OKLAHOMA GEOLOGICAL SURVEY
Chas. N. Gould, Director

Bulletin No. 40-C

OIL AND GAS IN OKLAHOMA

OIL AND GAS IN CREEK COUNTY, OKLAHOMA

By

John W. Merritt and O. G. McDonald

NORMAN
AUGUST, 1926

CONTENTS

Page
FOREWORD ---- 4
INTRODUCTION ---- 5
    Purpose of the chapter ---- 5
    Location and area ---- 5
    Topography and dainage ---- 6
    History of development ---- 6
    Acknowledgments ---- 6
AREAL GEOLOGY ---- 7
STRATIGRAPHY ---- 7
    Surface formations ---- 7
    Subsurface formations ---- 8
STRUCTURE ---- 11
    General Statement ---- 11
    Structure of the area ---- 12
    Origin of structural features ---- 17
    Conclusion ---- 34
RELATION OF FUTURE DEVELOPMENT TO STRUCTURE INTERPRETATION ---- 35
    General statement ---- 35
    Structural interpretation applied to exploitation ---- 35
    Structural interpretation applied to drilling ---- 36
OIL AND GAS DEVELOPMENT ---- 37
    General statement ---- 37
    Description of producing sands ---- 38
    Possible future production ---- 42
SUMMARY ---- 43
BIBLIOGRAPHY ---- 44

ILLUSTRATIONS

PLATE Page
I. Northeast-southwest cross-section of Creek County ....In Pocket
II. East and west cross-section of Creek County ....In Pocket
III. Map of Creek County showing zones of parallel faults 13
IV. Map of Creek County oil pools 37
V. Generalized cross-section of Creek County ....In Pocket
VI. Microphotographs of the "Wilcox," Hominy, Bartlesville and Elgin sands. (Courtesy of the Journal of Economic Geology)........39
VII. Creek County production map ....In Pocket

FIGURE
1. Index map of Oklahoma showing area covered by this report 5
2. Type structures of Creek County 15
3. Sketch showing how compaction of sediments over old topography would effect the overlying sediments 19
4. Sketch showing how compaction of sediments over old topography would effect the overlying sediments 21
5. Illustration of the principles of the strain ellipse....................25
6. Diagram of the possible origin of the northeast-southwest folds......31
7. Sketches showing the effect of progressive folding on the stratigraphic section during sedimentation 33
8. Well log of the McComb No. 1. Giving detailed description of strata below the Mississippi lime 42

FOREWORD

In 1917 the Oklahoma Geological Survey issued Bulletin 19, Part II, "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 year 1926, and doubtless new data will cause many changes in our present ideas.

The authors of the present paper, Messrs. J. W. Merritt and O. G. McDonald, consulting geologists of Tulsa, Okla., have studied the geology both surface and sub-surface of Creek County for a number of years, and are well qualified to speak on the subject. It is believed that the observations set forth by these men and the theories which are advanced, will be of material assistance to the oil geologists in locating future sources of production in Creek County. Their treament of the peculiar en echelon faults which are common in Creek County deserves especial attention.

This article in a modified form was published as a serial in the Oil and Gas Journal in the issues of July 1st, 8th, 15th, and 22nd, 1926. The Oklahoma Geological Survey is endeavoring to give the widest possible publicity to such data as will aid in developing the mineral resources of the State.

Therefore, this paper is republished as part C of the volume on Oil and Gas in Oklahoma.

August 1, 1926.

CHAS. N. GOULD
Director

OIL AND GAS IN OKLAHOMA

OIL AND GAS IN CREEK COUNTY, OKLAHOMA

By

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INTRODUCTION

PURPOSE OF THE CHAPTER.

Since the publication in 1917, of Bulletin No. 19, Pt. II, entitled "Petroleum and Natural Gas in Oklahoma", by the Oklahoma Geological Survey, a great amount of development has taken place in Creek County. Up to 1917, the major production in this county came from that portion of the Glenn pool lying within Creek County and from the Cushing pool. Since 1917 only two pools of major size have been developed, the Slick and Continental pools. The former was found on a broad terrace with minor local irregularities. The latter is made up of a group of small structures. All remaining new development has taken place upon small structures of all varieties, some production being found even in synclines. These small structures are difficult to map upon surface outcrops and are becoming increasingly hard to find. It is growing more and more evident that the discovery of new production in this county will depend upon the application of an interpretation of the nature and origin of these small structures. This chapter, therefore, besides describing the production of the county, will lay considerable emphasis upon a study of the nature of the structures here and attempt the interpretation of their origin.

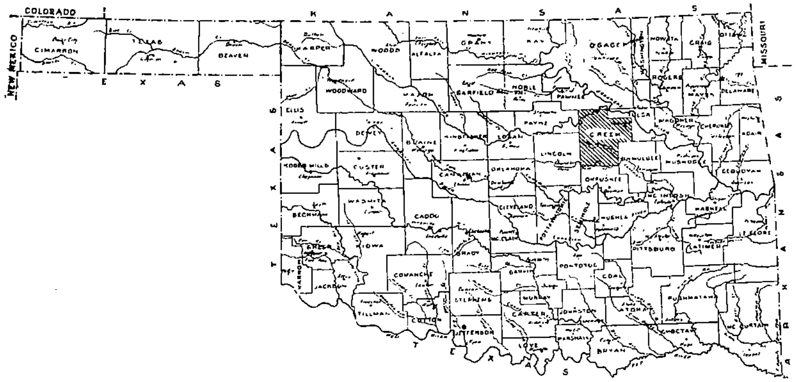

Figure 1.—Index map of Oklahoma showing area covered by this report.

LOCATION AND AREA.

Creek County is located in the northeast quarter of the State and extends from T. 14 N., to T. 19 N., inclusive, and from R. 7 E., to R. 12 E., inclusive. The area is approximately 963 square miles.

TOPOGRAPHY AND DRAINAGE.

Creek County, like the eastern portion of Osage County, lies within the "sandstone hills region", a belt of rather rugged country, fairly well covered by timber.

The county is drained by Cimarron River and its tributaries, and by Deep Fork and Little Deep Fork, tributaries of the North Fork of the Canadian, and by Polecat Creek which, like Cimarron, is tributary to the Arkansas.

The valleys of most of the streams tend to be V-shaped, with narrow flood plains, with the exception of Canadian River valley, which has a broad flood plain.

Hills in this county tend to lie in roughly parallel zones, trending northeast-southwest, frequently with steep escarpments on their east-facing slopes. The hills are usually capped by resistant sandstones (or limestones), especially when east-facing escarpments are found. Between these hill-ranges are lower lands of smoother topography developed in the softer strata. The most prominent escarpments are found in the northwestern part of the county where the Pawhuska limestone forms the resistant bed. Surface elevations vary from 600 to 950 feet.

HISTORY OF DEVELOPMENT

Active development in Creek County began in 1906, when the famous Glenn pool was discovered. The first well was completed in this pool in December, 1905, and by the end of 1906, about 110 wells had been drilled. The maximum production from the Glenn field was obtained in October of 1907, when 2,441,662 barrels were produced for the month. The Cushing field was opened in 1912, with the maximum production coming in June, 1915. The Slick pool was developed in 1919 and 1920, and activity continued into 1921. The Continental or Bristow pool was opened up in 1921 and 1922. During the period between the development of the Cushing pool and the Slick and Continental pools' activity, which was an era of prevailing high prices for oil, many smaller fields were discovered. Active development has continued in Creek County up to the date of the present writing. In recent years, also, some old shallow pools have been given new production from deeper sands.

ACKNOWLEDGMENTS.

The authors have made use of Bulletin 19 as far as possible in the preparation of the present chapter. Besides this, reference has been made to numerous articles touching this area and concerned with structural interpretations also of other areas, the stratigraphy and structure of which are similar to those of Creek County. One unpublished paper by Evan Just is also cited. A bibliography of the above articles will be found at the end of this report. The Creek County production map included herein was furnished by the Triangle Blue Print & Supply Company of Tulsa. The authors are also indebted for personal comments, criticisms, and suggestions to Luther White, Richard Hughes, L. L. Foley, Evan Just, and others.

AREAL GEOLOGY

The rocks appearing at the surface in Creek County have been most recently described by Gould in Bulletin No. 35 of the Oklahoma Geological Survey. They comprise a portion of the upper Pennsylvanian, and range from the Coffeyville formation upward to and including the Pawhuska formation. The Checkerboard limestone, which lies near the base of the Coffeyville formation, outcrops near Mounds and crosses the southeastern corner of Creek County. The upper limestone member of the Pawhuska formation caps the high hills near Drumright in the northwestern part of the County. The strike of these and intermediate formations is approximately N. 20° E., and the formations lie in belts of irregular width which cross the county in parallel form, as shown on the new Oklahoma geological map.[1]

STRATIGRAPHY

SURFACE FORMATIONS.

A brief description of the formations exposed at the surface in Creek County, largely quoted from Bulletin No. 35, of the Oklahoma Geological Survey, and arranged in ascending order, is as follows:

> *The Coffeyville formation* has an average thickness of about 300 feet. The lower part is made up largely of bluish or greenish-gray shales. In this portion, near the bottom, is found the Checkerboard limestone. The latter has a thickness of 2 or 3 feet and is bluish-white when freshly exposed and yellowish-white when weathered. It is fine grained and fossiliferous. The Coffeyville formation grades upward into sandstones of gray to brown color.
>
> *The Hogshooter limestone*, locally known as the Lost City limestone, is a single bed of limestone with a maximum thickness of about 20 feet where it enters the county just south of Sand Springs. It thins southward. It is well jointed and presents a "shelly" appearance upon weathered surfaces. Its color is medium to light gray. This is the basal formation of the Drum group.
>
> *The Nellie Bly formation* is made up of alternating beds of shale and hard gray sandstone. The thickness in the north-

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[1] Colored geologic map of Oklahoma, U. S. Geol. Survey, Washington, D. C.

ern part of the county is about 200 feet. It is the middle formation of the Drum group, and overlies the Hogshooter limestone and is immediately overlain by the Dewey limestone.

The Dewey limestone in Creek County is a shaley blue-gray limestone which frequently weathers to dark grayish-yellow or brown. It varies in thickness up to 8 or 10 feet. It is usually quite fossiliferous. It forms the upper member of the Drum group and is overlain by the Ochelata formation.

The Ochelata formation is essentially made up of shales, containing some sandstone and limestone members. Of the latter, the most prominent in this county is the Avant limestone, which, here, attains a thickness usually of 10 feet or less. It is a gray ferruginous limestone which weathers to a dark brown to a reddish-brown color.

The Elgin sandstone is a brownish-gray, heavy bedded sandstone of relatively even texture. At some places there are shale partings. It resists erosion fairly well and its upper surface forms an excellent stratigraphic boundary. Its thickness ranges in this county from 50 to 80 feet. It immediately overlies the Nelagony formation and is overlain by the Pawhuska formation.

The Pawhuska formation consists chiefly of red and gray shales, interbedded with gray sandstones and capped by one or two limestone beds known as the Pawhuska limestone. The sandstones range in thicknesss up to 20 feet and the limestones are from 2 to 5 feet thick. The whole formation in Creek County varies from 140 to 160 feet in thickness.

Two groups mentioned by Gould in Bulletin No. 35 should be noted here. The Copan, so named by Ohern in 1910, includes the lower portion of the Ochelata formation, the Dewey limestone, and the Nellie Bly formation. The Bristow, named by Fath in 1925, includes the Nelagony formation and the upper part of the Ochelata formation down to the base of the Tiger Creek sandstone, which latter, with the Avant limestone, form a part of the Ochelata formation.

SUBSURFACE FORMATIONS.

(See Plates I and II)

From the east side of the county the sediments dip westward at about 50 feet per mile and the elevation of the surface tends to rise. All formations, therefore, except the Pawhuska, are partly exposed and partly covered. All exposed rocks have been grouped with the surface formations and unexposed rocks thrown into the subsurface group. The latter are described briefly in descending order, as follows:

The Broken Arrow formation lies below the Dawson coal and above the Fort Scott limestone. The equivalents of this formation to the north named in descending order are, Labette shale, Pawnee limestone, Bandera shale, Altamont limestone, and Nowata shale. In its type locality the Broken Arrow has a thickness of 350 to 500 feet but thickens westward and southward. In Creek County the thickness is 800 feet or more, except in the extreme northeast corner of the county, where it has a thickness of 400 to 500 feet. This formation is made up largely of shales, with a few interbedded sandstones and limestones in the upper portion. The Cleveland sand is a part of this formation.

The Fort Scott limestone, according to Fath's bulletin on the Bristow quadrangle, comprises a zone of limestones, with interbedded shales making up a thickness of 100 to 200 feet. This zone is capped by the "Big Lime" of the drillers and includes at its base the Oswego limestone. The Wheeler sand is correlated with the latter.

The Cherokee Shale lies immediately under the Fort Scott limestone. This portion of the section is made up chiefly of shale with a few thin interbedded limestones and thicker bodies of sandstones. The Cherokee averages about 900 feet in thickness in this county, though it thins to 600 feet or less over the Cushing group of structures and is elsewhere found as thick as 1,100 feet. The shales vary in color from light to dark gray. Within the Cherokee are found the following oil producing sands, arranged in descending order: Prue, Red Fork, Bartlesville (or Glenn), Tucker (or Taneha), and Dutcher.

The Boone formation ("Mississippi lime") underlies the Cherokee shale in Creek County. A stratigraphic hiatus exists both above and below this formation. It is made up of a series of limestone beds sometimes separated by shale partings. The Boone ranges in thickness from a little over 200 feet up to 450 feet. According to Aurin, Clark and Trager[2] the "Mississippi limestone" is divisible lithologically into three members. The upper member is not found much south of the north line of this county. It is made up of a gray limestone and chert. The middle member is a black limestone and is found throughout the county. The lower member is a gray limestone and is absent in the Okmulgee district.

The Chattanooga shale underlies the Boone throughout the county and ranges in thickness from 5 to 70 feet in the logs used for the cross sections shown in this chapter. (See Plates I and II). There is a hiatus both above and below this formation. This shale is black and slaty and of fairly uniform texture.

The Misener sand, which is correlated with the Sylamore sandstone of eastern Oklahoma and Arkansas, is composed of thin, irregular patches of wind-blown sand believed by White and others to have been derived from the erosion of older sediments at the close of Devonian time. It would be, therefore, related rather to the Chattanooga shale overlying it than to the older underlying formations.

The Hunton formation, part of which correlates with the St. Clair marble of eastern Oklahoma, has not thus far been identified in

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[2] Aurin, F. L., Clark, G. C., and Trager, E. A. Notes on the subsurface, pre-Pennsylvanian Stratigraphy of the Northern Mid-Continent Oil Fields. Bull. Amer. Assoc. Pet. Geol. Vol. 5, No. 2, pp. 121-153, 1921.

Creek County, though it has been found in some wells in the east central part of Lincoln County. It is possible that this formation may later be found in the southwestern part of Creek County.

Where encountered in wells, this formation consists of a continuous white to gray dolomitic crystalline limestone, showing very little shale. The shales are very limey, or are really softer members of the limestone.

The Sylvan shale, shown in Luther White's[3] map of Northeastern Oklahoma, occupies most of Creek County south and west of Bristow. This shale where found overlain by Hunton is greenish blue to olive green in the upper five to fifteen feet. It is composed of a dark shale toward the base. It is very remarkable in its lithologic uniformity over broad areas and has long been recognized as a distinct formation. It is slightly calcareous and contains a few thin beds of limestone. Its total thickness ranges from 75 to 125 feet. The age of the shale, according to White, is Richmond, and may be correlated with the Cason shale of Arkansas.

The Viola limestone ("white lime"), which in the Arbuckle mountain area has a thickness of from 500 to 600 feet, ranges from 40 to 50 feet thick in Creek County, due to the absence of the lower beds. Here it is made up principally of two beds. The upper bed is a white to grayish, coarsely crystalline limestone and the lower bed is a dense brownish-gray limestone closely resembling lithographic stone. Due to its thinness, where exposed to erosion at the close of the Devonian it has been left frequently as outliers. This accounts for its absence in some well logs in this county. It has been correlated with the Fernvale limestone of the Harrison quadrangle.[4]

The Simpson formation is composed of post-"Wilcox" Simpson, the "Wilcox", the Tyner and the "Burgen." all overlapping the lower Simpson beds.[5]

The Simpson lies between two unconformities, one under the Viola and the other above the Arbuckle, and extends out beneath the post-Hunton unconformity.

The post-"Wilcox" Simpson is made up of a series of brown or gray sandy dolomitic limestones interstratified with some green shale and thin sandstone members. This attains a thickness at Stroud, Holdenville, Okemah and Cushing of as much as 140 feet.

The "Wilcox" is a white sandstone attaining a thickness of 50 to 200 feet. It has a pure, uniform character which differentiates it from the Tyner.

The Tyner formation is composed of green sandy shale interstratified with thin beds of sand and sandy dolomitic limestone. In the northern part of the county the basal portion is more dolomitic and becomes more sandy southward.

The "Burgen" (Hominy) sandstone, laid down in most of Creek County over the eroded surface of the Arbuckle limestone, is a well cemented glassy sandstone. Because of its siliceous cementation it is relatively non-productive. It may be absent in places because of islands of Arbuckle or "Siliceous Lime' in the "Burgen" sea. It reaches 50 feet or more in thickness.

The lower Simpson beds, composed largely of sandy shale and sand, which attain a thickness of 300 feet or more south of Wewoka, probably do not occur in much, if any, of Creek County.

The "Siliceous Lime" which is correlated with the Arbuckle limestone of lower Ordovician age, is found in several wells in Creek County. From this formation comes the "Turkey Mountain" sand production. It is generally thought to contain no shale breaks of a thickness noticeable in well logs, though one well shown on the accompanying cross-sections has two shale beds of from 10 to 20 feet in thickness in that portion of the section which the writers believe to be the "Siliceous Lime." Most generally this formation is chiefly made up of limestone, sandy limestone and sandstone beds.

Granite is found for certain in only one well in Creek County. This is located in sec. 22, T. 19 N., R. 7 E. where it was encountered at from 3,670 to 3,704 feet. In this well the granite is overlain by 600 feet of "Siliceous Limestone." Overlying the "Siliceous Lime" is the Tucker sand, while the "Wilcox" is missing. The granite is probably pre-Cambrian.

It is not known just what the topography of the granite surface in Creek County is, nor whether buried ranges of hills or mountains of granite may occur here. The single occurrence in Creek County is under the south end of the Cushing group of structures, suggesting a relationship between possible granite ranges and the larger structural features. This relationship will be discussed in a later paragraph.

STRUCTURE

GENERAL STATEMENT.

Since a large part of Creek County is well covered by timber and the greater number of hard outcropping sediments are sandstones with irregular thickness and extent, reconnaissance of the surface structures is very difficult. In addition to this, with a few exceptions, the surface structures are small and with relatively low structural relief. For these reasons it is the belief of the authors of this report that there is much undeveloped territory in Creek County underlain by small structures yet to be discovered which hold promise of future production. It is also their belief that a study of the typical structural conditions and their interpretations in Creek County will present a key to the whole Creek County problem which will be of value to operators interested in exploiting this territory.

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[3] Published in the Oil and Gas Journal, April 1, 1926. Also published as Bull. 40-B of the Oklahoma Geological Survey.

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

[5] See cross-section accompanying Luther White's map. Bull. Okla. Geol. Survey No. 40-B.

Since the structures of Creek County appear to have been formed by a relatively uniform group of forces, and seem to have a more or less definitely arranged pattern, and since certain types of structure appear to follow more or less fixed rules regarding position of axial plane, surface and subsurface dips, and the like, a correct interpretation of the origin of the structures in this county seems absolutely necessary, not only to the search for undiscovered anticlines, but also to the proper recommendations for the testing of any single structure. The authors, therefore, present this chapter on structure with a view to reach, if possible, the true interpretation of the forces acting in this general region, and the effect of these forces upon the rocks of Creek County.

STRUCTURE OF THE AREA

Regional structure. The rocks of this county strike from North 10 degrees, to North 20 degrees, East and dip Westward at an average rate of about 75 feet per mile. This general monoclinal dip is rarely to be found regular for any great distance, but is almost everywhere interrupted by faults and folds of various types. The faults are almost always normal and are usually arranged in groups. Within the groups these faults are en echelon. The folds take the form of synclines, domes or closed anticlines, plunging anticlines, and terraces or arrested monoclines. The anticlines are also frequently arranged en echelon, but less noticeably than are the normal faults.

Normal en echelon faults. Most of the faults of Creek County are normal and are arranged en echelon in fairly straight-line zones. These zones trend about North 10 degrees, to North 20 degrees, East, which is about the same as the normal strike of the rocks of the county. The faults themselves take a northwesterly direction making an angle of about 45 degrees with the line of the zone in which they lie. (See Pl. III). There is a striking parallelism between the individual faults in any single zone. There appears to be little difference between the number of faults with the downthrow on the northeast and the number with the downthrow in the opposite direction. These faults seldom exceed two miles in length (the maximum being about 3½ miles) and the throw is rarely in excess of 75 to 100 feet (with a maximum of 130 feet). The average length appears to be between a mile and a mile and a half while the average throw seems to be less than 50 feet.

Fath[6] states that these en echelon faults have their greatest displacement near the basement rocks, that the displacement decreases upward, and that many of the faults do not reach the surface. It is the opinion of the authors that the throw of the en echelon faults decreases downward. Their reasons for this belief will be set forth in a later paragraph.

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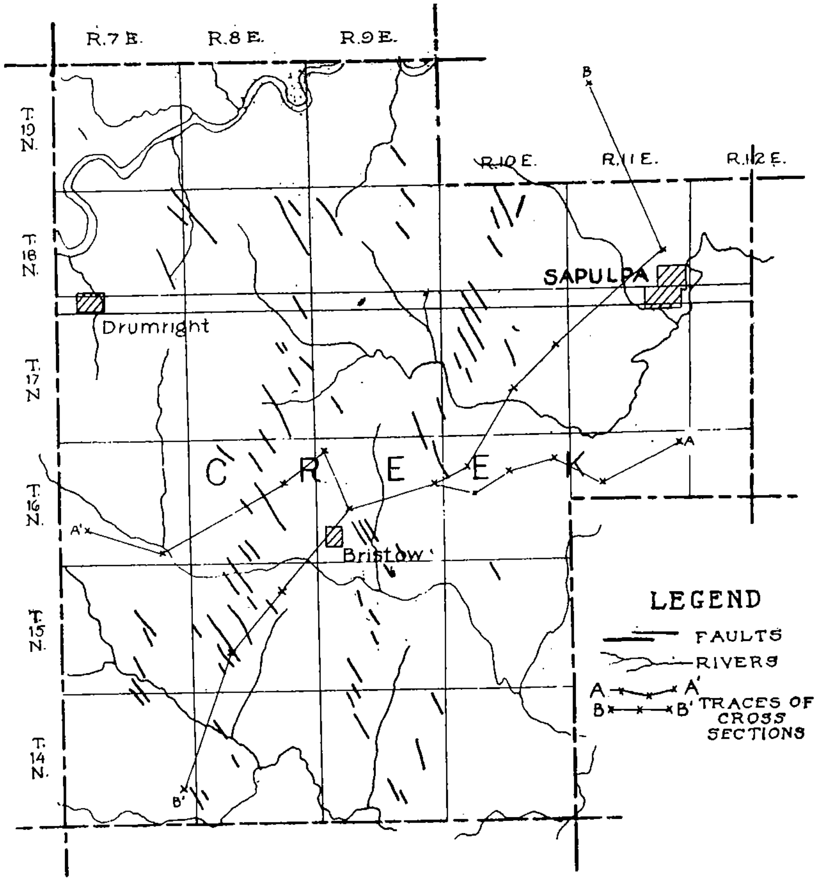
[6] Fath, A. E., Geology of the Bristow Quadrangle, Creek County, Oklahoma. U. S. Geol. Survey Bull. 759, p. 38, 1925.

PLATE III



MAP OF CREEK COUNTY SHOWING ZONES OF PARALLEL FAULTS

There are a number of surface phenomena accompanying these faults, such as slickensiding of sandstone and limestone beds, where cut by the faults, shearing and veining of sandstones and limestones in the zone of faulting, buckling of ledges into ridges following the fault trace, and the formation of abnormal dips probably by slumping toward the fault plane which may take place on either the upthrown or downthrown side of the fault, or on both sides.

Normal northeast-southwest faults. So far as the authors are aware, no northeast-southwest normal faults reach the surface in Creek County. It is suspected by several geologists, however, that some such faults occur in the Pennsylvanian rocks below the surface. Such an one is described by Fath[7] as cutting across the Slick field in Tps. 15 and 16 N., R. 10 E., marked by a series of dry holes. Several such faults have been mapped, however, in Hughes, Seminole and Okfuskee counties. The strike of these faults closely coincides with the trend of the en echelon zones in these counties. These faults range in length from 2 to 10 miles and in displacement from 100 to 300 feet.

Thrust Faults. The authors know of only one thrust fault in Creek County. This crosses the northwest quarter of Sec. 10, T. 18 N., R. 10 E. It strikes northeast and southwest and lies approximately at right angles with the trace of the en echelon faults, and parallel with the axes of the small northeast-southwest folds. Its best exposure is in a creek bank near the north side of the section, where a heavy limestone bed is cut by the fault at an angle of 40 to 45 degrees with the horizontal. The fault plane is well slickensided. The maximum throw is about 60 feet.

Large northeast-southwest folds. There are a number of anticlines in the county much larger than the average, such as the domes in the Cushing field. (See Fig. 2). The long axes of these folds lie more nearly north and south than those of the folds next to be described, and are closely parallel with the trend of the en echelon fault zones in this part of the county. As well as being larger areally, these anticlines usually also have much more pronounced structural relief. Maximum reverse dips on the Cushing structures range between 100 and 160 feet from top of dome, to the bottom of the deepest part of the syncline. These domes range from 1 to 3 miles in width and from 2 to 5 miles in length.

The structural relief on the surface of the Cushing group of structures is much lower than that on the producing sands. Beal[8] mentions this difference in interval between surface and lower formations showing the same in the form of tables. The increase in dip of the sub-surface formations over those at the surface ranges from 50 to 200 feet approximately. Beal also mentions the fact that the high point on the producing sands sometimes appears to be eastward from that on the surface beds.

Small northeast-southwest en echelon folds. It is to be observed that within the zones of en echelon faulting there is usually more or less intense folding, while between these belts there is little or no folding of any prominence. The folds in the fault zones may be grouped into three general classes. These classes will be described in this and the following two paragraphs. These folds rarely exceed a mile or two in length and may take the form either of domes or of open anticlines.

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[7] Op. Cit. p. 54.

[8] Beal, C. H., Geologic Structures in the Cushing Oil and Gas field, Okahoma and its relation to oil, gas, and water. U. S. Geol. Survey Bull. 658, p. 24, 1917.

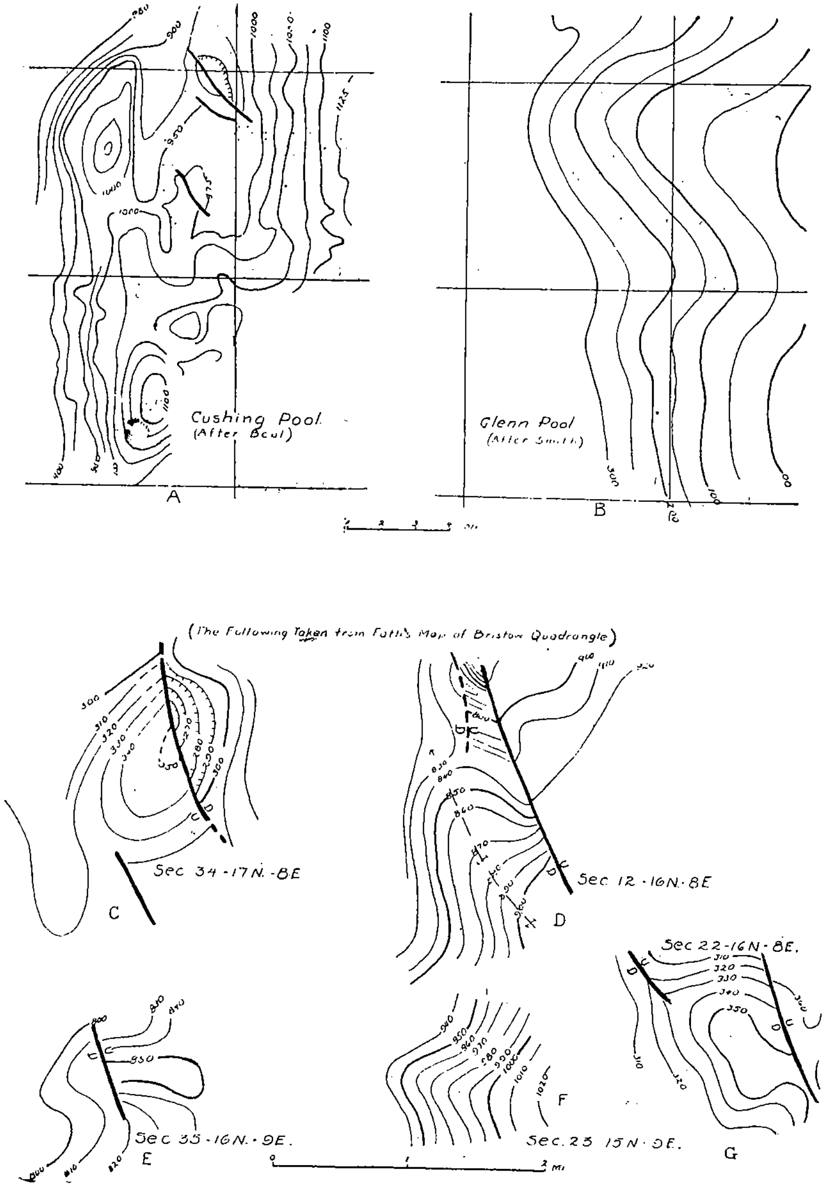

Figure 2.—Type structures of Creek County.
A—the long north-south anticline.
B—the large terrace type of fold.
C—the faulted northeast-southwest compression fold.
D—the plunging northwest-southeast fold.
E—the faulted east-west fold.
F—the plunging nose.
G—the faulted northwest-southeast plunging anticline.

The first class is that of anticlinal folds, the long axes of which lie northeast and southwest, approximately at right angles with the traces of the en echelon faults, and at an angle of about 45 degrees with the direction of the fault belt in which they occur. Like the larger folds of the Cushing field, the structural dips of these folds increase with depth. The surface formations show the reverse or southeast dip on these anticlines ranging from 5 to 10 feet up to 30 or 40 feet. The corresponding dip on the deeper subsurface formations is frequently double that on the surface formation above them. The authors have often observed that the axes of these anticlines are inclined westward, placing the top of the anticline on the oil sands west of the top of the same anticline on the surface formations. Sometimes this pitch of axial plane will shift the sub-surface apex as much as a quarter of a mile or more west of the surface apex. (See Fig. 6). Sometimes these anticlines are terminated on their northeast ends by faults.

Small northwest-southeast folds. This is the second class mentioned above, and into this group fall the folds whose long axes lie roughly parallel with the individual faults in the fault zones. (See Fig. 2). These folds are thought to decrease in intensity with depth. They are most usually found in the zones of faulting and, more frequently than not, are associated with the faults themselves. They appear to be less uniform in character than the class last described above.

Folds without regular pattern. Into this third class are thrown folds whose pattern is so irregular as to make classification difficult. They appear to be formed by the modification of one or the other of the folds described above.

Terraces. The most common form of terrace is that which has its greatest elongation roughly parallel with the strike of the rocks of the region, and also parallel with the lines of en echelon faults. Terraces of this sort may be several miles long and a mile or more wide, and may be modified by anticlinal, synclinal, or fault irregularities. Some of these terraces are very productive. Such a terrace is to be found occupied largely by the Glenn pool. (See Fig. 2). This terrace is crossed by flutings or slight anticlinal and synclinal parallel folds whose axes lie about at right angles to the long dimension of the terrace. The Slick pool is on another terrace which has an irregular surface. In this pool the more prolific wells are found upon the small "highs" which form these irregularities.

Terrace production is more frequently found upon the westward edge of the flattened area and part way down the steeper slope west of the "break" in the structure.

Another form of terrace has been observed whose longer dimension takes a diagonal course down the normal dip. It is much smaller than the examples cited above and has probably a distinctly different origin.

Minor irregularities. At no place in the county do the structure contours follow straight lines, nor are they anywhere spaced uniformly for any great distance. They rather follow irregularities in direction which may be due to the forces which combined to form the more prominent structures already described, or they may be due to such conditions of sedimentation as thickening and thinning of beds locally, or both. Since these small features are rarely significant as touching the problem of production, they will be ignored in the further discussion of the structures and their origin.

ORIGIN OF STRUCTURAL FEATURES.

General statement. Several theories have been advanced to explain the origin of the Mid-Continent types of structure. The authors will now attempt to discuss the greater number of these theories one by one, and to test, as far as possible, the applicability of these theories to the local problems in Creek County. After testing these theories the authors will bring up conditions which these theories do not satisfy, either wholly or in part, and will attempt to find a theory which seems to explain more completely the origin of Creek County structures. The reader must not allow himself to think that any simple theory will explain structural conditions in this county any more than in any other region.

Folding by vertical thrust. Gardner[9] in 1917 suggested that local folds may have been formed by vertical transmission of pressure from deep seated sources in the zone of rock flowage. It is possible that the presence of granite ridges at relatively shallow depths in the Mid-Continent region might suggest some such explanation for the structures overlying them. On the other hand, for every structure underlain by a prominent granite ridge there are hundreds that show no such relationship. Furthermore, the average Mid-Continent structure is very small and this fact alone precludes any such explanation, because it seems impossible for forces to come from the zone of flowage and apply themselves to such small areas. This theory, also, does not seem applicable to a territory in which structures are aligned and have definite axial arrangement.

Warping of sediments accompanied by faulting during deposition. McCoy[10] explains the faulting and folding of this area by the statement that during the deposition of the Pennsylvanian, two basins were formed, one in southeastern Kansas and one just north and northwest of the Arbuckles in central Oklahoma, leaving the territory of Tulsa, Osage, Creek, and Pawnee counties as a fulcrum between these two basins. The formation of these two basins, he believed, would cause tension in the fulcrum area which would be relieved by tension faults with northwest-southeast trend. In order to spread these faults over the territory in a northeast-southwest direction, he assumed a shift back and forth of the fulcrum point.

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[9] Gardner, J. H., Mid-Continent Oil Fields, Bull. Geol. Soc. America, vol. 28, pp. 685-720, 1917.

[10] McCoy, A. W., A short Sketch on the Paleogeography and Historical Geology of the Mid-Continent Oil District, and its Importance to Petroleum Geology. Amer. Assoc. Pet. Geol., Bull vol. 5, pp. 541-584, 1921.

In considering this explanation, it does not seem possible to develop enough tension to explain even a very small proportion of the faults actually found in the area, even if no readjustment by differential movement were considered. If small, sharply folded anticlines may be formed with little or no faulting, (and many cases may be cited), certainly a broad arch which is hundreds of miles across cannot be expected to develop tension faults upon its crest. Such slight folding would most readily and immediately be taken up in slight differential movement and readjustments.

Packing and condensation of sediments. Blackwelder[11], commenting upon the structures of east-central Kansas, believes compacting of sediments over buried topography will account for most of the anticlines in that region. He states that the folds do not take the form expected as a result of tangential compression, that the arrangement of the folds is not en echelon, as would be expected by tortional movement, and that there appears to be no relationship between adjacent faults and folds. He notes the divergence of beds away from the axes of the domes and states the belief that this divergence is best explained by the compacting of the sediments during deposition.

Monnett[12] explains the origin of some of the Mid-Continent structures also by the theory of compaction. He lays special emphasis, however, upon the effect of sand lenses in causing irregular consolidation of the sediments.

Powers[13] believes also in the efficacy of sedimentary compression during deposition, especially over old land surface irregularities, but, in order to explain the increase of structural dips with depth in many cases, he also invokes progress, either regular or spasmodic, uplift of the buried hills as partially responsible for the origin of at least some of the structures. Minor structures between certain "granite buttresses" he explains are due to compressive or local tangential forces.

Rubey[14] also agrees that gravitational compression has at least something to do with the formation of some structures in the Mid-Continent region. Many others follow the same line of reasoning as that adopted by the foregoing writers.

Lewis[15] has made a volumetric study of compaction of the silts in the Hudson River and states that clay silts there, when buried to a depth of 50 feet, suffer a reduction in pore space of about 55 per cent. Deposition there is very rapid.

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[11] Blackwelder, Eliot. The Origin of the central Kansas oil domes. Am. Assoc. Pet. Geol. Bull., vol. IV. No. 1, pp. 89-94, 1920.

[12] Monnett, V. E., Possible origin of some of the structures of the Mid-Continent oil fields. Economic Geology, vol. 17, No. 3, pp. 194-200, 1922.

[13] Powers, Sidney. Healdton oil field in Oklahoma. Economic Geology, vol. 12, pp. 594-606, 1917.
Granite in Kansas, Amer. Jour. Sci., 4th Ser. vol. 44, pp. 146-150, 1917.
Reflected buried hills and their importance in petroleum geology, Economic Geology, vol. 17, No. 4, pp. 233-259, 1922.
Structural geology of the Mid-Continent region, Bull. Geol. Soc. Amer. vol. 36, pp. 379-392, 1925.

[14] Rubey, W. W., Progress report on subsurface study of Pershing oil and gas field, Osage County, U. S. Geol. Survey, Bull. 751-B, 1924.

[15] Lewis, J. V., Fissility of Shale and its Relations to Petroleum. Bull. Geol. Soc. America, vol. 35, pp. 557-590, 1924.

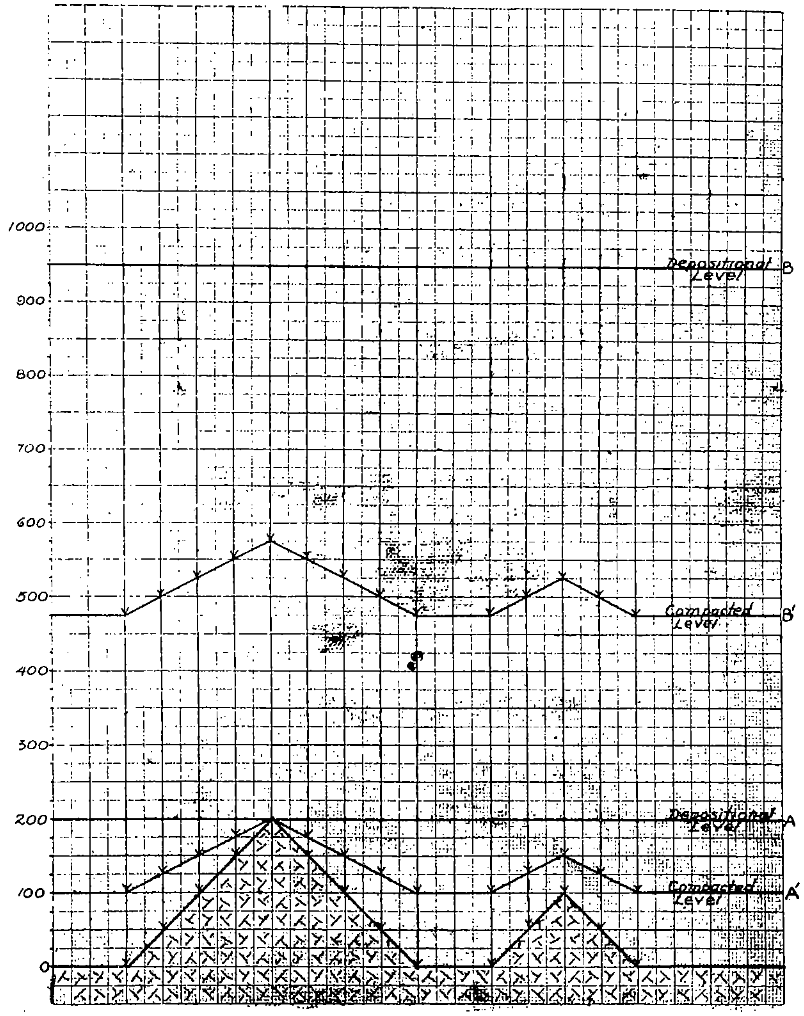

Figure 3. Quantitative sketch showing how compaction of sediments over old topography would effect the overlying sediments, if it is assumed that the sediments will compact as much as 50 per cent and that compaction does not take place until deposition is complete.

A is one level of completed deposition compacted to **A'**.

B is another level of comleted deposition compacted to **B'** and on the old surface the same as if **A** and **A'** were not present. It will be noted that compaction always takes place vertically, and that the diameter of the base of the reflected structure will be the same as the diameter of the base of the buried hill, regardless of the thickness of the sedimentary section. Also the amount of structural relief obtainable depends on the height of the buried hill and not upon the thickness of the sediments deposited above line **A.** Thus line **A** (200 feet of shale) compacted to line **A'** gives as much relief as **B** (950 feet of shale) compacted to **B'**. The stratigraphic interval will be the same to the side of the buried hill as directly over it. It seems obvious that compaction never waits until deposition has ceased before becoming effective, and that such an ideal condition as indicated above is never obtained in nature. Complete compaction means that the surfaces of all the individual particles are in contact and nothing but pore space remains.

Leith and Mead[16] show that clays have an average pore space of 27 per cent while shales have an average in pore space of 13 per cent. This reduction in pore space from clay to shale is almost identical with that found by Lewis in his Hudson River study.

Just,[17] after citing Leith, Mead, Lewis and others, concludes that even in extreme cases the compaction deformation in sediments would not exceed 35 per cent of the original volume (measured in amount of slump of overlying beds) and rapid compaction at beginning of deposition would lessen even this 35 per cent.

The authors concede that compaction does take place during deposition of sediments, and must be taken into consideration as a factor in discussing the origin of structure in sediments. They cannot however, consider compaction as any more than a minor element. The following observations militate against sedimentary condensation as the principal explanation for the origin of Mid-Continent structures:

(a) If all Mid-Continent structures must be explained as originating from compression of sediments during deposition over old land surface irregularities, the large number of these structures, and their relatively small size and frequent steep dips, makes necessary the presence of an old land surface of extremely rugged character. This rugged topography must have existed on top of the Mississippi lime or later, because the rocks of Mississippian age and older are less compressible and, furthermore, many unconformities below Mississippian rocks would tend to fill in the depressions and eradicate all but the most extreme irregularities over older land surfaces.

(b) If compaction is the chief element in the formation of structures in this region, one would expect a surface structure map of any and all parts of the region to show some resemblance to an ordinary surface topography map. General drainage patterns and the like, however, cannot be found, even in the modified form that one would expect.

(c) While there is an increase in structural dip on many of the Mid-Continent anticlines and domes as one progresses downward, which may be accounted for by compaction during deposition (See Fig. 4), this may more adequately be explained by progressive folding during deposition.

(d) Compaction cannot take place at once, but rather appears to be going on during the entire period of deposition, with probably the greatest amount of shrinkage in any one body of sediments taking place almost simultaneously with the deposition of that body. This is particularly well illustrated by the Hudson River clay silts. The tendency, therefore, will be for this immediate compaction to result

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[16] Leith, C. K., and Mead, W. J., Metamorphic Geology, 1915.

[17] Just, Evan, Unpublished manuscript, 1925.

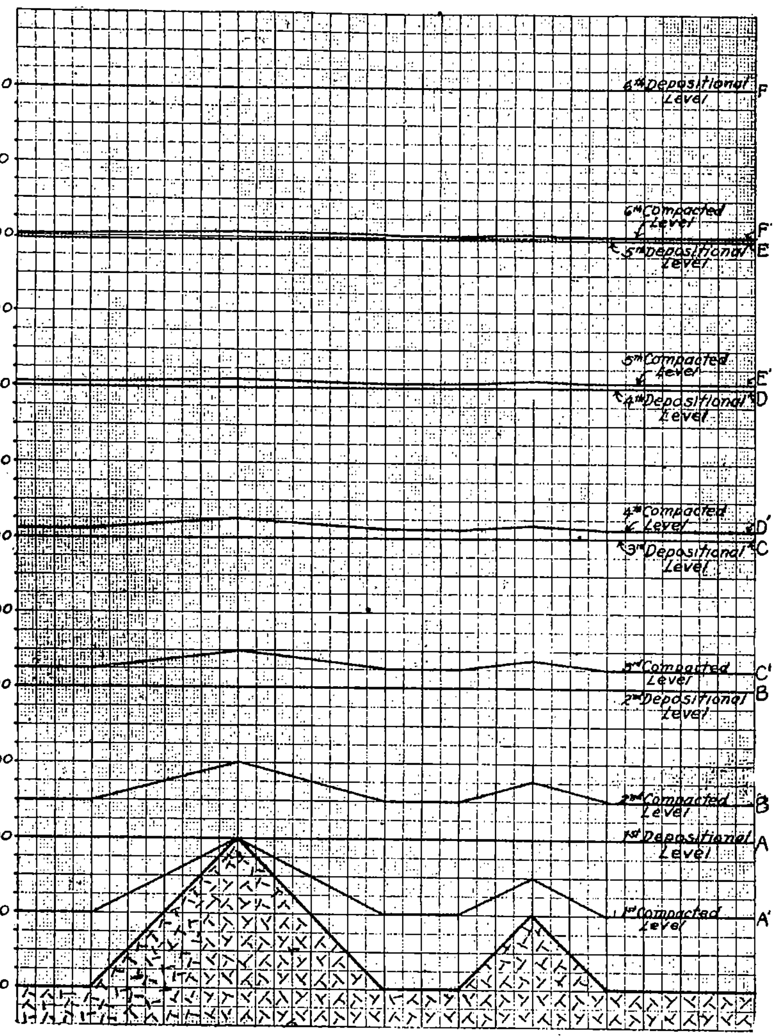

Figure 4. Quantitative sketch showing how compaction of sediments over old topography would effect the overlying sediments if it is assumed that the sediments will compact as much as 50 per cent, and that compaction takes place as deposition proceeds.

A is compacted to **A'**. On top of the compacted surface **A'** sediments up to **B** are deposited; these are compacted to **B'**. This process continues until **F** is compacted to **F'** and the compacted surface is almost flat. Also, the stratigraphic interval to the side of the buried hill is greater than that immediately above it, which condition can only be obtained by compaction during deposition or by progressive folding during deposition. Assuming complete compaction to take place at intervals of about 200 feet, by the time 1,200 feet of sediments are deposited and compacted, very little reflection of the old topography is noticeable. Recent observation has shown that complete compaction very nearly takes place after 100 feet of burial. The above case greatly exaggerates the amount the sediments above the Mississippi lime would compact, and doubles the depth at which complete compaction would probably take place. Since the buried topography does not generally reach within 2,400 feet of the surface in Creek County or northeastern Oklahoma, it does not appear that compaction can account for the type of structural features found there.

in the accumulation of more sediments in the compaction basins, (See Fig. 4), which would overcome a large proportion of the results expected from compaction should it all take place late in the period of deposition. Furthermore, after deposition has reached the tops of the buried hills, compaction structures being formed in the sediments being deposited, would tend to show themselves in the form of seafloor hills. These higher places would be much more subjected to the erosive effect of waves and currents and such water action would tend to remove them and reduce the sea floor to a dead level. This, therefore, would greatly reduce the effect of compaction in the formation of structures, especially as deposition continues to considerable depth.

(e) In order to explain some relatively deep closed synclinal basins by the compaction theory, one would have to have in the old buried topography an exceptionally deep, steep sided, closed basin, such as would only probably be found in karst topography. In some cases the topographic basin would have to be over 200 feet deep if we assume compaction takes place after deposition, and much more if it takes place during deposition, because early compaction during deposition would tend to obliterate the effect of compaction over such basins, for by the time the basin itself was filled with sediments the compaction would be almost complete and there would be relatively little settling of sediments lying above it. Basins of that character and depth are hardly to be expected in this region.

(f) Compaction would hardly explain the formation of a fault with a dome on one side and a closed depression on the other, especially where the structure contours are "D" shaped with the fault forming the straight side. A good example of this may be seen in Fath's map (U. S. G. S. Bull. 759, Pl. VIII) of the Bristow quadrangle in Creek County, sections 13 and 24, T. 17 N., R. 9 E. Many similar examples may be found in Creek County and elsewhere in the Mid-Continent area. (See Fig. 2).

(g) Many closed structures of the Mid-Continent area show steeper reverse dips than basinward dips. While this is not necessarily the rule, the frequency of their occurrence raises the question as to whether such variance of dip can be explained by compaction. To explain it by this theory requires the occurrence of buried topography with an equal number of hills with exceptionally steep east slopes.

(h) Subsurface studies have brought out the fact that axes of a great number of structures in this region plunge in a basinward direction, i. e. the high point on the the high point on the surface formations. Often this shift deep-lying strata is located in a basinward direction from

amounts to over a quarter of a mile, where subsurface formations are mapped at a depth of three thousand feet or more. This axial shift can in no manner be explained by compaction. (See Fig. 6).

(i) Many structures have been reported in which the folding decreases with depth. These cannot be explained by the compaction theory. The explanation of their origin will be found elsewhere in this chapter.

(j) Compaction cannot explain faults of the en echelon type, or even adjacent parallel faults of any frequency. Faults caused by compaction would tend to take directions at a tangent to the curve of the structural contour lines.

(k) At least one thrust fault has been found in Creek County. This cannot be explained upon the basis of the compaction theory.

Direct tangential compression. The earlier study by geologists of anticlines and synclines was carried on in regions where tangential compression on a large scale had taken place. Indeed the earlier production of oil came from such regions. Geologists familiar with that form of structure (Appalachian type, for instance) working later in regions of flat dip, such as the Mid-Continent area, naturally turned first to the tangential theory to explain the origin of our Mid-Continent structures. The forces of compression under this theory may be transmitted either horizontally through the sediments, or through the basement complex and by it into the overlying sediments in the form of more or less vertical movements.

It is not possible, however, to accept the tangential compression theory as applied through the sediments because of the incompetency of a sedimentary body of less than a mile in thickness to transmit such forces through a hundred or more miles of distance horizontally. If the Paleozoic sediments were subjected to severe thrusting from the Ozarks, as is assumed by some, there would be severe shearing and folding at the point of thrust which would die out rapidly and disappear long before the central region of Oklahoma and Kansas was reached. Besides, the Ozark uplift is not sufficiently great to cause any appreciable shortening in the sedimentary section. In fact, the very small shortening possibly caused by the synclinal form taken by the sediments between the Ozarks and the Rocky Mountains would most likely be taken up in rearrangement of sedimentary particles so that no crumpling of sediments would be necessary. It is to be noted that there are no steep and rapidly dying folds developed from the Ozarks westward.

On the other hand, the basement complex (crystalline rocks underlying the Paleozoic sediments) is amply competent to transmit horizontal thrusts, and Powers[18] explains the successive uplift of buried

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[18] Powers, Sidney, Structural Geology of the Mid-Continent Region, Bull. Geol. Soc. Am. vol. 36, pp. 379-392, 1925.
Reflected Buried Hills and their Importance in Petroleum Geology, Economic Geology, vol. 17, pp. 233-259, 1922.

hills in this region by this means. It does not seem possible, however, to explain the uplift of small more or less isolated points such as the buried hills (e. g. the Nemaha Mountains) in this way, especially at such great distances from the points of thrust, even granting the competency of the crystallines to transmit these forces. In the first place, the same type of folding (steep near point of origin, and rapidly dying out westward) would be expected in the crystallines as in the case of the sediments already mentioned. Such deformations would be reflected in the overlying sediments and should be found if they occur. To obtain a crumpling of the crystalline rocks by tangential compression would require forces much greater than are known to have been at work in the Ozarks. Gentle thrusts, however, would result in development only of broad arches and not in the formation of small local uplifts.

Such close folding as a result of tangential compression does occur, however in the Ouachita-Arbuckle-orogenic element. (Ouachita Mountains of Arkansas and Oklahoma with connecting Arbuckle and Wichita Mountains in Oklahoma). In such case, however, thrusting comes from the wrong direction to explain structural features in Oklahoma and Kansas as a result of direct tangential movement. Neither is the axial direction of the Ozark uplift parallel with the direction of the buried hills of northern Oklahoma and Kansas.

Rotational stress transmitted to sediments by shearing in the basement complex. Comparatively little literature is to be found developing this theory, as applied to the interpretation of the origin of the Mid-Continent structures. One of the earliest was Fath[19] who set out to explain the origin of the faults and anticlines of the northern Mid-Continent area by this theory. Fath, in the preparation of a report on the Bristow Quadrangle[20] discussed the possible origin of en echelon faults in this region with R. H. Wood, who was then with the U. S. Geological Survey, working on the Hominy Quadrangle immediately north of the Bristow Quadrangle, and the latter suggested tortional forces. Fath did not at that time think of an adequate source of those forces and this theory is not, therefore, advanced in this bulletin. Later, however, in U. S. Geol. Survey Professional Paper 128-C, he took up the discussion of the origin of the Mid-Continent structural features. He noted first that the alignment of the en eschelon fault zones, the major anticlines, and the Nemaha ridge is essentially parallel. He noted also that the pre-Cambrian rocks are very competent, that the Cambrian, Ordovician, and Mississippian rocks are competent but less so than the pre-Cambrian, that the Pennsylvanian rocks and Permian rocks are relatively incompetent. He states that the Ozark uplift has two phases: (1) late Mississippian or early Pennsylvanian and (2) post-Paleozoic. He states further that the Ozark uplift is the cause of the prairie plains monocline and that slight movements or readjust-

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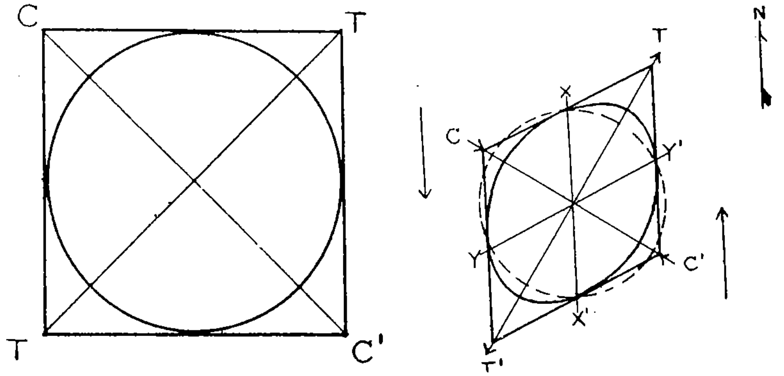
[19] Fath, A. E. The Origin of the Faults, Anticlines, and Buried Granite Ridge of the Northern Part of the Mid-Continent Oil and Gas Field, U. S. Geol. Survey, Prof. Paper 128-C, 1920.

[20] Fath, A. E., Structure of the Northern Part of the Bristow Quadrangle, Creek County, Okla., U. S. Geol. Survey, Bull. 661, pp. 69-99, 1918.

Figure 5. Illustrating the principles of the strain ellipse and its application to the interpretation of the structural features and showing the effect of shearing in the basement rocks, the origin of the parent forces, and the probable lines of weakness in the pre-Cambrian basement crystalline rocks.

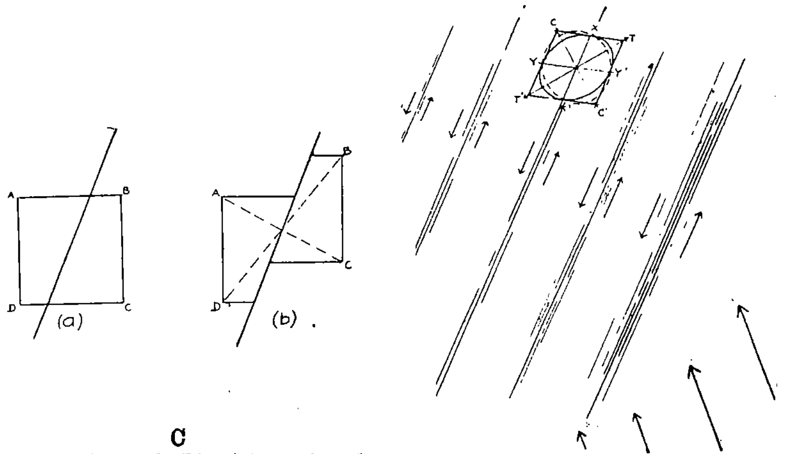


A

Illustrating the strain ellipse as developed by Leith. It is assumed that the square **CTC'T'** is a section of incompetent rocks, with the circle (representing the undeformed position of the strain ellipse), and the diagonal lines drawn on it for illustrative purposes.

B

If sketch **A** is deformed by forces acting as indicated by the arrows the circle becomes an ellipse, which means compression between **C** and **C'** and tension between **T** and **T'**. **XX'** and **YY'** are planes of no distortion or planes of maximum shear. If **CTC'T'** be a section of incompetent sediments overlying shearing planes in the crystalline rocks, it is clear that NE-SW compression folds would tend to develop between **CC'** and tension faults striking NW-SE would develop between **TT'**.



C

Sketches **(a)** and **(b)** picture the effect of shearing in crystalline rocks. **(a)** may be considered as an undeformed section of the rocks and **(b)** the same section faulted. Notice that the distance between **AC** in **(b)** is shortened, implying compression, and that **BD** is lengthened, implying tension. There is more lengthening than shortening. In northeastern Oklahoma there are more tension than compression faults.

D

Hypothetical sketch showing the probable lines of weakness and shearing in the basement crystalline rocks. The large arrows to the SE indicate the direction and intensity of the parent thrust coming from the Ouachita-Arbuckle orographic element. The small arrows along the shear lines show the relative movement of the shearing and its intensity.

ments took place during Pennsylvanian deposition intermittently. These he considers very significant. He observes the location and arrangement of the faults of this area and states that they originate from forces operating parallel with the direction of the en echelon line. He believes that the controlling forces must have been transmitted not by the sediments, which are not competent, but by the crystalline basement rocks, which are amply competent. Horizontal movements, he thinks, in the basement rocks set up rotational stress in the overlying weaker sediments and these stresses resulted in the formation of en echelon faults. He thinks many fault planes occur at depth and disappear before reaching the surface and that faults which may be found at the surface increase with depth. He believes that some anticlines were formed by the change from a fault into a fold toward the surface. Other folds, he thinks, are due to vertical displacements of master faults in the basement rocks. Depressions he explains by reverse displacements. Thus, combined horizontal and vertical movement may produce both folding and faulting. Also, he states that reverse movements at different intervals in the same place may compensate each other and produce greater folding in the upper than in the lower beds, as at the Cushing, Mount Pleasant and Shamrock domes in the case of the Wheeler and Layton closures. Fath admits the weakness of his theories to explain (1) reverse dips against fault planes, (2) why some vertical displacements along major faults did not reach the surface at some places where sediments are not over 1000 feet thick, and (3) divergence of some anticlinal axes from the direction which they would be supposed to take according to his theory. He explains the formation of the granite ridges as due to vertical movement along lines of weakness or master faults. This conforms with Moore's[21] hypothesis. In commenting upon Fath's work the authors wonder why he did not observe in the development of his tortional theory that at right angles to tension, causing the en echelon faults, there would also be compression. This is especially well shown by Mead[22] (see Fig. 5).

Heald[23] rather follows after Fath in favoring faulting along major zones of weakness with attendant secondary effects as being the cause of the origin of deformation in the northern Mid-Continent area.

Just[24] also explains the deformation of this region as originating from rotational stresses set up in post-crystalline sediments by horizontal movements along master faults in the basement complex. Like his predecessors, he fails to offer an explanation for the origin of the major movements. He goes one step further than Fath, however, in explaining many of the small folds associated with the en echelon faults as due to compression developed by the rotational stress.

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21. Moore, R. C., Geologic History of the Crystalline Rocks of Kansas, Bull. Am. Assoc. Pet. Geol. vol. 2, pp. 105-106, 1918.
22. Mead, W. J., Notes on the Mechanics of Geologic Structure, Jour. Geol. vol. 28, p. 505, 1920.
23. Heald, K. C., Discussion of Power's article. Bull. Geol. Soc. Am. vol. 36, pp. 379-392, 1925.
24. Just, Evan, The Origin of the Structural Features in Northeastern Part of the Mid-Continent Oil Field. An unpublished Master's thesis submitted at Wisconsin University, 1925.

Foley[25], working independently, coincides essentially with Just in discussing the immediate causes of the origin of the faults in Creek and Osage Counties, Oklahoma, but he goes further and attempts to discover the origin of the major forces causing the development of the rotational stresses. He performed experiments in which he covered two wooden blocks with wax and moved one block horizontally relative to the other, developing a master shear plane, above which the wax was deformed. This caused in the wax faulting and folding of the en echelon type. He thinks the major forces were brought about by a thrust from the Ozarks toward the Kansas granite ridge, using the latter as a buttress, and explained the granite ridge as probably originating from forces coming from farther west, possibly from the Rocky Mountains. If one considers, however, that the thrust forces in the region between the granite ridge and the Ozarks came from the uplift of either one or the other or both of these elements, it does not seem possible to develop sufficient shortening in the upper sediments to account for any appreciable deformation even if the latter should be competent to transmit these forces. On the other hand, if the thrust is transmitted through the crystallines from one point to another, it does not seem possible for any one small element (ridge) in the crystallines to act as a buttress to movements in the crystalline mass itself. Also, according to his theory, his master shear zones would tend to follow a northwest-southeast direction as well as the direction shown by Fath. The former shear zones would develop *en echelon* faults at right angles both in direction and trend with those found on the structure map. Such are not known to occur in any appreciable amount.

For reasons set forth in preceding paragraphs the authors believe that deformative forces other than gravity must be discovered to explain the types of deformation found particularly in northeastern Oklahoma and Kansas. Logically, one should look for the evidence of these forces in the areas of greatest deformation in this region and trace the effect of that deformation into the adjacent areas in which these forces moved. The area of greatest deformation near here is the Ouachita portion of the Ouachita-Arbuckle orogenic element in the southeastern part of Oklahoma and the southwestern part of Arkansas.

A study of the structure of the North American continent quickly discloses a series of lines of weakness in both late and early rocks, with a great predominence in direction favoring north and south lines. Lines of weakness such as folding or faulting where uplift occurs, even though modified by erosion, tend to cause the formation of topographic features which tend to follow straight lines. With the exception of cuesta topography and dike topography, erosion features over old lines of weakness are the only types which follow straight lines. Cuesta topography is formed over tilted sediments where harder beds resist erosion and tend to form ridges with gentle dip slopes and steep slopes

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25. Foley, L. L., The Origin of the Faults in Creek and Osage Counties, Oklahoma, Bull. Am. Assoc. Pet. Geol. vol. 10, pp. 293-303, 1926.

in the opposite direction caused by undercutting. This type of structure does not necessarily presuppose an igneous basement. Dikes, resisting erosion, especially where cutting much less resistant sediments, frequently form straight ridges. The dike rock, however, was originally injected into fault or joint openings and its presence presupposes earlier lines of weakness and really fall into the first class. Cuestas, also, frequently are eroded into very irregular lines by the more active work of some stream systems than others crossing them, and consequently would not tend to form straight ridges for great distances without some considerable local changes of direction. Therefore, where one finds straight-line topographic features, he naturally expects to discover that this topography is controlled by structure showing movements along previous lines of crustal weakness.

Some of the prominent lines of weakness in the United States are as follows: California Coast Ranges, Sierra Nevada fault block, majority of basin ranges, faults and folds of the high plateaus, Rocky Mountains, Ozarks, Illinois-Wisconsin flexure, Cincinnati arch, and the Appalachian Mountain systems. Closely parallelling these is the buried granite ridge of Kansas, sometimes called the Nemaha Mountains, which extends from northern Oklahoma, across Kansas, to the southern part of Nebraska. In reality this ridge falls about half way in direction between that of the Appalachian region and that of the Rocky Mountains. This granite ridge is, of course, minor in character to those first mentioned. Also, all across the country are thousands of minor lines of weakness which give the continent a "grained" character as mentioned by van der Gracht.[26]

Upon the surface of the pre-Cambrian rocks in the Mid-Continent region are deposited sediments of Paleozoic and later age of varying thickness. It is reasonable to suppose that the pre-Cambrian rocks had been much disturbed prior to Paleozoic deposition, and that most, if not all, of the post-Cambrian disturbances of the Mid-Continent area took place following lines of weakness developed in pre-Cambrian time. During, and even subsequent to Paleozoic time, orogenic activity took place (especially around the eastern and southern sides of the northern Mid-Continent region) forming the Ozarks and the Ouachita-Arbuckle orogenic element and forming the prairie plains monocline. The seat of this activity, as evidenced by the intense folding in the Ouachita Mountains, appears to be in that region, lying to the south and southeast of the Kansas-Northern Oklahoma portion of the Mid-Continent area.

The direction of the forces originating in the Ouachita region, as related to the Northern Oklahoma-Kansas region, appears to be northward, (See Fig. 5), with the amount of force dying out westward from the Ouachita Mountains toward the Arbuckles and Wichitas. The resultant of this thrust would be rotational in character and would be west of north. This thrusting movement, acting upon the basement rocks, would result in re-opening lines of weakness in these rocks in northern Oklahoma and Kansas which already had a northeast direction about at 45 degrees with the resultant thrust mentioned above. The thrusting would set up a horizontal differential shearing in the crystallines which would follow these lines of weakness. The amount of shearing would tend to diminish westward and northward from the Ouachita region.

The effect of this shearing would be to set up in the overlying incompetent beds rotational stresses which would result in the formation of dome-type compression anticlines and tension faults. These folds and faults would follow the lines of shear and be related directly to them. The folds would tend to have long axes in a northeast-southwest direction and the direction of the faults would tend to be in a northwest-southeast direction, about at right angles with the anticlinal axes, and both at about 45 degrees with the lines of shear. (For illustration of the principles applying to this type of structure, see Fig. 5 and Fig. 6).

While in the crystalline rocks the dominant movement will be essentially horizontal, there will doubtless be some raising or lowering of the surface of the crystallines on one side or the other of the shear zones, especially at points closer to the region of thrust. These vertical movements would give rise to folds and faults in the overlying sediments with lines corresponding to the direction of the shear zones. These features are apt to be larger and more prominent than the en echelon faults and smaller anticlines caused by rotational stresses over the shear zones. Faults caused by vertical movements in the basement rocks along shear zones would tend to diminish in displacement toward the surface, sometimes even resolving themselves into folds with axes parallel with the line of the underlying shear.

Besides the series of en echelon faults and folds, there are in this region folds whose axes closely parallel the direction of en echelon faults. These can easily be formed by the change of such faults upward into slumps or dips. A modification of the en echelon type of fold (northeast-southwest axis) by folding over buried en echelon faults (northeast-southwest) may result in any number of types of irregular folds. The en echelon folds, it must be borne in mind, are compression folds, while the plunging anticlines caused by slumping against or over en echelon faults are tensional in character.

Sometimes (See Fath's structure map of the Bristow Quadrangle) D-shaped closed synclines are found with the straight side formed by a normal fault. These synclines are always on the down-thrown side of the fault. The amount of throw in a normal fault is always greatest in the middle and diminishes to extinction toward its ends. Such closed synclines are, therefore, formed by the simple slumping of the down-thrown element. Sometimes these occur directly opposite D-shaped closed anticlines on the opposite side of the fault. This type of structure is impossible to explain by any other means, such as sedimentary compaction. (See Fig. 2).

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[26] Van der Gracht, W. A., J. M., Discussion of Foley's paper, Bull. Am. Assoc. Pet. Geol., vol. 10, p. 302, 1926.

It is clear to be seen that under ideal conditions the amount of throw in a tension fault in sediments caused by horizontal movement in basement rocks along shear zones will be directly related to (1) the amount of horizontal movement tending to stretch the sediments in the direction of elongation of the strain elipsoid, and (2) the thickness of the sedimentary prism. Assuming, therefore, a fixed amount of horizontal movement at a given point, the amount of vertical readjustment due to stretch would increase upward from the basement rocks. This readjustment may take the form of a simple normal fault rising from the basement rocks upward with increasing throw toward the surface, or it might be changed by passage through more plastic rocks such as shales into slump or tension folds. On the other hand, since both the tensional and compressional readjustments following the movement in the basement rocks along the shear zones are local in character and must balance each other more or less, and the incompetency of the sediments does not permit the transmission of shear from the crystallines to the surface, the mild resistence of friction in the more plastic sediments and the lateral slip of the sedimentary beds will tend to readjust these beds so as to mask effects of the stresses set up by basement shear. If a thick enough sedimentary prism overlay the crystalline shear zone, therefore, it is conceivable to expect tension faulting to increase in throw upward until a point is reached where horizontal (possibly rotating) movements in the beds would begin to diminish the vertical readjustments. From this point vertical readjustments would decrease upward till at some point horizontal movements between beds would entirely mask lower structures and no disturbance would result. This accounts for the fact that many en echelon faults decrease with depth, often disappearing before reaching the "Wilcox" horizon. This fact has been called to the attention of the authors by Richard Hughes and others, as applicable to Seminole and adjacent counties. These geologists have mentioned, also, the continuance of northeast-southwest faults in the same region, mentioning the fact that they appear to increase in throw with depth. These latter faults are explained in an earlier paragraph.

In the case of the en echelon type of folds, formed by the compressional element of rotational stresses, the most active forces are set up right at the contact of the sediments with the basement rocks where the horizontal movement is greatest. In the Creek County region, as elsewhere in this part of the Mid-Continent area, the thrusting component set up by the shearing of the basement rocks is from the southeast side. This would result in steeper anticlinal dips on that side of the axis and gentler on the other. This would cause the formation of asymmetrical (or lop-sided) folds, as shown in Fig. (6) which causes the axial plane of the anticline to plunge northwestward. This axial plunge is so great that in some cases folds of this type have their high point on the "Wilcox" sand as much as a quarter of a mile northwest of the axis of the surface anticline. This lack

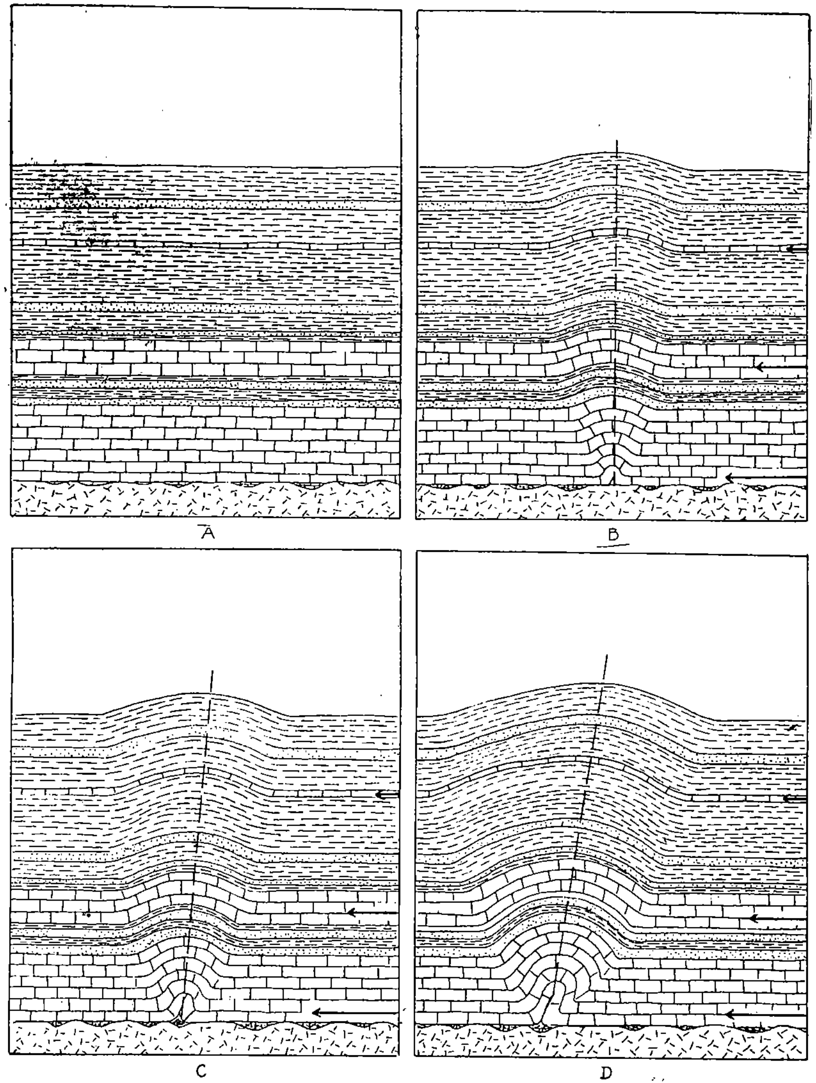

Figure 6. Diagrams of the possible origin of the northeast-southwest folds with their frequent shift of the axial plane to the west. If sketch **A** be an undeformed cross-section taken between **CC'** of sketch **B** in Figure 5, then **B**, **C** and **D** above show the progressive effect of this compression. The greater movement in the basement crystalline rocks is always in the segment southeast of the zones of shearing (Figure 5, sketch **D**). This in turn causes the greatest compressive forces in the sediments to come from the southeast. This compression is greatest on the lower beds, tending to drag them under the upper beds. Arrows indicate the relative intensity of the horizontal movement in the beds.

of symmetry is notably absent in the larger anticlines following the direction of the shear zones and caused by direct vertical movements, and is not noticeable in the slump folds due to faulting.

Where either vertical movements in the basement rocks or rotational stresses caused by horizontal shearing of the basement crystallines affect the overlying sediments in uplifting them periodically during sedimentation, it is conceivable that the sediments would be deposited more thinly over the uplifted portions, and the result would be an increase in the sedimentary intervals away from the structural axes. (See Fig 7). This would tend to make the deeper beds in the anticlines show steeper structures than the beds found toward the surface. This would further emphasize the same effect (shown in Fig. 5) due to greater compression of the folds near the basement rocks by rotational compression stresses, in the case of the en echelon type of folds. On the other hand, especially in the case of vertical movements in the basement rocks transmitted to the overlying sediments, it is conceivable to expect occasional reverse or reactionary movements causing the reverse condition to take place, as in the case of the Cushing structure already cited.

This covers the discussion of all structural features of Creek County, with the exception of the one thrust fault already mentioned. The direction of this thrust fault is closely parallel with that of the axis of the en echelon type of fold and roughly at right angles with the direction of the en echelon faults. This only adds to the proof of compression forces set up by the rotational stresses already described. The relative absence of these thrust faults proves the incompetency of the sediments of this region, where thrusts result in folding more than in overthrust faulting.

As mentioned by Thom[27] in his remarks upon Foley's paper, there are a number of thrust faults in the region just north of the Ouachita Mountains. These strike in a direction slightly north of east, and about at right angles with the direction of the Ouachita thrust, and are due directly to that movement. They are accompanied by numerous normal faults which probably largely followed the active thrusting action and are due to relaxation and readjustment.

As previously stated, it is to be noted that the faults which follow a northeast-southwest direction are most common in the southern part of the northeastern Okahoma area. These northwest-southeast faults, however, persist in great numbers until the Kansas line is reached, when they die out rather rapidly. Less data, however, is available in a large way for southern Kansas. The small folds, which take the form of "noses" in Seminole, Lincoln, Okmulgee, Creek and Tulsa counties, increase in structural prominence and a greater percentage of them are closed into dome form as Osage County is reached. The structural relief of the small anticlines which is very prominent in Osage County gradually dies out into Kansas. This change

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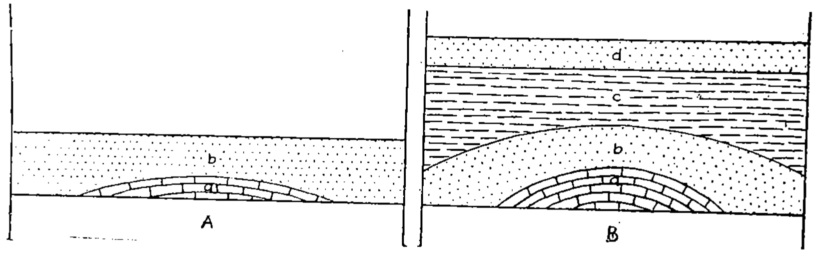
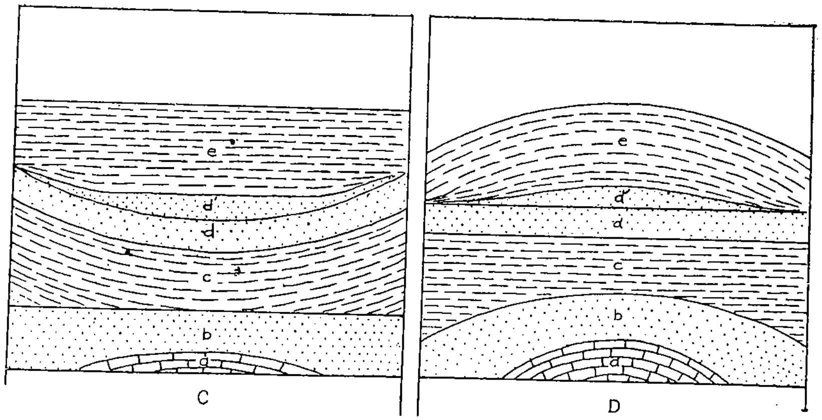
[27] Thom, W. T., Jr., Discussion of Foley's paper, Am. Assoc. Pet. Geol. Bull. vol. 10, No. 3, p. 301, 1926.

Figure 7. Sketches showing the effect of progressive folding during sedimentation on the stratigraphic interval, also what might be obtained if the direction of the vertical movement was reversed then continued again upward. This may be a possible explanation of the abnormal conditions found on the Cushing structure.



(a)—limestone strata being folded upward.
(b)—sand deposited on limestone. Note the increase in the stratigraphic interval on the flanks of **(a)**, the same result as obtained by compacting during deposition. The vertical scale is greatly exaggerated in these sketches.

As folding continues, sand **(b)** is folded along with the limestone **(a)**. Shale **(c)** and sand **(d)** are deposited on the folded surface of **(b)**. Sediments **(c)**, **(d)** and others would probably be deposited while folding is in progress and should be shown folded slightly. These details were left out for simplicity.



If the postulated folding is due to vertical movement along a buried fault plane in the basement rocks and if this movement be reversed, **(d)** would be depressed as shown. Continued deposition of sand would tend to fill in the depression and form **(d')**. Shale **(e)** would then be deposited on **(d')**. That reverse movements can take place along fault planes has been observed in cross-sections of faults in many cases.

Movement upward again would produce the effect shown, namely, an increase in the stratigraphic interval on the apex of a folded bed combined with an increase in the interval on the flanks of other beds, and a bed with less structural relief (or closure) than either of the beds above or below it. If **(d')** had not been deposited, **(d)** would have less structural relief than the other beds but there would not be an increase in the thickness of the sand on the apex of **(d)** but an increase in the thickness of shale **(e)** instead.

in structural character as one progresses northward is probably due largely to three things: (1) decrease in thrusting effect as one proceeds away from the region of the origin of that force, causing diminuation in the amount of the resultant shear in the crystallines and its effect upon the overlying sediments, tending to cause decrease in both folding and faulting northward; (2) thinning of the sedimentary overburden northward, causing the surface rocks in Osage County, for instance, to be nearer the crystalline shear zones than in Creek or Okfuskee counties so that the structure at the surface in Osage County would more nearly be correlated with sub-surface structures in the counties southward and thus have more relief than the surface structures in the latter counties; and (3) change northward in the character of the sediments, thus bringing about a different result from the same submerged forces when acting upon those sediments. In the Kansas area there is more true shale and fewer sandstones, and more limestones than in northern Oklahoma. The shales of the northern Oklahoma area, especially in the group of counties in which the en echelon faults predominate, are most frequently apt to be of a sandy character. It is to be noted also that the en echelon type of faults dissappears both eastward and westward where, largely, more limestones and true shales appear as also, northward into Kansas. Sandstones and sandy shales readjust themselves by breaking rather than by folding. Clay shales fold rather than break. Limestones, allowing for the time element, (though brittle to sudden shocks) easily fold by recrystallization of the calcite particles and gliding of the crystals. Such folding is, however, very difficult to obtain by placing sandstones under stress. Thus, it is to be seen that northward into Kansas, where clay shales and limestones prevail, the pressure component of the rotational stresses is taken care of, as elsewhere, by folding, while the tension component is also taken care of by folding because the rocks are less apt to fault than the sandstones and sandy shales of northern Oklahoma. Further evidence of the effect of the forces on the more brittle rocks of the sandstone area of northern Oklahoma is the thrust fault in northern Creek County which would have taken the form of a compression fold had it been in the clay shale-limestone area.

CONCLUSION.

In the preceding paragraphs, numerous theories advanced to explain the origin of the various types of deformation in the northern Mid-Continent area have been described and discussed. While here, as elsewhere, no single theory will suffice to explain the sum total of the whole structural problem, the theories of differential settling or compaction, folding by vertical thrust, warping of sediments accompanied by faulting during deposition, and direct tangential compression all fall far short of solving the complete problem. On the other hand, as developed in the foregoing arguments, rotational stress transmitted to sediments by shearing in the underlying crystalline rocks, may be invoked to explain the origin of all forms of deformation in

Creek County and the adjacent territory. The authors by no means declare that other forces are not present to a sufficient extent somewhat to modify some of the deformation features of this region, but that such forces are not necessary to explain the types of deformation found here. The rotational stress theory is not a purely hypothetical assumption applied to this region, but the work of such stresses has been noted by the writers in many other parts of the country. Too frequently the student thinks only of metamorphic areas when considering problems of shear and rotational stress. Some of the following examples outside of the Mid-Continent area show effects of rotational stress in areas of slight deformation, or in areas in which the sediments are not metamorphosed: en echelon anticlines in the Los Angeles basin of southern California[28]; en echelon structures in the plains area of central eastern Colorado,[29] where as also in California both the major fault and the secondary en echelon faults and folds are clearly seen and their relationships marked; en echelon structures in the plains area of southeastern New Mexico[30] where en echelon folds and faults were mapped over a considerable distance.

RELATION OF FUTURE DEVELOPMENT TO STRUCTURE INTERPRETATION

GENERAL STATEMENT

Oil in Creek County, as elsewhere, usually occurs in porous sandstone or limestone beds accompanied by salt water. In such cases oil accumulation is found, logically, in traps formed by anticlines, lenses, monoclines where frictional resistance caused by sudden change in dip retards movement, and in dipping beds cut off on upward edges by faults which place impervious sediments in contact with upper edges of porous oil-bearing beds. Where salt water is absent in quantity, as in one sand particularly in southern Creek County, oil accumulates by gravity into the synclines.

STRUCTURAL INTERPRETATION APPLIED TO EXPLOITATION.

As set forth in the opening paragraph, there are doubtless in Creek County a large number of favorable structures which, because of the masking effect of vegetation, absence of outcrops or presence of imperfect or confusing outcrops, are yet undiscovered. Since a large proportion of the structures found and tested have proved to be prolific sources of oil and gas, no remaining favorable structure should be left undrilled. If the structural interpretation brought out in the foreging portions of this work are to have a practical value, they should aid in the search for undiscovered structures in this county and the adjacent areas.

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[28] Ferguson, R. N., and Willis C. G., Dynamics of Oil Field Structure in Southern California, Bull Am. Assoc. Pet. Geol. vol. 8, pp. 576-583, 1924.

[29] Merritt, J. W., Confidential unpublished report, 1924.

[30] Merritt, J. W., and McDonald, O. G. Unpublished confidential report, 1925.

DESCRIPTION OF PRODUCING SANDS.

The Musselman sand, which has been found productive of gas in the Cushing pool, occurs there at about 700 feet and attains a thickness of about 25 feet.

The Layton sand is productive of oil and gas principally in the northern part of the Cushing field, but also in the area between Drumright and Bristow and in another area a few miles south of Shamrock. It ranges in thickness from 20 to 100 feet, with an average of about 50 feet. Some places it is absent. It underlies a hard limestone 10 to 20 feet thick, often called the Layton lime. This lime sometimes contains gas. The sand is coarse-grained, comparatively soft, porous, and fairly uniform in texture and porosity. It occurs at depths ranging from 1,200 to 1,500 feet, depending upon the locality. Saturation within the sand is incomplete and irregular, due to cross bedding and other irregularities in sedimentation. Layton oils are usually of high gravity. In the Cushing field the Layton ranks highest in gravity, with Bartlesville next and Wheeler last. An excellent description of this sand, as well as the other principal sands of the Cushing field is to be found in Beal's[31] paper on that field.

The Jones sand, which produces gas at about 1,730 feet in the Cushing area, is relatively unimportant in Creek County. It attains a thickness, where productive, of about 25 feet.

The Cleveland sand also is of relatively no importance in Creek County. Its average thickness is less than that of the Jones sand. It occurs on the Cushing structure at about 1,920 feet and contains only small shows of oil and gas.

The Wheeler sand (correlated with the Oswego Lime) is productive chiefly on the Cushing structure. Of the Fort Scott group, composed of an upper limestone, an intermediate shale which sometimes grades into coal, and a lower limestone, the upper limestone member is frequently called the "Big Lime" and the lower member is called the "Oswego Lime." Frequently, (especially if one member is found missing), the two have been confused. On the whole, however, the Fort Scott is one of the most persistent and uniform horizons lying above the Mississippi lime and makes an excellent mapping horizon. The lower member, or Oswego lime, frequently changes in character from lime to sandy lime or even sandstone. Such is the case where it is called the Wheeler sand. This sand, as also in the case of the Bartlesville and the Layton, is not saturated completely. In its most important producing locality the Wheeler production covered about 11 square miles for oil and 21 square miles for gas.

The sand attains a thickness of 60 or 70 feet, but with an average thickness of considerably less. In the Cushing area, the Wheeler "sand" is a coarse grained brownish limestone which includes porous or sandy layers that contain the oil. Sometimes the upper limestone member

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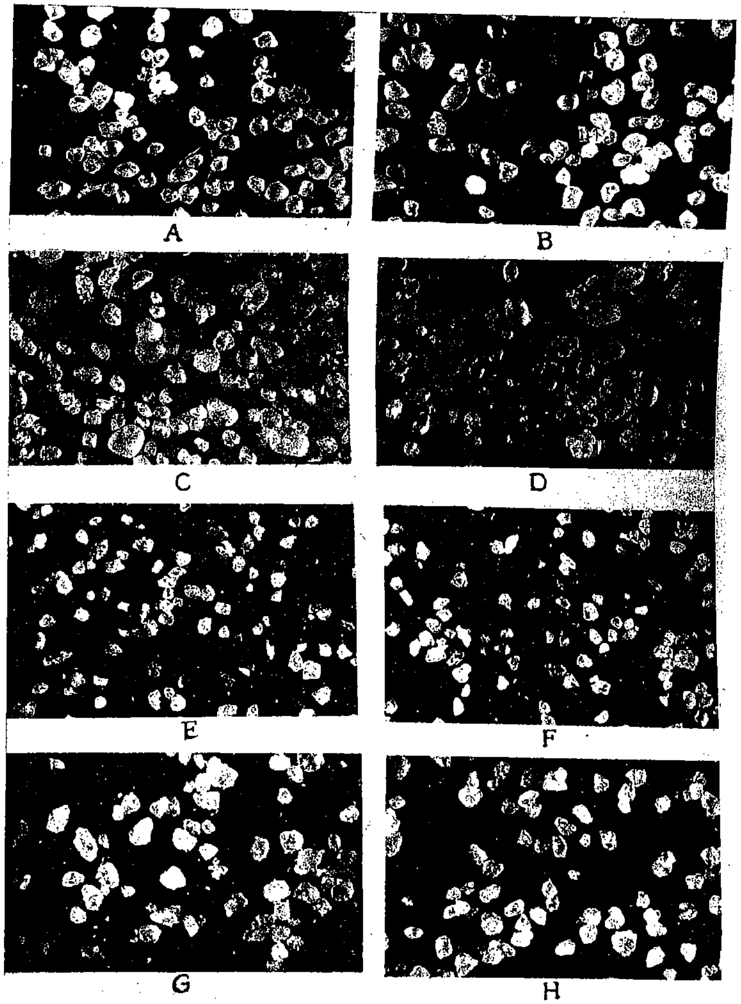
[31] Beal, Carl H., Geologic Structure in the Cushing Oil and Gas Field, Oklahoma and its Relation to the Oil, Gas and Water, U. S. Geol. Survey, Bull. 658, 1917.

PLATE VI



A and **B** Microphotographs of Wilcox sands.
C and **D** Microphotographs of Hominy sands.
E and **F** Microphotographs of Bartlesville sand.
G and **H** Microphotographs of Elgin sand.

(Courtesy of the Journal of Economic Geology) carries gas in paying quantities. In the same area this sand is found at a depth of about 2,250 feet.

The Prue sand reaches its major importance in T. 14 N., R. 8 E., where it produces from synclines. Here the sand is found at about 2,390 feet and has an average thickness of about 50 feet. Elsewhere this sand produces from anticlines.

The Skinner sand is productive of oil and gas in relatively small quantity in the Cushing and Glenn pools. At the former locality it is found at about 2,620 feet with a thickness of about 20 feet. In the Glenn pool it occurs at about 1,050 feet.

The Red Fork sand is chiefly important in the eastern and northeastern parts of Creek County where it is found at depths ranging from 1,300 to 1,450 feet. Its thickness ranges from 20 to 60 feet. In this county it is productive mainly in the Red Fork, Sapulpa, and Glenn pool areas.

The Bartlesville (Glenn) sand is by far the most uniformly productive sand throughout Creek County, with its chief production coming from the northern half of the county.

This sand is usually brown and grades from fine sandy shale to coarse grained sand. The general appearance of the grains of the Bartlesville sand may be seen from the microphotograph (Plate 6 E and Plate 6 F). The grains appear to be poorly sorted with a predominance of angular grains and a small percentage of well rounded grains.

The sand attains a thickness sometimes of as much as 200 feet, being thickest in the south central part of the county and thinning out northward and eastward. It is found at about 1,450 feet in the northeast corner of the county, 2,300 feet in the southeast, 2,500 feet in the northwest and 3,170 feet in the southwest. It occurs generally over the whole county, though may be locally missing, sometimes possibly cut out by faulting.

The Bartlesville is found abundantly productive on terraces, anticlines and sometimes on monoclines where lensing or change in porosity causes barrriers to form to hold the oil or gas accumulation. The sand is never completely saturated, usually only the upper portion being productive. Sometimes, however, alternate water and oil bearing streaks occur. Despite irregularities, however, the Bartlesville is well liked by operators because of the staying qualities of the production and the slower initial decline and the great ultimate yield.

The quality of the oil in the Bartlesville is much better than that in the Dutcher, the "Turkey Mountain" and some of the other sands, and is very well liked for refining purposes.

The Tancha (Tucker, Booch) sand occurs at from 1,650 to 1,750 feet in depth in the northeast part of the county, 2,500 in the southeast and 2,800 feet in the northwest. It accounts for some fair production of oil and gas in the northern, central and eastern parts of the county. Its thickness ranges from 25 to 50 feet. Its importance is less than that of most of the other sands mentioned in this description.

The Dutcher sand attains considerable importance in Creek County. Its best productive areas lie in the eastern, central and southeastern parts of the county. This sand thins out from the Bristow area northward and northwestward until it appears to be entirely absent. Almost everywhere encountered this sand yields a showing of oil or gas. It produces from anticlines, terraces and faulted monoclines.

The Dutcher appears to be found in Creek County in two horizons, separated by a shale break. Sometimes the upper, sometimes the lower, and sometimes both are missing in well records. Production may occur in either or both in the same well, and sometimes one will contain oil and the other water, more frequently than not the upper and lower respectively. The Dutcher zone varies in thickness up to over 100 feet. Upon favorable structure this sand has yielded some phenomenal initial production, many wells yielding over 5,000 barrels and one well on the "Poor Farm" structure southwest of Bristow over 15,000 barrels initial. This lenticular character of the Dutcher sand accounts for many dry offsets to good producers. The Dutcher is found at from 1,800 feet in the northeast part of the county to 3,450 in the southwest.

The Misener sand has been well described as to distribution and general character elsewhere in this paper. Because of its discontinuous lenticular character, it is thought to be of relatively little potential economic value in Creek County. It correlates with the Mounds sand of Beggs. Its chief occurrence in this county is in T. 15 N., R. 10 E., and lapping over into the township east.

The "Wilcox" sand is an important factor in the oil and gas production of Creek County. This sand ranges in thickness up to 200 feet and over, probably averaging slightly less than 100 feet, and is found at depths ranging from 1,900 feet in the northeast part of the county to 4,000 feet in the southwest corner. It is a pure white sand made up largely of highly angular grains, with some few rounded large etched grains, and more small rounded grains. This sand is difficult to distinguish from the "Burgen" but is considered a much more uniform fine grained sand. The "Wilcox" produces chiefly from well defined anticlines, usually domes, and because of this and also because of the fact that the "Wilcox" is usually much more closely folded than the higher formations, these productive areas are relatively limited in size. This sand has been very prolific in some places, sometimes exceeding 30,000 barrels per acre. The oil is of high gravity and is much sought for because of its good refining qualities. This sand is productive in a belt across the northern part of the county and again in the central and southern parts. (See Pl. IV).

The "Siliceous Lime" ("Turkey Mountain" sand), which is the upper weathered or porous part of the Arbuckle limestone, has been found productive in the northeastern part of Creek County. The production is confined to the upper truncated surface of this limestone body and not to any one horizon in that limestone. The upper 20 feet consists of pure to sandy dolomitic limestone and below that is a dense dolomitic limestone containing quartz fragments and crystals. Wherever the Arbuckle limestone has been entirely drilled through in this region the drill has passed into granite. The upper surface of this limestone, therefore, may be considered as the last chance for production in the downward search for oil and gas.

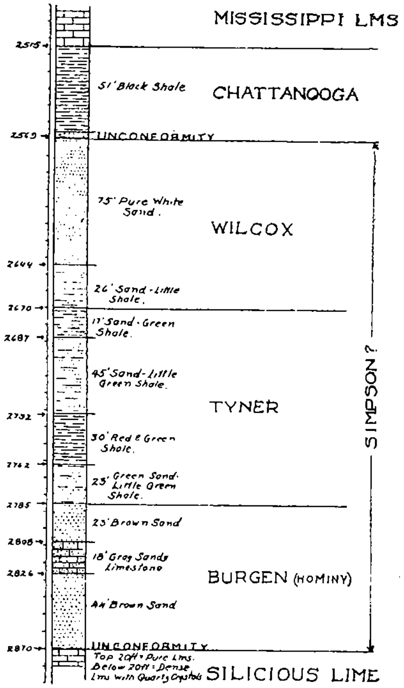


Figure 8. Well log of McComb No. 1 in the SE. of the SW. of the NW. of sec. 10, T. 17 N., R. 11 E., giving a detailed description of the strata below the Mississippi lime. Samples were collected and identified by Luther White.

POSSIBLE FUTURE PRODUCTION

It may be inferred from the last paragraph above that the lowest probable productive stratigraphic horizon has been reached and all intervening possible pay sands penetrated here or there in this county. Future production, therefore, as far as Creek County is concerned, will have to be found in structures as yet undiscovered or developed or in structures not yet developed to the deepest known pay horizon. Methods for the search for new structures in this county have been suggested in earlier paragraphs. On the other hand, for making deeper tests on already developed structures only sufficient courage, coupled with good geologic judgment as to what kind to structure to test, and as to possible occurrence in that particular area of the desired deeper sand under favorable conditions, is requisite.

SUMMARY

In order to aid in the writing of a new bulletin covering oil and gas development and future possibilities in Oklahoma, to replace Bulletin No. 19, pt. II, published in 1917 and now out of date and out of print, the authors have prepared this chapter covering Creek County.

This county occupies an area of about 963 square miles in the northeast quarter of the state, lying in the sandstone hills portion of that part of Oklahoma and drained by Cimarron River and tributaries of the Arkansas system and Deep Fork and Little Deep Fork of the Canadian system. The area is rough and hilly, with surface elevations ranging from 600 to 950 feet.

Development began actively in 1906 in the Glenn Pool area and continues active to the present day. During this time probably all the larger available producing areas have been found and their production outlined.

The rocks outcropping at the surface comprise the upper formations of the Pennsylvanian, and the rocks penetrated by the drill range downward through the Pennsylvanian, Mississippian, Devonian, Silurian, Ordovician and Cambrian and into granite. The chief unconformities come below the Pennsylvanian, below the Chatanooga and Misener, below the Viola, below the Burgen, and below the Arbuckle.

The general structure of the region is that of a westward dipping monocline, interrupted by anticlines, terraces, synclines and faults. The faults are mostly normal (only one thrust fault being recorded) and strike northwestward and tend to fall in en echelon belts trending northeast-southwest. Some northeast-southwest en echelon compression folds and a few larger northeast-southwest anticlines lying more northward than the compression folds just mentioned are found. Some tension folds in the form of northwestward plunging anticlines also occur, together with a number of folds of irregular shape probably caused by a combination of forces.

The authors discuss many theories previously formulated to explain the origin of the numerous small structures of this portion of the Mid-Continent field, such as vertical uplift, compacting, direct tangential compression, and various phases of the rotational stress theory. They find the formation of such small structures by direct uplift difficult to explain. They find the shape and position of the structures, together with the absence of close folding and other evidences of intense thrusting between the Mid-Continent fields and the Ozarks (the supposed source of tangential thrust) arguing against that theory as an explanation of the origin of the small structures. They present diagrams and other arguments proving the inadequacy of compaction as the cause of the formation of these structures. Following this, they conclude that, while some structural conditions in the northern Mid-Continent area may be explained in part by one or more of the other theories, that of rotational stress set up in the sediments by horizontal movements in the basement complex, caused by thrusts originating in the Ouachita Mountain region of southeastern Oklahoma and northwestern Arkansas, best serves as an explanation of the origin of the structural forms found in the northern Mid-Continent area. The authors admit, of course, the possibility that some of the other forces mentioned may have slightly modified the effects of the group of forces finally accepted as chiefly responsible.

From the above studies the authors believe that an application of the accepted rotational stress theory may lead to the discovery of many small obscure or hidden structures in this as well as adjacent counties, and may be followed by the development of additional production. An application of the same theory also is made to the relative evaluation of different types of structure and to the choice of drilling sites on the various kinds of structures discovered.

Following the structural discussion the writers describe the sands and production of the following horizons in Creek County: Musselman, Layton, Jones, Cleveland, Wheeler (Oswego lime), Prue, Skinner, Red Fork, Bartlesville (Glenn), Taneha, (Tucker, Booch), Dutcher, Misener, "Wilcox," and "Turkey Mountain" ("Siliceous Lime"), and indicate possibilities of future production in these sands within the county.

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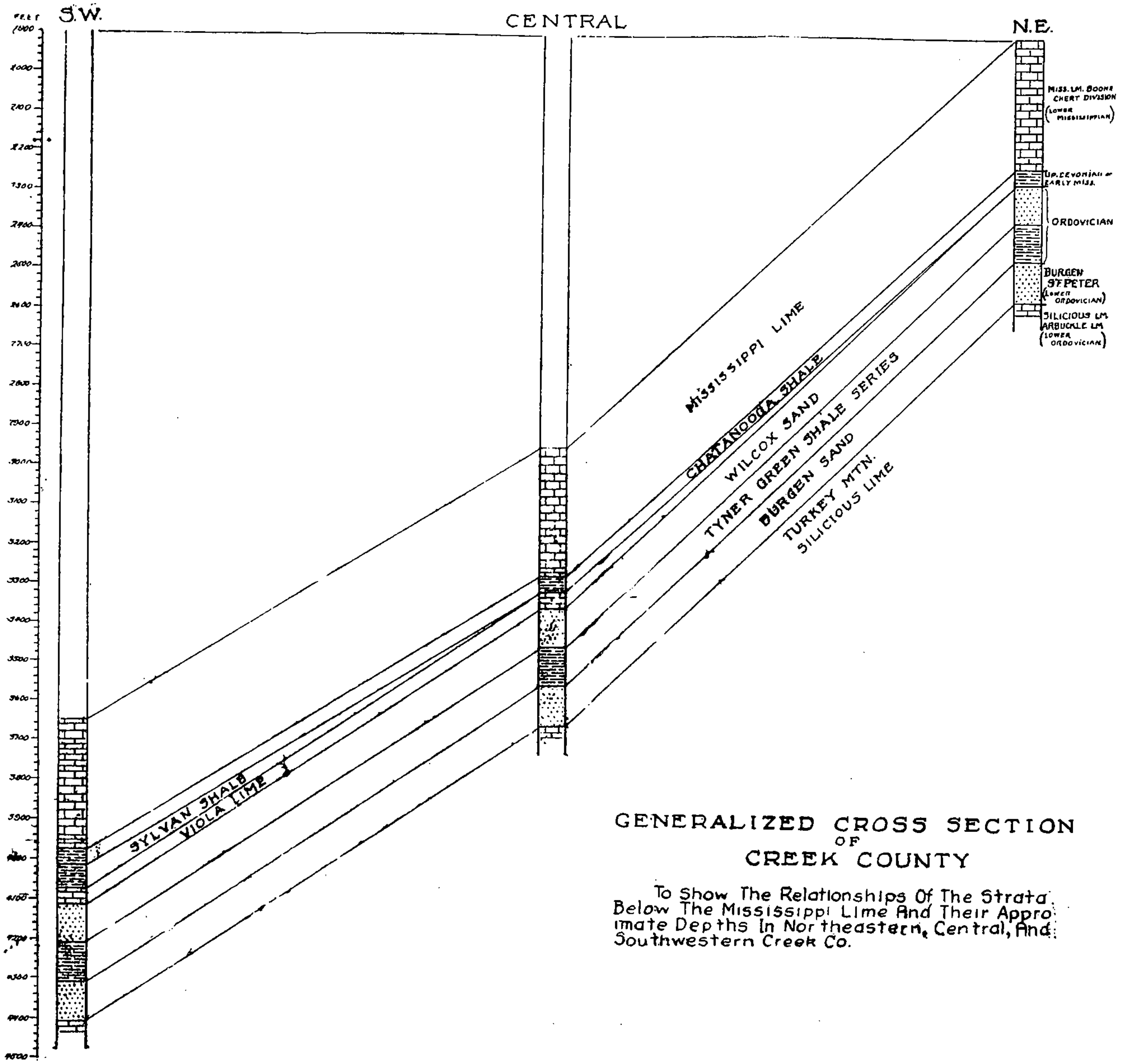
PLATE V



GENERALIZED CROSS SECTION
OF
CREEK COUNTY

To Show The Relationships Of The Strata Below The Mississippi Lime And Their Approximate Depths In Northeastern, Central, And Southwestern Creek Co.