pp. 30, 48, 1909.

[37] Drake, N. F., Report on the Colorado coal field of Texas, Texas Geol. Survey, Fourth Ann. Rept., pp. 374 et seq., 1893; (Reprint), University of Texas Bull. No. 1755, pp. 16 et seq., 1917.

[38] Shaw, E. W., Stratigraphy of the Gulf Coastal Plain as related to salt domes, Washington Acad. Sci., Jour., vol. 9, No. 10, p. 289, May 19, 1919.

summarized as follows the thicknesses of the sediments of these ages in Louisiana and eastern Texas:

"The aggregate thickness of the Cenozoic is commonly between 5,000 and 7,000 feet, the Eocene being 2,500 to 3,000, Oligocene and Miocene 2,000 to 2,500, and the Pliocene and Quaternary from 1,000 to 3,000. The upper Cretaceous seems to have the thickness ranging from 1,500 to 2,500 and the lower Cretaceous, where present, from a feather edge to about a thousand feet. Over a large area in coastal Louisiana and Texas the aggregate thickness of the various Cretaceous, Tertiary, and Quaternary formations probably ranges between 8,000 and 12,000 feet and may average about 10,000 feet.

"Apparently most of the formations thicken somewhat toward the coast but the average or aggregate amount of thickening is unknown. To the east there is a notable thinning and rise of certain formations at least; beds lying at a depth of 2,000 feet near Mobile lie at far greater depths two hundred miles to the west and a similar distance from the coast."

Structure of the Gulf Coastal Plain.

The Cretaceous and later sediments under the Coastal Plain have a general dip of 100 feet or less to the mile toward the Gulf, but those in the Mississippi embayment of the Gulf Plain lie in a downwarped trough of older rocks, where their general dip is toward the Mississippi, which runs through the middle of the embayment. The general dip just indicated is however broken by many small salt domes in Texas and Louisiana, by some faults and by several large domes and anticlines, among which are the Sabine uplift and Preston, Jackson, and Hatchetigbee anticlines. (See figure 1.)

The Preston anticline,[39] in northeastern Texas and southeastern Oklahoma, extends southeastward as far as Gober, Fannin County, Tex., and is in line or nearly in line with the trend of the Criner Hills uplift,[40] a subsidiary uplift in the Paleozoic rocks that lies south of and roughly parallel with the Arbuckle uplift of southern Oklahoma, which involves not only Paleozoic but pre-Cambrian rocks. As the southeast end of the Arbuckle uplift is concealed by rocks of Cretaceous age its extent

[39] Stephenson, L. W., A contribution to the geology of northeastern Texas and southern Oklahoma, U. S. Geol. Survey, Prof. Paper 120, pp. 133, 159-160 and Plate 17, 1919.

[40] Taff, J. A., Preliminary report on the geology of the Arbuckle and Wichita mountains in Indian Territory and Oklahoma, U. S. Geol. Survey, Prof. Paper 31, Plate I and pp. 47-50, 1904.

in this direction is not known, but L. W. Stephenson[41] has expressed the opinion that the Preston anticline is probably directly related to it and that the folding of the Cretaceous strata in the anticline was merely incidental to the upbowing of the underlying basement rocks.

The Sabine uplift,[42] also called the Sabine peninsula,[43] lies in northwestern Louisiana and northeastern Texas. It is in line with the general southeastward trend of the Preston anticline and is not far south of a straight line projected S. 60° E. from the Arbuckle uplift, whose general trend is in this direction. Although the Sabine uplift and Preston anticline are structural features involving Tertiary, Cretaceous, and probably Paleozoic or older rocks and are thus of Cretaceous or later age, they perhaps occupy the site of one or more pre-Cretaceous anticlines and represent merely an accentuation of the earlier anticlines.

The view that there is a relation between the structure of the Cretaceous and Tertiary sediments of the Gulf Coastal Plain and the structure of the underlying Paleozoic or older rocks has been expressed by other geologists, especially those who have studied the problems presented by the salt domes of the coastal plain. The generally accepted opinion regarding these domes are that they lie along lines of fracture in the Paleozoic or older rocks. These lines of fracture, as well as the Sabine uplift and other folds here mentioned, may have been first produced in the Paleozoic or pre-Paleozoic rocks prior to the Cretaceous period and further movement may have taken place during Cretaceous or later time.[44]

[41] Stephenson, L. W., op. cit., p. 160.

[42] Harris, G. D., Oil and gas in northwestern Louisiana with special reference to the Caddo field, Louisiana Geol. Survey, Rept. for 1909, Bull. 8, Plate 1 and pp. 5-8, 1908. Oil and gas in Louisiana with a brief summary of their occurrence in adjacent States, U. S. Geol. Survey, Bull. 429, Plate 1, figure 1 and p. 9, 1910.

Matson, G. C., and Hopkins, O. B., The DeSoto-Red River oil and gas field, Louisiana, U. S. Geol. Survey, Bull. 661, pp. 117-118, and Plate 7, 1918.

Powers, Sidney, The Sabine uplift, Louisiana: Amer. Assoc. Petroleum Geologists, Bull., vol. 4, no. 2, pp. 117-136, 1920.

[43] Harris, G. D., Rock salt—its origin, geological occurrences and economic importance in the State of Louisiana, Louisiana Geol. Survey, Rept. for 1907, Bull. 7, Plate 24, and pp. 79-80, 1908.

[44] Since the transmittal of the present paper for publication a paper by Powers (Amer. Assoc. Petroleum Geologists, Bull., vol. 4, no. 2, pp. 117-136, 1920) has been published in which he expresses a similar view regarding the Sabine uplift.

Concealed rocks of the Gulf Coastal Plain.

The relations of the rocks along the borders of the Gulf Coastal Plain show that the pre-Cambrian, Cambrian, Ordovician, Silurian, Devonian, Carboniferous (including Mississippian, Pennsylvanian and Permian) rocks are overlain by Cretaceous and younger beds. Rocks of these ages underlie the entire Gulf Plain, but their age and character at any particular place can be determined only by deep wells that penetrate the basement rocks, though their general character may be inferred at some places with a fair degree of certainty for a short distance from their outcrops. For example, the pre-Cambrian crystalline rocks that are exposed in the Appalachian region of Alabama doubtless extend many miles southwestward beneath Lower and Upper Cretaceous beds, and similar rocks that are exposed in the Arbuckle Mountains of southern Oklahoma doubtless extend at least several miles southeastward beneath Lower Cretaceous beds.

Rocks belonging to the Pennsylvanian series are, so far as known, the youngest Paleozoic rocks that lie beneath the Gulf Plain except those in a small area along Red River in northern Texas and southern Oklahoma, where the underlying rocks are Permian. No Triassic and Jurassic rocks are known to underlie any part of the Gulf Plain, but some geologists postulate the occurrence there of Permian or Triassic rocks in order to explain the source of the enormous quantities of salt and other minerals of the numerous salt domes of Texas and Louisiana.

E. T. Dumble[45] says:

"In all the region east of Llano [Central Mineral region of Texas] * * * the latest Paleozoic rocks are those of the Bend formation, which is basal Pennsylvanian, and these are only known contiguous to the Llano border.

"Along the southeastern border of the Llano region the Cretaceous in places overlaps the Bend and lies upon the older Paleozoics. Along the southern line the Bend seems to be entirely absent. The evidence of further westward extension of the underlying Bend is found in its exposures along the western border of the Llano area and is obtained from well drilling. A well

[45] Dumble, E. T., The geology of east Texas, University of Texas Bull. No. 1869, pp. 11-13, Feb., 1920.

southwest of Uvalde passed entirely through the Cretaceous into black shale which is believed to represent the Bend. Wells north and west of Uvalde have encountered similar materials below the Cretaceous. The Bend is also well developed in the Paleozoic area west of the Pecos. This would indicate that during the Bend the Llano area was a peninsula extending northward from the Llanoria land mass.''

The extent of the rocks of Pennsylvanian age underneath the Coastal Plain in eastern Texas is not known, but, as pointed out by Dumble,[46] they are probably confined to the extreme western and northern borders of the Coastal Plain in that State. Sidney Powers,[47] who has collected much information on deep wells in eastern Texas, says:

''Recent borings, * * * starting in one instance in the Tertiary and in the other instances in the Cretaceous, at Waco, Georgetown, Maxwell, San Antonio, and Leon Springs, find pre-Cambrian schist beneath the Cretaceous at depths of 3,700, 1,100, 3,000, 1,800 and 1,100 feet, respectively.''

Wells at and near Fort Worth, Tex., have penetrated sandstone and shale of Pennsylvanian age,[48] and a well at Dallas, Texas, has penetrated rocks of apparently the same age.[49] Wells on the Preston anticline have revealed the presence of the Caney shale, of Mississippian age, and the Glenn formation, of Pennsylvanian age, directly underneath the strata of Lower Cretaceous age, as far southeast as Denison, Texas.[50]

In Arkansas no wells have passed through the Cretaceous rocks south of Nashville. A well at that place penetrated rocks of apparent Carboniferous age.[51]

[46] Idem.

[47] Powers, Sidney, The Butler salt dome, Freestone County, Texas, this Journal, (4), vol. 49, p. 141, 1920.

[48] Winton, W. M., and Adkins, W. S., The geology of Tarrant County, Univ. of Texas Bull. No. 1931, pp. 25, 107-114, March, 1920.

[49] Fuller, M. L., Relation of oil to carbon ratios of Pennsylvanian coals in north Texas, Economic Geology, vol. 14, no. 7, p. 541, Nov., 1919.

[50] Hopkins, O. B., Powers, S., and Robinson, H M., Structure of the Madill-Denison area, Oklahoma and Texas, with notes on the oil and gas development in that and adjoining areas, U. S. Geol. Survey, Bull. (in press.)

[51] Miser, H. D., and Purdue, A. H., Asphalt deposits and oil conditions in southwestern Arkansas, U. S. Geol. Survey, Bull. 691-J, p. 290, 1918.

Deformation of rocks in the Arbuckle and Wichita mountains.

Although several unconformities[52] separate the Paleozoic formations in the Arbuckle Mountains, the beds were folded and faulted mainly during two periods.[53] The first of these periods occurred near the close of the Mississippian epoch or near the beginning of the Pennsylvanian epoch, when the western part of the region was probably elevated high enough to form mountains. The land formed by this uplift remained above sea level during a large part of the Pennsylvanian epoch, but before the close of the epoch it was submerged, in part at least, and the Franks conglomerate of Pennsylvanian age was deposited across it on the eroded edges of the older strata. The second period of folding and faulting occurred near the close of the Pennsylvanian epoch and prior to the deposition of the nearly flat-lying "Red Beds," the oldest of which are of very late Pennsylvanian or early Permian age. At this time also the rocks in the Arkansas Valley and the Ouachita Mountains were closely compressed into numerous east-west folds and were faulted at many places.

The history of the Wichita Mountains was regarded by J. A. Taff as similar to that of the Arbuckle Mountains.[54] The Arbuckle and Wichita areas, being land during much of the Pennsylvanian epoch, were outliers of the main Pennsylvanian land mass to the southeast or formed a part of it.[54a]

[52] Taff, J. A. Preliminary report on the geology of the Arbuckle and Wichita mountains in Indian Territory and Oklahoma, U. S. Geol. Survey, Prof. Paper 31, 1904.

Reeds, C. A. A report on the geological and mineral resources of the Arbuckle Mountains, Oklahoma, Oklahoma Geol. Survey, Bull. 3, 1910.

——The Hunton formation of Oklahoma, this Journal (4), vol. 32, pp. 256-268, 1911.

[53] Taff, J. A. Op. cit., pp. 15, 33-35, 37-38, 1904. U. S. Geol. Survey Geol. Atlas, Tishomingo folio (No. 98) pp. 5, 7, 1903.

[54] Taff, J. A., U. S. Geol. Survey, Prof. Paper 31, p. 80.

[54a] Since this paper was written R. C. Moore gave a paper before the Chicago meeting of the Geological Society of America, in December, 1920, in which he presented the conclusion that there was only one main period of folding and faulting in the Arbuckle Mountains. This period, which was accompanied by orogenic movements in the Ouachita Mountains and Arkansas Valley, he places in the late Pennsylvanian. One of the principal features of his evidence for this conclusion is that the Franks conglomerate is not equivalent to the Wapanucka limestone, as was held by Taff, but is in general the equivalent of the Seminole conglomerate which is regarded as being late Pennsylvanian in age and which is thus much younger than the Wapanucka limestone.

Buried Pennsylvanian hills in northern Texas and southern Oklahoma.

Sidney Powers[55] says:

"Information concerning the extent of this former land area [Pennsylvanian land area in east-central Texas] * * * is being secured by the subsurface discoveries at Healdton, Oklahoma, and at Electra, Burkburnett, and Petrolia, Texas, and in the area south and east of these fields. Granite of pre-Cambrian age has been found beneath the Petrolia field, in Clay County, at a depth of 4,240 feet in the Texas Company Byers No. 41 and in a well 7 miles north of St. Jo, Montague County, at 3,007 feet. Limestone, which has been identified as probably of Ordovician age, occurs above the granite in the Byers well below 3,750 feet and in Ball No. 1, 5 miles north of Myra, Cooke County, below 2,195 feet (identified by Dr. J. A. Udden). However, most of the massive limestone found in the deep wells in the Red River section is supposed to be of Pennsylvanian age, unconformable with the overlying Cisco beds [of Pennsylvanian age]. These buried hills are interpreted as outliers of the main land area to the southeast."

The buried hills just mentioned lie not far south of the Arbuckle and Wichita mountains and doubtless stood above sea level during much of the time in the Pennsylvanian epoch that these two regions were land. The occurrence of limestone of supposed Pennsylvanian age beneath the unconformity in the buried hills region and the occurrence of the Cisco [Pennsylvanian] beds above it indicate that the folding and uplift in this region, which has been described by Powers and others,[56] took place during the Pennsylanian epoch.

Trans-Mississippian extension of Appalachian land area.

J. C. Branner has presented much evidence in support of the theory that the "old Appalachian land area crossed

[55] Powers, Sidney, The Butler salt dome, Freestone County, Texas, this Journal, (4), vol. 49, p. 142, Feb., 1920.

[56] Powers, Sidney, Idem.

——Ordovician strata beneath the Healdton oil field, Oklahoma (Abstract), Geol. Soc. America, Bull., vol. 28, p. 159, 1917.

——The Healdton oil field, Oklahoma, Econ. Geology, vol 12, pp. 594-606, 1917.

Hager, Lee, Red River uplift has another angle, Oil and Gas Jour., pp. 64-65, Oct. 17, 1919.

Merritt, J. W., Pennsylvanian sedimentation around Healdton Island, Amer. Assoc. Petroleum Geologists, Bull., vol. 4, No. 1, pp. 47-52, 1920.

what is now the lower Mississippi Valley from northern Alabama to the pre-Cambrian area northwest of Austin, Texas.''[57] His conclusions are so important that practically all his summary is here quoted.

''I. The Ouachita anticline [uplift] is the structural equivalent of the Cincinnati-Nashville arch * * * .

II. The Coal Measures drainage of the Illinois-Indiana-Kentucky basin flowed westward through the Arkansas valley into a Carboniferous mediterranean sea.

III. The drainage of the Coal Measures region south of the Ouachita anticline [uplift] flowed westward and entered this sea north of the Texas pre-Cambrian area.

IV. The drainage of both the Arkansas and Texas Carboniferous areas was reversed about the end of Jurassic times, when orographic movements over southeast Arkansas, eastern Texas, Louisiana, and Mississippi submerged the former extension of the Appalachian watershed and admitted the early Cretaceous sea across the Paleozoic land as far north as southern Illinois.

V. This depression was not a deep one (Hilgard)[58] and did not all occur at one time, for there have been subsequent disturbances of a more or less similar nature in the same region.

VI. The evidences of these depressions are:

1. The reversed drainage of the Arkansas valley.

2. The reversed drainage over the Carboniferous area of central Texas.

3. The submerged eastern end of the Ouachita uplift.

4. The eastward slope of the peneplain of the Ouachita region.

5. The direction of the faults and folds near the eastern exposure of the Lower Coal Measures in Arkansas.

6. The great [Balcones] fault through Texas near the Tertiary border, having a downthrow of 1,000 to 1,500 feet on the south and east sides.

7. Eruptive rocks accompanying the Texas [Balcones] fault and the Tertiary border through that State and Arkansas to the Arkansas river.

8. Hot springs near the same line.

9. Faults in Alabama with a downthrow of 10,000 feet or more on the northwest side.

10. The thickness of the Cretaceous and Tertiary sediments over the depressed area: from 4,000 to 10,000 feet.

VII. The southwestern or central Texas end of the Appalachian land area was formerly covered by Cretaceous sediments,

[57] Branner, J. C., The former extension of the Appalachians across Mississippi, Louisiana, and Texas, this Journal, (4), vol. 4, pp. 357-371, 1897.

[58] Hilgard, E. W., On the geological history of the Gulf of Mexico, this Journal, (3), vol. 2, p. 394, 1871.

but it has since been uncovered by erosion; farther east it is still concealed.

VIII. The Carboniferous beds uncovered in Texas all belong to the Upper Coal Measures; it is inferred that a greater thickness is still covered.

IX. The character of both the Silurian [Cambrian, Ordovician, Silurian, and Devonian] and Lower Coal Measures [Mississippian and Pennsylvanian] sediments of the Ouachita uplift show that they came from the south, so that the land area must have been in that direction during Paleozoic times.

X. The sea occasionally invaded both the Arkansas and Texas synclinal troughs during Coal Measures times, but coal-forming conditions obtained in the Texas syncline later than in the Arkansas basin.

XI. The Tertiary depression was probably more marked on the Arkansas than on the Tennessee side of the embayment; this is shown by the Cretaceous border being concealed by the Tertiary deposits in Arkansas, while in Tennessee, Mississippi and Alabama they are exposed in a broad belt.''

Arthur Winslow, who studied the Carboniferous rocks in the Arkansas Valley in Arkansas about 30 years ago, expressed the opinion that ''the similarity between the structure of this area and that of the Carboniferous area in Pennsylvania is not a mere accident, but is due to a trans-Mississippian extension of the same cause.''[59] He thus appears to to have believed in the extension of the Appalachian land area across the lower Mississippi Valley.

The opinion that the Appalachians extended westward across the lower Mississippi Valley into Texas has also been expressed by other geologists, though they have held that there were times when the lower part of this valley was submerged, so that the Paleozoic land area to the west was disconnected during such times from the main part of the Appalachian land area to the east. The opinions of different paleogeographers on this matter as they are expressed on their maps are given below for the Paleozoic era, and for the Triassic and Jurassic periods.

Stuart Weller,[60] who published two paleogeographic maps in 1898, held that the southern end of the Appalachian land area extended westward across the lower

[59] Winslow, Arthur, The geotectonic and physiographic geology of western Arkansas, Geol. Soc. America, Bull., vol. 2, p. 231, 1890.

[60] Weller, Stuart, Classification of the Mississippian series, Jour. Geology, vol. 6, pp. 306-308, 1898.

Mississippi Valley just before the beginning of Mississippian time and during Osage time.

T. C. Chamberlin and R. D. Salisbury,[61] on several maps published in 1906, show land extending from the Appalachians westward across the lower Mississippi Valley to and beyond Texas during early, middle, and late Cambrian, middle Ordovician, Niagaran, Onondagan, Upper Devonian, Mississippian, and Pennsylvanian times; they show embayments occupying the lower Mississippi Valley during Helderberg and Hamilton times, and do not show any submergence in this part of the valley during Triassic and Jurassic times.

W. B. Scott,[62] on his paleogeographic maps of North America published in 1907, showed the lower Mississippi Valley to be "land or unknown" during Ordovician, Silurian, and Upper Carboniferous times, showed that it was submerged during Devonian and Lower Carboniferous times, and that it was land during Triassic and Jurassic times.

Bailey Willis, on his paleogeographic maps published in 1909[63] and 1910,[64] designates the lower Mississippi Valley as "Land or sea; more likely sea" during early Cambrian, Middle Ordovician, Silurian, Middle Devonian, Mississippian, Pennsylvanian, latest Paleozoic, and Triassic times. He designates it as "Land or sea; more likely land" during late Jurassic time, and holds that it was submerged by epicontinental marine waters during "Late Middle and Upper Cambrian" times.

A. W. Grabau[65] has published maps showing the paleogeography of North America (1) at the end of "Upper Cambric" time, (2) in early "Beekmantownian" time, (3) at the end of "Beekmantownian" time, (4) at the end of Chazy time, and (5) at the end of Trenton time, and in

[61] Chamberlin, T. C., and Salisbury, R. D., Geology, vols. 2 and 3, Henry Holt & Co., New York, 1906.

[62] Scott, W. B., An introduction to geology, The Macmillan Co., 1917.

[63] Willis, Bailey, Paleogeographic maps of North America, Jour. Geology, vol. 17, 1909.

[64] Willis, Bailey and Salisbury, R. D., Outlines of Geologic history with especial reference to North America, The University of Chicago Press, 1910.

[65] Grabau, A. W., Physical and faunal evolution of North America during Ordovicic, Siluric, and early Devonic time, Jour. Geology, vol. 17, pp. 209-252, 1909.

Willis, Bailey, and Salisbury, R. D., Outlines of Geologic history with especial reference to North America, pp. 44-88, University of Chicago Press, 1910.

none of them does he show a westward extension of the Appalachians across the lower Mississippi Valley.

Charles Schuchert[66] holds that there was a land connection between Texas and the Appalachians during the "Upper Acadic" (Middle Cambrian) and "Upper Siluric," but he[67] and E. O. Ulrich[67] hold that the Appalachian land area was separated by epicontinental seas from the land area in Louisiana and eastern Texas at all other times during the Paleozoic era. Schuchert[68] also holds that no part of the present Gulf Coastal Plain was submerged during the Triassic and Jurassic periods, except southern Texas, which he thinks was submerged during late Upper Jurassic time.

Llanoria as a positive element and its location by paleogeographers.

All paleogeographers agree that Llanoria was one of the positive elements of North America during the Paleozoic era, and was thus undergoing erosion during most of the era, but although they agree as to its general location they differ as to its boundaries. This disagreement, however, is not surprising, as the outlines of Llanoria changed from time to time, and as our knowledge of these changes is very scant.

Willis states as follows:[69] "It is bounded by the Gulf of Mexico on the southeast; on the north it probably extends to the folded zone of Paleozoics in Indian Territory [Oklahoma]; and on the west it appears to be separated by the zone of folding in central New Mexico from the similar [positive] elements in Colorado and Arizona." On a recent map he[70] shows that the land area under discussion was connected with Ozarkia to the north and

[66] Schuchert, Charles, Paleogeography of North America, Geol. Soc. America, Bull., vol. 20, maps, 1910.

[67] Ulrich, E. O., and Charles Schuchert in Chas. Schuchert, Paleogeography of North America, Geol. Soc. America, Bull. vol. 20, maps, 1910.

Ulrich, E. O., Revision of the Paleozoic systems, Geol. Soc. America, Bull., vol. 22, fig. 7, 1911.

Ulrich, E. O., The Ordovician-Silurian boundary, Int. Geol. Cong. XII, Canada, 1913, C. R., pp. 660-667, 1914.

[68] Schuchert, Charles, op. cit.

[69] Willis, Bailey, A theory of continental structure applied to North America, Geol. Soc. America, Bull., vol. 18, pp. 394-395, 1909.

[70] Willis, Bailey, Discoidal structure of the lithosphere, Geol. Soc. America, Bull., vol. 31, Plate 11, 1920.

was disconnected from Appalachia to the east, from Mexia (a new name for the positive area in Mexico) to the southwest, and from Colorado Land to the northwest. Schuchert[71] considered that it extended from Columbia (old name for positive element in Mexico) northeastward across eastern Texas into Louisiana and into southern Arkansas. The Llano (Central Mineral) region he placed on its northwest border. Ulrich[72] agrees with Schuchert's location of the Paleozoic land area in Louisiana and eastern Texas except that he says it was disconnected from Columbia by an embayment running northeastward from Mexico across Texas, passing just east of the Central Mineral region, and then connecting with the west end of the embayment in the Ouachita geosyncline.

Conclusions.

Conclusions regarding the Paleozoic land area under discussion can not be very definite, as the rocks that formed it have been entirely concealed by Cretaceous and later rocks, but the conclusions presented below appear to be justified by the evidence at hand.

A land area, which has been called Llano by Willis, Schuchert, and Ulrich and Llanoria by Dumble and Powers, existed in Louisiana and eastern Texas during much if not most of the Paleozoic era and during the Triassic and Jurassic periods of the Mesozoic era. It varied in outline from time to time. It may have occupied a part of the area of the present Gulf of Mexico; at times it was doubtless connected with large land areas that occupied at least much of central and northern Texas, southern Oklahoma, and southern Arkansas, and for short periods it may have extended eastward across the lower Mississippi Valley and joined the southwest end of the Appalachian area. It furnished most of the sediments that formed the clastic rocks of Pennsylvanian age in north-central Texas and those of Ordovician, Silurian, Mississippian, and Pennsylvanian age in the Ouachita Mountains and Arkansas Valley of Arkansas and Oklahoma. At times, as during the Devonian period, it had

[71] Schuchert, Chas., op. cit., p. 470, and plate 49.

[72] Ulrich, E. O., Revision of the Paleozoic systems: Geol. Soc. America, Bull, vol. 22, fig. 7 on page 368, 1911.

very little relief but at other times, as during the Ordovician and Silurian periods and the Mississippian and Pennsylvanian epochs, it was mountainous. It was depressed and entirely submerged during Lower Cretaceous time, and later depressions carried the sea across it during Upper Cretaceous and Tertiary times, so that its rocks are now covered and concealed by deposits of these ages. The discovery of pre-Cambrian schists directly beneath Cretaceous strata at Waco, Georgetown, Maxwell, San Antonio, and Leon Springs, Tex., suggests that the rocks of this buried land area were similar to the crystal-line rocks that are now exposed in the Piedmont Plateau of the eastern United States. If so such rocks underlie the Cretaceous strata over much of Louisiana, eastern Texas, and perhaps adjoining areas to the south and east. Prominent structural features of the Gulf Coastal Plain, including the Preston anticline and Sabine uplift, may mark the location of some of the folds that were produced in the rocks on the old land area but that have undergone further movement since they were buried by Cretaceous and later sediments. The increase in the intensity of the folding of the rocks in the Ouachita Mountains and Arkansas Valley toward the south suggests that the deformation of the basement rock of the Gulf Plain south of these regions was still greater.

The results of future deep drilling in the Gulf Coastal Plain and further study of the Paleozoic and older rocks that are exposed around the borders of the Gulf Plain will add greatly to our imperfect knowledge of the old land area considered in this paper.