GEOLOGIC STRUCTURE OF THE NORTHWESTERN PART OF THE PAWHUSKA QUADRANGLE, OKLAHOMA.

By K. C. Heald.

INTRODUCTION.

SCOPE OF PAPER.

This paper describes those geologic features of a portion of the Pawhuska quadrangle, Okla., which bear on the occurrence, discovery, and development of commercial quantities of oil or gas. The rocks that crop out in the area are shown in a generalized stratigraphic section, but the characteristics and extent of certain beds of value in mapping the structure of the region are described fully. The probable character of the rocks to a depth of 4,000 feet below the surface is also given, and some evidence is presented by graphic representation of well records and stratigraphic sections.

The regional structure is but briefly described, and minor structural features that have no probable bearing on the accumulation of oil and gas are ignored; but all local structural features that may prove of economic value through their relation to oil or gas pools are described in detail. Both regional and local structure are shown on the structure map.

In accordance with the strictly economic purpose of the paper the productive beds are treated in detail as to location, extent, relation to anticlinal structure, etc., in the producing fields of the area. The dry holes that have been drilled are listed, and the evidence which they furnish is presented. There is a short discussion of factors which bear on the presence or absence of oil or gas in the untested portions of the region. Suggestions as to the best localities for testing are given, and the possibility of oil accumulations below the present generally recognized producing beds is discussed.

LOCATION.

The area examined is in northeastern Oklahoma, just south of the Kansas line and about 90 miles west of the Missouri line. It covers the northwestern part of the Pawhuska quadrangle, in Osage County, including T. 29 N., Rs. 8 and 9 E., and large parts of

21544°—19—Bull. 691——5

T. 28 N., R. 9 E.; T. 29 N., R. 8 E.; and T. 27 N., R. 8 E. (See fig. 20 and Pl. XIII.)

FIELD WORK.

The field work on which this report is based was done in the fall and winter of 1916, about five months being spent in the area. A reconnaissance was first made over much of the territory, which was subsequently in part mapped in detail. Detailed mapping was preceded by primary triangulation, in which many temporary bench marks were used. The elevations of these marks were determined by reference to permanent United States Geological Survey bench

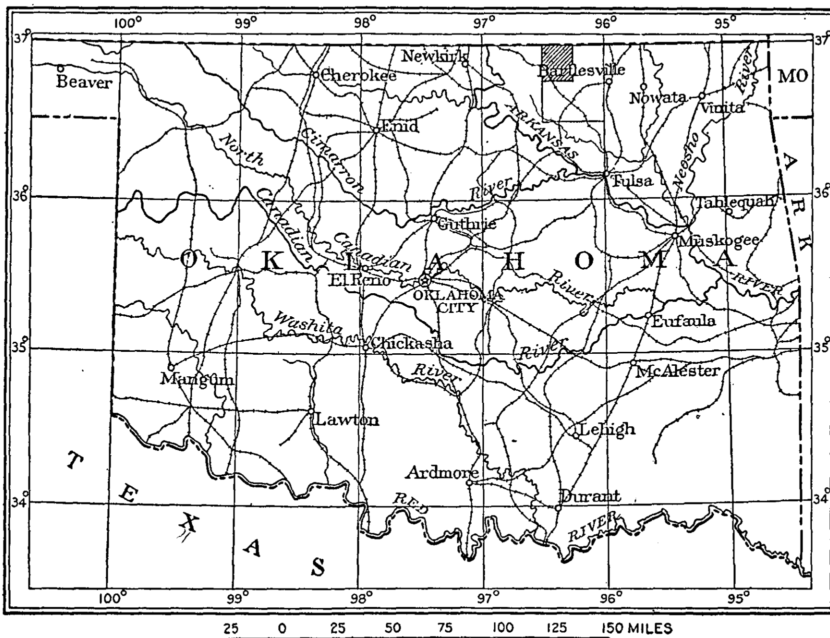
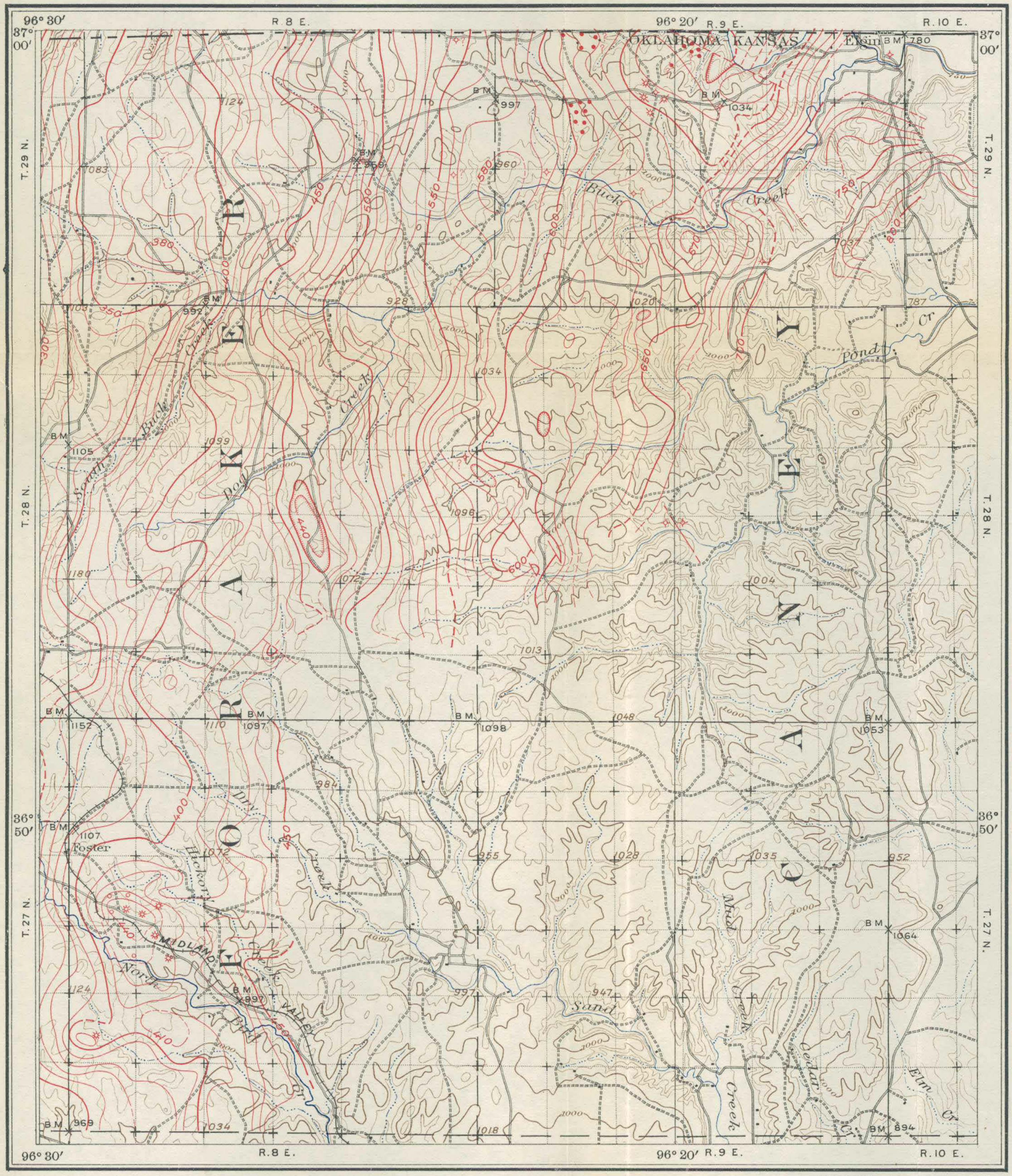


FIGURE 20.—Index map of Oklahoma showing the area covered by this report.

marks, of which there are 11 in the area examined. The elevations of the temporary bench marks were within 2 feet and in most instances within 1 foot of the correct elevation. This triangulation was necessary, as during a great part of the field season the writer was unassisted, and location and elevation had to be determined by this means. Work was done from Hewins, Elgin, Foraker, and Grainola, and from ranch and farm houses throughout the area.

ACKNOWLEDGMENTS.

The writer is glad to acknowledge the generous assistance given him by Carl D. Smith, who as a former geologist of the United States Geological Survey, had examined the Pawhuska quadrangle and who supplied field notes, maps, and well records; R. V. L.



LEGEND

Structure contours drawn on a horizon 200 feet below the Oread limestone
(*Depression contours are hachured*)

Fault

Well rig

Oil well

Oil well abandoned

Gas well

Dry hole

Gas well abandoned

MAP OF THE NORTHWESTERN PART OF THE PAWHUSKA QUADRANGLE, OSAGE COUNTY, OKLAHOMA

Showing topography and geologic structure

Scale $\frac{1}{125,000}$

1 ½ 0 1 2 3 4 5 Miles

1 ½ 0 1 2 3 4 5 Kilometers

Interval of surface contours 50 feet

Interval of structure contours 10 feet

Datum is mean sea level

1918

Stratton, of the Survey, who assisted the writer throughout the month of October; J. George Wright, commissioner for the Osage Indians, for data on the oil industry; and W. W. Barr, superintendent for the American Pipe Line Co. in northern Osage County, for well records and general information. Courtesies too numerout to mention specifically were extended by many of the residents of the area.

GEOGRAPHY.

RELIEF.

The surface of the area consists in large part of long, flat-topped ridges with irregular outlines, separated by steep-sided, many-branched valleys. These ridges radiate eastward and southeastward from the Foraker escarpment, which rims the western edge of the area and through which the valley-forming streams have thus far been unable to push their courses. The tips and sides of the ridges

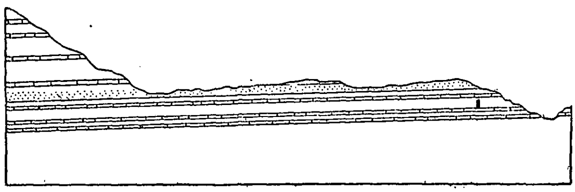


FIGURE 21.—Hypothetical section illustrating the terracing in the northwestern part of the Pawhuska quadrangle, Okla.

descend to the valley bottoms in a series of terraces whose position and extent are determined largely by the resistant qualities of the limestones and sandstones and the relatively easy breaking down and removal of the intervening beds of shale. This terracing occurs on a much broader scale on the tops of the ridges, the general result being as shown in figure 21.

Except in their lower courses the valleys have narrow bottoms with very thin coatings of soil, through which the underlying rocks project. The channels of the streams are in large part cut through rock, and almost everywhere they are rock bottomed. This is true even near the valley mouths, where the valleys are wide and floored with 10 to 40 feet of alluvial soil. The streams meander across the valley bottoms except in times of flood, when they may overflow their banks and occupy almost the entire width of the valley floor.

The character of the topography has determined the location of the roads which follow the flat upland surfaces as far as possible, avoiding the valley bottoms with their meandering stream beds. Good roads ascending the steep valley sides and ridge tips are rare, and any attempt to confine travel to the section lines, as is done in some parts of the country, would be impracticable.

DRAINAGE AND WATER SUPPLY.

The area is drained by Buck Creek, Pond Creek, Sand Creek, North Bird Creek, and their tributaries. Although these four streams originate in a comparatively small area, their courses diverge like the sticks of a fan, and they empty into Caney River at widely separated points. The streams are intermittent. During years of heavy or moderate rainfall there is running water from source to mouth, but a single season of dry weather is sufficient to lower the water level, and the water stands in pools that have no surface connection, although in many places there must be subsurface flow. These pools are small near the headwaters, but as Caney River is approached larger and larger pools are encountered, some of them being over half a mile long with a maximum depth of about 15 feet.

Water for domestic use is obtained from wells and a few springs. It is rarely necessary to drill deeper than 50 feet to obtain an ample supply. Records of wells drilled for oil, even in places that appear most unpromising with respect to probabilities of finding water, show that fresh water may be expected above a depth of 500 feet, and that one or more water sands which carry potable water are almost invariably encountered before that depth is reached.

Water for use in drilling is usually obtained by pumping from a pool in the bed of a creek, or, if excessive lift or distance prevent, by tank wagons or better still by drilling a water well before the oil well is begun. All the water in the district is hard, containing much lime that leaves scale in boilers and thereby shortens their lives. The lime also makes the water less suitable for many domestic uses, hence cistern water is often utilized instead.

CULTURE.

The Midland Valley Railroad crosses the southwestern part of the area under discussion, and all trains stop at Blackland station. A branch line of the Atchison, Topeka & Santa Fe Railway passes through Elgin, Kans., an unincorporated town of about 350 inhabitants, at the northeast corner of the area. The nearest and most accessible town to the extreme northwestern corner of the area is Cedarvale, Kans., a station on the Santa Fe and the Missouri Pacific railways.

Most of the land is given over to stock raising. Cultivation is largely confined to the valley bottoms, where, by combining farming and stock raising, a comfortable living may be made.

Wagon or motor travel is limited to the principal roads, which are very poor, considering the abundance of road metal available. Even the trunk roads, connecting towns, are in places studded with boulders and coursed by gullies. Culverts or bridges are absent except within a mile or two of a town, and much grading is needed.

STRATIGRAPHY.

ROCKS EXPOSED.

AGE AND GENERAL CHARACTER.

The surface rocks of this area (see fig. 22) are limestones, sandstones, and shales of upper Pennsylvanian age, all of which contain layers with well-preserved marine fossils, showing that they were laid down in sea water, but are accompanied by some thin, lenticular beds of coal and beds of clean, fine-grained swamp clays with plant remains (*Neuropteris scheuchzeri*) that indicate swamp or land conditions. Ripple marks, worm trails, mud cracks, and footprints of quadrupeds in some of the sandstones show that the materials forming the beds were laid down on tidal flats, flood plains, or other low places where they were not submerged at all times or where the water was very shallow.

The limestones are not uniform in character throughout the stratigraphic section, but individual beds usually have distinguishing characteristics that aid in the identification of isolated outcrops. It is doubtful if any single bed of limestone persists without a break across the area, but zones of limestone in which there are apparently always one or more beds with the same distinguishing characteristics undoubtedly do so persist, and the average thickness of the beds in such a zone is remarkably uniform over wide areas.

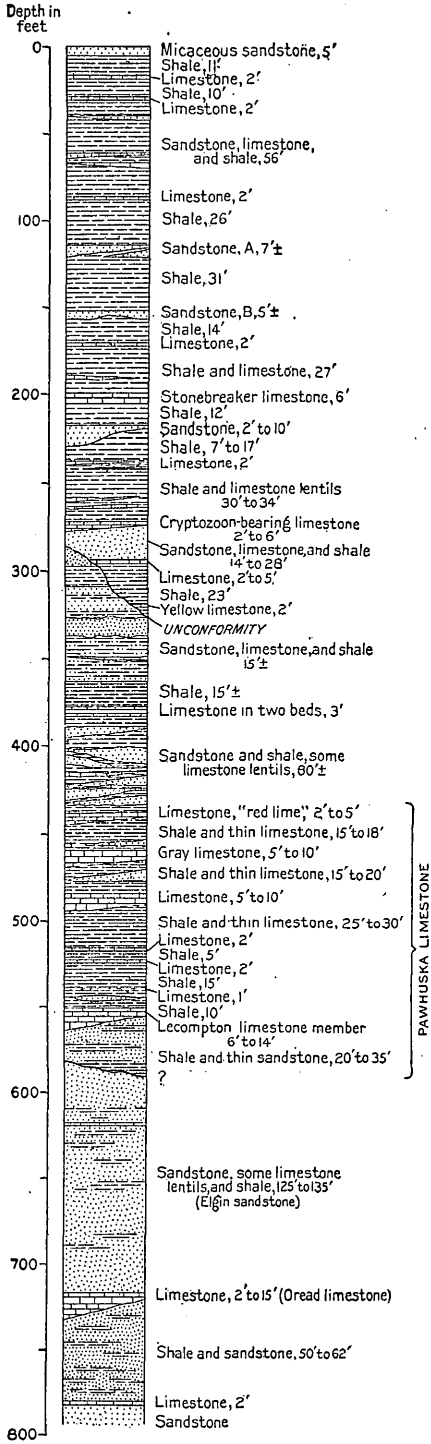


FIGURE 22.—Generalized stratigraphic section showing rocks exposed in northwestern part of Pawhuska quadrangle, Okla.

The sandstones are without exception lenticular, and few single beds extend over large areas. However, isolated beds of sandstone are seldom observed. Usually there is a series of sandstones and shales, with perhaps some thin limestone, in which the sandstone is much the most prominent rock. Such series extend quite across the area, and their thicknesses are fairly uniform. Within such series the rocks vary greatly from place to place. At one point it may be observed that the series is made up of four resistant ledges of sandstone with intermediate beds of shale. Half a mile distant it may show six ledges of sandstone with intervening shale beds. At one place 90 per cent of the thickness of the zone may be occupied by sandstone; at another 40 per cent of the total thickness will be shale. The conditions are shown graphically in figure 23.

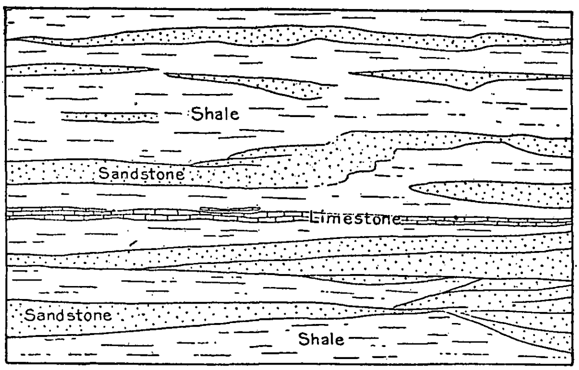
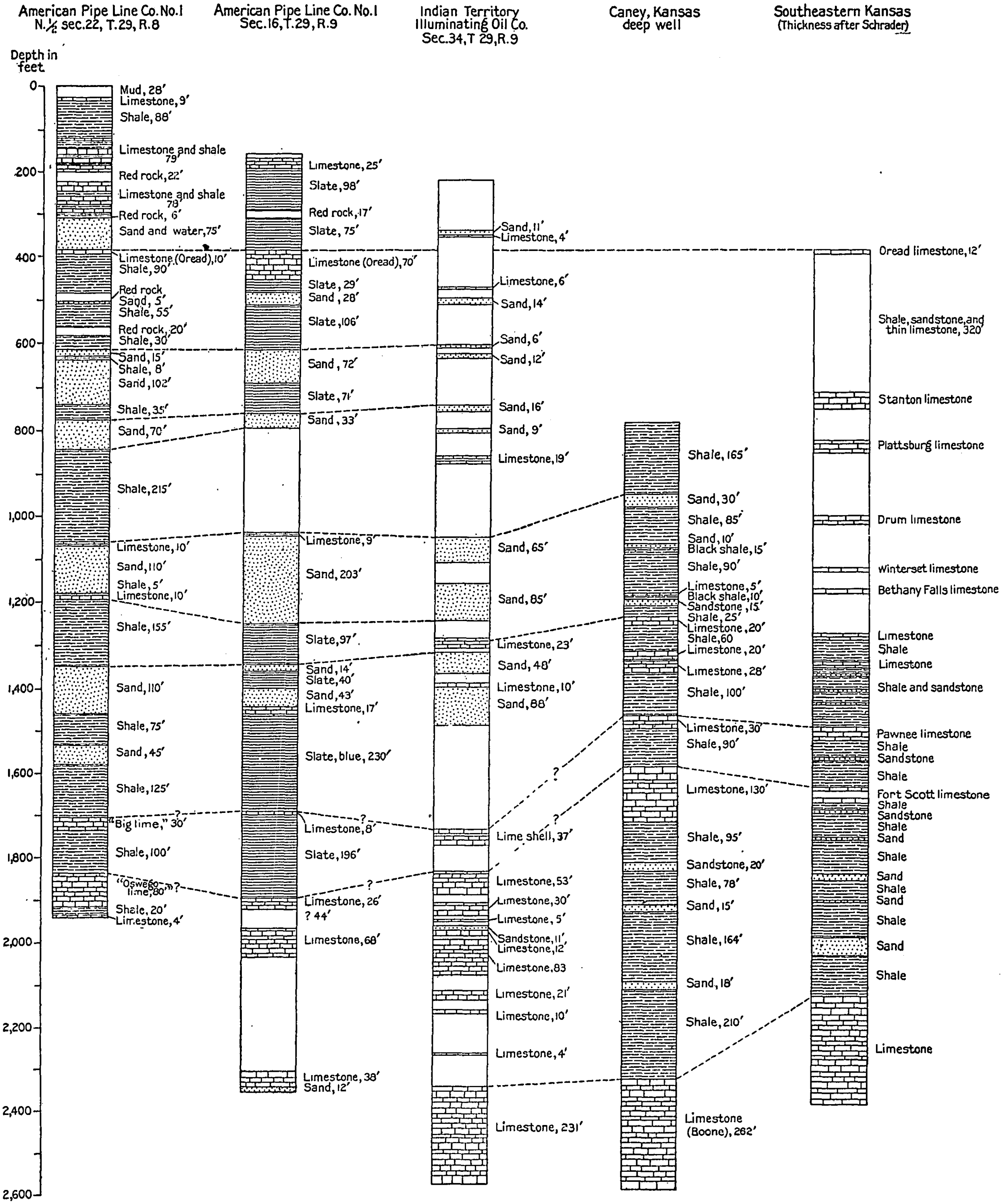


FIGURE 23.—Cross section illustrating lenticularity of sandstone beds. Vertical scale very much exaggerated.

The shales range in character from clean clayey material in which no trace of grit may be detected when it is ground between the teeth to beds that appear to contain over 50 per cent of sand. Some of the shale beds maintain uniform characteristics throughout the region, but more of them do not. A bed that is almost pure clay in one place may have a large percentage of sand in another. The color is no more characteristic than is the physical character. Some beds are of the same general color wherever they were observed, but in others the color is not so uniform, so no definite rule for recognition of individual beds may be laid down.

In the following paragraphs only those beds that are useful as "key rocks" will be described in detail. The general relations, thickness, and sequence of the beds are shown in figure 22 and Plate XIV. The columnar section shows the stratigraphic position of the key rocks and the general character of the intervening beds. Many of the names given to the beds in this report have been employed merely to facilitate references to them.



RECORDS OF WELLS DRILLED IN THE NORTHWEST CORNER OF THE PAWHUSKA QUADRANGLE, OKLA., COMPARED WITH THE UPPER PORTION OF THE RECORD OF THE CANEY DEEP WELL AND THE GENERAL STRATIGRAPHIC SECTION OF THE PENNSYLVANIAN ROCKS IN THE INDEPENDENCE QUADRANGLE, KANS.

KEY ROCKS.

SANDSTONE B.

The bed here called sandstone B, which was found of use in determining the attitude of the strata in a strip along the western edge of Tps. 28 and 29 N., R. 8 E., lies about 215 feet below the top of the Foraker limestone. It is 1 to 8 feet thick and is one of the most persistent sandstones in this part of the section. Its weathered surface is in most localities a reddish-brown; its fresh surface cream-colored to light coffee-brown, in places with small specks or blotches of darker color. It is made up of very fine grains of translucent quartz, which are very poorly rounded, set in a calcareous or siliceous cement. The character of the bedding is not uniform. At one locality the rock weathers into smooth, almost rectangular slabs; at another into gnarly chunks with no hint of regularity. No fossils that could be definitely proved to belong to this bed were seen in any outcrop, but it is believed that a fossiliferous sandstone at the crossing of Sand Creek in sec. 30, T. 28 N., R. 8 E., occupies this horizon.

The above description could apply, in large part, to other sandstones in this part of the section, and perhaps sandstone B may be most certainly identified by the shale beds above and below it. The shale above is a nonfissile gray or brown "gumbo," sticky when moist, and carrying many small included grains of limestone. It is possibly though not certainly marine. The shale below is distinctly a marine shale. In places it is full of fossils (particularly *Chonetes granulifer*) and has many thin, short lentils of limestone. It is brownish gray and shows much limonite stain. Though it is not markedly fissile, its fracture is quite distinct from that of the overlying shale.

Sandstone B is best exposed on the hilltops overlooking Buck Creek, South Buck Creek, Dog Creek, and their tributaries in Tps. 28 and 29 N., R. 8 E.

STONEBREAKER LIMESTONE.

The Stonebreaker limestone, which is the highest prominent one above the "red lime," lies about 45 feet below the top of sandstone B. In the interval, which is largely filled with shale, there are two or three thin beds of limestone, but in most places these beds have inconspicuous outcrops, and, though they appear to be remarkably continuous and crop out through a wide area, they can not be followed with the ease and certainty with which the Stonebreaker can in most places be traced.

The Stonebreaker limestone ranges in thickness from 2 to 16 feet. Its weathered surface is in most localities strongly stained with limonite, giving it a dirty-yellow, blotched appearance. The fresh surface is dark blue to light gray, with ocher-yellow limonite stains. It is hard and tough and contains few fossils except scattered *Fusulina* and crinoid segments.

In the northwestern part of the area, where this limestone was first observed by the writer, there appears to be but one bed. In the southern part, west of Pearsons Switch, there are two beds, either of which may be locally the more prominent. As these two beds, with an intermediate shale interval, occupy a vertical space of only 12 feet, it is important to distinguish between them and to be certain on which one elevations are taken in determining the structure, for otherwise a wrong impression of the exact configuration of the warped surface of the beds may be obtained.

In the few places where it was seen, the overlying shale contains numerous marine fossils, particularly segments of crinoid stems. Even where the rock itself could not be seen, these segments were frequently observed in the soil cover. The underlying shale, also rarely seen, does not appear to be of marine origin in the northern part of the area, where it is best exposed. It is light gray except where it is stained with limonite, is sandy, and carries muscovite mica and many small fragments of carbonaceous matter. A persistent bed of hard, compact micaceous sandstone, 12 to 18 feet below the top of this limestone, also helps in its identification in the northern part of the area. In the southern part this sandstone thickens greatly and is very sparingly micaceous, being indistinguishable from other sandstones of the region.

The limestone is named from the Stonebreaker ranch, where it is well exposed.

CRYPTOZOON-BEARING LIMESTONE.

The *Cryptozoon*-bearing limestone lies about 70 feet below the Stonebreaker limestone in the northern part of the area and about 60 feet below it in the southern part of the area. North of T. 27 N. the interval between the two is occupied by shale, thin beds of limestone, and a thin bed of sandstone. In T. 27 N. the sandstone thickens and is in places the most prominent bed in the stratigraphic section, capping hilltops and littering the slopes with loose fragments. Some of the intervening limestones are locally prominent and may be of assistance in mapping the structure. None of them appear to be continuous, however, nor have they characteristics which make it possible to recognize them easily and with certainty. Both these last-named qualities the *Cryptozoon*-bearing limestone has, and because of them it is of great value in determining the structure of the region.

The bed is in most places from 1 to 3 feet thick. Although other layers of limestone in places immediately overlie or underlie it, they may as a rule be easily distinguished from it by their physical character. The weathered surface of the limestone is usually of a characteristic dark-gray color; the fresh surface a clean dark blue-gray. The limestone is very hard and remarkably brittle and splits almost

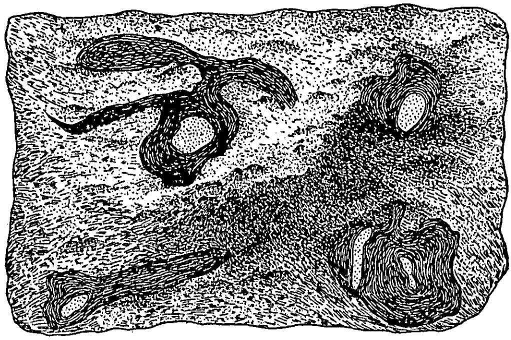


FIGURE 24.—Sketch of rock fragment showing characteristic shapes of Cryptozoa in the *Cryptozoon*-bearing limestone.

like glass under the blows of a hammer. It has a lack of invertebrate fossils which is remarkable in view of the abundant beautifully preserved forms in adjacent beds that may be in direct contact with it. The feature which makes it easily recognized is the presence of Cryptozoa, irregular forms that are the fossil remains of organisms whose nature has not been precisely determined. In many instances it is possible to detect a bryozoan, a fragment of shell, or a

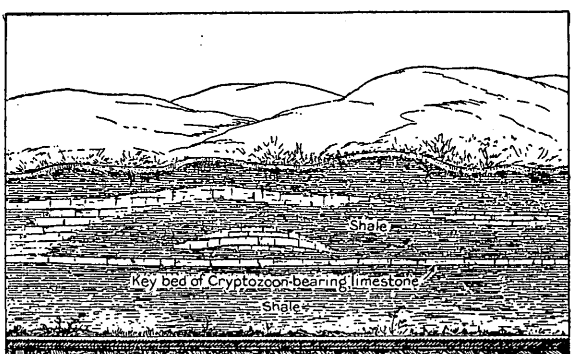


FIGURE 25.—Sketch illustrating conditions observed in railroad cut between Pearsons Switch and Blackland, Okla.

segment of crinoid stem near the center of the form. These fossil remains were apparently the nuclei around which the Cryptozoa formed. Figure 24 is a rough sketch showing the general appearance of these fossils. Similar forms were seen in the Stonebreaker limestone and in a thin limestone above the Stonebreaker in the southern part of the area. Both these beds are so different in hardness, texture, and other physical characteristics from the *Cryptozoon*-bearing limestone that no confusion can arise.

There is a good exposure of the bed above described in a railroad cut between Pearsons Switch and Blackland. The conditions observed there are shown in figure 25. It will be noted that the bed bearing the Cryptozoa is the only one that is continuous. Although it is improbable that this thin bed is absolutely continuous throughout the area, it is apparently very much more nearly continuous than associated beds and was traced for miles by the writer without a break being detected.

A short interval below the *Cryptozoon*-bearing limestone there is an unconformity, and as a result the sequence of beds below it is not even approximately the same in different parts of the area. Where erosion cut the deepest into the underlying sandstone series hollows were scooped out in which three limestone beds with intervening shales were laid down, but locally one, two, or all of these limestones may be absent.

West of Pearsons Switch the *Cryptozoon*-bearing limestone is overlain in places by 12 feet of light-gray, ocherized fossiliferous limestone, and its dull-gray surface is largely hidden by float from the overlying bed. This overlying bed is lenticular and is quite similar to beds of less thickness and extent observed in other parts of the area. It follows that if elevations are taken on the uppermost bed of the overlying limestone instead of on the *Cryptozoon*-bearing limestone, which presumably will be used as a basis for determinations of altitude over much of the surrounding district, an error of 12 feet will be introduced, on the assumption that continuous beds of limestone are laid down on planes that are approximately flat.

PAWHUSKA LIMESTONE.

The Pawhuska limestone as here defined (see fig. 22) is made up of a series of limestone beds separated by shale with some associated lenses of sandstone, the whole resting on the Elgin sandstone and in places attaining a thickness of approximately 130 to 180 feet. Except in the highest and lowest beds the appearance of the outcrops and the physical character of the several limestones are very similar, so that it is usually impossible to say at what horizon in the succession any particular outcrop belongs unless its position with respect to the highest or lowest bed in the series can be determined. Usually any limestone occurring in this interval has been called "Pawhuska limestone," but the limestone exposed at the town of Pawhuska is believed to occur in the middle of the succession. The formation is named from its exposure in the Pawhuska quadrangle.

The highest bed of the formation as here delimited was called in the field the "red lime" because in some places it has a conspicuous outcrop of a rust-red color. Outcrops similar in color were observed in the *Cryptozoon*-bearing limestone and in the Lecompton limestone member, near the base (see fig. 22), so this color is not in itself a reliable criterion upon which to base the identification of the "red lime." However, the prominent rust-red color is present in comparatively few places, and elsewhere the colors of the weathered and fresh surfaces are distinct from those of the underlying limestones.

The most frequently observed color of the weathered surface of the "red lime" is a distinctive brownish gray; that of the fresh surface a blue gray with a reddish tinge. The greatest observed thickness of this bed was 7 feet, but the maximum thickness may be considerably greater, as the base of the bed is in most places concealed. In fact, as a rule the bed does not appear as a ledge, but instead as a line of disconnected fragments of float.

The rock is very hard and brittle and splits with a sharp, clean fracture under a heavy blow. The bedding is massive, and fragments of float may be of considerable size and are characteristically of irregular form. The distribution of fossils in this bed is far from uniform. At one point the rock may be full of invertebrate remains; at another there may be scarcely a trace of life.

Above the "red lime" (the topmost bed of the Pawhuska limestone) is a series of sandstones. About 20 feet below it are the light-gray limestone beds that make up the greater part of the thickness of the Pawhuska limestone. This 20-foot interval is in places entirely occupied by shale, but much more commonly it also contains sandstone which is indistinguishable in color and texture from that overlying the "red lime." A very thin limestone, so full of fossil *Fusulina* as to resemble a layer of dirty-yellowish rice, is also present in places and is extremely helpful as a horizon marker.

Below the sandstone and shale just described there is a succession of limestones and shales with lenses of sandstone. The limestones are prominent and by their resistance to erosion have produced terraced hill slopes on which each terrace is rimmed by a line of gray limestone float. The thickness of the beds varies from place to place, and it does not seem probable that any single bed is continuous throughout the region. The limestones are light gray on both weathered and fresh surfaces, hard, and tough. They are abundantly fossiliferous in some places, but show almost no trace of fossils in others. The bedding is massive. The light-gray surface is blotched with cinnamon-brown, and in the blotches fossils, particularly *Fusulina*, appears to be more abundant than elsewhere in the beds. The lowest limestone in the Pawhuska formation is characterized by many large corals (*Campophyllum torquium*) which are very abundant in this bed at many localities and which were not noticed in any of the other beds. This limestone is the Lecompton of Kansas.

The shales between the limestones are so covered by soil and vegetation that their character is difficult to determine. With one exception they appear to be greenish-gray and are more or less sandy. The exception is the bed which immediately overlies the Lecompton limestone, and which therefore presumably corresponds to the Tecumseh shale of Kansas. This shale is red on both weathered and fresh surfaces, and the color is evident in many localities in spite of the cover of soil and grass. No fossils were observed in this shale except in one locality where it contained many beautifully preserved specimens of *Campophyllum torquium.*

The following is a complete section of the Pawhuska limestone:

Section of Pawhuska limestone near the center of sec. 31, T. 29 N., R. 9 E.

	Feet.
Limestone, reddish brown on both weathered and fresh surfaces, extremely hard, fossiliferous	10
Shale, gray; has some thin beds of gray sandstone	15
Limestone, light gray on both weathered and fresh surfaces, massive, fossiliferous; weathers rough	6+
Concealed	11
Thin limestone	1+
Concealed	6
Limestone. Lower part of exposure has light-gray weathered surface with cinnamon-brown blotches and some hematite-red markings; fossiliferous (*Fusulina* and crinoid stems). Top bed has dirty-gray weathered surface and dark-gray to brownish-blue fresh surface	10+
Concealed	21
Limestone, light gray with cinnamon-brown blotches on weathered surface, fossiliferous (*Fusulina*, crinoid stems, etc.)	2+
Concealed	17
Limestone, impure	1
Shale, red at top, concealed at base	11
Limestone, Lecompton member, light gray on weathered and fresh surfaces, massive, fossiliferous (corals)	6+
Shale, red, with lenticle of white thin-bedded sandstone	22
Elgin sandstone (reddish brown, fine grained, massive).	

OREAD LIMESTONE.

The outcrop of the Oread limestone crosses the Kansas-Oklahoma line at Elgin, Kans. Massive blocks of its float litter the hillside just west of Elgin, and it is well exposed farther west, along the Elgin-Cedarvale wagon road. The outcrop may be followed south into Oklahoma for many miles beyond the limits of the area described in this paper. It appears in the valleys of Caney River, Buck Creek, and Pond Creek and many of their tributaries. In some places it forms conspicuous cliffs; in others it is either completely concealed by débris from the overlying beds or is absent. This makes it extremely difficult to trace with certainty. Wherever it forms a cliff there is, of course, no difficulty, and even where there is a disconnected line of float the task is fairly easy, but there are localities where the horizon which it should occupy may be followed for more than a mile and no glimpse of even a fragment of float from the bed be obtained. In some places its horizon is marked by benches on the hill slopes and by changes in the vegetation. At such places the soil which forms a thin cover over the limestone will not support a thick stand of large trees, while on the adjacent sandstone ledges, which crop out both above and below the Oread, good-sized trees are abundant. Where such conditions occur it is fairly simple to follow the bed and to locate many outcrops that might easily be overlooked, but throughout much of the country where this limestone should crop out no indication of its position may be gained by examination of the surface.

The thickness of the Oread limestone varies from place to place. The greatest thickness measured was 19 feet; the least was 3 feet. A fair average of the thickness in the area described in this report is probably about 10 feet.

Both weathered and fresh surfaces of the Oread limestone are gray. At most of the observed exposures the upper beds are lighter in color than the lower ones, but this is by no means an absolute rule. In a few localities the weathered surface of the rock is stained a bright reddish brown by limonite, but such occurrences are of small extent. The rock is in massive beds which are in places strongly jointed. Solution cavities are fairly numerous and in places make the surface of the bed somewhat rough, but such cavities do not appear to attain large size, even where the beds are heaviest. Fossils are numerous in many localities but are so thoroughly incorporated in the rock that they can not be extracted for determination.

Overlying the Oread limestone is the Elgin sandstone. At many places where good exposures were visible this sandstone was observed to be in direct contact with the limestone. It is a fine to medium grained sandstone, reddish brown to gray on both weathered and fresh surfaces, massive, rather soft, ripple marked in places, and with some rather inconspicuous cross-bedding. Marine fossils indicate that it was laid down under the sea, but the ripple marks show that the water was shallow, and plant remains, which are common in places, show that it was formed on or near the shore line. Neither invertebrate nor plant remains are numerous.

Below the Oread there may be either a sandstone or a shale. In most of the observed localities the limestone lies on a bed of sandstone so similar in character to the one just described that the two beds can not be certainly distinguished where the limestone is not visible. The thickness of this sandstone is not regular. In some places it is a massive bed of which 15 or 20 feet is exposed and the base is concealed by soil. In others it is much thinner, and in one or two of the observed localities it appears to be entirely missing, the Oread resting directly upon greenish-gray sandy shale.

ROCKS NOT EXPOSED.

IMPORTANCE.

Knowledge of the character of the rocks underlying any region that is to be tested for oil or gas is of very great importance. Although many of the oil and gas fields of the United States were discovered by random drilling that took little or no account of the subsurface conditions, there can be no doubt that much labor and money that have been wasted in drilling where there was little or no chance of finding anything of economic value might have been saved if conditions in the region to be tested had first been considered more carefully.

THICKNESS CONSIDERED.

The thickness of the rocks that should be considered in preparing for drilling operations is determined by the depth to which the drill is likely to reach. In the Mid-Continent field few wells are deeper than 4,000 feet, and accordingly no rocks which lie deeper than that will be discussed. As the rocks at the surface dip to the west, and as no marked angular unconformity is known to exist between them and the rocks lying beneath the surface, it seems fair to assume that the underlying rocks also dip in that direction. Accordingly, a well 4,000 feet deep near the eastern part of the area will penetrate older strata than one drilled to the same depth farther west, provided the mouth of the one to the west is not lower than the one to the east, which, as the surface of the land rises toward the west, is improbable.

SOURCES AND RELIABILITY OF INFORMATION.

In most regions there are two sources of information regarding the character of the beds underlying the surface. One lies in the outcrops of the beds which if continuous pass under the area concerning which information is desired. The information obtained from this source is of slight value. The character of the beds and even their succession may change entirely within a very short distance, as is shown graphically in figure 26. Even though the character and thickness of the beds did not change, there would be abundant opportunity for error. Independent observers working on the same outcrop frequently disagree as to the thickness, character, and other features of the beds, even in regions where exposures are good. In northeastern Oklahoma and southeastern Kansas, where hill slopes are commonly mantled with soil and vegetation and where the entire thickness of a bed is rarely visible, errors in observations of outcrops may be both numerous and serious.

The possibility of differences between the characteristic features observed at the outcrop and those which are present below the surface

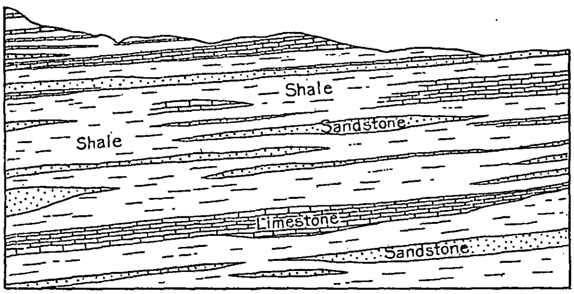


FIGURE 26.—Hypothetical cross section showing changes in the stratigraphy that would make observations on the outcrops of beds of small value.

at some point remote from the outcrop is directly proportional to the distance between the two points. Accordingly, the greater the depth of the strata that are being considered the more inaccurate must be the conclusions concerning their character. Where the rocks dip toward the west about 30 feet to the mile and the surface of the ground rises toward the west 20 feet to the mile, which are approximately the conditions in northeastern Oklahoma, the outcrop of a bed encountered in a well at 4,000 feet below the surface, if the bed were persistent, would be at least 80 miles east of the well.

A good well record furnishes the most accurate information that is commonly available about the rocks below the surface, particularly if it is supplemented by samples of the rocks that were penetrated. On the other hand, a poor record may be worse than no record at all, for it may lead to wrong conclusions that will seriously affect the value of the work that is based on it. Among the many factors that combine to determine the value of a record are the type of drill used (whether core drill, churn drill, or rotary);

whether or not samples of the formations were kept; the manner in which the depth to the several beds was ascertained; the skill of the drillers in determining the character of the rocks penetrated; and the care taken in recording observations. A final factor, which is sometimes the most important one, is the ability of the geologist to interpret and apply the facts recorded in the well logs.

CARBONIFEROUS ROCKS.

PENNSYLVANIAN SERIES.

Beneath the Oread limestone, which crops out along the eastern border of the area under consideration, lie between 1,700 and 2,000 feet of sediments of Pennsylvanian age. This estimate of thickness is based on study of the records of deep wells that have been drilled within this area and on the work done by Schrader[1] in the Independence quadrangle, Kans., to the northeast. A fair figure for the average thickness is 2,000 feet. The greater part of these sediments is shale, but there are also limestones and sandstones in beds ranging from some that are very thin to some more than 150 feet in thickness.

According to such well records as are available the heaviest beds of sandstone are in the middle third of the section. The lower third of the section, which includes the Cherokee shale, if it is present, is occupied largely by limestone. This condition is very different from those prevailing to the east and south, where the Cherokee shale is the formation that contains the heaviest beds of sandstone, and it may be of great economic importance, as the sandstone beds in the Cherokee shale are the most prolific reservoirs of oil in the Mid-Continent oil field.

A plausible explanation of this change in the character of the strata immediately overlying the Boone (Mississippian) limestone is that the Cherokee shale was never deposited over this area and that the limestone and shale series which takes its place belongs to an older formation, of Chester or possibly Morrow (Pottsville) age. According to this hypothesis these older rocks must have stood above the general level to which the region was reduced before the deposition of the Cherokee shale, forming an eminence when it was a land surface, an island after the inundation of the region by the sea, and projecting above the layers of the Cherokee shale that were laid down on its flanks. Another possible explanation is that the sandstones of the Cherokee are replaced by limestones in this region and that there is no unconformity. This hypothesis is a little more difficult to believe, as it would postulate that at this point there was

[1] Schrader, F. C., U. S. Geol. Survey Geol. Atlas, Independence folio (No. 159), p. 4 and generalized section, 1908.

clear, quiet water in which limestones would form, while in immediately adjacent regions the waters were loaded with the mud and sand which when deposited formed the typical Cherokee shale. In order to maintain this difference of conditions during the time necessary for the formation of limestones of the thicknesses shown in the well records (Pl. XIV) very delicate adjustment of the sediment-depositing currents would be necessary. The correctness or incorrectness of either of these hypotheses can not be established without more proof than is at present available. If fragments of the limestones lying below the horizon of the Fort Scott limestone could be obtained it is possible that they might contain fossil remains that would determine the age of the beds from which they came and so settle the question very simply, and it is to be hoped that such evidence will be forthcoming.

Distinguishing characteristics in the different limestones, shales, and sandstones are apparently very difficult for the drillers to detect, and therefore they frequently reach erroneous conclusions concerning the position in the stratigraphic section of the bottoms of wells which they are drilling. Such errors may lead to the abandonment of a well before it has been drilled deep enough to afford an adequate test of the possibilities of finding oil in the locality. Much of this difficulty is unavoidable. The wells must pass through many limestones that resemble each other very closely and through bed after bed of shale no one of which has any easily noticeable characteristic that would make it a good horizon marker. However, more care in observation by drillers would furnish much more reliable data than are usually available. For example, the presence of beds of coal is rarely noted, although it is known that numerous thin coal seams are present in this section. Although it is improbable that any of these beds extend great distances, notation of their presence in the well records would be of great assistance in correlations involving comparatively short distances.

Another important piece of evidence that is overlooked by many drillers is the color of the shale. Some drillers are scrupulously careful in recording colors, but others report all soft clayey strata as "shale" or "slate" and make no reference to the color. Beds of red shale should be of particular assistance as horizon markers. Shale of this color is comparatively rare in the lower part of the Pennsylvanian series of northeastern Oklahoma, so there should be small likelihood of confusing different horizons when correlating between wells, and this color is so conspicuous that only a very thin bed would pass unnoticed by the drillers. Red shale has been found in the Tecumseh, Weston, Lane, Cherryvale, Galesburg, Labette, and Cherokee shales. The beds in the Lane, Galesburg, and Labette shales appear to be present in but a few localities. Those in the

Tecumseh, Weston, Cherryvale, and Cherokee shales appear to have a much broader extent, and any thick bands of red shale that may be encountered in drilling will probably be parts of one or another of these formations.

Beds of black shale are of much less value as horizon markers. The color is not so distinctive as red, and a wet blue shale may sometimes be recorded as black. Furthermore, in northeastern Oklahoma black shales are not confined to a few horizons but have been found in every shale formation between the Oread limestone and the base of the Pennsylvanian series. It may be stated as a general rule, however, that thick layers of black shale are more numerous near the base of the Pennsylvanian than in its upper portion, and that thick, closely spaced layers of this color will not be encountered above the Pawnee limestone.

A third point that may lead to confusion and serious errors in interpreting the data furnished by well records is the inability or neglect of some drillers to distinguish between limestone and sandstone. Limestones are recorded as sandstones and vice versa because the driller's decision as to the character of the rock is based on the way it cuts or dulls the bit, the rapidity with which it is penetrated, and the " feel " of the impact of the drill as transmitted by the drilling cable, more than on examination of the cuttings.

If these failings could be overcome the record of churn-drill operations would be sufficiently accurate to justify very definite statements concerning the nature and age of the strata in the 2,100 feet immediately underlying the surface of the area.

MISSISSIPPIAN SERIES.

Below the rocks belonging to the Pennsylvanian series are older sediments. Although no drilling in the area under consideration has gone deep enough to ascertain the nature of the rocks that lie more than 200 or 300 feet below the horizon of the Cherokee shale, some notion of their general character may be obtained by consideration of the features which they show at their outcrops in northeastern Oklahoma, southwestern Missouri, and northwestern Arkansas and by study of the records of deep wells that have been drilled in Caney and Iola, Kans.

The Mississippian series in southwestern Missouri, northwestern Arkansas, and northeastern Oklahoma is made up of rock of Chester age above and the Boone limestone below. The rocks of Chester age are black and dark-colored shales and equally somber-colored limestones. No such series of dark-colored rocks has been recorded in the logs of deep wells drilled in or near the northwest corner of the Pawhuska quadrangle, so it may be assumed that the Chester epoch is not represented by sediments in the area under consideration, although the Boone limestone, which lies unconformably below the rocks of Chester age in eastern Oklahoma, is believed to underlie the entire area.

The Boone limestone in northeastern Oklahoma attains a maximum thickness of about 350 feet, the greater part of which is interstratified chert and limestone. Both limestone and chert are light colored.[1]

The deep well drilled at Caney, Kans. (see Pl. XV), penetrated 262 feet of limestone which immediately underlies the Cherokee shale and which is ascribed to the Boone formation by Schrader.[2] The Iola deep well (Pl. XV) penetrated 168 feet of so-called "Mississippi lime" and 24 feet of arenaceous limestone,[3] both of which probably belong to the Boone formation and give it a thickness of 192 feet. As Iola is about 70 miles northeast of Caney, it may be concluded that the Boone thickens toward the southwest and is very probably thicker in northeastern Oklahoma than it is in central and southern Kansas. This conclusion is strengthened by the thickness observed at its outcrop in northeastern Oklahoma. A fair estimate for its thickness in the northwest corner of the Pawhuska quadrangle is 350 feet.

DEVONIAN ROCKS.

It is estimated by the writer that at least 150 feet of black shale, sandstone, and perhaps limestone of Devonian age lie unconformably below the rocks of the Carboniferous system. This estimate is based on the measured thickness of about 100 feet at the outcrop of these beds in northeastern Oklahoma,[4] the observed tendency of the Devonian rocks to thicken toward the west in the region where they crop out, and on the thickness of these rocks in a well drilled at Caney, Kans. (Pl. XV), which penetrated 35 feet of black bituminous shale, 207 feet of limestone, and 11 feet of sandstone ascribed by Schrader[5] to the Devonian.

The Chattanooga shale, which is the youngest Devonian rock in this region and therefore the one which will be first encountered in a well, is a black carbonaceous shale of uniform character. In most places it contains so high a percentage of organic matter that when

---

[1] Snider, L. C., Geology of a portion of northeastern Oklahoma: Oklahoma Geol. Survey Bull. 24, p. 26, 1916. Siebenthal, C. E., Mineral resources of northeastern Oklahoma: U. S. Geol. Survey Bull. 340, p. 190, 1907.

[2] Schrader, F. C., U. S. Geol. Survey Geol. Atlas, Independence folio (No. 159), p. 4, 1908.

[3] Haworth, Erasmus, Kansas Univ. Geol. Survey, vol. 9, pl. 6, 1908.

[4] Snider, L. C., Geology of a portion of northeastern Oklahoma: Oklahoma Geol. Survey Bull. 24, p. 20, 1916.

[5] Schrader, F. C., U. S. Geol. Survey Geol. Atlas, Independence folio (No. 159), p. 4, 1908.

freshly broken it emits an odor of decay.[1] This shale is easily recognized at its outcrop and should be identified with almost equal facility when it is encountered in borings.

The Sylamore sandstone, the basal member of the Chattanooga shale in some localities in northeastern Oklahoma, southwestern Missouri, and northwestern Arkansas, is phosphatic, coarse-grained, locally conglomeratic sandstone which has a maximum observed thickness in Oklahoma of 35 feet.[2] It is bounded by unconformities, so that no uniform thickness may be assumed for it. It is absent in much of the area where it would be exposed at the surface if it were present, and the same conditions presumably continue toward the west.

SILURIAN (?), ORDOVICIAN, AND CAMBRIAN ROCKS.

Silurian rocks are not known to be present in northern Oklahoma. Siebenthal[3] says that "formations of Silurian age * * * are wanting in all the western part of the Ozark region." However, it is entirely possible that they are present below the surface of the area under consideration. Schrader[4] assigns to this system 375 feet of crystalline gray, bluish-gray, and brown limestone, which was passed through in drilling the deep well at Caney, Kans. (Pl. XV), and correlates it with the St. Clair marble, which is present in east-central Oklahoma.[2]

Below the Silurian, if present, are rocks of Ordovician age. The deep wells at Caney, Neodesha, and Iola, Kans. (Pl. XV), penetrate magnesian limestones, dolomites, shales, and sandstones of this age, which also crop out in the Ozark region and in eastern Oklahoma. Notable among the sandstones is the St. Peter, which is more than 100 feet thick in some parts of eastern Oklahoma and southwestern Missouri. It is very uniform in character and of broad distribution. Schrader[4] believes that a sand 46 feet thick that was encountered in the Caney deep well about 897 feet below the base of the Chattanooga formation corresponds to the St. Peter sandstone.

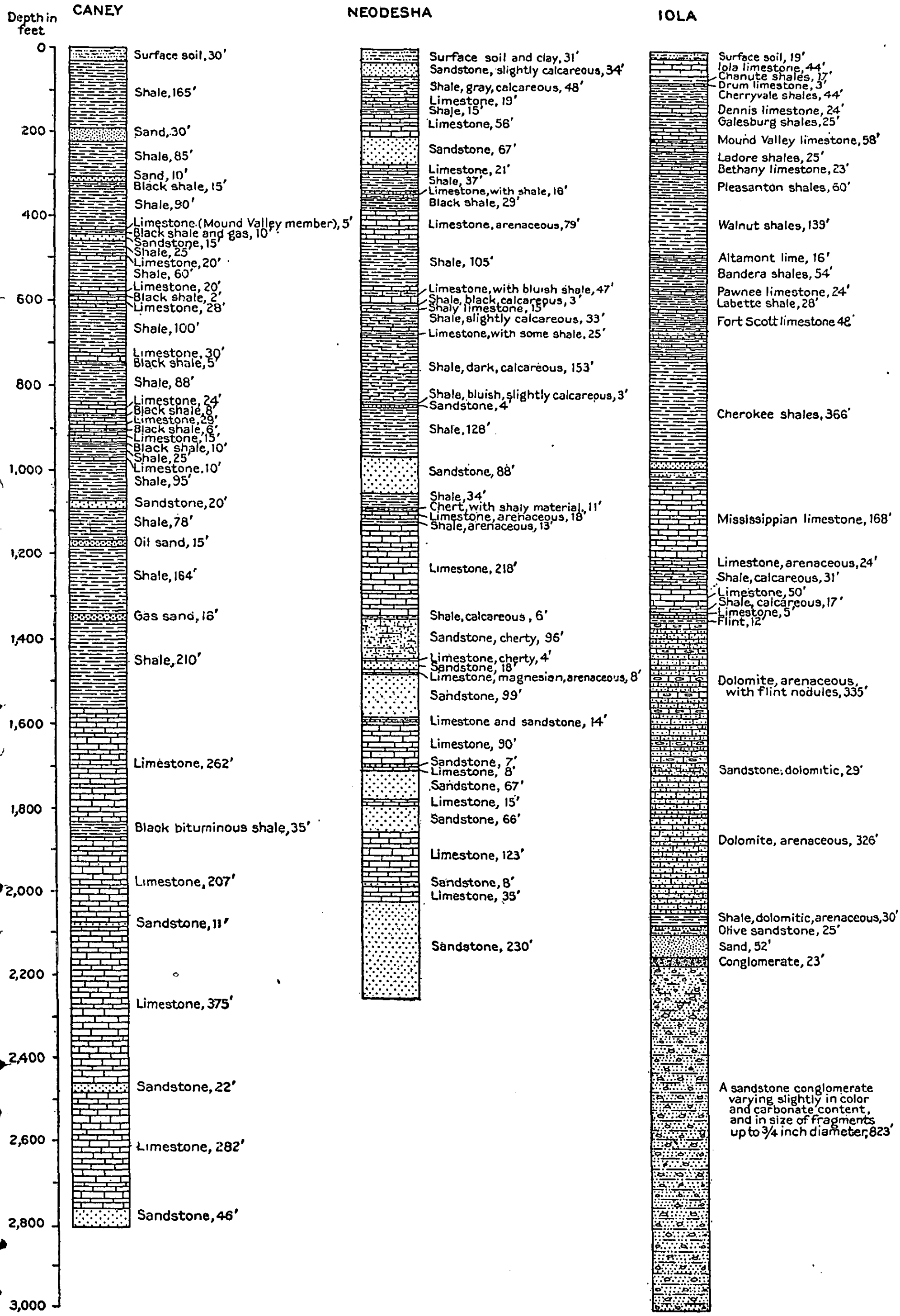
Below the St. Peter sandstone there are limestones, dolomites, and sandstones probably extending considerably below the limit of 4,000 feet which was mentioned as the thickness of strata that would be discussed. The lowest sedimentary formation that would be encountered in a well 4,000 feet deep drilled near the eastern edge of the

[1] Taff, J. A., U. S. Geol. Survey Geol. Atlas, Tahlequah folio (No. 122), p. 2, 1905. Adams, G. I., and Ulrich, E. O., U. S. Geol. Survey Geol. Atlas, Fayetteville folio (No. 119), p. 3, 1905.

[2] Taff, J. A., op. cit., p. 3.

[3] Siebenthal, C. E., Origin of the zinc and lead deposits of the Joplin region: U. S. Geol. Survey Bull. 606, p. 25, 1915.

[4] Schrader, C. F., U. S. Geol. Survey Geol. Atlas, Independence folio (No. 159), p. 4, 1908.



RECORDS OF DEEP WELLS AT CANEY, NEODESHA, AND IOLA, KANS., SHOWING THE CHARACTER OF THE UPPER PART OF THE PRE-PENNSYLVANIAN ROCKS OF SOUTHEASTERN KANSAS.

area under consideration would probably be an arkosic sandstone of great thickness and of Cambrian age. Such a sandstone has been recorded in deep wells drilled in eastern Kansas and western Missouri, and it apparently extends over a large area.

STRUCTURE.

DEFINITION.

The term "structure" is used in this report in its general sense, to mean the attitude of the strata, whether horizontal, inclined, folded, or broken by faults. Structure must not be confused with the configuration of the surface of the ground. The dips of the rocks may coincide exactly with the surface slopes, or they may be exactly opposite. Anticlines, or upfolds of the strata, may underlie

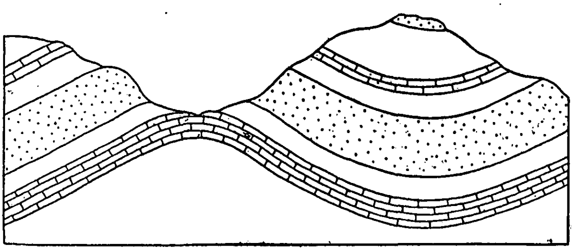


FIGURE 27.—Cross section showing possible position of anticline below valley and of syncline below hill.

valleys, and synclines, or downfolds of the strata, may underlie hills, as is shown graphically in figure 27. In most regions the structure bears a definite relation to the topography, but the relations are so different for different regions that it is impossible to make a rule which will apply to all types of country.

REGIONAL STRUCTURE.

The general structure of the region is monoclinal. The rocks throughout the region dip almost due west at an average rate of about 35 feet to the mile. The dip, however, is far from uniform. In some localities the rocks dip westward at triple the average rate, and these steepenings are compensated by areas where the westward dip is very low. If the earth and rock were all stripped from above the key horizon on which the structure contours are drawn, a broad, flat, westward-sloping plain would be exposed to view. The surface of this plain would be marked by low, smoothly rounded hills or knolls; broad, smooth-crested, westward-pitching ridges; short, shallow valleys opening to the west and broadening at their mouths until they merge into the westward monocline of the regional structure; and a few small oval depressions. The evenness of the surface would be further interrupted by a few low, inconspicuous almost vertical fault scarps trending in a general northwesterly direction.

DETERMINATION OF STRUCTURE.

The structure of the beds that contain the oil and gas pools of Oklahoma is believed to be the principal factor that has determined the location of those pools. It is therefore evident that study of the structure in this region is of great economic as well as scientific interest. Although experience has shown that as a rule the folding of the beds that lie at or near the surface of the ground does not conform exactly to that of the beds lying at some depth, it is believed that in eastern Oklahoma there is a considerable degree of parallelism and that an accurate map of the surface structure of this region gives at least an approximation of the deep-seated structure.

The configuration of the surface of a bed may be mapped if the elevations of a great many points on the surface of the bed are known, the accuracy of the mapping depending of course on the number of elevations available. As no single bed crops out over the surface of such extensive areas as are commonly mapped, it is necessary to choose some bed as a key horizon and refer the elevations taken on the outcrops of other beds to that key horizon. This is done by determining the distance between the bed on which the elevation is taken and the key horizon, subtracting that figure from the elevation taken (if the bed lies above the key horizon), and so determining the elevation of the key horizon at that point. For example, if an elevation of 500 feet above sea level is determined on a bed, and it is known that this bed is 90 feet higher in the stratigraphic section than the key horizon, the elevation of the key horizon at that point would be 500 minus 90, or 410 feet above sea level. No allowance need be made for offsetting of beds by folding where the dip of the strata is less than 5°.

The bed chosen for a key horizon may be the lowest bed that crops out on the surface of the region to be mapped, or it may be a bed which does not crop out in the area. It is important that the bed occupy such a position in the stratigraphic column that all the elevations determined in the region to be mapped will lie either on it or on beds above it—none on beds below it. The reason for this is that an avoidable error may be introduced when elevations are not determined on the lowest visible bed. The configuration of the beds that lie closest to the oil sands must be learned, to avoid any mistakes which thickening or thinning of the overlying strata might introduce. This point is illustrated in figure 28, in which the dashed line represents the outcrop of a prominent, easily traced bed of limestone, and the solid line the outcrop of a thin bed, traceable with difficulty, which lies below the prominent bed. Both beds crop out on opposite sides of a valley. The figure shows elevations determined at adjacent points on the two beds, so that the interval between the beds can be ascertained. If the prominent upper bed were arbitrarily chosen as the key horizon the structure contours (see p. 80) would show a flat surface with no dip, whereas structure contours on the lower bed would show that there is a dip of 20 feet between the outcrops on opposite sides of the valley. It may be argued that angular unconformity, thickening or thinning of the beds, folds that do not appear at the surface, and other irregularities in the beds below the surface may change conditions so that the contours drawn on a key horizon above the lowest exposed bed would represent a surface more similar to that of the deep-lying oil sand than that shown by contours drawn on a lower bed, and that a great degree of accuracy in mapping the surface structure is not justified when so many factors may combine to render that accuracy of no practical value. The answer to this argument is that it is never justifiable to hazard an avoidable error that may be of some magnitude.

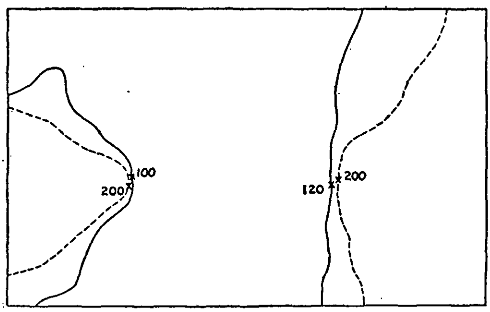


FIGURE 28.—Sketch illustrating the importance of contouring lower bed rather than upper bed when determining structure.

A knowledge of the stratigraphy is of the first importance if the structure of a region is to be accurately determined. Many measurements must be made to determine the thickness of the several formations, and the physical and regional characteristics of the beds must be learned. Otherwise observations on isolated rock outcrops will be of little value, as it will be impossible to say what relation the bed upon which the observation is taken bears to the key horizon.

Study of the stratigraphy is accompanied or followed by determination of the elevation of many points on the beds. These determinations may be made either by spirit level or by an aneroid barometer. The form of spirit level most commonly used is known as an alidade, which is used on a plane table. Elevations determined by spirit level are much more accurate than those determined by barometer, but barometric work may be done advantageously in timbered country where level work would be extremely slow and laborious. Both methods were used by the writer in the work described in this paper. In the spirit leveling a system of control was first extended from United States bench marks, of which there are several in this region, and the location and elevation of many conspicuous points, including windmills, derricks, flags in tree tops, chimneys, and stone piles on hill crests, were obtained and plotted on the plane-table sheet. After the control was established it was a simple matter to determine the location and elevation of any point provided three of the control points were visible. Location was sometimes determined by the relation of the point occupied to a section corner or a quarter corner, and under such conditions the elevation might be determined by triangulation to a single control point. Where the nature of the structure called for particularly detailed work a stadia rod was employed. The elevation of the plane table was first determined by triangulation, and then the location and elevations of many surrounding points were determined by sights to the stadia rod. At some places the location of every other point was determined by pacing, and its elevation by barometer. This resulted in a small saving of time. The barometer was also read at the stations whose elevation was determined by stadia, and a curve was constructed to permit correction of any error in barometric elevations.

In timbered regions where use of the plane table would be so slow as to be impracticable foot traverses were run along outcrops of beds. Distances were determined by pacing, directions by compass, and elevations by barometer. Such traverses were always made double by returning over the course and taking a second barometer reading at each station. Stations were usually marked by a blaze on a tree so there would be no difficulty in finding them. The stations were so spaced that not more than 10 minutes was required to pass from one to another. By this means a good check was obtained and accurate work was made possible. This work is necessarily very slow.

REPRESENTATION OF STRUCTURE.

The structure of the area under consideration is shown by means of contour lines or lines of equal elevation on Plate XIII. All points through which a single contour line is represented as passing are at the same elevation. A contour is a line drawn to represent the intersection of a horizontal plane and the surface which is being depicted. An ideal horizontal plane is a body of still water, and a line showing where such a body of water meets the land would be a contour. Imagine that the sea has covered a part of the area shown on Plate XIII and that the surface of the sea stands, for example, 500 feet above the present sea level; then the contour line marked 500 would represent the shore line. All the territory mapped with contour lines of lower denomination—490, 480, 470, etc.—would be below the surface of the sea, and the territory mapped with contour lines of greater denomination—510, 520, 530, etc.—would be above sea level. This same conception may be applied to any contour line.

It is often possible to draw two almost opposite conclusions from a single group of elevations, and two sets of contours based on the same group of elevations may depict very different conditions, as is shown in figures 29 and 30. Because of this possibility, it is very desirable that an observer contour his map while he is in the field, where he can check the correctness of any important conclusion.

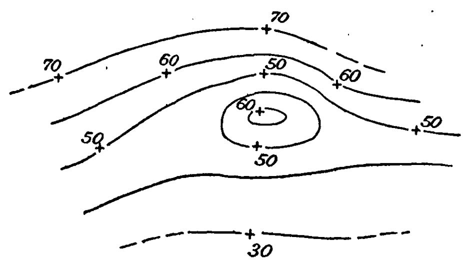


FIGURE 29.—Structure contours representing a small anticline, based on 10 elevations.

If the left-hand edge of the structure map in this report (Pl. XIII) is compared with the right-hand edge of the map showing the structure in the adjoining Foraker quadrangle,[1] it will be noted that although the general form of the structure shown on the two coincides, there are some discordances. This is particularly noticeable at the lower edges of the two maps. The discordance is due, at least in part, to the fact that the contouring in the two areas was done on beds at different horizons. A further reason for the discordance is the fact that the structure mapping for the extreme southeast corner of the Foraker quadrangle is based on comparatively few elevations and hence is more generalized than that for the adjacent part of the Pawhuska quadrangle. The writer believes that the structure in the southeast corner of the Foraker quadrangle is without doubt essentially as it is represented, but he does not consider the mapping as accurate in detail as the work in the adjoining part of the Pawhauska quadrangle, and where there is conflict between the contours representing structure in the two areas the more recent work in the Pawhuska quadrangle should be accepted as the more accurate.

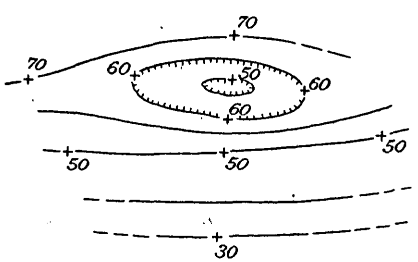


FIGURE 30.—Structure contours representing a small syncline, based on the same group of elevations that was used in figure 29.

LOCAL STRUCTURAL FEATURES.

The term local structure is here used to designate perceptible divergences from the regional structure. Only those features of the

[1] Heald, K. C., The oil and gas geology of the Foraker quadrangle, Osage County, Okla.: U. S. Geol. Survey Bull. 641, pl. 2, 1916.

local structure that are believed to be of economic importance will be discussed in this paper.

PEARSONS SWITCH ANTICLINE.

The Pearsons Switch anticline, named from its proximity to Pearsons Switch, on the Midland Valley Railroad, is by far the most pronounced fold in the area. It lies in secs. 17, 18, 19, and 20, T. 27 N., R. 8 E., and is accompanied by two small subsidiary domes, one in sec. 29 and the other in sec. 30, T. 27 N., R. 8 E. The highest point of the fold appears to be in the extreme southeast corner of sec. 19, T. 27 N., R. 8 E., and from this point the beds slope in all directions but most steeply to the northeast, in which direction they slope for a short distance at a rate of about 100 feet to the mile. The vertical component of this dip is about 40 feet. The outline of the anticline is rather irregular, showing several spurs or scallops, the most pronounced of which is a long eastward-trending point at the extreme north end of the fold. The anticline is capped by a heavy sandstone that lies some 18 feet below the top of the Stonebreaker limestone. The shape of the fold was determined by elevations taken on this sandstone and on the *Cryptozoon*-bearing limestone, which crops out on the western, southern, and eastern flanks. It is possible for confusion to arise in mapping this anticline, as there are beds of limestone both above and below the *Cryptozoon*-bearing limestone, which resemble it closely in color and brittleness. Also there is an unconformity below the *Cryptozoon*-bearing limestone, and the character of the beds a short distance below it may be entirely different at two closely adjacent localities.

The minor domes south and southwest of the main anticline are both low, oval, smoothly outlined folds. The eastern one has an axis about three-fourths of a mile long, trending northwest. The dip to the northeast does not exceed 10 feet in vertical amount and is at the rate of about 60 feet to the mile. That to the southwest is a little steeper. On the northwest and southeast the dips are extremely gentle. This dome is capped by the same sandstone that crowns the main Pearsons Switch anticline, and the structure was outlined from elevations on this sandstone and on the *Cryptozoon*-bearing limestone, which crops out to the north, east, and south. No actual dips to the northeast were seen, and the correctness of the mapping depends on that of the measured interval between the top of the sandstone and the top of the limestone.

The dome in sec. 30 is more pronounced than the one just described, although it is not so large. It lies in the southwest corner of the section. Its axis, which is about a quarter of a mile long, trends in a northwesterly direction. This small dome is superposed on an anticlinal fold whose flanks dip to the northwest, southwest, and southeast, but not to the northeast. The axis of this fold is more than a mile long and trends southwest, pitching in the same direction. The steepest dip is to the southwest. The dome is capped by the Stonebreaker limestone, and elevations on this limestone, supplemented by observations on the sandstone lying a short distance below it, were used in determining the structure. At this place the Stonebreaker limestone is in two beds about 8 feet apart, and care must be taken not to confuse them.

ROUND TOP ANTICLINE.

The Round Top anticline is in the south-central part of T. 28 N., R. 8 E. At its tip, near the center of sec. 32, there is a slight dome-like swelling. The axis of this fold trends almost due west and is about 2 miles long. There is no dip to the east except on the east flank of the little dome in sec. 32, but there are gentle dips to the northwest, west, and southwest. The most pronounced inclination is at the west end, where the beds slope westward at a rate of about 90 feet to the mile. The anticline is capped by the Stonebreaker limestone, and most of the elevations on which the contouring is based are on this bed. Exposures are very fair and the bed can be traced with little difficulty.

TRIANGLE DOME.

The Triangle dome lies in secs. 21 and 28, T. 28 N., R. 8 E.; its center is just south of the quarter corner between the two sections. It is so irregular in outline that it is not possible to define any axial line. The steepest dips are on the east and west sides of the dome, where the rocks incline about 75 feet to the mile. The vertical amount of the east dip is about 10 feet. On the north and south the dips are extremely gentle, although in both directions they are unmistakable. This dome is capped by sandstone B, and its form was determined by elevations on this sandstone, the Stonebreaker limestone, and the sandstone below the Stonebreaker limestone. The two last-named beds crop out on the flanks of the fold. Some difficulty was experienced in tracing the beds, and there may be minor errors in the outline of the fold as mapped, but there is no doubt about its general shape.

UPPER DOG CREEK ANTICLINE.

The Upper Dog Creek anticline is a long, relatively narrow fold near the axis of which Dog Creek has cut its valley. It trends southwestward, and its flanks slope northwest and southeast. Its structure is not "closed," as there is no dip to the northeast. The axis, which is about 3 miles long and slightly curved, runs from the east-central part of sec. 20, T. 28 N., R. 8 E., to the northeast corner of sec. 30, T. 28 N., R. 8 E. The highest formation exposed in this anticline is sandstone B. The shape of the contours was determined by elevations on sandstone B, the Stonebreaker limestone, a limestone between the Stonebreaker and the *Cryptozoon*-bearing limestone.

RICEROCK ANTICLINE.

The Ricerock anticline lies in secs. 7 and 18, T. 28 N., R. 9 E., and secs. 12 and 13, T. 28 N., R. 8 E. The axis trends a little north of west from the quarter corner between secs. 7 and 18, T. 28 N., R. 9 E., to the quarter corner between secs. 11 and 12, T. 28 N., R. 8 E. From this axis the beds dip northwest and southwest. To the east the fold dies out in a flat terrace almost a mile broad, which on the east merges with the regional dip. The steepest dip on the fold is on its tip, where the beds incline to the west about 800 feet to the mile. On the flanks the dips probably average about 60 feet to the mile. The formation capping this anticline is a sandstone about 20 feet above the "red lime" in the stratigraphic column. A thin bed of limestone, thickly filled with tests of *Fusulina*, was of great assistance in mapping the structure, as it furnished an easily identified, thoroughly reliable horizon on which to determine the relative elevations of different parts of the fold.

UPPER POND CREEK DOME.

The Upper Pond Creek dome lies in sec. 19, T. 28 N., R. 9 E. It is a low, almost imperceptible bulge, bounded on the northeast by a small fault with a throw of 10 feet or less. Dips on the other flanks average about 60 feet to the mile. A cross section of this fold from northwest to southeast would show a very low, flat arch. One from southwest to northeast would show half such an arch abruptly terminated by a vertical fault scarp.

The shape and outline of this dome were determined by elevations on several of the resistant limestone beds of the Pawhuska formation. The bed that caps the fold is the first heavy limestone below the "red lime."

DRENNAN ANTICLINE.

The Drennan anticline lies in secs. 31 and 32, T. 29 N., R. 8 E., and the northern part of sec. 6, T. 28 N., R 8 E. It has a curving axis about 2 miles long which trends in a general southwesterly direction and pitches in the same direction. The beds do not dip to the northeast except at the extreme northeast end of the fold, where there is a small, low domelike swell about half a mile long and a quarter of a mile wide. On the northeast side of this dome there is a dip to the northeast, the vertical extent of which is about 10 feet. The dips in all directions on the flanks of this anticline are very gentle. The fold was outlined by elevations on the *Cryptozoon*-bearing limestone, which caps the dome at its northeast extremity, and by elevations on the Stonebreaker limestone and sandstone B.

There is a low, heart-shaped dome about half a mile in diameter in secs. 20 and 29, T. 29 N., R. 8 E., which may lie on a continuation of the axis of the Drennan anticline. The center of this minor dome is near the north line of sec. 29, about 1¼ miles north of the little dome at the northeast end of the Drennan anticline.

STONE HOUSE ANTICLINE.

The Stone House anticline is a short, inconspicuous fold in secs. 15 and 16, T. 29 N., R. 8 E. Its axis, which is about a mile long, trends a little south of west and pitches in the same direction. The fold is open toward the east, where it flattens out and merges with the general westward dip of the regional monocline. In all other directions the dip is at a rate of about 50 feet to the mile. Most of the elevations by means of which this fold was determined were taken on the *Cryptozoon*-bearing limestone and beds only a short distance above and below it.

LOWER DOG CREEK DOME.

The Lower Dog Creek dome lies in secs. 24 and 25, T. 29 N., R. 8 E., and secs. 18 and 19, T. 29 N., R. 9 E., near the point where Dog Creek joins Buck Creek. It is a very low symmetrical uplift about 1¼ miles long and 1 mile wide. The top is very flat, and dips in all directions are gentle. The long axis trends a little west of south from the middle of the SW. ¼ sec. 19, T. 29 N., R. 9 E., to the middle of the SE. ¼ sec. 25, T. 29 N., R. 8 E. The outline of this dome was ascertained from elevations on several of the limestone beds of the Pawhuska formation. Owing to their similarity there was some difficulty in determining just where each bed belongs in the section, and for this reason there is a possibility that the exact outlines of the fold are not depicted with perfect accuracy, although there can be little doubt concerning its general shape.

LOWER BUCK CREEK ANTICLINES.

The Lower Buck Creek anticlines are two small domes with irregular outlines, one lying in secs. 28, 29, 31, and 32, T. 29 N., R. 9 E., and the other in secs. 27, 28, 32, and 33, T. 29 N., R. 9 E. The western dome is the smallest. Its highest point coincides almost exactly with the corner between secs. 28, 29, 31, and 32, and from this point the rocks slope in all directions—to the east at an average rate of about 50 feet to the mile, but to the north and south at only 10 or 15 feet to the mile. The maximum vertical extent of dip in any direction except west is about 10 feet. The outline of the fold is gourd shaped, with the neck of the gourd to the north. The axis of the dome is a curving line trending a little west of north over a distance of about a mile.

The eastern anticline is much more pronounced than the one just described. The center of this fold is in the NE. ¼ NE. ¼ sec. 33, T. 29 N., R. 9 E., and from this point the rocks slope in all directions with an average dip of about 50 feet to the mile except to the south, where the dip is about 30 feet to the mile. The vertical extent of the dip to the north, east, and south is about 20 feet and to the west about 40 feet. This anticline is a little less than a mile long, and its long axis trends a little west of north. Its width is about three-quarters of a mile.

The contouring on both of these domes was done on limestone of the Pawhuska formation, particularly on the Lecompton limestone member. The highest bed exposed in the folds is about 25 feet below the top of the Pawhuska formation.

BENCHMARK ANTICLINE.

The Benchmark anticline covers more ground than any other of the anticlines described in this report with the exception of the Pearsons Switch anticline. However, its departure from the regional dip is not so pronounced as that on several of the other folds. It is a broad, low bulge about 1½ miles long and 1 mile wide. The principal axis runs northwest from the middle of the NW. ¼ sec. 22 to the NW. ¼ sec. 16, T. 29 N., R. 9 E. The sides and ends of the fold are roughly parallel, giving it a rude oblong shape. The steepest dip is to the west, and in that direction the rocks slope about 40 feet to the mile. On the east the dip is about half that amount. On the northeast the anticline is probably bounded by a fault with a small vertical displacement. The presence of this fault is inferred from the fact that the measured intervals between the Lecompton and Oread limestones are much greater on the north side of the anticline than they are on the south side and from the divergence of structure contours drawn on the Oread limestone from those drawn on the Lecompton limestone. This discordance might be explained equally well by assuming an angular unconformity, and the writer is not convinced that this is not the correct explanation. More work must be done before the structure can be defined with certainty.

There are two minor protuberances on the anticline. One is a long, low, relatively narrow bulge, which conforms in direction with the axis of the anticline. It is roughly bottle shaped, with the neck of the bottle pointing to the southeast. The other is a gentle swell at the northeast corner of the anticline. Between the two raises there is a narrow saddle or syncline, which, however, is itself a part of the major anticline.

The contours are based on elevations on the lower beds of the Pawhuska formation, on a stray limestone in the Elgin sandstone, and on the Oread limestone. The Lecompton limestone member, near the base of the Pawhuska formation, was of particular value in outlining this fold.

LIMESTONE FLAT TERRACE.

In sec. 32, T. 29 N., R. 9 E., and secs. 5 and 8, T. 28 N., R. 9 E., there is a marked change in the rate of the regional westward dip, the rocks flattening out toward the west, making a terrace about 1 mile broad and 3 miles long. At the south end of this terrace is the Ricerock anticline, and the north end of it dies out a little west of the Lower Buck Creek anticlines. The "step" of the terrace is not absolutely horizontal but slopes to the west at a rate of about 10 feet to the mile. On its surface there are two very small anticlines and at least one correspondingly small syncline, but these features are relatively minor parts of the terrace as a whole. The rock that caps the terrace is the highest bed of the Pawhuska limestone, and the elevations that proved the existence of the terrace were taken on the limestone ledges that make up the Pawhuska limestone. At its west edge the rocks forming this terrace pitch to the west at a rate of about 60 feet to the mile, and at the east edge they rise to the east with a somewhat gentler slope.

OIL AND GAS.

PRODUCING FIELDS.

Not more than 3 per cent of the area described in this report has been proved to contain either oil or gas in commercial quantity. Territory which is at present furnishing oil or gas or which has furnished one or the other in the past covers about 3 square miles out of a total area of about 110 square miles, so the above estimate is very liberal. The producing area is in two widely separated tracts, one in the extreme northeast corner of the area, the other in the extreme southwest corner. They are separated by territory in which not even a trace of oil or gas has been found and which has been little prospected.

ELGIN FIELD.

A small portion of the Elgin field lies in the area treated in this report. There are three distinct groups of producing wells situated in secs. 16, 17, and 20, respectively, of T. 29 N., R. 9 E. The group in sec. 16 contained four oil wells at the time of the writer's visit, in November, 1917. All four of these wells are in the northeast corner of the section and are so closely spaced that they drain a very small area. The exact production of the wells was not determined, but it is very small. The oil is derived from a sand about 400 feet above the Fort Scott ("Oswego") limestone, and only one bed produces either oil or gas. The only record pertaining to this group of wells obtained by the writer is that of well No. 4. It shows that the well was drilled in August, 1912, and according to local authorities the well has been producing ever sine. The oil sand in this well lies at a depth of about 1,400 feet. The wells in this group are on the northeast flank of the Benchmark anticline. On the northeast there may be a small fault; its presence was inferred but has not been established.

The group of wells in sec. 17 comprises four small producers, all in the northwest corner of the section, close to the Oklahoma-Kansas line. A fifth well in the extreme northeast corner of sec. 18 really belongs to this group. This cluster of wells is a part of a larger group, the remaining portion of which lies to the north in Kansas. The oil in these wells is believed to come from the Fort Scott limestone, or from a sandstone just above it. This belief is based on information procured from residents of the region and could not be confirmed, as no records of the wells in this group have been obtained. The average initial production of the individual wells was stated to be about 25 barrels. There is no indication of anticlinal structure, of a structural terrace, or of a fault that might have caused the accumulation of oil at this particular place, and it must therefore be concluded either that the folding of the deeper beds does not resemble that shown on the surface, or else that some other factor, such as lenticularity of the sands or changes in the porosity of the containing beds, must be the controlling feature.

The wells in sec. 20 all lie in the northwest corner of the section. There are six producing oil wells in this group, and they drain an area of about 80 acres. The initial daily production of each well was said to average about 25 barrels. This production has dwindled until now the total daily production of all six is about that amount. The oil comes from a sand that is about 400 feet above the Fort Scott limestone. The only available record of the wells in this group is that of No. 2, which was drilled in August, 1912. The producing sand in this well lies at a depth of 1,545 feet and is probably approximately the same as that in the other groups of wells which have been described. The surface structure in the northwest corner of sec. 20 and also in the immediately surrounding region is that of an unbroken monocline, dipping to the west. There is no indication of a dip in any other direction, and accordingly there is no apparent structural reason why the oil should have gathered at this point.

Besides the small oil fields in the Elgin region there was a gas field, which was abandoned some years ago. In this field there were four wells that obtained a rather small volume of gas from comparatively shallow depth. Three of these wells were in the SW. ¼ sec. 17 and one in the NW. ¼ sec. 21, T. 29 N., R. 9 E. The gas came from a sand about 1,200 feet above the Fort Scott limestone (sandstone in the Cherryvale shale?). This little field was on the southwest flank of the Benchmark anticline. The well that was best located with respect to the surface structure was about half a mile from the axis of the fold. A deep test hole that reached what was called the "Mississippi lime" at a depth of 2,140 feet was drilled in this field in 1916 in the hope of discovering either oil or gas below the former producing sand. The limestone does not correspond to the "Mississippi lime" of oil pools to the southeast and is probably the Fort Scott limestone. This test was a failure.

PEARSONS SWITCH FIELD.

The first well in the Pearsons Switch field was completed in August, 1916, with an initial production of about 4,000,000 cubic feet of gas per day. Between that time and the date of the writer's visit to the field, in December, 1916, five more wells were completed and four others were being drilled. The field includes parts of secs. 17, 18, 20, and 30, T. 28 N., R. 8 E., and may also extend into adjoining sections. The outline of the area that will be productive is as yet unknown and can not be determined until a great deal more drilling has been done. To judge from the structure it should include much of the W. ½ sec. 17, the E. ½ sec. 18, the E. ½ sec. 19, the W. ½ sec. 20, the central part of sec. 29, the SW. ¼ sec. 30, and probably the territory lying between the separate portions of the field mentioned. The six wells that were completed before January, 1917, will not drain more than a quarter of the probable producing area described above. In other words, the field was less than 20 per cent developed prior to January, 1917, even though it is assumed that the beds from which the oil and gas are obtained in the wells now drilled are the only ones that will produce gas in this field.

The gas from the Pearsons Switch field is said to be dry, and no trace of oil was observed in the neighborhood of the wells. The initial daily production of the wells ranged from about 4,000,000 to about 16,000,000 cubic feet. The initial rock pressure was 250 pounds in all the wells. The gas in the different wells comes from beds at the same general horizons, but these beds probably do not represent sheet sands. From the lenticularity of sandstone beds which crop out in the region to the east and which are believed to occupy approximately the same horizon as the producing beds in the Pearsons Switch field, it is improbable that the gas obtained in the different wells comes from precisely the same beds. Rather there is a zone which contains interfingering beds of sandstone, any one of which may be gas bearing. In some of the wells there are gas-bearing beds at three distinct horizons. In others there are but two. The heaviest production was stated to come from the lowermost sand. There may be other productive beds close below those which have already been discovered, as none of the wells whose records were obtained were drilled below the third gas-bearing sandstone.

The average depth of the wells is a little more than 800 feet. The highest producing sand is about 400 feet below the top bed of the Pawhuska limestone. The lowest is some 330 feet deeper. The name of the productive bed and its exact relation to oil or gas bearing beds elsewhere in Oklahoma and Kansas could not be established from the information that is at present available. However, it is certain that the gas produced in the Pearsons Switch field comes from a sand that lies above the principal oil-producing beds of the Oklahoma fields to the south and east, and it therefore appears probable that in the underlying beds there are some which will be productive, with the added probability that these lower beds may contain oil as well as gas. At least two wells should be drilled deep enough to test the possibilities of the deep-lying rocks. These wells should be bored to the "Mississippi lime" and should penetrate that formation at least 300 feet. Good locations for these wells are those occupied by well No. 1 in sec. 18 and well No. 1 in sec. 20. The Fort Scott limestone should be encountered about 1,200 feet below the present bottoms of these wells, and the "Mississippi lime" from 200 to 500 feet lower.

The anticlinal structure of the rocks is probably the principal factor that has caused the accumulation of gas at this place. The basis for this statement is the fact that every well in the field is on an anticlinal fold. However, such a statement can never be made without some reserve unless drilling around the edges of the anticline shows that where anticlinal structure is absent there is no appreciable amount of oil or gas. In order to be absolutely certain of the part played by anticlinal folding it will also be necessary to determine the outline of the gas-bearing sand. It appears entirely possible that the folding in the deep-lying rocks is not exactly similar to that at the surface. This is indicated by the fact that the wells that have the largest yield are not the ones which are most favorably located with respect to surface structure. If the gas-containing sands are fairly uniform in texture the largest volume of gas should be concentrated at the highest point of the fold, but well No. 1 in sec. 18 had an initial daily flow of only 3,726,000 cubic feet as opposed to an initial flow of 16,071,000 cubic feet for well No. 1 in sec. 20, notwithstanding the fact that the well in sec. 18 appears to be in the center of the fold and the well in sec. 20 appears to be on its flank. It will probably be possible to prove or disprove this supposition that the subsurface structure may not accord with the surface structure when a little more development work has been done, as excellent records of the formations passed through are being preserved by the company operating in this field, and these records should furnish sufficient data for contouring the surface of one of the gas sands, or of some adjacent bed.

DRY HOLES.

In January, 1917, there were 13 dry holes in the area whose structure is shown on Plate XIII. Their locations are given in the following list. Those which are marked on the map with a query were not seen by the writer and have been located from the township plats on file at the Osage Agency at Pawhuska.

Dry holes in northwestern part of Pawhuska quadrangle, Okla.

Location.				Company.	Elevation of mouth of well (feet).	Record on file.
Quarter.	Section.	T. N.	R. E.			
NE.	13	28	8	(?)	(?)	No.
NE.	13	29	8	(?)	(?)	No.
NW.	22	29	8	American Pipe Line Co.	1,012	Yes.
SW.	23	29	8	Aiken, Fancher & Boggs Drilling Co.	950±3	No.
NW.	25	29	8	Prairie Oil & Gas Co.	(?)	Yes.
NW.	13	29	9	H. H. Douglas (?)	(?)	No.
NW.	15	29	9	Wah-shah-she Oil Co.	889	No.
SW.	16	29	9	American Pipe Line Co.	1,051	Yes.
NW.	22	29	9	German-American Oil & Gas Co. (?)	1,020	No. [a]
NW.	28	29	9	Hazelwood Oil Co. (?)	(?)	No.
NW.	29	29	9	Barnsdall Oil & Gas Co.	827±10	No.
NE.	30	29	9	do.	874	No.
NE.	34	29	9	Indian Territory Illuminating Oil & Gas Co.	1,012	Yes.

[a] Local reports stated that this well had produced some oil, but the truth of these reports could not be proved by the writer.

With the exception of the hole in the NW. ¼ sec. 22, T. 29 N., R. 9 E., and possibly the one that is reported to have been drilled in the NW. ¼ sec. 13, T. 28 N., R. 8 E., none of these failures were well located with respect to anticlinal structure. If the location of the last-mentioned test is correctly shown on the structure map (Pl. XIII), it was drilled very close to the axis of an anticlinal fold which has pronounced dips in three directions. This well was not found by the writer, in spite of a search that consumed over an hour, so it appears at least possible that the location given on the township plats at the Osage Agency is in error, and that the anticline has not been tested.

The most important thing learned from the records of the dry testholes that have been drilled in this area is that the Cherokee shale, or at least the sandstones which in most places make up a considerable part of that formation, seem to be absent from the northern part of the area. The fact that above the horizon of the Cherokee shale there are many heavy beds of sandstone suitable to serve as reservoirs for oil and gas is only slightly less important.

UNPROVED AREA.

The oil and gas possibilities of about 95 per cent of the territory described in this report may be considered unproved. This estimate is based on the supposition that each wildcat test either condemns or proves a quarter of a square mile.

There are three principal factors which must be taken into account in considering the possible oil and gas production of any untested region. First there must be a source of oil and gas—some bed in which these minerals may originate. The principal source of much of the oil and gas that has been found in eastern Kansas and Oklahoma is believed to be the carbonaceous beds of the Cherokee shale. This formation appears to be absent from at least a part of the area here discussed. The fact that oil and gas have been found at comparatively shallow depths in this area shows that the Cherokee shale is not the only source of these minerals, although the comparatively small size of individual wells and pools that obtain their oil from rocks above the horizon of the Cherokee shale in this area indicates that the higher source is far from being as productive as the Cherokee. There is no good reason for assuming that a source capable of supplying a moderate amount of oil and gas does not exist in the Pennsylvanian strata underlying the entire area under discussion, and it is also possible that the Cherokee shale may be fully developed under some parts of the area. This formation is believed to be present east, south, west, northwest, and perhaps north of this area and is the principal oil-bearing formation in many fields.

The second requisite for the presence of accumulations of oil and gas is a bed or succession of beds suitable to act as a reservoir that will retain such accumulations. In the Mid-Continent field large oil and gas pools are invariably in porous beds that are overlain and underlain by shale. Many of the sandstones of the Pennsylvanian series have the proper texture to permit the oil and gas to gather in them, and these sandstones are commonly roofed and floored by heavy beds of shale through which the oil and gas can not pass. This succession of pervious and impervious rocks has been observed in every well drilled in the region, regardless of whether or not oil was found. Accordingly there can be no doubt that requisite reservoir rocks for the accumulation of oil are present.

The third important factor is anticlinal structure. The largest producing fields of Oklahoma are located on anticlines, as are also many of the pools of less importance. However, anticlinal structure does not appear to be absolutely necessary. This is shown by the groups of wells in secs. 17 and 20, T. 29 N., R. 9 E., where the structure appears to be that of an uninterrupted monocline. It is possible that in the sections cited there is anticlinal structure which does not appear at the surface and which may have caused the accumulations of oil and gas, but unless such deep-seated structure is proved to exist it is best to assume that the surface structure is a true reflection of that in depth. A conservative statement concerning the Mid-Continent field is that if all other factors controlling the accumulation of oil and gas are equal, an anticline is by far the most favorable place for their accumulation, and in prospecting an untested region the anticlines should receive the first attention. In the area under consideration there are anticlines which are believed by the writer to be sufficiently pronounced to have an effect upon oil and gas accumulation.

To sum up, this area is probably underlain by a source of oil which if not equal to the Cherokee shale should still furnish quantities of commercial importance; there are in the area rocks in the proper succession and of the proper texture to contain and retain the oil; and the area has anticlinal structure similar to that which has induced oil accumulation in other parts of the Mid-Continent field.

OIL IN PRE-PENNSYLVANIAN ROCKS.

The presence of commercial accumulations of oil in the rocks underlying the Pennsylvanian strata depends upon the same factors that determine its presence in the younger beds, namely, there must be a source in which the oil originates and pervious beds which can contain the oil and which will release it when they are penetrated by the drill. Anticlinal structure is a third factor which is undoubtedly of great importance, although it may not be an absolute necessity for oil accumulation.

The black shales of the Chattanooga formation (Devonian) are believed by the writer to be one of the most probable sources of oil in the pre-Pennsylvanian rocks. These shales contain a large percentage of organic matter, and it is at least possible that temperature and pressure conditions have been such as to convert a portion of this organic matter into oil or gas. A second possible source is the thick body of fossiliferous limestone of Silurian, Ordovician, and Cambrian age which underlies the rocks belonging to the Devonian system. At the time this limestone was formed it undoubtedly contained organic matter, and it seems at least possible that some of this organic matter has since been converted into oil or gas.

There are several sandstones among the pre-Pennsylvanian rocks which are doubtless at least locally suited to serve as reservoirs for oil or gas. The deep well at Caney, Kans. (Pl. XV, p. 76), passed through three beds of sandstone, 11, 22, and 46 feet thick. The lowermost of these sandstones was about 1,000 feet below the top of the Boone limestone ("Mississippi lime").[1] The record of the well bored at Neodesha, Kans. (Pl. XV), which reached a depth of more than 1,300 feet below the top of the Boone limestone, mentions many beds of sandstone, some of them more than 100 feet thick.[2] A well at Iola, Kans. (Pl. XV), reached a horizon almost 1,800 feet below the top of the Boone limestone and passed through many beds of sandstone and of sandy limestone. The heaviest bed of sandstone had a thickness of 52 feet and was encountered 1,045 feet below the top of the Boone limestone.[3] Logs of other wells in southeastern Kansas that have passed below the Boone limestone report heavy beds of sandstone higher in the stratigraphic section than the one mentioned here.

Further evidence of the presence of deep-lying sandstones is found at the outcrops of the older formations in eastern Oklahoma, southwestern Missouri, and northwestern Arkansas. Notable among these formations are the Sylamore sandstone member, which underlies the black shales of the Chattanooga formation and which in places attains a thickness of about 35 feet,[4] and the St. Peter sandstone, of Ordovician age, which in places attains a thickness of more than 100 feet. The Sylamore sandstone is irregular in its distribution and may be absent from this region.

Nothing is known about the anticlinal structure in the pre-Pennsylvanian rocks underlying the area treated in this report. It appears improbable that folding in these older rocks is exactly similar in form or location to the anticlines and synclines that appear at

---

[1] Schrader, F. C., U. S. Geol. Survey Geol. Atlas, Independence folio (No. 159), p. 4, 1908.
[2] Haworth, Erasmus, Kansas Univ. Geol. Survey, vol. 9, pp. 60, 63, 64, 1908.
[3] Idem, pl. 6.
[4] Taff, J. A., U. S. Geol. Survey Geol. Atlas, Tahlequah folio (No. 122), p. 3, 1905.

the surface of the ground. Any folding or faulting that took place before Pennsylvanian time would of course not appear on the present surface. The subsequent arching of the beds that formed the anticlines on the present surface must have affected both Pennsylvanian and pre-Pennsylvanian strata, but as the deformation in the pre-Pennsylvanian beds is believed to have been brought about by a series of stresses many of which preceded the deposition of the Pennsylvanian rocks, it is evident that the resultant deep-seated structure is probably different from that in the overlying beds. However, the folding of the surface beds may furnish some indication of the probable location of deformation in the pre-Pennsylvanian rocks. Observation has shown that in many regions the rocks have yielded along some general lines of weakness to the stresses that have tended to deform them in successive ages, and that folding resulting from movements widely separated in time would nevertheless be to a great extent localized along a comparatively narrow zone. This rule is believed by the writer to apply in northeastern Oklahoma, and it therefore appears probable that where there is a definite zone of folding in the surface beds a similar zone probably exists in the deep-lying rocks, and that wells testing the deep beds should be largely confined to such zones of weakness.

Opponents of deep drilling argue that although several wells have been sunk far below the top of the Boone limestone no oil or gas has been obtained, and furthermore that no showings of oil or gas have been noted at the surface where pre-Pennsylvanian rocks crop out in northeastern Oklahoma, southwestern Missouri, and northwestern Arkansas. However the same arguments could, in times past, have been applied to regions such as northwestern Louisiana and northern Texas, where the presence of oil and gas in tremendous quantity is now established. Furthermore, the deep test wells that have been drilled have not been entirely discouraging, as several of them are reported to have found showings of oil or gas. Perhaps the most authentic of these reports is that concerning the deep well at Caney, Kans. (Pl. XV), in which showings of gas were reported at three distinct horizons, and of oil at two.[1]

The fact that almost no showings of oil appear along the outcrops of the pre-Pennsylvanian rocks in northeastern Oklahoma is slightly discouraging, but it must be borne in mind that only a few hundred feet of the upper part of these older beds are exposed in that region, and that farther east, in Arkansas, and farther south, in Oklahoma, where the lower beds come to the surface, they are in places saturated with asphaltic material, proving that they once contained oil in com-

[1] Schrader, F. C., U. S. Geol. Survey Geol. Atlas, Independence folio (No. 159), p. 4, 1908. Haworth, Erasmus, Kansas Univ. Geol. Survey, vol. 9, p. 66, 1908.

mercial quantities and indicating that they still contain valuable accumulations of oil and gas where erosion has not permitted them to escape. Testing these lower sands, even in the midst of an oil field, is nevertheless "wildcatting."

A good locality for a deep test well is believed by the writer to be anywhere in sec. 18, T. 27 N., R. 8 E. This locality appears to be in a zone of weakness along which lie the folds that are believed to have trapped the oil of the Shamrock, Cushing, Jennings, Cleveland, Boston, and Hominy pools.

RELATIVE VALUE OF THE ANTICLINES FOR OIL AND GAS.

CONSIDERATIONS.

In estimating the value of an anticline for oil and gas production one of the most important considerations is the gathering ground. The oil and gas do not originate in the crest of the anticline, where the accumulation is most generally found, or even on its flanks, unless the anticline is a very large one. They must come from a very considerable area, particularly if the oil sands are comparatively thin, as they are in many oil fields in northeastern Oklahoma. It is believed that the oil and gas were originally disseminated through the rocks in minute quantities, and that all these scattered drops of oil and bubbles of gas have moved through the water-saturated rocks until they reached a point which for some particular reason retarded their progress. The factors that caused this movement are not thoroughly understood, but it is known that the direction of the movement was up the dip of the rocks, and therefore toward the surface of the ground—that is, oil tends to rise, and conversely, it apparently has difficulty in sinking. Accordingly, when it reaches a point such as the crest of an anticline, where it would have to go downward to progress farther, it must stop. It may be safely assumed that the oil will travel straight up the dip of the rocks if the rocks are continuously porous. The gathering ground of any anticline is, then, the ground from which the oil, following this tendency, would ultimately reach the crest of the anticline.

A second factor is the ability of the anticline or other minor structural feature to arrest the progress of the oil and gas. This depends to a large degree upon the "closure" of the fold. Many anticlines do not dip away from some central point on all sides, and it is obvious that there is at least one place on such a fold where the oil or gas may move on through the fold without being arrested by its inability to move downward. It has been found, however, that a very considerable change of dip may be almost as effective in stopping the progress of the migrating oil and gas as an actual reversal of dip, and that these minerals have great difficulty in moving past points where the rocks are approximately level. If, then, the axis of an anticline does not plunge steeply, there is a good chance that the fold will retain some oil, even though there is one direction toward which the beds in it do not dip.

A third factor is the capacity of the anticline. The writer believes that in a small minor fold on a monocline the chances of oil accumulation are also small, although the probability of gas being present is good. This may be explained by the fact that gas is more volatile than oil and will therefore pass more rapidly through the rocks. When the oil and gas begin to migrate, the gas will precede the oil and will fill to their capacity any minor domes and wrinkles. When the slower-moving oil reaches these small folds there is no room for it in the folds, and it accordingly crowds around their edges and passes on.

A fourth factor is the shape of the anticline. A very large flat anticline with a large gathering ground might supply many small wells. A similar anticline with a relatively small gathering ground might give only "shows" of oil, because the oil might be disseminated through the flat beds that form the crest. Oil occupying an anticline rising sharply to a crest or to a central point would tend to be concentrated at that crest or central point, and wells on such an anticline should have a larger daily yield and would yield more oil during their lifetime.

A fifth factor is the development work which has been done. Proof of the presence of oil is always better than theoretical arguments. A small anticline with an oil well on it is a better property than a much more promising-looking fold that has not been tested. There are so many factors any one of which may make structural work on the surface of no avail that there can be no "sure thing" in untested territory, and even beds showing the most evident anticlinal structure may prove dry of oil.

The relation of the structure shown at the surface to that in depth is a factor that is known for only a few of the oil fields of Oklahoma. This relation is difficult even to guess, but it seems probable that certain general rules may be laid down for some sections of Oklahoma when a little more work has been done on the surface and on the structure as shown by the well records. It is important to know the general degree of similarity of the folds shown at the surface and those in the oil sands, both as regards size and outline, also whether the deep-lying anticlines tend to be vertically below those at the surface, and if not, whether or not any broad general rule may be applied concerning the direction in which the deep folds tend to lie from those above them.

There are not enough well records available to make possible any such study of that portion of the Pawhuska quadrangle which is considered in this paper. One interesting divergence was noted, however. In the old shallow gas field in the southwest corner of sec. 16, T. 29 N., R. 9 E., the only two available records indicate that the gas-bearing stratum dips deeply to the southeast. This is almost at right angles to the dip which appears on the surface.

ORDER OF IMPORTANCE OF THE ANTICLINES.

By far the most promising fold in the area under consideration is the Pearsons Switch anticline. It has a broader gathering area than any of the other minor structural features described in this paper; it is a closed fold with a minimum reversed dip of 30 feet down which the oil would have to push to escape; together with the minor domes to the south it is the largest anticline in the area; and the fact that it contains at least gas had been demonstrated in January, 1917, by six shallow gas wells.

Second in importance is the Benchmark anticline. This fold has a broad gathering ground and ample capacity to store a large quantity of oil or gas. The reversal of the regional dip is slight, but even without such a reversal the broad terrace would probably serve to arrest the movement of the oil and cause it to gather in a pool of commercial size. This anticline, like the Pearsons Switch anticline, has already been tested. Several oil and gas wells and two dry holes have been drilled on its flanks, and one oil well, which was not seen by the writer, is shown on the township plats at the Indian office at Pawhuska to be near the anticlinal axis.

The order of importance of the other anticlines in this area is believed by the writer to be as follows: Triangle dome, Drennan anticline, Round Top anticline, Upper Dog Creek anticline, Lower Dog Creek anticline, Ricerock anticline with Limestone Flat terrace, western Lower Buck Creek anticline, Upper Pond Creek dome, Stone House anticline, and the eastern Lower Buck Creek anticline.

LOCALITIES FOR TESTING.

In choosing a locality for drilling on an untested anticline, the shape of the fold is the first consideration. If the fold is a dome the very top is the most favorable point for testing; if it is an elongated anticline some point along or near the axis should be chosen; if it is a terrace, the well should be drilled near the point of greatest change in dip, where the steep dip below the "step" of the terrace meets the flat upper surface.

The shape of the fold is not the only factor to be considered. If there is an appreciable amount of oil or gas in the fold, it will underlie at least several acres, and the well may be drilled a short distance from the point which is structurally the most favorable without affecting the adequacy of the test. An important factor is the accessibility of the locality. If possible, it should be either close to a road or in such a place that a good road may be made to it with little difficulty.

Another important consideration is the relation of the locality to water supply. If possible it should be chosen close to a good supply such as a creek, a good well, or a reservoir, or, if no supply is available when the locality is selected, near a point where a dam may be constructed to impound a sufficient amount of rain water for use in drilling. It should be borne in mind that the distance which the water must be lifted is of more consequence than the distance which it must be carried horizontally, unless the latter is very great, and therefore that it is easier and less expensive to get water to a locality at a low level some distance from the source than to raise it to a locality which is not far removed but which is high above the source.

Finally, unnecessary drilling should be avoided. There is seldom an adequate reason for drilling a well on the exact summit of an anticline if transferring the site a short distance will decrease by 100 or 200 feet the amount of drilling that must be done.

The writer's conception of the best localities for testing the anticlines described in this paper and the probable depth to the Fort Scott limestone at each locality are given below:

Pearsons Switch anticline: Deepen well No. 1 in sec. 18 and No. 1 in sec. 20, T. 27 N., R. 8 E. Fort Scott limestone about 1,100 feet below the lowest horizon which is at present producing gas in these wells.

Round Top anticline: 1,500 feet east of west line and 2,000 feet south of north line of sec. 32, T. 28 N., R. 8 E., in the bottom of small valley tributary to Sand Creek. Depth to Fort Scott limestone about 2,000 feet.

Triangle dome: 2,000 feet west of east line and 200 feet south of north line of sec. 28, T. 28 N., R. 8 E., on hilltop. Depth to Fort Scott limestone about 2,100 feet.

Upper Dog Creek anticline: 2,500 feet west of east line and 600 feet south of north line of sec. 20, T. 28 N., R. 8 E., in bottom of valley of Dog Creek. Depth to Fort Scott limestone about 1,900 feet.

Ricerock anticline: 1,000 feet east of southwest corner of sec. 7, T. 28 N., R. 9 E., on top of low ridge. Depth to Fort Scott limestone about 1,700 feet.

Upper Pond Creek dome: 2,000 feet east of west line and 2,000 feet north of south line of sec. 19, T. 28 N., R. 9 E., in valley. Depth to Fort Scott limestone about 1,600 feet.

Drennan anticline: 1,500 feet south of northwest corner of sec. 32, T. 29 N., R. 8 E., on flat. Depth to Fort Scott limestone about 1,900 feet.

Stone House anticline: 1,000 feet north of southwest corner of sec. 15, T. 29 N., R. 8 E., in valley. Depth to Fort Scott limestone about 1,900 feet.

Lower Dog Creek dome: 2,300 feet south of north line and 900 feet east of west line of sec. 30, T. 29 N., R. 9 E., in bottom of valley of Buck Creek. Depth to Fort Scott limestone about 1,600 feet.

Western Lower Buck Creek anticline: 600 feet west of northeast corner of sec. 32, T. 29 N., R. 9 E., in bottom of valley, on section line. Depth to Fort Scott limestone about 1,400 feet.

Eastern Lower Buck Creek anticline: 1,000 feet west of east line and 200 feet south of north line of sec. 33, T. 29 N., R. 9 E., in bottom of valley. Depth to Fort Scott limestone about 1,400 feet.

Benchmark anticline: 1,500 feet east of west line and 1,500 feet south of north line of sec. 16, T. 29 N., R. 9 E., on long spur. Depth to Fort Scott limestone about 1,500 feet.

The estimated depths to the Fort Scott limestone are based on the assumption that the stratigraphic conditions throughout the district are practically the same as those observed in wells drilled in the northeast corner of the area.