OKLAHOMA GEOLOGICAL SURVEY

Chas. N. Gould, Director

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THE PERMIAN OF WESTERN OKLAHOMA

AND

THE PANHANDLE OF TEXAS

By

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THE PERMIAN OF WESTERN OKLAHOMA AND THE PANHANDLE OF TEXAS

INTRODUCTION

The object of this paper is to present certain facts which have recently come to light regarding the Permian rocks of western Oklahoma and the Texas Panhandle, and particularly to correct certain errors of correlation, the responsibility of which must be charged to the senior author who first mapped and described these formations some twenty years ago. This paper is by no means intended to be the final word on the subject, but simply to present our best information as of October 1926. New data which are constantly being secured by scores of geologists who are scrutinizing the records of the deep drilling in the region will doubtless cause a revision of many of the current opinions.

The authors are under great obligation to Frank C. Greene and R. L. Clifton for a reading of the manuscript, to J. V. Howell, C. Don Hughes and C. Max Bauer of Amarillo for suggestions regarding the location of the axis of the Anadarko Basin, and particularly to Dr. Roy A. Wilson for a revision of the paragraphs dealing with the paleogeography of the region.

EARLIER WORK ON THE PERMIAN OF THE REGION

In 1905 the senior author[1] published Water Supply Paper No. 148 of the U. S. Geological Survey. In this paper was presented the classification of the Permian of the then Territory of Oklahoma as shown on next page.

It will be noticed that two conspicuous gypsum-bearing formations were described, namely, the Blaine and the Greer. The Blaine gypsum was supposed to be confined to the northern part of the Territory, not having been traced farther south than northwestern Canadian County. The Greer gypsum, which was believed to lie at a higher level than the Blaine, and to be separated from it by the Woodward formation, was exposed mainly in the southwestern counties along the various branches of Red River and their tributaries. In this report the outcrops of the Greer were divided into an "eastern area" and a "western area." The rocks of these two areas were supposed to occur at the same stratigraphic horizon.

1. Gould, Chas. N., The geology and water resources of Oklahoma: U. S. Geol. Survey, Water-Supply Paper 148, 1905.

Section of Oklahoma Permian Red Beds

Quartermaster formation	
Greer formation	Mangum dolomite member
	Collingsworth gypsum member
	Cedartop gypsum member
	Haystack gypsum member
	Kiser gypsum member
	Chaney gypsum member
Woodward formation	Day Creek dolomite member
	Whitehorse sandstone member
	Dog Creek shale member
Blaine formation	Shimer gypsum member
	Medicine Lodge gypsum member
	Ferguson gypsum member
Enid formation	

In 1906 the senior author[2] published Water-Supply Paper No. 154, and in 1907 Water-Supply Paper No. 191.

In Water-Supply Paper 154, the ledges comprising what was then thought to be the Greer gypsum were traced from their type locality, Greer County, Oklahoma, across southern Collingsworth, Donley, and Armstrong counties, Texas. The gypsum and interbedded shales constituting the Greer were found to be exposed in Palo Duro Canyon along the south (Prairie Dog) fork of Red River. The thickness of the formation was given as 180 feet, above which was 275 feet of red clay-shale and sandstone which was assigned to the Quartermaster formation.

In Water-Supply Paper 191, the same formation, the Greer, was noted both in Palo Duro Canyon in southeastern Randall County, and also in the Valley of South Canadian River in northeastern Potter and southeastern Moore counties. The Permian red beds above the Greer were called Quartermaster. Along the Canadian River the supposed Quartermaster was marked by the fact that it there contained two members, thought to be lentils, one of gypsum, the Saddlehorse gypsum lentil, and the other of dolomite, the Alibates dolomite lentil, "which so far as known do not appear elsewhere in Texas or Oklahoma."[3]

The following section of the Greer and Quartermaster formations, as the terms were then used, and which may be considered typical of the region, was made on the bluffs north of

2. Gould, Chas. N., Geology and water resources of the eastern portion of the Panhandle of Texas: U. S. Geol. Survey, Water-Supply Paper 154, 1906.
Geology and water resources of the western portion of the Panhandle of Texas: U. S. Geol. Survey, Water-Supply Paper 191, 1907.
3. Gould, Chas. N., Op. cit., p. 16.

Canadian River at the Leaverton ranch, southeastern Moore County, Texas.

Section of Permian Red Beds, Southeastern Moore County, Texas

			Feet
Quartermaster	Alibates lentil	Red shale on slope	60
		White massive dolomite forming cap of bluff	10
	Saddlehorse lentil	Red shale	50
		White gypsum	4
		Red shale	8
		Blue shales	6
		Red shale and soft red sandstones with satinspar in lower part	140
Greer		Massive white gypsum in ledges	10-20
		Red shale	25

It was in the latter report, Water-Supply Paper No. 191,[4] that the senior author first called attention to the domes, synclines and other forms of geologic structure along the Canadian River in the Texas Panhandle. These facts having been duly embalmed in the literature were forgotten until 1917, when a planetable survey of the region was made. In 1918 a well was located more than 200 miles from the nearest oil and gas production. This well, which is now known as Mastersons No. 1, located on the John Ray Dome in northeastern Potter County, which came in in the spring of 1919, was the first producing gas well in the now famous Amarillo field.

LATER WORK ON THE PERMIAN

Very little detailed work has been done on the classification of the Permian of the Panhandle of Texas since the publication of the two Water-Supply Papers already referred to.

In 1924 Patton[5] published a report on Potter County, Texas, using the classification then in vogue. A few references have been made to the geology of the various bulletins of the American Association of Petroleum Geologists[6] and in the Oil and Gas

4. Idem.
5. Patton, Leroy T., The Geology of Potter County, Texas: Bureau of Economic Geology, University of Texas Bull. No. 2330, 1923.
6. Pratt, Wallace E., Oil and Gas in the Texas Panhandle: Bull. Am. Assoc. Pet. Geol., vol. 7, No. 3, pp. 237-246, 1923.
Harrison, T. S., Porphyry at Amarillo: Bull. Am. Assoc. Pet. Geol., vol. 7, 7. No. 4, pp. 434-439, 1923.

Journal,[7] but in none of these papers has any attempt been made to revise the stratigraphy of the region. Powers[8] in 1922 called attention to the "Amarillo Hills" underlying the domes along the Canadian River in the Panhandle of Texas, and the senior author[9] of this paper in 1923 first used the term Amarillo Mountains to apply to a buried granite ridge believed to extend northwest from the Wichita Mountains along the line of the Canadian River domes as far as the New Mexico line. In 1926 Bauer[10] presented a paper on the subject at the Dallas meeting of the American Association of Petroleum Geologists.

REVISION OF THE PERMIAN CLASSIFICATION OF WESTERN OKLAHOMA

As the result of a field conference held in southwestern Oklahoma in January 1924, several important facts regarding the stratigraphy of the Permian red beds in that region were brought to light. It was in a paper published by the senior author embodying the conclusions arrived at in this conference, that the location of the great structural trough in southwestern Oklahoma, named the Anadarko Basin, was first outlined.[11] At that time no one suspected the lateral extent of this syncline. Subsequent studies have shown that this great trough extends northwest-southeast across southwestern Oklahoma and much of the Panhandle of Texas paralleling the Wichita-Amarillo uplift which lies to the south for a distance of approximately 300 miles.

Another very important fact brought out by the 1924 conference was the correlation of the various gypsum beds. It was shown that the Blaine gypsum could be traced from northwestern Canadian County, Oklahoma, south around the eastern end of the Anadarko Basin in Stephens County, and back on the south side of the basin to connect with the "western area" of the Greer. It was demonstrated that the "eastern area" of the Greer lay at a higher stratigraphic horizon than the Blaine, separated from the latter by the Dog Creek, Whitehorse, and Day Creek formations. The writer suggested that the name "Greer" be abandoned and for the gypsum comprising the "eastern area" of the "Greer," he proposed the name Cloud Chief.

Subsequent studies have demonstrated that certain other changes should be made in the classification of the Permian

7. Lockwood, C. D., Geology of Panhandle is a mystery: Oil and Gas Journal, Vol. 23, No. 43, p. 30, March 18, 1926.
8. Powers, Sidney, Reflected buried hills and their importance in petroleum geology: Econ. Geology, Vol. XVII, No. 2, p. 249, 1922.
9. Gould, Chas. N., Crystalline rocks of the plains: Geol. Soc. of America, Bull. vol. 34, p. 552, 1923.
10. Bauer, C. Max, Oil and Gas fields of the Texas Panhandle: Bull. Am. Assoc. Pet. Geol., vol. 10, No. 8, pp. 733-746, August 1926.
11. Gould, Chas. N., A new classification of the Permian red beds of southwestern Oklahoma: Bull. Am. Assoc. Pet. Geol., vol. 8, No. 3, p. 323, 1924.

rocks of Oklahoma. As a result of data secured on a field conference held in northern Oklahoma, March 1926, the Enid has been subdivided into six formations, named in ascending order: Stillwater, Wellington, Garber, Hennessey, Duncan and Chickasha.[12] The terms Enid and Woodward are now used only as group names. The present status of the matter is shown in the following table which attempts to correlate the Oklahoma Permian red bed formations with those found in Texas.

Correlation Table of the Permian Formations of Oklahoma and Texas

Texas	Oklahoma	
Double Mountain	Quartermaster Cloud Chief Day Creek Whitehorse Dog Creek Blaine Chickasha Duncan	Woodward
Clear Fork	Hennessey Garber	Enid
Wichita (Albany)	Wellington Stillwater	

It has not been found possible to definitely correlate all the various Permian formations exposed in the Panhandle of Texas with those of Oklahoma by means of surface exposures, because of the fact that the greater part of the surface outcrops in this region consist of a blanket of rocks, chiefly sands, conglomerates, clay and caliche of late Tertiary age, which in most places cover and conceal the underlying Permian. However, several of the higher Permian formations may be traced by means of a study of well logs from their outcrops in western Oklahoma across the Texas Panhandle, and some of the more deeply buried Permian beds have also been so traced.

It is the wish of the authors of this paper to correct the present classification of the Permian where the same is known to be in error, and to set forth our present information of the classification and correlation of these formations.

MAJOR STRUCTURAL FEATURES

In order to understand the general stratigraphic problems, it will be necessary to discuss briefly the major structural features of the region.

12. Aurin, Fritz L., Officer, H. G., and Gould, Chas. N., Subdivisions of the Enid formation: Bull. Am. Assoc. Pet. Geol., vol. 10, No. 8, pp. 786-799, August, 1926.

In the region of the southern part of the High Plains in western Oklahoma, the Panhandle of Texas and northeastern New Mexico discussed herewith, there are two structural highs, the Wichita-Amarillo Mountains, and the Ancestral Rocky Mountains; also two structural lows, the Anadarko Basin lying north of the Wichita-Amarillo range, and a syncline or basin heretofore unnamed, lying south of the Wichita-Amarillo range. For this latter structural trough the name Palo Duro Basin is proposed. The general arrangement of these structural features and their relation to the features in the southern part of the Great Plains is shown on the map (Plate I.)

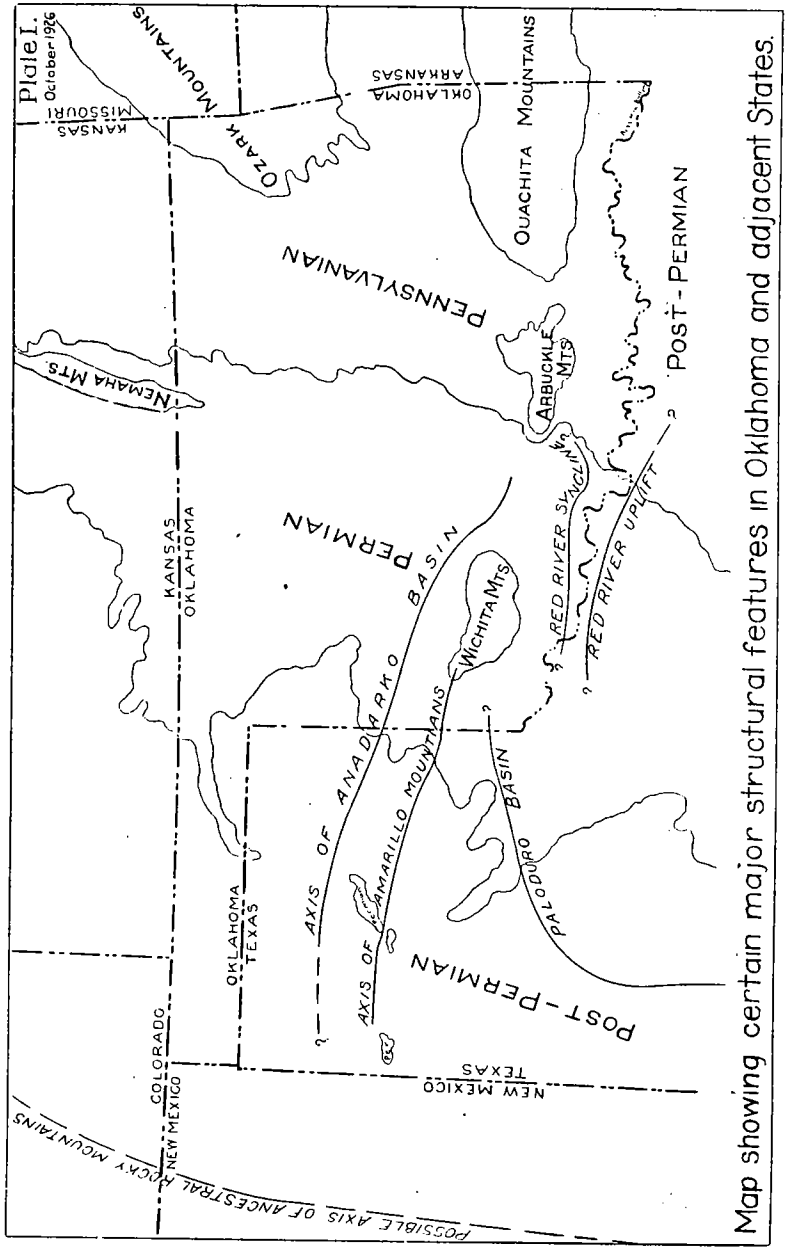
AMARILLO MOUNTAINS

Studies chiefly by numerous petroleum geologists working in the Panhandle region during the past few years, have demonstrated certain salient facts regarding the general structure of the region. The dominant structural feature of the Panhandle of Texas as understood at this time, determined largely by the study of well logs, is a major fold largely concealed by sedimentary rocks, underlain by a core of igneous rocks, chiefly granite, flanked by arkosic material or "granite wash," and probably by older Paleozoic sediments and covered by a ledge of limestone known locally as the "Big Lime." To this fold several names have been applied by workers in the field, such as Amarillo Hills, Amarillo Mountains, Panhandle anticline, Panhandle folds, and Panhandle arch. In order to avoid confusion of terms the name Amarillo Mountains will be used in this article to describe this major fold, this being the name first applied to this structural feature as a whole.[13]

Most geologists now believe that the Amarillo Mountains consist of a northwestern projection of the Arbuckle-Wichita Mountain axes, but whether in direct allignment with the Wichita axes or standing *en eschelon* is not definitely known. This fold enters the Texas Panhandle in Wheeler County and extends northwest across Gray, Carson, Hutchinson, Potter, and Moore counties into Hartley County. The length of the Amarillo Mounains is now believed to be in excess of 150 miles; its width is about 40 miles. Its elevation, using the "Big Lime" as a datum bed, averages 1,500 feet. The granite core appears to be not so wide. The axis of this buried ridge as now understood is shown on the map (Plate II.)

The Potter County fault is believed by many geologists to lie mainly south of the axis of the main fold, and to cut this fold at an acute angle in southwestern Moore County, Texas.

13. Op. cit. Crystalline rocks of the Plains: p. 552.



According to this interpretation the Bravo dome in northwestern Oldham County represents a high peak in the main range of the Amarillo Mountains.

However, many geologists now believe that the Bravo dome represents a separate, probably short ridge, more or less parallel to the Amarillo Mountains and separated from the main ridge by the Potter County fault. In this opinion the junior author concurs. It is also his present opinion that another fault parallel to the main axis of the Amarillo Mountains occurs in Beckham County, Oklahoma, and Wheeler County, Texas. According to this interpretation, the Amarillo Mountains would represent a horst between the Beckham County fault on the north and the Potter County fault on the south.

On the map (Plate II) presented herewith the location is given of the axis of the Amarillo Mountains, which conforms as nearly as possible to the consensus of opinion of the greater number of geologists now working in the Panhandle of Texas. It does not, however, represent the ideas of the junior author of this paper, who would end the axis of these mountains in western Moore or eastern Hartley counties. According to this interpretation the Bravo dome represents a separate ridge, probably short, and parallel to the main axis. In this opinion several geologists, notably C. Max Bauer, concur.

ANCESTRAL ROCKY MOUNTAINS

Another subsurface feature present in this part of the Great Plains has had an important influence on the stratigraphy of the Paleozoic rocks of the Panhandle; namely, the Ancestral Rocky Mountains. The name Ancestral Rocky Mountains was proposed by Lee[14] to describe a buried mountain range located in the western part of the High Plains. As located by Schuchert,[15] this range runs practically north and south extending from the region of the Black Hills south about as far as Clovis, New Mexico. This mountain range is believed to be a part of the great land mass Siouxia, which, during early Paleozoic time occupied much of what is now the north-central United States, as will be explained later in this article. It is now believed that during Pennsylvanian times the Ancestral Rocky Mountains were elevated to form a range of considerable size and during late Pennsylvanian and Permian times they were eroded thus forming a source of the sediments laid down over the Great Plains during these periods.

14. Lee, W. T., Early Mesozoic physiography of Southern Rocky Mountains, Smithsonian Miscellaneous Collections, Vol. 69, No. 4, 1918.
15. Schuchert, Charles, Text book of Geology, Part II, Historical Geology: 2nd. revised edition, p. 425, 1924.

Rich[16] has described a "buried granite mountain range" underlying the western Great Plains 30 to 70 miles east of the front range of the Rocky Mountains extending from Corona, New Mexico, northeastward for a distance of nearly 300 miles. The authors now believe that when all data have been collected these uplifts will be found to represent a general line of folding or series of folds which constitute the Ancestral Rocky Mountains.

ANADARKO BASIN

Paralleling the Amarillo Mountains on the north is the great structural trough, the Anadarko Basin, first mentioned in southwestern Oklahoma.[17] This syncline enters the Texas Panhandle from Oklahoma in northern Wheeler County and extends north and west for many miles. Enough records are not yet available to definitely outline the western limits of the basin, but it now appears probable that when the data are all in, the Anadarko Basin will be found to extend practically the entire length of the Amarillo Mountains. The location of the western end of the Anadarko Basin and its relation to the Potter County fault and the Bravo dome represents the conception of the senior author after consultation with a number of representative geologists now working in the Amarillo region. The junior author would end the basin in southeastern Hartley County and in this idea Bauer would concur. Clifton[18] extends this basin into Dallam County, Texas, and perhaps as far as southwestern Cimarron County, Oklahoma. Greene[19] would extend the western end of the basin into southeastern Hartley County.

It is obvious that sufficient data are not now available to enable us to write the final word on the subject.

PALO DURO BASIN

As studies have been carried forward on the geology of the southern part of the Great Plains during the past few years, it has become evident that there is a great structural trough lying south of the Arbuckle-Wichita-Amarillo mountain uplift. Neither the exact location nor the extent of this great syncline or basin are now definitely known.

16. Rich, John L., A probable buried mountain range of early Permian age east of the present Rocky Mountains in New Mexico and Colorado: Bull. Am. Assoc. Pet. Geol., vol. 5, No. 5, pp. 605-608, 1921.
17. Gould, Chas. N., Bull. Am. Assoc. Pet. Geol., vol. 8, No. 3, p. 323, 1924.
18. Clifton, R. L., Oil and Gas in Oklahoma, Woods, Alfalfa, Harper, Major, Woodward, and Ellis counties: Oklahoma Geological Survey Bull. 40-A, 1926.
19. Greene, Frank C., Subsurface Stratigraphy of western Oklahoma: Oklahoma Geological Survey Bull. 40-D, 1926. Map accompanying.

In 1922 Howell[20] described a syncline which he called the Red River syncline, passing east and west in Jefferson, Cotton, and Tillman counties, Oklahoma. In 1925 Hoots[21] described a great basin in western Texas. This may or may not be part of the same structural low as that described by Howell. On the new colored geological map of Oklahoma by Miser, a syncline is shown in western Harmon County at about the point indicated by Hoots on his map of Texas. In shape and outline this latter basin as it occurs in the Panhandle of Texas appears to differ from the Anadarko Basin in that it is probably shallower and more nearly circular in outline. The dips from the axes of the Wichita and Amarillo Mountains northward to the axis of the Anadarko Basin at most places are relatively steep; while the dips south from the mountains are more gentle.

For this structural low which lies south of the Amarillo Mountains, the authors propose the name Palo Duro Basin. The name is from Palo Duro Canyon, the deepest gash cut by nature on the Great Plains, which is located in Briscoe, Armstrong and Randall counties, Texas, which are in the northern part of the basin.

CHARACTER OF SEDIMENTS

GENERAL STATEMENTS

Before taking up the discussion of the Permian formations in more detail, a brief explanation of the various subsurface formations encountered by the drill will be given.

Generally there is a thickening of all beds recorded in well logs going down the dip off the axis of the Amarillo Mountains toward the Anadarko Basin. Logs of wells taken at intervals along the strike of the beds whether near the crest of the Amarillo Mountains or farther down the slope, reveal a very constant interval between recognizable horizons.

HIGHER BEDS

Using Carson County as a well log type, the first Permian formation encountered is the Day Creek (Alibates) dolomite, which here outcrops on the surface. Below the Day Creek lies 300 or 400 feet of red sands, red shale, and occasionally a thin bed of gypsum or lime, probably anhydrite. The so-called "quicksands" of the Hutchinson-Carson County oil fields are found in this zone. As will be shown later this probably represents the Whitehorse sandstone and Dog Creek shales.

20. Howell, J. V., Structural Factors in the Accumulation of Oil in Southwestern Oklahoma: Econ. Geol., vol. 17, No. 1, pp. 23-25, 27, 1922.
21. Hoots, H. W., Geology of a Part of Western Texas and southeastern New Mexico: U. S. Geol. Survey, Bull. 780-b, p. 113, plate III and VIII, 1925.

The next formation encountered is the Blaine gypsum, usually easily recognizable, averaging 300 feet thick. Below the Blaine there occurs a series of red shale, anhydrite, sand, and salt, averaging about 1,000 feet in thickness. Due to the fact that there are no definite markers within this series in the center of the Panhandle, and also because of the fact that salt is always predominant, this series of rocks is generally known to drillers as the "salt group" or "salt series." It is very probable that this series is the approximate equivalent of the Chickasha, Duncan, and possibly of other formations of the Permian of Oklahoma.

Encountered below the salt series, and resting on the so-called "Big Lime," is a bed of red and blue shales from 250 to 300 feet thick. In most logs this shale bed is one of the best markers in the Panhandle. Many geologists consider that these beds represent, in part at least, the Hennessey and Garber formations.

THE "BIG LIME"

The formation known as the "Big Lime" is usually encountered in wells at about 2,100 feet. As will be shown later it is now believed that the upper part of the "Big Lime" is Permian and the lower part Pennsylvanian. This formation consists of a series of limestone, shale, dolomite, and anhydrite, with limestone predominating, the general color being white, gray, or blue. In Carson and Hutchinson counties, the upper 300 or 400 feet is composed of anhydrite, with dolomite below; to the east and northeast, much blue shale appears. Over the crest of the Amarillo Mountains the Permian "Big Lime" is 400 to 600 feet thick, and probably 800 feet on the flanks. About 800 feet below the top, near the mountains, granite-wash occurs, and away from the mountains the section is sometimes more than 1,800 feet thick. Below the main part of the "Big Lime" a few miles north of the mountains there is sometimes a series 200 feet thick, consisting of shale, with streaks of lime, granite-wash, dolomite, and anhydrite. This zone is about three miles wide and lies a few miles north of the mountains parallel to them. It is a transition zone of granite-wash to the south grading into dolomites and lime to the north.

The chief production of both gas and oil occurs in dolomites in the "Big Lime" and in the granite-wash. Gas appears in dolomite just below the anhydrite bed about 400 feet below the top of the lime, the depth to the gas depending on the distance of the well from the axis of the Amarillo Mountains; the oil usually occurs just above sea level.

OKLAHOMA GEOLOGICAL SURVEY

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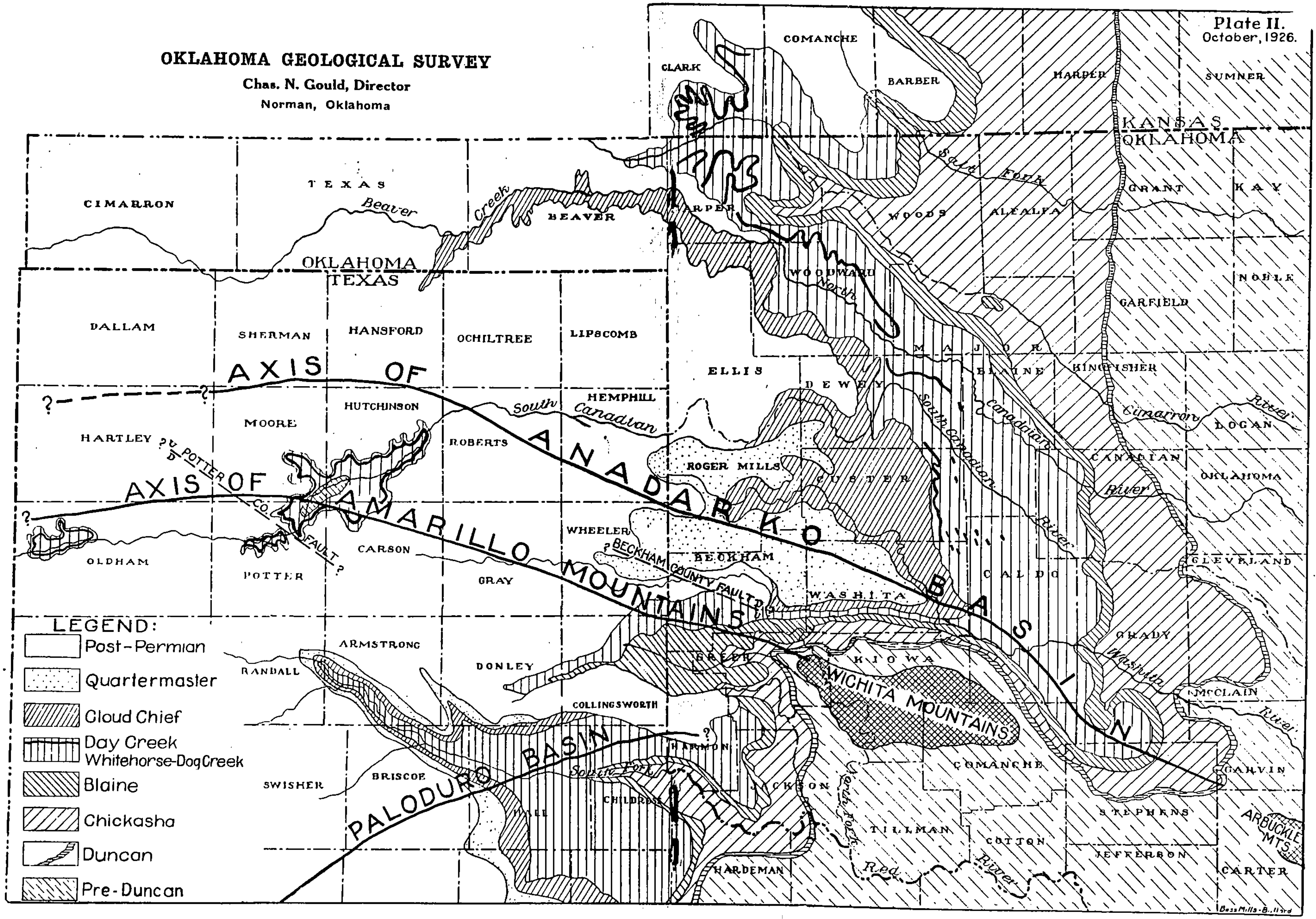

AGE OF THE "BIG LIME"

One of the problems perplexing the oil geologists in the Panhandle region today is the geological age of the "Big Lime," this being the chief oil and gas producing horizon. Chiefly on account of lack of data the question is not easy of solution. Fossils from deep wells are rare, and it is very difficult to correlate this subsurface formation by means of well logs with any definitely known surface horizon. Without at this time entering into a lengthy discussion of the subject, and citing the various arguments which must of necessity as yet be based on incomplete data, the authors wish to state that the present judgment of most geologists who have studied the question most carefully, and who are in a position to have correct opinions on the subject, is that the "Big Lime" includes sediments of both Wellington and Stillwater age. This will include the Flint Hill series, (the Council Grove, Chase, and Marion groups) of Kansas, and the Albany-Wichita of Texas.

It is still a moot question as to whether or not the lower part of the "Big Lime" represents rocks of upper Pennsylvanian age. The junior author basing his opinion on rather meager fossil evidence, believes that such is the case, and that the base of the Permian occurs with the first appearance of granite-wash and red shales.

CORRELATION OF FORMATIONS

GENERAL STATEMENT

Having discussed briefly the various formations encountered by the drill in the Panhandle region, we will next take up in order certain Permian formations of Oklahoma and north-central Texas and attempt their correlation with the beds encountered in the Texas Panhandle.

It has already been stated that it now appears probable that the upper part of the "Big Lime" of the Texas Panhandle is the equivalent of the Wellington plus the Stillwater, and that the red shale over the "Big Lime" probably represents the Garber and Hennessey of Oklahoma. The lower part of the "Big Lime" may represent Pennsylvanian limestone and shale.

Whatever may be the correlation of these beds, it is evident that a marked change in sedimentation occurred at the close of "Big Lime" time. What had been a shallow clear sea in the Panhandle region became charged with mud, and the Permian basin became the gathering ground for sediments originating probably both in the Ancestral Rocky Mountains to the northwest, and in the Arbuckle-Wichita Mountains to the southeast. The upper part of the Enid group, the Duncan and Chickasha formations, includes the salt series and the shale beds which rest upon the "Big Lime."

PERMIAN ROCKS

DUNCAN SANDSTONE

The Duncan sandstone of Oklahoma is now known to be the approximate equivalent of the San Angelo sandstone of Texas which is considered the base of the Double Mountain formation of Texas. The Duncan is encountered in the Sayre oil field of Oklahoma at a depth of from 1,100 to 1,200 feet.

In Beckham County, Oklahoma, the Duncan sandstone is about 100 feet thick and lies from 275 to 350 feet below the Blaine gypsum. This interval, which represents sediments of the Chickasha formation, increases down the dip but remains practically constant to the west along the strike. The Duncan appears to be present in Wheeler County, about 50 miles west of the Sayre fields, where it is shown in the log of the Pulaski gas well, eight miles northwest of Shamrock, as being twenty feet thick.

The Duncan finds its maximum development around the east end of the Anadarko Basin where it ranges up to 250 feet in thickness. It becomes less conspicuous to the west along the north flank of the Wichita Mountains and in Greer County, Oklahoma. Sawyer[22] writes: "The basal part of the Duncan apparently represents the rapid waste of an adjacent land, the detritus from which became less coarse as the land was worn down." Thus it appears that the sediments which formed the Duncan came from the Arbuckle Mountains and reached westward up the Anadarko Basin into Wheeler County, Texas, where they feather out or are replaced by red shale or salt.

CHICKASHA FORMATION

In the Sayre field, Beckham County, Oklahoma, the Chickasha formation varies in thickness from 275 to 350 feet, and is generally shown in well logs as red shale with subordinate amounts of lime or gypsum. To the west, the identity of this formation is lost with the disappearance of the Duncan. In Moore, Hartley, and Dallam counties, Texas, and in Cimarron and Texas counties, Oklahoma, the amount of sand present in well logs at this horizon just below the Blaine, is striking.

22. Sawyer, Roger W., Areal geology of a part of southwestern Oklahoma: Bull. Am. Assoc. Pet. Geol., vol. 8, No. 3, p. 313, 1924.

BLAINE GYPSUM

The Blaine gypsum, the lowest formation exposed on the surface in the central Panhandle region, is one of the most wide spread formations of the Permian red beds of America. It has been traced on the surface from a point near the head of Medicine River, Barber County, Kansas, south across the state of Oklahoma as far as the Colorado River, Texas, a distance of 600 miles. In the central Panhandle it occurs along South Canadian River in Potter and Moore counties, Texas. It is recognized in the logs of the greater number of wells drilled in the Panhandle of Texas and the Panhandle of Oklahoma, and in adjacent parts of northeastern New Mexico and southwestern Kansas. Since it is the first hard formation of any consequence encountered in the Panhandle country, it is generally conspicuous in well logs. It is often difficult, if not impossible, to determine either the exact top or the base of the formation, but the bulk of the gypsum is usually easily noted on a plotted log.

The Blaine as exposed in the eastern end of the Anadarko Basin, consists of a zone of several gypsum ledges with interbedded shales aggregating a thickness of about 50 feet. In its type locality, in Blaine County, Oklahoma, it averages 75 feet thick and consists of three heavy gypsums separated by red clay shales. According to a correlation by C. Don Hughes[23] the Blaine gradually thickens to the west where it is 120 feet thick in a well located seven miles north of Mountain View, Oklahoma, sec. 9, T. 8 N., R. 15 W.

The Blaine may be traced by means of core-drilling records, well logs, and surface outcrops from the head of the Anadarko Basin west to the New Mexico line. There is a gradual thickening to the west. Through Potter and Oldham counties, Texas, the well logs show a gradation into a formation, usually called limestone by the drillers, which is probably anhydrite. The heavy gypsum ledges in the valley of the Canadian River in northeast Potter County, Texas, are considered by the authors of this paper to be the Blaine formation.

The Blaine horizon has been traced from its known outcrop along the south side of the Anadarko Basin north of Hobart, thence westward passing near the towns of Carter and Delhi, Oklahoma, to Shamrock, Wheeler County, Texas, where the formation is exposed over the crest of the fold which represents the buried Amarillo Mountains. A few miles west of Shamrock, the Blaine is lost under a mantle of remnant Tertiary sands which make up the Llano Estacado.

23. Gould, Chas. N., A new classification of the Permian red beds of Oklahoma: Bull. Am. Assoc. Pet. Geol., vol. 8, No. 3, p. 339, 1924.

Across Gray County, Texas, to the west of Shamrock, the logs of the wells are none too good and while it is possible to determine the location of the Blaine, one cannot be sure of either the top or base of the formation.

Upon entering Carson County, Texas, the Blaine stands out boldly as a recognizable unit in well logs. In the Tipton gas well in northeastern Carson County, 220 feet of Blaine was penetrated, the top of which was found at 635 feet. It is present through the oil fields to the north and is found in the wells drilled to the west along the crest of the main fold of the Amarillo Mountains. In Potter County, Texas, the wells encounter from 310 to 340 feet of Blaine gypsum.

On passing to the south of the Amarillo Mountains off the John Ray Dome on the down throw side of the Potter County fault, there is a striking thickening of the Blaine. One is able to determine the same section as that encountered to the north. but all the beds have thickened. The Blaine is here 700 or 800 feet thick, and is indicated in well logs as lime, salt, and gypsum. This thickened section continues to the west across the structurally low area of eastern Oldham County, Texas. On mounting to the crest of the Bravo Dome, western Oldham County, the Blaine has again thinned to its normal thickness of 450 feet and is shown in well logs as lime instead of gypsum. However, there can be no doubt of its being the Blaine, as it underlies the Day Creek (Alibates) dolomite about 300 feet, and this dolomite forms the surface rock of the Bravo Dome.

DOG CREEK SHALES

The Dog Creek shales are present in Wheeler County, Texas, where in the Dozier Hills, southwest of Shamrock, they occupy their normal position between the Whitehorse sandstone and the Blaine gypsum. While the Dog Creek shales appear to be present in several wells to the west as shown by red shales, their western extension is not now known. The senior author is of the opinion that future investigations may show that the Dog Creek shales and Whitehorse sandstone will be found to merge farther west. On the other hand, the junior author believes that the sediments forming the Dog Creek shales came from the southeast and that the formation is separated by a continuous unconformity from the Whitehorse sandstone which is believed to have come from the northwest, the unconformity dying out to the west with the disappearance of the Dog Creek shales.

WHITEHORSE SANDSTONE[24]

The Whitehorse sandstone of the Oklahoma section is encountered in the Sayre field about 175 feet above the Blaine where it is more than 100 feet thick. It is exposed on the surface southwest of Shamrock, Wheeler County, Texas, where it forms the Dozier Hills. In the earlier reports by the senior author the sands forming the Dozier Hills were called Quartermaster,[25] but it is now believed that in this region the Quartermaster and the Cloud Chief are confined to the Anadarko Basin and to the region south of South Fork of Red River.

Sands varying in thickness are shown in well logs at this horizon of the Whitehorse for many miles to the west. The sand being red is oftentimes, no doubt, indicated as "red rock" or "red beds." This series of sand is well exposed on the surface in the breaks of the Canadian River in Hutchinson, Carson, Potter, and Moore counties, Texas, where it varies from thin to medium thick-bedded, soft, red sands, with sandy red shale partings, and an occasional thin lens of gypsum. The most prominent of these gypsum lenses was named Saddlehorse gypsum, listed in a former report.[26] The quicksand shown in logs of wells in the Hutchinson-Carson County oil field, is water-soaked Whitehorse sandstone. In Water-Supply Paper 191[27] this series of red sands and shales lying between the Blaine (there called "Greer") and the Alibates was known as Quartermaster. However, on account of its stratigraphic position above the Blaine, and its similar physical aspect to the Whitehorse in other regions, it is the present belief of the authors that these rocks are Whitehorse, (possibly including Dog Creek also) and not Quartermaster. In this correlations the authors agree with Clifton.[28]

DAY CREEK ("ALIBATES") DOLOMITE

It has already been stated that at the time when the Permian rocks in the Panhandle of Texas were first described, the gypsums, the oldest formations exposed, were called "Greer" and the overlying red sandstones were designated as Quartermaster. The Quartermaster was thought to contain two lentils,

24. Clifton, R. L., Stratigraphy of the Whitehorse sandstone: Oil and Gas Journal, vol. 25, No. 2, p. 70, June 3, 1926.
25. Gould, Chas. N., Geology and water resources of the eastern Panhandle of Texas: U. S. Geol. Survey, Water-Supply Paper 154, 1906.
26. Gould, Chas. N., Geology and water resources of the western Panhandle of Texas: U. S. Geological Survey, Water-Supply Paper 191, 1907.
27. Op. cit.
28. Op. cit.

one of gypsum, the Saddlehorse, and one of dolomite, the Alibates.

The Alibates is composed usually of two beds, two to four feet thick, of dolomite separated by red shales. This dolomite afterwards proved of much assistance to geologists, in that it formed the best horizon of reference in the region for the purpose of running levels to determine structure. The three most prominent surface domes in the Texas Panhandle; namely, John Ray, 6666, and Bravo, were determined from levels run to the Alibates dolomite. In Hutchinson and Carson counties, Texas, the Alibates contains chert which steadily increases in amount to the west across Potter and Oldham counties, Texas. In some well logs of the northwestern part of the Panhandle this horizon is designated as "flint."

Since the revision of the classification of the Permian red beds of Oklahoma, geologists have not been in agreement as to the place to be assigned to the Alibates. Its stratigraphic position above the Whitehorse would indicate that it is the approximate equivalent of the Day Creek. In general appearance also it resembles the Day Creek. On the other hand, so far as we are aware, the Alibates has not yet been traced, either on the surface or by means of well logs to correlate with the Day Creek.

Our present opinion is that the Alibates is the equivalent of the Day Creek. In this respect we agree with Clifton.[29] We, therefore, recommend that the name Alibates be dropped.

CLOUD CHIEF GYPSUM

Succeeding the Day Creek (Alibates) in scattered localities along the Canadian River, there are to be seen deposits of red sandy shale, never so far as known, exceeding 60 feet in thickness. The stratigraphic position of this shale would indicate that it is correlative with the Hackberry shale of the Kansas section or the lower part of the Cloud Chief of the Oklahoma section.

It is now believed that the Permian red beds containing gypsums exposed along the south side of Beaver Creek in Beaver County, Oklahoma, extending as far west as southeastern Texas County, Oklahoma, belong to the Cloud Chief formation.[30] This series of gypsum-bearing beds has been traced practically un-

29. Idem. p. 70.
30. Gould, Chas. N., and Lonsdale, John T., Geology of Texas County, Oklahoma: Okla. Geol. Survey, Bull. 37, pp. 22-25, 1926. Also same authors Geology of Beaver County, Oklahoma: Okla. Geol. Survey, Bull. 38, 1926.

interruptedly from the type locality of the Cloud Chief in Washita County, Oklahoma, north and west across Custer, Dewey, Woodward, Ellis, Harper, and Beaver counties, Oklahoma, to connect with the exposures in southeast Texas County, Oklahoma. At this place a sandstone lying a few feet above the gypsum resembles very much the Big Basin sandstone first described by Cragin[31] in Clark County, Kansas. The senior author now suspects that eventually the Cloud Chief of Oklahoma will prove to be the practical equivalent of the Hackberry shales of southwestern Kansas, and that the Quartermaster of Oklahoma represents the time equivalent of the Big Basin of Kansas.

The Cloud Chief and overlying Quartermaster should be shown in logs of wells drilled in the Anadarko Basin in the region north of the Amarillo Mountains in the Panhandle of Texas. Both formations are believed to occur in Palo Duro Canyon.

One point which should be mentioned in this connection is the relation of the Day Creek-"Alibates" dolomite to the overlying Cloud Chief. Certain geologists would consider the Day Creek as the basal member of the Cloud Chief. So far as the senior author now recollects there is only one place in Oklahoma where both the Day Creek dolomite and Cloud Chief gypsums occur on the surface in the same locality. This is in the region near Weatherford, in southeastern Custer County, at which place the Cloud Chief gypsums lie a short distance above the Day Creek. It might be well to consider the Day Creek as the basal part of the Cloud Chief, and certainly no violence would result from this reclassification.

Another problem as yet unsolved is the geological age of the red beds exposed on the surface in western Texas and north-central Cimarron counties, Oklahoma.[32] These rocks have been considered Triassic in age by several geologists, but the senior author of this paper has always been of the opinion that they are Permian. It is greatly to be hoped that drilling throughout the region will throw light on this most vexing problem.

TRIASSIC ROCKS

Lying unconformably above the Permian of the Panhandle of Texas, are rocks of Triassic age consisting of variegated clays and red to gray sandstones. These formations are exposed in Palo Duro Canyon and along Cimarron River in western Potter and Oldham counties. The Triassic rock of this region has

31. Cragin, F. W., The Permian system in Kansas: Colorado College Studies, vol. 6, pp. 46-48, 1896.

32. Rothrock, E. P., Geology of Cimarron County, Oklahoma: Oklahoma Geol. Survey Bull. 34, pp. 26-31; also Oklahoma Geol. Survey Bull. 37, pp. 25-26, 1926.

been described under the names Tecovas and Trojillo formations.[33]

CRETACEOUS ROCKS

In Cimarron County, Oklahoma, and in Dallam County, Texas, rocks of Cretaceous age (Purgatoire and Dakota) are exposed on the surface. The Oklahoma formations have been described by Rothrock[34] and those in Dallam county, Texas, by the senior author of this paper.[35]

TERTIARY ROCKS

The highest formation on the Great Plains is a mantle composed of sand, clay, conglomerate and caliche of late Tertiary age which covers and obscures all older formations, except along certain streams where this rock has been removed by erosion.

PALEOGEOGRAPHY OF WESTERN OKLAHOMA AND THE PANHANDLE OF TEXAS

Most geologists who have studied the Panhandle have made some attempt to interpret the paleogeographical conditions of the region. That the opinions of the various men do not always coincide is due largely to the complexity of the problem and the lack of data. The time has not yet arrived when the final word on the subject may be written. All that the present authors are attempting to do is to present their interpretations of somewhat obscure data, well recognizing that very probably in the light of more complete information many of these opinions must be thrown into the scrap heap.

According to our best interpretation of existing data the paleogeography of the Panhandle region appears to have been as set forth below. In this matter we attempt to follow Schuchert[36] as elucidated by Wilson.

During Proterozoic time the region was a land mass of low relief. The same conditions probably obtained during the early and middle Cambrian. The extensive sea invasion which occurred over a great part of North America during upper Cambrian and lower Ordovician times, possibly covered much of this area and laid down basal clastics followed by limestone beds

33. Gould, Chas. N., Geology and water resources of the western portion of the Panhandle of Texas: U. S. Geol. Survey, Water-Supply Paper 191, pp. 21-29, 1907.

34. Op. cit., Bull. 34, Oklahoma Geol. Survey.

35. Op. cit. Water-Supply Paper 191.

36. Schuchert, Charles, Text-book of Geology, Part II, Historical Geology: 2nd. revised edition, 1924.

represented in the Arbuckle and Wichita mountains by the Reagan sandstone and the Arbuckle limestone. We have little evidence of these deposits in the Panhandle region at this time.

During practically all of late Ordovician, Silurian, and Devonian times this region was a positive area standing above water, being part of the southern extension of the great land mass Siouxia, which during these periods occupied much of the west-central part of what is now the United States. During these times, so far as we know, there were no deposits laid down in this region, and erosion probably carried away much of the early Ordovician sediments.

It was during early-middle Mississippian (Osage) time, represented in the Ozark Mountains by the Boone formation and in the Rocky Mountains by the Madison limestone, that the seas again invaded the region and beds of limestone were deposited. This was followed by a retreat with a reinvasion during the late Mississippian (Chester) time. The seas again retreated at the close of the Mississippian and did not return until the opening of the Allegheny epoch (late-early Pennsylvanian). During the remainder of the Pennsylvanian the region was more or less constantly flooded by the southwest retreating seas of the Pennsylvanian and early Permian.

It was about the middle of the upper Paleozoic, probably during the Pennsylvanian, that there occurred the two great uplifts which have had a tremendous effect on the later geologic history of the area. These were the Amarillo Mountains and the Ancestral Rocky Mountains. Of these uplifts the latter was the most important.

The present interpretation of the origin of the Amarillo Mountains is that they represent the northwestern continuation of the Wichita-Arbuckle-Ouachita system, the sediments of which had been laid down in the Ouachita embayment during early and middle Paleozoic times. This system of mountains is now considered by many geologists to represent the western continuation of the Appalachian Mountains which were uplifted at the time of the Appalachian Revolution. The elevation of the entire system appears to have been progressively southwestward and westward, beginning with the northern Appalachians (Green Mountains) and continuing through the southern Appalachian Mountains, the Ouachita Mountains, the Arbuckle Mountains, the Wichita Mountains, and finally extending to the Amarillo Mountains. The authors are not certain that these interpretations satisfy all known conditions. It is probable that new data will cause us to modify our present opinions.

The second great uplift which affected the Panhandle region was the prehistoric mountain range which Lee[37] and others have called the Ancestral Rocky Mountains. It is a well known fact that during a great part of Paleozoic time the great land mass Siouxia occupied much of what is now the central United States including the states of the northern Great Plains. When Siouxia was a positive element, no deposits of importance were laid down in the region. About the time of the Appalachian Revolution, during Pennsylvanian time, a mountain range was elevated extending probably north and south, across Siouxia. Neither the exact location nor the exact limits of this range are definitely known, but our best evidence would indicate that it extended southward from near the present location of the Black Hills, across western Nebraska, Kansas, Oklahoma, and eastern Colorado, about as far south as the heart of the Llano Estacado in the southern part of the Panhandle of Texas and eastern New Mexico. It would appear quite probable that the buried granite ridge described by Rich[38] in northeastern New Mexico, is a part of the same general uplift. The cause of this uplift of the Ancestral Rocky Mountains is unknown, but it may have been due to batholythic intrusions beneath the pre-Cambrian granite.

These two mountain masses, the Ancestral Rocky Mountains and the Amarillo Mountains, were probably elevated at somewhere near the same time, and had arrived at their full height during late Pennsylvanian time. It is, of course, quite probable that erosion was contemporaneous with elevation, but it is also logical to believe that, in general, elevation proceeded faster than erosion, and that at the period of greatest elevation these mountains stood possibly several thousand feet above the surrounding plains. During late Pennsylvanian time the Amarillo Mountains were surrounded by seas, as is shown by granite wash in limestones on their flanks. There was apparently a struggle between the agents of elevation and of erosion, so that instead of being high mountains, the region consisted of a series of low islands or an archipelago.

Geologists are now coming to believe that it is partly to the Ancestral Rocky Mountains that we must look for the source of a considerable part of the Pennsylvanian and early Permian sediments of the Panhandle region and of the adjacent parts of Kansas, Oklahoma, Colorado, New Mexico and Texas. The Per-

37. Lee, W. T., Early Mesozoic physiography of the southern Rocky Mountains: Smithsonian Misc. Coll., vol. 69, No. 4, July, 1919.
Building of the Southern Rocky Mountains: Geol. Soc. Amer. Bull., vol. 34, pp. 285-308, 1923.

38. Rich, John L., A probable buried mountain range of early Permian age east of the present Rocky Mountains in New Mexico and Colorado: Bull. Am. Assoc. Pet. Geol., vol. 5, No. 5, pp. 605-608, 1921.

mian deposits probably represent the net result of sediment carried into the southwestward retreating seas by rivers flowing from the northwest, north, northeast, east, and southeast. The matter of the quantitative value of each of these sources remains to be determined.

The Ancestral Rocky Mountains were being eroded during Permian time and their sediments were distributed over the great tidal flats by occasional invading shallow marine waters which now and then covered their vast flats and deltas. The Amarillo Mountains were for the most part covered by the "Big Lime" deposition and were completely submerged by the deposition which started at the close of "Big Lime" (Wellington) time. It is apparent from a well log study of Potter County,[39] Texas, that uplift and erosion occurred on the John Ray dome at the close of "Big Lime" time. There is some evidence that desert conditions obtained in this region during part of Permian time. The eastern part of the Panhandle received sediments from the southeast up to the end of Dog Creek time. At the same time in the western part of the Panhandle, the Ancestral Rocky Mountains were loading the Permian tidal flats. Apparently at the end of Dog Creek time the Ancestral Rocky Mountains furnished the greater part of the material for deposition and out of it came the Whitehorse beds.

The vast beds of gypsum and salt bear testimony to the fact that throughout long ages this was a region of enclosed basins in which saturated solutions were evaporating. Cephalopods and other marine fossils in the horizon of the Blaine gypsum are evidence of invasions of the ocean. Across this central region (center of Panhandle) the only formations that are continuous are the "Big Lime," Blaine, and Whitehorse, the whole section between "Big Lime" and Blaine being lost in the salt group. Well logs reveal a number of prominent sands in the western Panhandle below the Blaine, which disappear to the east as the Duncan disappears to the west.

Thus, according to our interpretation, was formed the great series of clastic red beds with occasional layers of marine and brackish water strata, which by late-lower Permian times had filled the Anadarko Basin, covered the Amarillo Mountains and a large part of the nearly base-level Ancestral Rocky Mountains.

In studying the Permian of North America it should be constantly kept in mind that only the lower Permian, as the term is understood by Europeans, is present in this country. Whether the upper Permian was ever deposited in this country

39. Patton, Leroy T., Geology of Potter County, Texas: Bureau of Economic Geology, University of Texas, Bull. No. 2330, 1923.

or whether it has been removed by erosion is not now known. It is generally believed that the glaciation present in other parts of the world came at the close of our American Permian and before the deposition of much of the European Permian.

It is the present opinion of the authors that the Anadarko Basin, which parallels the Wichita Mountains and the Amarillo Mountains on the south, representing the north downwarp off of the main axis of these mountains, first came into existance at the time that these mountains were elevated; that is, during Pennsylvanian times. This opinion is substantiated by the fact that practically all the Permian formations are comparatively thin along the axis of the Amarillo Mountains and thicken conspicuously on going down the flanks of the mountains toward the axis of the Anadarko Basin.

During the greater part of Mesozoic time the Panhandle and adjacent parts of the Great Plains stood out of the water. Sea invasions marked the Mesozoic and during late Jurassic time (Logan sea), the deposits of which are developed in adjacent areas in New Mexico. The Triassic is represented by terrestial and fresh water beds. The other invasions occurred during Comanchean and Cretaceous times when the seas extended from the Gulf of Mexico to the Arctic Ocean and covered much of the Panhandle. These deposits have been largely removed by post-Mesozoic erosion.

At about the close of the Mesozoic, or probably in early Tertiary time, there occurred a period of upheaval and mountain building throughout western North America, known as the Rocky Mountain Revolution. During this time the Arbuckle and Wichita mountains were again elevated. It is believed that the same upheaval affected the Amarillo Mountains and that they were also re-elevated at this time. It is quite probable that this general uplift affected the various structural features of the Panhandle including the Ancestral Rocky Mountains, the Amarillo Mountains, and more particularly the Anadarko Basin.