OKLAHOMA GEOLOGICAL SURVEY
Chas. N. Gould, Director

Bulletin No. 40-J

OIL AND GAS IN OKLAHOMA

Notes on

PENNSYLVANIAN PALEOGEOGRAPHY

WITH SPECIAL REFERENCE TO SOUTH-CENTRAL OKLAHOMA

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NORMAN
MARCH, 1927

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FOREWORD

In 1917 the Oklahoma Geological Survey issued Bulletin 19, Part II, entitled "Petroleum and Natural Gas in Oklahoma." This volume was so popular that the supply was soon exhausted, and for several years copies have not been obtainable.

The present Director has seen the need of a revision of this bulletin. On account of the lack of appropriations he has not been able to employ sufficient help to compile the data, and has called on some twenty representative geologists throughout the state to aid in the preparation of reports on separate counties. These gentlemen, all busy men, have contributed freely of their time and information in the preparation of these reports.

It will be understood that the facts as set forth in the various reports represent the observation and opinion of the different men. The Oklahoma Geological Survey has every confidence in the judgment of the various authors, but at the same time the Survey does not stand sponsor for all statements made or for all conclusions drawn. Reports of this kind, are at best, progress reports, representing the best information obtainable as of the date issued, and doubtless new data will cause many changes in our present ideas.

Mr. Robert H. Dott, the author of this paper has had a number of years experience in geological work, both surface and subsurface in southern Oklahoma. His own studies, supplemented by data secured from other geologists, is embodied in this report, which it is belived will be of assistance to the geologists of the state, especially to the workers on subsurface problems in south-central Oklahoma.

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INTRODUCTION

In this paper the writer will attempt to show the general distribution of seas which deposited Pennsylvanian sediments in Oklahoma, and to indicate the age and effect of mountain movements. The writer is more familiar with the area in the vicinity of what is generally called the Arbuckle Mountains, and a more detailed discussion will be given of that area.

The western limits of some of the seas were taken from some unpublished maps of Mr. Frank C. Greene, and those of others were determined from a series of cross-sections prepared by Richard Hughes and John E. Millar, Jr. The writer believes that the original eastern shore lines were not far from the present outcrops.

The writer's interest in this problem started while working under Mr. Alex W. McCoy, who contributed the first paper dealing with the paleogeography of the Mid-Continent region.[1] Buchanan[2] has shown the correlation of Mississippian formations and the distribution of Mississippian seas. Gould and Wilson[3] have recently discussed the startigraphy, areal geology and paleogeography of the upper Paleozoic rocks of Oklahoma.

ACKNOWLEDGMENTS

This opportunity is taken to thank Frank C. Greene, Richard Hughes and George S. Buchanan for valuable suggestions, Dr. Sidney Powers and Professor W. H. Twenhofel for valuable criticisms, and A. L. Beekly, Chief Geologist of the Mid-Continent Petroleum Corporation, for permission to publish this material.

PHYSIOGRAPHIC FEATURES

The area known as the Arbuckle uplift should be divided into two distinct parts, the Arbuckle anticline and the Hunton Arch. The Arbuckle anticline is a prominent topographic feature trending in a northwest-southeast direction in southwestern Murray County (See Fig. 1). To this topographic feature the term "Arbuckle Mountains"

1. McCoy, A. W., A short sketch of the Paleogeography and Historical Geology of the Mid-Continent oil district and its importance to petroleum Geology: Bull. Amer. Assoc. Pet. Geol., Vol. 5, 1921.
2. Buchanan, Geo. S., Unpublished manuscript.
3. Gould, Chas. N., and Wilson, Roy A., The Upper Paleozoic rocks of Oklahoma: Okla. Geol. Surv., Bull. 41, 1927.

is restricted by the people of the region, and it is so designated on the topographic sheet of the Ardmore quadrangle.

The Hunton Arch is a northward plunging anticlinal nose with an axis slightly west of north-south, trending through western Pontotoc County, northward into the Seminole area. The greater part of this anticline is buried beneath Pennsylvanian strata.

In 1902 Taff[4] applied the term "Hunton Anticline" to a small fault block in the northwest corner of the Atoka quadrangle. In 1904 the same author[5] applied the same term to a northward plunging anticline occurring in the south-central part of Stonewall quadrangle, discernible at the surface in the outcrops of lower Paleozoic formations.

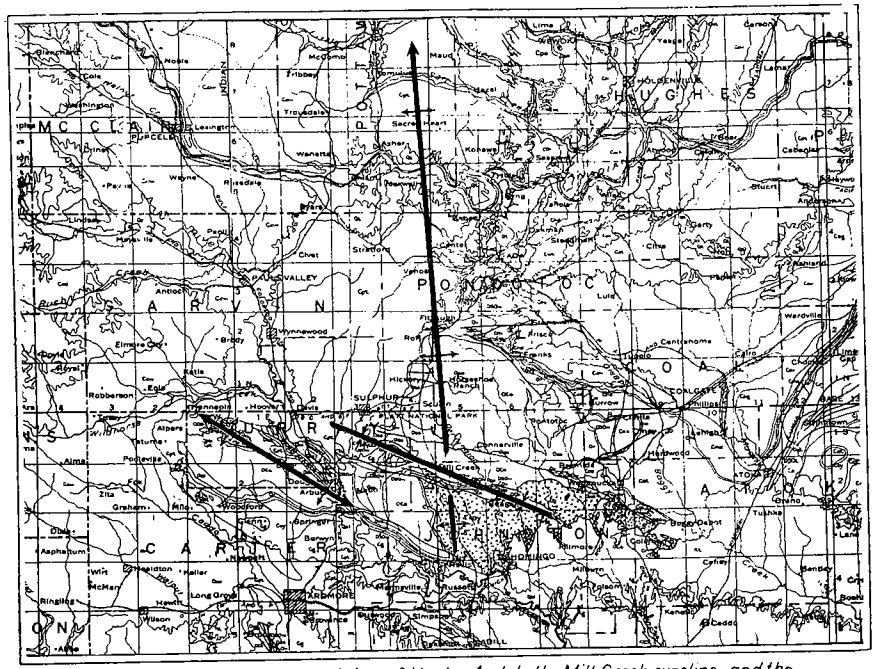

Figure 1. Geologic map showing relation of Hunton Arch to the Mill Creek syncline and the Arbuckle anticline

In recent years sub-surface mapping on the Hunton limestone has shown the northward continuation of this fold beneath the Pennsylvanian cover, at least into the Seminole area. Taff's "Hunton Anticline" has thus become known as the "Hunton Arch."

4. Taff, J. A. U. S. Geol. Survey Geol. Atlas, Atoka Folio (No, 79), p, 7, 1902.
5. 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, p. 39, 1904.

To the east of the Hunton Arch, and extending thence northeastward into Arkansas, lies the Pennsylvanian coal basin which contains the maximum development of Pennsylvanian sediments in Oklahoma. East and south of the coal basin in Oklahoma and Arkansas lies the great area of intense folding known as the Ouachita Mountains.

To the north of the coal basin in Oklahoma and Arkansas is a southwestward plunging fold which may be regarded as a spur of the Ozark Mountains, and which, for lack of a better name, the writer will call the "Ozark Arch."* Like the Hunton Arch, the greater part of this structure is covered by Pennsylvanian sediments, but its southward extension seems to be definitely established by subsurface mapping.[6,7] The Seminole area seems to lie in a large saddle between the north end of the Hunton Arch and the south end of the Ozark Arch.

STRATIGRAPHY

Before entering upon a discussion of Pennsylvanian paleogeography and the history of these structural features, it will be well to point out certain details of correlations as now understood. These correlations are shown in the accompanying table.

Powers[8] states that the oldest Pennsylvanian rocks in Oklahoma are found in the Springer formation of the Ardmore basin. The lowest Pennsylvanian beds in the coal basin are found in the upper Caney shale, and are separable from the lower Caney on faunal evidence. These shales grade upward into the Wapanucka limestone, and with it form the equivalent of the Morrow formation of the Ozark area, and of the Dutcher sand in the central Oklahoma oil fields. The Morrow-Wapanucka group has been shown by Mather[9] and others to carry a fauna of strong Mississippian affinity, though with sufficient Pennsylvanian invertebrates and plants to establish its lower Pottsville age.

In the coal basin the Wapanucka limestone is succeeded and apparently off-lapped by a series of coarse sandstones and shales, aggregating some 7,500 feet in thickness, designated the Atoka formation by Taff. This is in turn succeeded by the Hartshorne, McAlester, Savanna, Boggy, Thurman, Stuart, Senora and Calvin formations. These nine formations are usually referred to by authors as equivalent to the Cherokee formation of Kansas.

At present, but three definite statements relative to the stratigraphy and correlations of these various groups can be made:

*This arch should not be confused with the Ozark dome.

6. White, Luther H., Subsurface distribution and correlation of the pre-Chattanooga ("Wilcox" Sand) series of northeastern Oklahoma: Okla. Geol. Surv., Bull. 40-B, 1926.
7. Thom, W. T., Jr., Structure map of northeastern Oklahoma: U. S. Geol. Survey, 1925.
8. Powers, Sidney, Personal communication.
9. Mather, K. F., The Fauna of the Morrow Group of Arkansas and Oklahoma: Denison University Bulletin, Vol. XVIII, 1915.

1. David White and Girty[10] have shown that the coal in the McAlester formation in Arkansas is older than the coal in the Cherokee formation in Kansas.

2. Some part of the Savanna formation is generally regarded as equivalent to the Bluejacket sandstone, which at Pryor lies 200 feet above the base of the Cherokee formation.

3. The Wetumka shale, which overlies the Calvin sandstone, is equivalent to the Fort Scott limestone, which occurs above the Cherokee formation.

In the Tahlequah and Muskogee quadrangles, all rocks below the Boggy formation, and above the Morrow group, have been in the past, grouped into one formation, the Winslow.[11] It is much thinner than its assigned equivalents to the south, being about 1,000 feet thick, while the combined maximum thickness of the Atoka, Hartshorne, McAlester and Savanna formations is 10,000 feet.

While formational thickening from north to south is not surprising, this amount is so great that in the writer's mind, the Atoka formation is distinctly older than the Winslow formation, and represents the oldest post-Wapanucka formation in the Mid-Continent region.

Overlying the Atoka formation in the coal basin, Taff mapped successively the Hartshorne sandstone and McAlester shale, which constitute a series of sandstones and shales aggregating some 3,500 feet in thickness. The McAlester shale contains coal beds. These formations are probably the ones which are contemporaneous with the Winslow formation.

Both in the outcrops and well logs it is rather difficult to draw any definite limits for these various groups, so the writer has assumed that the Booch sand is equivalent to the Hartshorne sandstone, and has arbitrarily drawn the base of the Winslow formation at the base of this sand. The subsurface distribution of this formation in Seminole, Okfuskee and Creek counties was determined from cross-sections prepared by Richard Hughes and John E. Millar, Jr.

In the Ozark area the Winslow formation is succeeded by the Cherokee formation, a series of gray to black shales 450 to 1,000 feet thick, containing some sandstone members notably the Bluejacket sandstone, in the Vinita quadrangle. This has been correlated with the widespread Bartlesville sand and with the Savanna sandstone of the coal basin.

The Winslow-Cherokee contact is rather difficult to determine. From the areal mapping shown on the new state map in Muskogee, Waggoner and Mayes counties, it would seem that the base of the Bluejacket sandstone is the top of the Winslow formation. This would

10. White, David and Girty, Geo. H., The Arkansas Coal Field, Reports on Paleontology: U. S. Geol. Survey, Bull. 326, 1907.
11. Taff, J. A., U. S. Geol. Survey, Geol. Atlas, Tahlequah Folio (No. 122), 1905.

make the upper part of the Winslow formation equivalent to that part of the Cherokee formation which lies below the Bluejacket sandstone. This is indicated in Bulletin 35, Oklahoma Geological Survey.

For the purposes of this paper, the base of the Cherokee formation is placed a short distance below the Bartlesville sand and at the base of the Savanna sandstone.

The upper limit of the Cherokee formation in northern Oklahoma and Kansas has been defined as the base of the Fort Scott limestone. There has been considerable uncertainty as to the exact equivalent of this limestone south of Arkansas River. In Bulletin 35, Oklahoma Geological Survey, the base of the Fort Scott limestone is placed somewhere in the Wetumka shale, thus making the Cherokee formation of Kansas and northern Oklahoma equivalent to the Savanna sandstone. Boggy shale, Thurman sandstone, Stuart shale, Senora formation and Calvin sandstone of the coal basin. These groups consist of alternating sandstones and shales aggregating some 4,000 feet in thickness.[12] The Senora formation in the vicinity of Henryetta contains considerable quantities of coal, which probably approximate the age of the coals of Kansas.

Because of the excellence of the early work on the Pennsylvanian stratigraphy of Kansas, and because of the uniform distribution and development of the formations in Kansas, Nebraska, Missouri and Iowa, the nomenclature as used in Kansas has become standard for the middle and upper Pennsylvanian of the lower Missouri Valley.

The Kansas units have never been recognized south of Arkansas River, due to abrupt and decided changes in lithology in northern Oklahoma. Recent work has shown that they can be identified in a broad way, and it seems advisable to the writer that an attempt be made to do so.

In the preceding discussion of the Cherokee formation, and in the following discussions, the writer's interpretation of equivalencies is set forth, and the Kansas formational names are used instead of the numerous unit names of the Oklahoma literature, many of which, in the light of these suggestions, should be regarded as members, rather than formations.

In the main, the correlations as shown in the tables accompanying the preliminary edition of the new Oklahoma Geological Map, and appearing in Bulletin 35, Oklahoma Geological Survey, have been followed.

In many collections from beds below the Francis formation (as defined by Morgan[13]) in the vicinity of Ada, the writer found the

12. Taff, J. A., U. S. Geol. Survey, Geol. Atlas, Coalgate Folio (No. 74), 1901.
13. Morgan, Geo. D., Geology of the Stonewall Quadrangle: Bureau of Geology, Bull. 2, 1924.

brachipod *Chonetes mesolobus* to be the dominant form, and to be conspicuous by its absence from the Francis formation. Morgan's faunal chart[14] indicates the same thing. Greene[15] has shown that this species is limited to the Des Moines group (Cherokee and Marmaton formations) of the northern Mid-Continent area.

If the equivalency of the Cherokee formation be as indicated above, then Taff's Wetumka, Wewoka, Holdenville and Seminole formations belong to the Marmaton formation as recognized in Kansas, Missouri and Iowa.

Overlying the Cherokee formation in Kansas, the Marmaton formation begins at the base with the Fort Scott limestone, and this is succeeded by alternating shales and limestones. These same members have been recognized in northern Oklahoma, though they do not all carry the same nomenclature. About half way between the state line and Arkansas River, the Altamont and Pawnee limestones coalesce, forming the Oologah limestone, or the "Big lime" of drillers.

In the upper part of the Marmaton formation occurs a thin but persistent limestone known in northern Oklahoma as the Lenapah limestone. In Kansas this limestone is overlain by the La Cygne shale, which forms the upper member of the Marmaton formation, and is in turn overlain by the Hertha limestone, the basal member of the succeeding Kansas City formation.

In southern Kansas the top of the Marmaton formation is the top of the La Cygne shale and the base of the Hertha limestone. In northern Oklahoma, the Checkerboard limestone lies at about the same horizon as the Hertha, and both it and the Lenapah can be recognized in well logs.

The Lenapah limestone lies near the horizon of the Cleveland sand and is approximately equivalent to the Seminole formation of the Hunton Arch area. The top of the Marmaton formation has been drawn below the Checkerboard limestone and above the Lenapah limestone and its equivalents.

Following the Marmaton formation in Kansas occurs the Kansas City formation, which from its good development over Kansas, Missouri and Iowa, and the excellence of the exposures in the type locality, has received more study and is probably better known than any other Pennsylvanian formation in the Mid-Continent area. In northern Oklahoma, because of lithologic changes, the various members, and in fact, the formation as a whole, have not been recognized. The nomenclature in present use is shown in the accompanying correlation table.

14. Op. cit.
15. Greene, Frank C., Discussion of Morgan's paper: Bull. Amer. Assoc. Pet. Geol. Vol. 9, No. 2,, p. 335, 1925.

One detail is worthy of discussion. Above the middle of the Kansas City formation occurs the Drum limestone. At the State line this limestone splits into an upper and lower member, with a shale parting, the three known as the Hogshooter limestone, or lower Drum, the Nellie Bly formation, and the Dewey limestone, or upper Drum. The Hogshooter limestone is the same as the Lost City limestone near Tulsa, and the Dewey limestone has been correlated with the Belle City limestone of the Hunton Arch area. Some geologists regard the Hogshooter limestone as the equivalent of the Layton sand.

In the Hunton Arch area, the time equivalent of the lower part of the Kansas City formation seems to be present in the Francis formation and Belle City limestone. The overlying Vamoosa formation is considered equivalent to formations in Kansas overlying the Kansas City formation, indicating a break in deposition and an erosion interval above the Belle City limestone.

That part of the Kansas City formation above the Dewey limestone shows a decided change in lithology in Creek and Osage counties. Instead of the alternating shales, limestones and occasional sandstones of Kansas and northeastern Oklahoma, equivalent strata have sandstones more prominently developed, particularly in the Copan and lower Ochelata formations.

Fath[16] suggests that the sediments as exposed in the Bristow quadrangle must have been derived from a land mass to the south.

The Vamoosa formation of the area of the Hunton Arch is considered the time equivalent of the three formations which in Kansas succeed the Kansas City formation, namely; the Lansing, Douglas and Shawnee formations. In northern Oklahoma the names Nelagoney, Elgin and Pawhuska have replaced the Kansas terms. Their total thickness is 1,300 feet.

According to Morgan, the Vamoosa formation in the Hunton Arch area is composed mainly of coarse chert conglomerate, with a small thickness of shale at the base. He found no fossils, so the age of this formation has not been definitely established. He gives a thickness of 260 feet as average for the formation in the Stonewall quadrangle. It seems likely that the Vamoosa formation of the Hunton Arch area is equivalent to only a small part of its ascribed equivalents, with a large unconformity either above or below. This unconformity represents the continuation of the break in the Hunton Arch area, which occurs above the Belle City limestone. In Creek and Osage counties this break is not present, and the coarse upper Kansas City beds are overlain by similarly coarse Bristow, upper Ochelata and Nelagoney sediments, all of which are succeeded by the similar Elgin sandstone, of lower Shawnee age, and it by the limestones and shales of the Pawhuska formation.

16. Fath, A. F., Geology of the Bristow Quadrangle, Creek County, Oklahoma: U. S. Geol. Survey, Bull. 759, pp. 9-10, 1925.

From the above, it will appear that the coarse Vamoosa conglomerate is equivalent to the deeper-water deposits of the Pawhuska (Shawnee) formation, while the underlying Douglas and Lansing formations are represented in the Hunton Arch area by an hiatus.

Overlying the Vamoosa formation, probably conformably and overlapping to the south, is the Ada formation, consisting of slightly fossiliferous shales, asphalt-impregnated sandstones and limestone conglomerates. These sandstones were probably derived from the Simpson formation, and the conglomerates from the Arbuckle, Viola and Hunton limestones. A thin fossiliferous Pennsylvanian shale has been found in wells in western Pontotoc, northern Murray and eastern Garvin counties, to overly unconformably, folded and faulted lower Paleozoic formations. This deposit may belong to the Ada formation.

Overlying the Ada formation, and overlapping still farther to the south is a series of red shales, sandstones, arkosic sandstones, limestones and near the outcrops of the lower Paleozoic formations, limestone conglomerates. The shales and limestones contain a few fossils.

All the above make up the Pontotoc terrane of Morgan and include his Vanoss, Stratford and Konawa formations. They are the first to show distinctive red beds conditions and form part of what have for years been termed red Pennsylvanian. The Ada and Pontotoc formations are considered to be equivalent to the Wabaunsee formation of Kansas.

GEOLOGIC HISTORY AND PALEOGEOGRAPHY

The Mississippian period in Oklahoma closed either with a complete emergence of the area, or more likely, a partial emergence with small relic seas, whose Mississippian faunas were mingled with those of the first Pennsylvanian invasion. The oldest Pennsylvanian sediments are found in the Springer formation in the Ardmore basin. In the coal basin the oldest Pennsylvanian strata are in the upper part of the Caney shale and the overlying Wapanucka limestone, and their northern equivalent, the Morrow formation. The approximate limits of the sea in which these beds were laid down are shown on the first paleogeographic map (Fig. 2).

The first stage of Pennsylvanian history was closed by an important uplift, that of the Ozark Arch and the Hunton Arch, probably along a common axis, with the resultant withdrawal of the sea to the southeast into the trough which later became the coal basin. In this retreating sea were deposited coarse, clastic sediments of Atoka age, the material having been derived from the Hunton Arch and from a land mass to the east which later developed into the Ouachita overthrust.

This shrinking of the sea into the coal basin is the second stage in the history (Fig. 3). The Mississippian element in the Wapanucka-

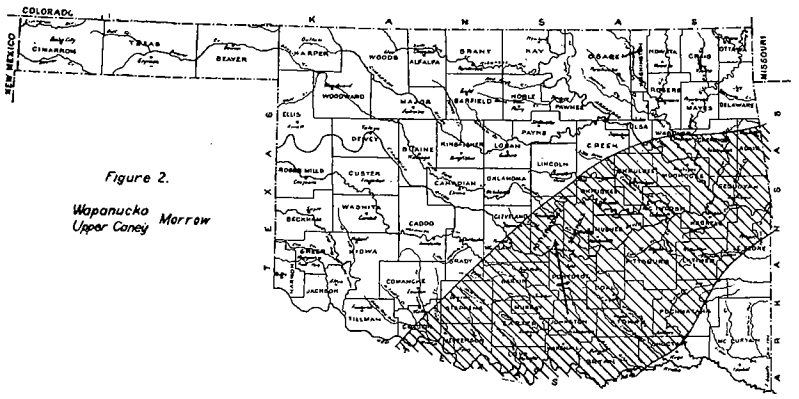

Figure 2.

Wapanucka
Upper Caney
Morrow

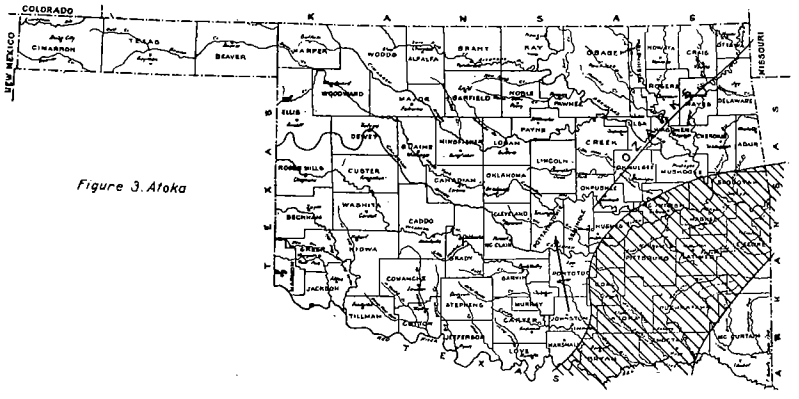

Figure 3. Atoka

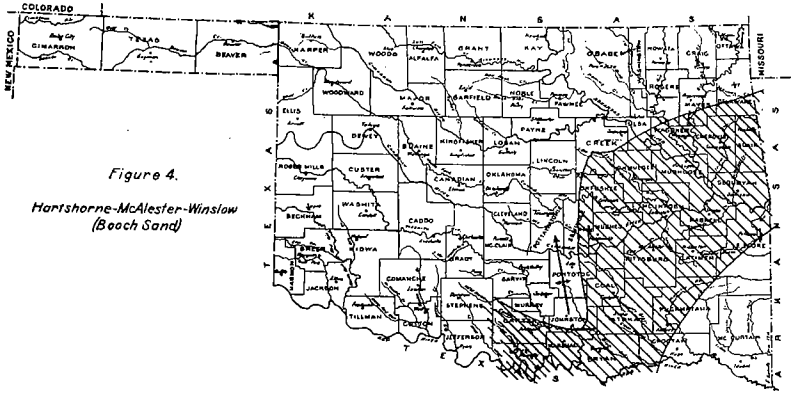

Figure 4.

Hartshorne-McAlester-Winslow
(Booch Sand)

Morrow fauna was completely extinguished, and does not appear in any of the succeeding faunas.

The third stage opened with a gradual transgression of the sea from the coal basin, with an overlapping northward and westward over the upturned edges of the Wapanucka limestone and associated beds, encroaching well up onto the east and southeast flanks of the Hunton Arch and Ozark Arch (Fig. 4). The offlap of the Atoka formation, and the succeeding overlap of the Hartshorne and McAlester beds are shown in Morgan's mapping in T. 1 N., R. 7 E.

The fourth stage was marked by a complete submergence of the Ozark Arch during Cherokee time, and a spreading of the sea to the westward, as far as Grant and Garfield counties (Fig. 5). By virtue of this westward spreading of the sea, combined with the gradual encroachment of the overthrusting Ouachita sheet and filling of the coal basin, the southern connection on the east side of the Hunton Arch was gradually closed, this being accomplished in Marmaton time.

That a minor oscillation took place in the Hunton Arch area has been shown by Morgan in his discussion of the Boggy overlap.[17] Not until Boggy time did the sea begin to cover this uplift, during which time a narrow arm of the sea advanced as far south as T. 3 N., R. 5 E., overlapping the eroded edges of the lower members of the Cherokee formation and the underlying McAlester, Hartshorne, Atoka, Wapanucka and Caney formations. A slight uplift caused a retreat of the sea into the coal basin, whence it slowly readvanced, depositing the coarse Thurman sandstone, and later the quiet-water deposits of the Stuart shale and Senora formation. Then followed another slight uplift, and the deposition of the Calvin sandstone, possibly as an offlapping deposit, bringing the Cherokee period to a close. It should be noted that up to this time, the axis of the Hunton Arch had never been submerged since its formation.

The fifth stage (Marmaton period) opened with a readvance of the sea. In the Hunton Arch area, this was marked by the closing of the southeast connection, and a progressive overlap southwestward toward the top of the Hunton Arch (Fig 6). By Holdenville time the farthest advance of the Boggy sea was reached, and Boggy deposits were overlapped by Holdenville deposits. Advance continued through the Marmaton and into the succeeding Kansas City time. A connection was probably established with the Texas sea on the west side of the Hunton Arch.

Toward the close of the Marmaton period, in the latter part of Wewoka time, occurred the second important mountain movement which had a widespread effect upon the structure of a large part of Oklahoma and Arkansas, though with only a minor effect upon deposition and the distribution of the seas.

17. Morgan, Geo. D., The Boggy Overlap: Bureau of Geology, Cir. No. 2, 1924.

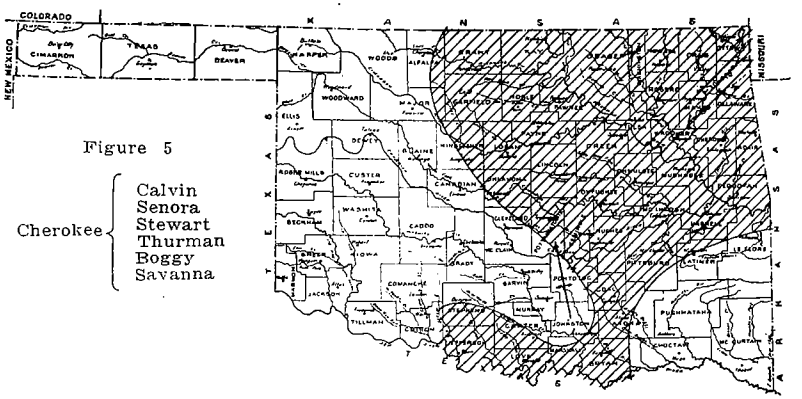

Figure 5

Cherokee
- Calvin
- Senora
- Stewart
- Thurman
- Boggy
- Savanna

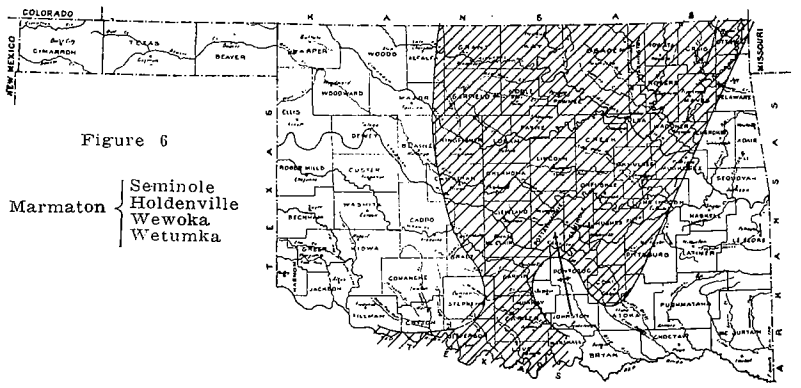

Figure 6

Marmaton
- Seminole
- Holdenville
- Wewoka
- Wetumka

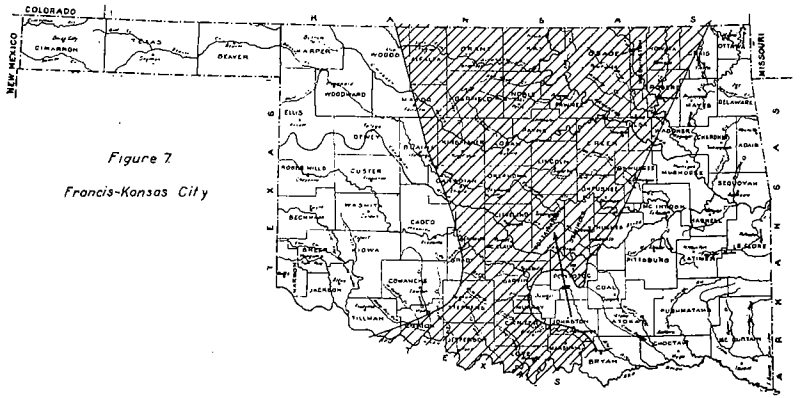

Figure 7

Francis-Kansas City

This movement has been described by Dake[18] as the Ouachita overthrust. According to his interpretation the mass of highly folded rocks known as the Ouachita Mountains in Oklahoma and Arkansas, with lithologic facies far different from that of the Hunton Arch-Arbuckle area, has been overthrust as a great sheet "scores of miles."

The advance of this overthrust deformed the great thickness of pre-Pennsylvanian and lower Pennsylvanian strata so that they now have the form of a great geosyncline. This now forms the coal basin of Oklahoma and the Arkansas Valley syncline of Arkansas. The front edge of the Ouachita overthrust sheet was named the Choctaw fault by Taff. The axis of the geosyncline forms a great arc, concentric with the Choctaw fault and its Arkansas extension, and with the Ouachita Mountains generally.

In the Boston Mountains, in northern Arkansas, is a system of east-west faulting, parallel to the east-west trend of the north edge of the Ouachita Mountains and with the intervening syncline. In the Ozark Arch area of northeastern Oklahoma occurs a similar fault system, here trending northeast-southwest, parallel to the axis of the Coal Basin syncline and the Ouachita Mountains at that point.

Approaching the Hunton Arch, these faults take a more nearly north-south trend, and are present at the surface in beds as young as middle or upper Wewoka. Examples are the Yeager fault in Tps. 6 to 8 N., R. 10 E., a small fault in T. 9 N., R. 11 E., and the Morris fault in Tps. 11 to 14 N., R. 14 E. In beds younger than middle Wewoka, long belts of en echelon faulting are shown on the new Oklahoma geological map. According to Hughes[19] some of these belts of *en echelon* faulting overlie subsurface faults with a north-south or slightly northeast-southwest trend which have not affected beds younger than the upper part of the Wewoka formation.

On the areal map of the State it will be seen that a decided swing in the strike of all beds older than Wewoka has taken place in southern Hughes and eastern Pontotoc counties as though bent around locally by the force of westward thrusting. This probably was accompanied by slight local uplift in the area of the Hunton Arch as suggested by a coarse conglomerate composed of angular pebbles occurring in the upper part of the Wewoka formation, overlying a fossiliferous shale. This is exposed in sec. 4, T. 3 N., R. 7 E.

This suggested uplift was followed by a return to more quiet water conditions, and the deposition of fossiliferous shales, limestones and sandstones in upper Wewoka, Holdenville and Seminole time. Advance continued toward the top of the Hunton Arch, and a basal conglomerate was formed from fragments of lower Paleozoic limestones in Seminole time.

18. Dake, C. L. The Problem of the St. Peter Sandstone: Bull. Missouri School of Mines, Vol. 6, No. 1, p. 55, 1921.
19. Hughes, Richard, Personal Communication.

Little change occurred in the rest of Oklahoma other than a gradual westward migration of the limits of the sea incidental to the continued continental tilting.

The sixth stage, that of the deposition of the Kansas City formation, was marked in the Hunton Arch area by continued overlap and submergence of more of the Arch. This took place during the earlier part of the stage, the sediments consisting of very fossiliferous shale, some sandstones and limestone conglomerates of the Francis formation and the overlying Belle City limestone (Fig. 7).

Essentially similar conditions prevailed in northern Oklahoma and Kansas, during which time the limestone and shales of the lower Kansas City formation were deposited, namely: Hertha limestone, Ladore Shale, Bethany Falls limestone, Galesburg shale, Winterset limestone, Cherryvale shale and Drum limestone.

A little later than mid-Kansas City time occurred the third and last great mountain movement, the uplift of the Arbuckle anticline. This uplift is thought to be another case of thrusting, as suggested by the following facts:

STRATIGRAPHY

The Glenn formation (Cherokee and Marmaton) has a great thickness and high angle of dip on the south side of the Arbuckle anticline, and its equivalents are apparently absent due to non-deposition on top of the Hunton Arch only a few miles distant.

Where the equivalents of the Glenn formation overlap onto the Hunton Arch, they are found to be quite thin and in decided disconformity to the older, underlying formations. On the south side of the Arbuckle anticline, on the contrary, the thick series of Glenn formation has been folded up in entire conformity with the older (lower Paleozoic) beds.

The overlap on the Hunton Arch apparently came from the north and east, so obviously the Glenn formation of the south side of the Arbuckle anticline was not deposited in the same basin as were the equivalents in the Hunton Arch area. To the writer, such an abrupt change in thickness (15,000 feet in T. 3 S., R. 1 E., to nothing in T. 2 N., R. 3 E.) is as significant, and as indicative of deposition in widely separated provinces, as is the great difference in lithology between the lower Paleozoic limestones of the Hunton Arch-Arbuckle area and the equivalent clastic sediments of the Ouachita area, some 15 miles distant, a relationship which Dake[20] can explain only by over-thrusting.

STRUCTURE

That part of the Hunton Arch which lies near Mill Creek, in northern Johnston County, has been much crumpled and faulted, with a trend in the faulting parallel to the axis of the Arbuckle anticline.

20. Op. cit.

This system of crumpling, of which the Mill Creek syncline is the major feature, has very much the appearance, on the areal map, of a zone of buckling, resulting from pressure from the southwest. That the Mill Creek syncline is deep can be judged by the fact that the Wapanucka limestone and even part of the younger Glenn formation has been down-folded so as to lie in contact with beds of Ordovician age, and are not far distant from the outcrop of pre-Cambrian granite, a structural relief of some 10,000 feet. The great depth of the syncline, in proportion to its width is highly suggestive of intense buckling.

Apparently the Hunton Arch as it appears today has been buckled transversely, the part north of Mill Creek acting as a buttress, the part in the Tishomingo area having been pushed northward by the thrusting forces. If this interpretation is correct, and conditions are comparable to those in the Ouachita area, the counterpart of the Choctaw fault is to be found in the Washita River gorge in the vicinity of Crusher, between Berwyn and Dougherty.

It is hardly conceivable that the depth of the Mill Creek syncline could have resulted solely from downward movements, but that there would have been some upward movements in the Hunton Arch, both in the Tishomingo area and north of the Mill Creek syncline.

The axis of the Hunton Arch has been further broken by transverse faults into a number of large blocks, one of which was found by the writer to extend westward into Garvin County, under the Pontotoc terrane cover. The magnitude of the uplift is shown by the fact that fossiliferous Pennsylvanian shales rest directly upon the Simpson formation in T. 1 N., and T. 2 N., whereas in T. 3 N., this deposit rests upon Hunton limestone and younger beds. This is shown by the accompanying cross sections (Fig. 11). The writer believes that all east-west faulting in this area is to be correlated with the Arbuckle movement.

Ignoring for the moment the down faulted and downfolded blocks on the east side of the Hunton Arch, it will be noted from the areal map that the outcrops of Wapanucka limestone on the east end of positive fault blocks at Clarita and Stonewall have an alignment parallel to that of the Ordovician rocks of the Hunton Arch, suggesting that these two blocks represent part of the original form of the Arch rather than decided and individual uplifts as has been suggested by other authors, and that the Franks graben and Wapanucka syncline are downfolded segments of this same arch. A thrust from the south conceivably could have produced this condition.

Assuming the formation of the Franks graben to have been caused by the Arbuckle movement, we can place its age as post-Francis, since beds of Francis age are the youngest found in this locality. If the writer correctly understands the discussion of Goldston's paper by

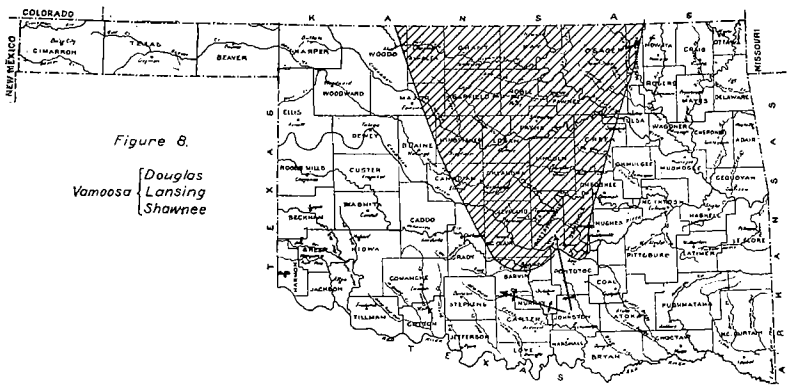

Figure 8.

Vamoosa { Douglas / Lansing / Shawnee

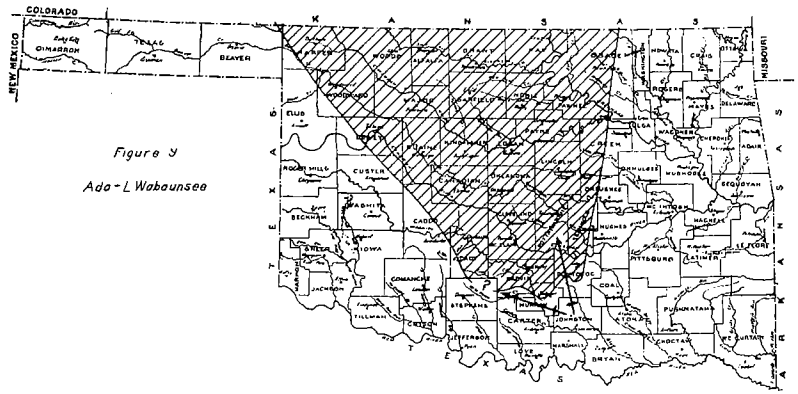

Figure 9

Ada - L Wabaunsee

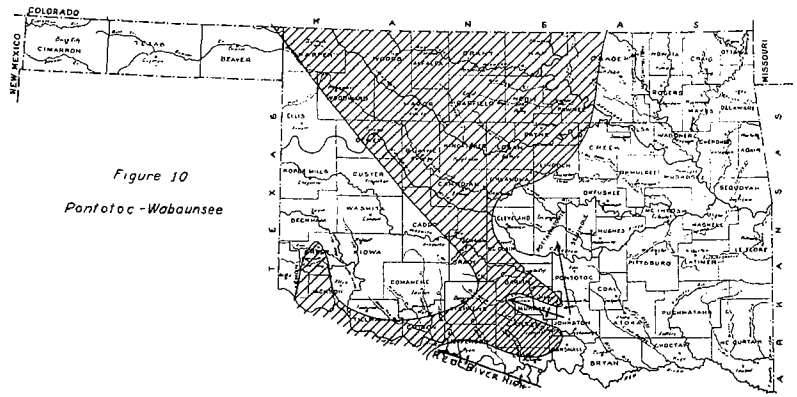

Figure 10

Pontotoc - Wabaunsee

Girty and Roundy[21], Goldston's Hoxbar member is younger than Taff's original Glenn, which was limited at the top by the Seminole formation. From this it follows that the Hoxbar is equivalent to the Francis formation. Since the Hoxbar member is structurally conformable with the older Glenn formation, and was involved in the Arbuckle folding, it offers further evidence of the mid-Kansas City age of the Arbuckle movement.

This uplift marks the end of Kansas City deposition in the Hunton Arch-Arbuckle area, with its effect evident in the coarse and thick clastic material forming the Bristow and Ochelata formations of northern Oklahoma, deposited in upper Kansas City time, a period represented by emergence and erosion in the Hunton Arch-Arbuckle area.

The Arbuckle uplift probably drove the sea far to the north, so that it did not again encroach on the axis of the Hunton Arch until Shawnee time, when the coarse Vamoosa conglomerate was deposited. (Fig. 8).

During Lansing and Douglas time, while the Hunton Arch was emerged, coarse near-shore deposits were formed in Creek and Osage counties.

The seventh stage in Oklahoma's Pennsylvanian history represents an advancing sea, in which were deposited materials derived from the newly elevated Arbuckle Mountains, as well as from the Ouachitas and the Hunton Arch.

In northern Oklahoma, the limits of the seas were not greatly different from those of the preceding periods. In all probability, the Texas connection which was closed by the Arbuckle uplift remained closed during this period.

The eighth and last stage of Pennsylvanian history opened with a continuous overlap and encroachment of the sea onto the Hunton Arch with the deposition of the Ada formation (Fig. 9), followed by that of the Pontotoc terrane (Fig. 10). The fossiliferous shales found resting upon the Simpson formation in a well in sec. 29, T. 2 N., R. 3 E., and upon the Hunton limestone in a well in sec. 5, T. 3 N., R. 3 E., may belong to the Ada formation.

During Pontotoc time the streams draining the Hunton Arch, particularly the Tishomingo area had cut to the granite core, and arkosic sandstone resulted. Where the shore line lay in contact with the old limestones, massive conglomerates were formed.

The red shales of the Pontotoc terrane are suggestive of terrestrial conditions of deposition. The conglomerates are apparently marine, and the writer collected some undetermined gastropods from the Hart limestone in sec. 31, T. 3 N., R. 4 E. Morgan lists a few marine forms from the Pontotoc terrane. A possible explanation of apparent grading

21. Girty, Geo. H., and Roundy, P. V., Notes on the Glenn formation of Oklahoma, with consideration of new Paleontologic evidence: Bull. Amer. Assoc. Pet. Geol., Vol. 7, p. 331, 1923.

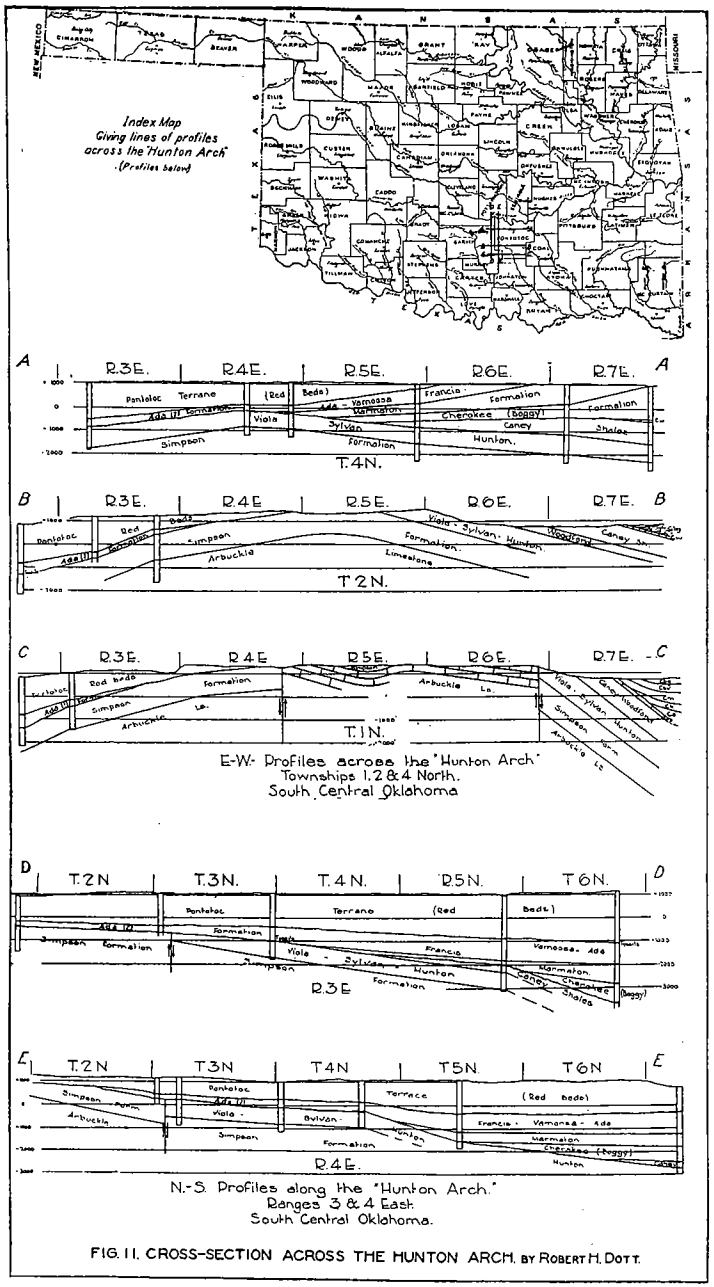

FIG. 11. CROSS-SECTION ACROSS THE HUNTON ARCH. BY ROBERT H. DOTT.

from terrestrial to marine conditions so close to the mountains, and what seems most incongruous, mountainward rather than seaward, is that the Mill Creek syncline was of such magnitude that though narrow, was deep enough to permit a small re-entrant of the sea on the very flanks of the mountains. If so, this was the initiation of the Anadarko basin, which was of considerable importance during later deposition.

Sometime during Pontotoc time, a southern connection was established around the west end of the Arbuckle anticline, and shales, conglomerates, limestones and some arkosic sandstones were deposited south of this anticline, over the upturned edges of all formations from Ordovician to upper Pennsylvanian.

Final withdrawal of the sea from this area was effected at the end of Wabaunsee time, the sea gradually receding westward.

SUMMARY

The writer has endeavored to show that the first important Pennsylvanian uplift took place after Wapanucka time, and consisted in the uplift of the Ozark Arch and Hunton Arch, causing a withdrawal of the sea into a small area in southeastern Oklahoma.

Following this uplift, the sea spread gradually westward and northward, in progressive overlap, gradually submerging these uplifts, the Hunton Arch much more slowly than the Ozark Arch, with minor oscillations temporarily halting the advance.

A second important movement occurred in the upper part of Marmaton time, which resulted in the westward overthrusting of a great sheet of highly folded rocks, ranging in age from Cambrian to lower Pennsylvanian. This movement formed the Coal Basin and Arkansas Valley syncline, and set up a system of faulting in the Ozark Arch and possibly in the Hunton Arch, concentric with the Ouachita thrust. This movement had little effect on the position of the sea, as the center of the basin had shifted to the northwest. Overlap continued on the Hunton Arch until middle or late Kansas City time.

Then followed the third and last movement, the Arbuckle uplift, which the writer regards as another overthrust. This drove the sea far to the north, with a readvance in Shawnee (Vamoosa) time, and continued overlap and final submergence of all but the very top of the Hunton Arch in Ada time.

Continental tilting, which preceded the Appalachian revolution was effective in gradually forcing the Pennsylvanian seas to the westward. During Wabaunsee (Pontotoc) time complete and final emergence of the Arbuckle-Hunton Arch area occurred.

Correlation of Pennsylvanian Formations and Oil Sands.

North Arbuckles	Central OKLAHOMA	Drillers' Terms	Northern OKLAHOMA		KANSAS (Standard)	
Pontotoc	Pontotoc		Eskridge Shale Neva limestone Elmdale Shale Sand Creek fm. Buck Creek fm.		Wabaunsee fm	Eskridge Shale Neva limestone Elmdale Shale Americus limestone Admire shale Emporia limestone Willard shale Burlingame ls.
Ada formation						
Vamoosa	Vamoosa	Ponca Hoover	Pawhuska fm. Elgin sandstone		Shawnee fm.	Scranton shale Howard limestone Severy shale Topeka limestone Calhoun shale Deer Creek ls. Tecumseh shale Lecompton ls. Kanawa shale
Break ?	Break ?	Carmichael Endicott	Nelagoney formation	Bristow formation	Douglas fm.	Oread limestone Lawrence shale Iatan limestone Weston shale
Break ?	Break ?		Ochelata formation (Avant ls.)		Lansing fm.	Stanton limestone Vilas shale Plattsburg ls. Lane shale
Break Belle City ls.	Break Belle City ls.		Drum Dewey ls. Nellie Bly fm. Hogshooter ls	Copan formation	Kansas City fm.	Iola limestone Chanute shale Drum limestone Cherryvale shale Winterest ls. Calesburg shale Bethany Falls ls. Ladore shale Hertha limestone
Francis fm.	Francis fm.	Layton	Coffeyville formation (Checkerboard ls.)			
Seminole Holdenville	Seminole Holdenville	Cleveland Squirrel	Lenapah limestone Nowata shale		Marmaton fm	LaCygne shale Lenapah limestone Nowata shale Altamont limestone Bandera shale Pawnee limestone Labette shale Fort Scott ls.
Wewoka	Wewoka	Big Lime	Oolagah limestone			
Wetumka	Wetumka	Peru sand Oswego-Wheeler	Labette shale Fort Scott ls.			
Calvin Senora fm. Stuart shale Thurman ss. Boggy shale Savanna ss.	Calvin Senora fm. Stuart shale Thurman ss. Boggy shale Savanna ss.	Skinner Perryman Red Fork Pink lime Bartlesville	Cherokee		Cherokee shale	
McAlester shale Hartshorne ss.	Winslow fm.	Tucker Booch	Winslow		Absent	
Atoka fm. Wapanucka ls. Upper Caney shale	Absent Morrow	Dutcher	Absent Morrow		Absent Absent	
Break Lower Caney shale	Pitkin	Lyons	Pitkin Mayes (Mississippian) Boone		Absent Boone	