THE HEALDTON OIL FIELD, CARTER COUNTY, OKLAHOMA.

By CARROLL H. WEGEMANN and KENNETH C. HEALD.

INTRODUCTION.

The first well in the Healdton field, the greatest oil field yet discovered in the "Red Beds" area of Oklahoma, was drilled by the Red River Oil Co. (now the Dundee Oil Co.) in August, 1913, on the farm of Wirt Franklin, in the NE. ¼ sec. 8, T. 4 S., R. 3 W. This well is on the southwest side of the pool, and probably had it been drilled a quarter of a mile farther southwest it would have missed the pool entirely. The initial production was not large, being estimated at about 25 barrels a day, but the news of the finding of oil in this area created great excitement. Crowds from Ardmore, 20 miles east of the field, and from Waurika, 25 miles west, as well as from the surrounding country, watched with keen interest the drilling of the second well by the Red River Co., half a mile northwest of No. 1, on land belonging to Mary McClure. This well came in at 300 barrels a day, and during the year after its completion the development of the field was extremely rapid. Some of the later wells were reported to have initial productions of 4,000 to 5,000 barrels a day. A branch railroad was built from Ardmore to the new towns of Wilson and Ringling, situated respectively southeast and south of the field, and a settlement of hastily constructed shacks and tents known as Ragtown grew up in the field itself.

The Magnolia Pipe Line Co. extended a branch from Bowie, Tex., to the Healdton field by way of Waurika, but the output of the field was so great that the line was unable to handle all of it, and operators placed their oil in earthen reservoirs and steel storage tanks. During a thunder storm in the summer of 1914 several of the tanks were struck by lightning and a great quantity of oil was destroyed by fire. Oil in earthen reservoirs deteriorated, losing by evaporation its gasoline and other volatile constituents, and great quantities of crude oil were lost by the washing away of the dikes which formed the reservoirs. The entire losses in the field were enormous, and the depression in the oil market in the autumn of 1914 tended to retard drilling, which has not yet (March, 1915) been actively resumed.

In October and November, 1914, a field party of the United States Geological Survey made an accurate survey of the Healdton pool, and through the courtesy of operators the logs of practically all the wells (about 275) were obtained.

With more than the usual amount of data at hand, it has been possible to contour in great detail the surface of one of the oil sands of the field and thus to determine precisely the nature of the structure on which the accumulation of the oil depends. The structure is much more irregular than is generally conceived, and its irregularities, which are described in this report, probably control the distribution of gas and have much to do with the variations in production of oil in adjacent wells.

LOCATION OF THE FIELD.

The Healdton field (Pl. III) lies on the west border of Carter County about 25 miles north of Red River, which forms the south boundary of the State of Oklahoma. The field may be reached from Waurika, about 25 miles west and a little south of it, on the Chicago, Rock Island & Pacific Railway, or from Ardmore, which lies 20 miles to the east of the field, on the Atchison, Topeka & Santa Fe Railway. From Ardmore a branch railroad runs to Ringling, 5 miles south of the field.

About 12 miles northeast of the Healdton field is the west end of the Arbuckle Mountains, and midway between the mountains and the field is the small Wheeler oil field, opened in 1904. Some 10 miles northwest of the Healdton field are the gas wells near Loco, the first of which was drilled about six months before the Healdton field was discovered. (See fig. 3.)

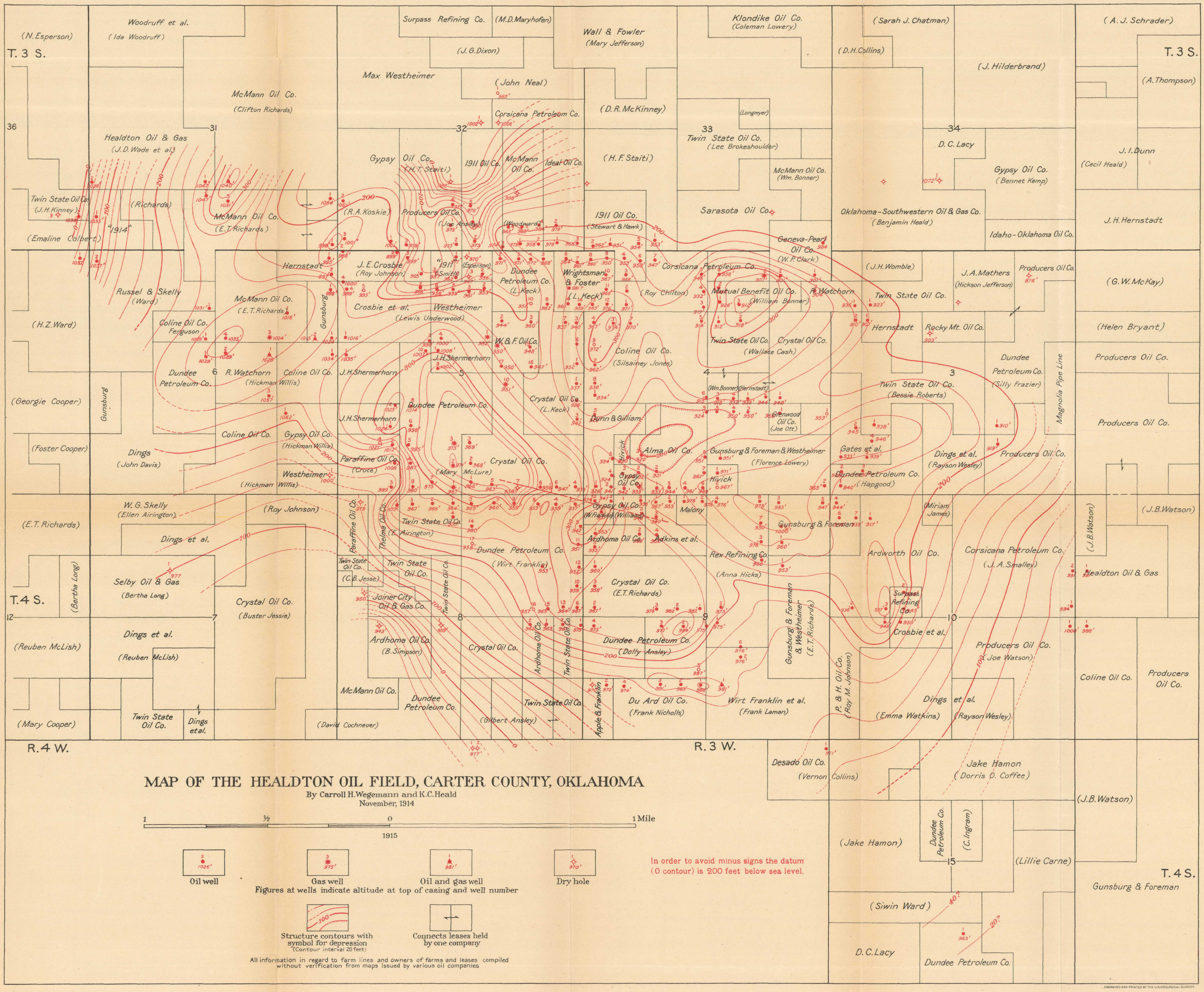
TOPOGRAPHY AND DRAINAGE.

The Healdton field is on the boundary between the belt of sandy timbered country that borders the Arbuckle Mountains in this region and the rolling plains that lie in Oklahoma southwest of the mountains. The relief is not more than 150 feet over the entire field, and rock outcrops are very few.

The area is drained by comparatively small southward-flowing branches of Red River, which have cut their channels but little below the comparatively level surface of the region. The drainage net is simple.

STRATIGRAPHY.

The surface rocks in the Healdton field consist of alternating beds of red and gray shale, brown, white, and red sandstone, and thin beds of conglomerate the pebbles of which are principally quartz. They belong to the series of strata known as the "Red Beds" and are of Permian age. The precise nature of the conditions under which the Permian beds were formed is not clear. To the south, in Texas, they were put down, in part at least, in an ocean, as is shown by the



MAP OF THE HEALDTON OIL FIELD, CARTER COUNTY, OKLAHOMA

By Carroll H. Wegemann and K. C. Heald

November, 1914

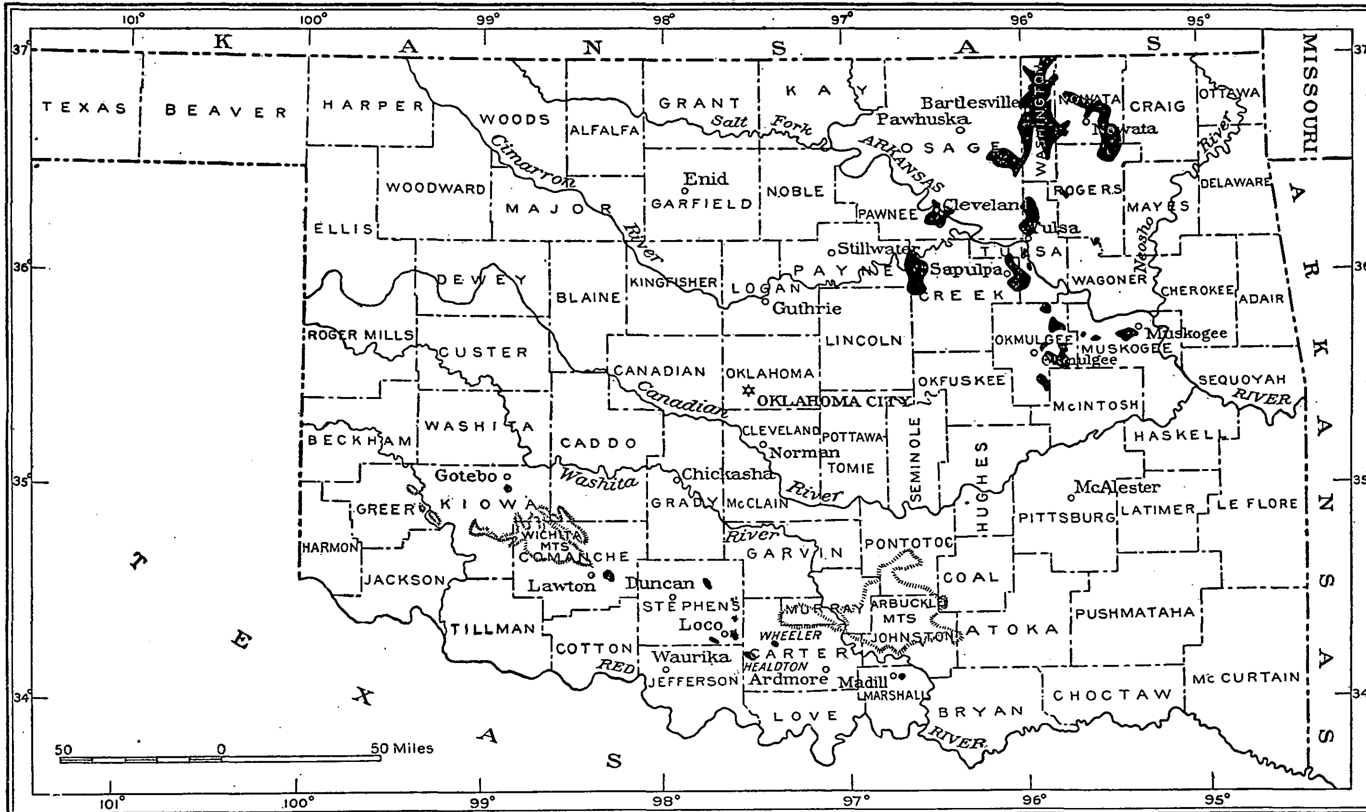


FIGURE 3.—Index map of the oil and gas fields of Oklahoma.

presence of limestones which bear marine shells; but farther north, in the area under discussion, which lay nearer to the old shore line, the conditions of sedimentation appear to have been rather fluviatile or estuarine. The beds are at least in part of fresh-water origin. The bones of animals that were probably land forms are found among them, and plant remains occur at certain localities.

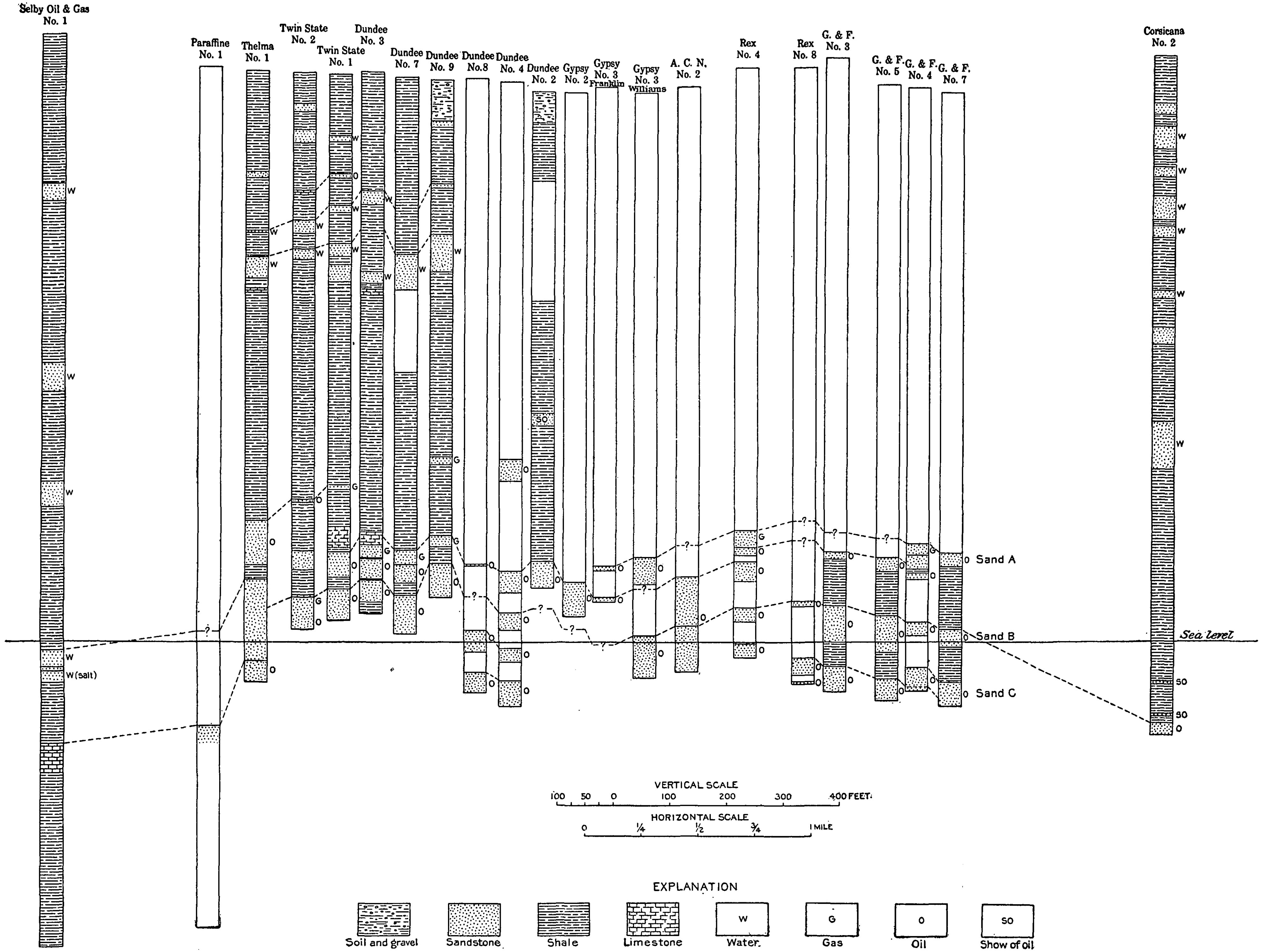
Some of the sandstone beds are very irregular in thickness and are replaced laterally by shale, but others, such as the sandstone that forms the escarpment in the Duncan gas field, 20 miles north of Healdton, can be traced for 50 to 75 miles, showing that they must have been put down under conditions which allowed considerable regularity of deposition. However, although certain groups of sandy beds persist over great areas, the individual beds of sandstone that compose the groups are in themselves irregular. The broad extent of such deposits does not preclude the possibility of their deposition by rivers.

The origin of the red color of certain of the Permian beds is a question that has been much discussed. It seems probable that the red color of the beds does not necessarily imply aridity of climate during their deposition. That the beds were red when originally deposited is presumably to be conceded, although it must be admitted that in certain beds the red color has been changed to blue or bluish gray, and vice versa. At the present day red soils are formed as a rule in warm, moist climates, where vegetation is abundant and surface weathering deep, and it seems reasonable to suppose that similar conditions of climate and weathering prevailed at the time of the formation of the "Red Beds," at least in the region from which the sediments were derived. If, however, vegetation had been abundant in the waters in which the red sediments were deposited, it is probable that the carbonaceous matter would have acted as a deoxidizing agent, changing the color of the sediments with which it was mingled from red to blue. The whole problem of the deposition of the "Red Beds" is not well understood.

The red color of the Permian extends to depths of 200 to 300 feet below the surface on the Healdton dome, but, as is abundantly proved by the logs of the wells, the lower limit of the red color is by no means at a constant horizon. Shale beds which are in one well blue are in another red, and vice versa, the color changing from place to place.

How many feet of Permian beds have been removed by erosion from this area can only be surmised. In the present work the general relations of the strata at Healdton and those in the Loco, Duncan, and Lawton fields have been determined with a fair degree of certainty, and if, as stated by Taff,[1] the highest peaks of the Wichita Mountains

[1] Taff, J. A., Preliminary report on the geology of the Arbuckle and Wichita mountains, in Indian Territory and Oklahoma: U. S. Geol. Survey Prof. Paper 31, pp. 74-75, 1904.



LOGS OF WELLS ALONG NORTH LINE OF SECS. 8 AND 9, T. 4 S., R. 3 W., HEALDTON OIL FIELD, OKLAHOMA.

were in all probability never covered by the Permian sea, there must have been less than 1,500 feet of Permian beds removed by erosion in the Lawton area. The rocks at the surface in the productive area at Lawton are probably about 500 feet stratigraphically above those at the surface in the Healdton field. It may be inferred, therefore, that from 1,500 to 2,000 feet of Permian beds have been removed by erosion from the central part of the Healdton dome, and as the plain on the crest of the Arbuckle Mountains, which was formed in pre-Cretaceous time, is only 400 feet higher than the surface at Healdton, it is evident that the greater part of the erosion of the Permian was accomplished prior to the Cretaceous period. As is shown in what follows, the Permian probably extends to a depth of 800 or 900 feet below the surface in the Healdton field, so that the thickness of the formation as originally deposited was probably about 2,500 feet.

As exposed along the Arbuckle Mountains, the contact of the Permian with the underlying beds is unconformable, the flat-lying Permian strata overlapping the edges of the steeply dipping Ordovician, Devonian, and Carboniferous rocks.[1]

Similar unconformable relations prevail along the Wichita Mountains, and there is evidence that the older rocks were rather deeply trenched by erosion before the Permian was deposited over them. The unconformity appears to be comparatively local in extent and to owe its origin to the Wichita-Arbuckle uplift, inasmuch as it does not appear in Clay County, Tex., where the contact of the Permian and the underlying Pennsylvanian is exposed. In the Texas region the Cisco, which is the uppermost formation of the Pennsylvanian, is, as far as appearances go, conformable with the Wichita, the lowest formation of the Permian, and it is, in fact, difficult to recognize the boundary between the two formations.[2] In the region between Clay County and the Wichita-Arbuckle uplift the base of the Permian is nowhere exposed.

In the Healdton field, which is about 12 miles distant from the Arbuckle Mountains, the well logs afford considerable evidence that the unconformity so conspicuous along the mountains is present. Limestone is practically absent from the first 800 or 900 feet of strata below the surface, but at greater depth in certain wells thick beds of limestone are encountered. (See Pl. IV.) The sandstone beds in the non limestone-bearing series can be correlated from well to well throughout the field by making due allowance for errors in recording the strata passed through in drilling. No break or unconformity in the series is apparent. Where, however, thick beds of limestone are encountered they appear to be at different horizons in different wells and bear no definite relation to the sandstone beds,

[1] Taff, J. A., op. cit., p. 72.

[2] Gordon, C. H., Geology and underground waters of the Wichita region, north-central Texas: U. S. Geol. Survey Water-Supply Paper 317, p. 19, 1913.

as if separated from them by unconformity. Under these conditions it appears reasonable to assume that the shale and sandstone beds, predominantly red near the surface and gray or blue at depth, are of one age, the Permian, and that the thick limestone beds below, which alternate with light or dark gray shales and which seem to be separated from the overlying series by an unconformity, are older and presumably of Pennsylvanian age. The principal oil and gas bearing beds are, according to the above classification, near the base of the Permian.

A tentative correlation between the strata of the Healdton and Loco fields seems to show that the gas-bearing sands at Loco are several hundred feet stratigraphically above the oil sands at Healdton. The facts on which this correlation is based are as follows: A little east of the center of sec. 21, T. 4 S., R. 3 W., is an outcrop of asphaltic sandstone similar in character to a rock which is exposed at numerous places in the Loco field, particularly in sec. 25, T. 3 S., R. 5 W., where it was at one time mined. The probable equivalent of the sandstone in sec. 25 is encountered at a depth of 40 feet in well No. 4 of the Oklahoma Diamond Oil & Gas Co., drilled in the SE. ¼ sec. 10, T. 3 S., R. 5 W. A comparison of the log of this well with that of well No. 1, drilled by the Red River Oil Co. on the Clydie Ingram farm, a little over half a mile west of the outcrop of asphaltic sandstone in sec. 21, T. 4 S., R. 3 W., shows considerable similarity, and it therefore appears possible that the asphaltic sandstone in sec. 21, T. 4 S., R. 3 W., represents the same bed that is exposed in the Loco field. This sandstone seems to have been encountered at a depth of 12 feet in the Clydie Ingram well.

The Clydie Ingram well is a dry hole, almost 2 miles southwest of the productive area at Healdton, and it is impossible to make accurate correlations between it and the Healdton wells. It seems probable, however, from a comparison of the logs, the known dip of the rocks from the Healdton dome toward the well in sec. 21 being taken into account, that the probable equivalent of one of the gas-bearing strata in the Loco field which was encountered in the Ingram well at 670 feet lies within 100 or 200 feet of the surface on the crest of the Healdton fold.

A general correlation of the beds exposed in the Healdton field with those appearing at the surface near Loco and also in the Duncan and Lawton fields may be made on the basis of a series of sandstones that constitute the surface rocks in the sandy wooded area northeast of the Healdton field. The same beds are found southwest of the field, where also they are timber covered. They appear to be the same as the sandstone beds that constitute the surface rocks from Loco north to the grahamite mines in sec. 6, T. 2 S., R. 4 W., and form the timbered ridge which runs from the vicinity of the grahamite mines northwestward to a point 4 miles southeast of the Duncan gas wells. It appears probable that the sandstone hills that lie just east of the Lawton oil and gas field are formed by this same sandstone, inasmuch as the next higher ridge-forming sandstone in the Lawton region is the same as the sandstone which forms the escarpment or rim rock of the Duncan gas field and which is the first prominent bed above the timbered sandstone series of the grahamite mines.

Except for a few plant remains the Permian beds in the Healdton field are unfossiliferous. Two small collections of leaves were obtained. They have been examined by David White, and his descriptions are given below.

SE. ¼ SW. ¼ sec. 4, T. 4 S., R. 3 W. Surface fragment of ferruginous sandstone containing plant remains. The fragment is filled with miscellaneous drifted and waterworn plant vestiges, many of which are small fragments belonging perhaps to the genus Walchia. Obscure remains of seeds are also present. This rock does not appear to contain conclusive evidence as to its age, though it is probably Paleozoic.

A number of small fragments obtained by breaking up a piece of reddish sandstone, rather coarse grained, contain drifted and somewhat waterworn bits of vegetation. The plant débris consists of very small pieces and is mostly so macerated or abraded as to render specific identification impossible.

The material includes fragments of a lobed pinnule which, from its form and nervation, probably belongs to Callipteris, a distinctly Permian genus. Several fragments of gymnospermous twigs apparently represent a species of Walchia, nearly related to if not identical with *Walchia gracilis* Daws. A very small fernlike fragment, with decurrent lamina, may be either Callipteris or Pecopteris. A peculiar fragment of a scale probably belongs to a fructification found in the Permian of the Southwest. It is very closely related to Noeggerathia. Two specimens containing portions of neuropteroid pinnules are comparable to *Neuropteris gleichenioides*. Portions of two seeds are recognized, one of them being probably referable to the genus Cardiocarpon.

There is scarcely room for doubt as to the Paleozoic age of the sandstone which contains this material, and, notwithstanding the extremely fragmentary character of the débris and the very small number of specimens, I do not hesitate to regard the beds as Paleozóic. The specific evidence indicates that the sandstone is probably Permian.

Two other fragments of sandstone accompany the collection just described. The larger fragment is strewn with comminuted plant débris, none of which is generically determinable, although it is probable that a number of megaspores are present. The small fragment contains a seed of the type referred to the genus Walchia. This seed is evidence of the Permian or latest Pennsylvanian age of the bed from which the specimens were obtained.

Fragments of sandstone the grains of which are cemented with chalcedony were seen at several places on the northwest flank of the Healdton dome. This sandstone resembles in every respect certain beds that are found in the Trinity sand, of Cretaceous age, where that formation is exposed along Red River, about 30 miles south of the Healdton field. Nowhere in Healdton was this sandstone noted in place, but about halfway between Hewitt and

Ardmore numerous blocks of it were found on a wooded knoll just north of the road. The blocks are only 4 or 5 inches in thickness and appear to be practically in place. The underlying shale is oxidized for a depth of about 2 feet, being rusty brown in color. It is possible that this sandstone is in reality of Cretaceous age and is the last remnant of a comparatively thin sheet of Cretaceous beds which were at one time spread over this country.

It is believed that prior to the deposition of the Cretaceous strata the land areas were reduced by erosion almost to a plain, which is now represented by the flat surface forming the crest of the Arbuckle Mountains. The sandstone outcrop on the Hewitt-Ardmore road, above mentioned, is about 200 feet below this plain on the Arbuckle Mountains, so that if these beds are in reality Cretaceous the plain must have been somewhat irregular in order to allow their deposition at a level considerably lower than that of the mountain area. The supposition that the beds are Cretaceous is supported only by lithologic similarity, which, however, in a rock of so peculiar a character should have considerable weight.

GEOLOGIC HISTORY.

As is evident from the nature of the Paleozoic rocks exposed in the Arbuckle Mountain uplift, conditions of sedimentation were almost continuous from the Cambrian to the close of the Mississippian. Slight oscillations of the sea floor probably took place, but were not of sufficient magnitude to produce any pronounced unconformity. At the close of Mississippian time an uplift of the mountain mass now represented by the Arbuckle Mountains occurred and a great lens of conglomerate of Pennsylvanian age, known as the Franks conglomerate, was laid down. Marine conditions were reestablished and continued during Pennsylvanian time, at the close of which the mountains were again uplifted and their surface was eroded into deep valleys. Once more the land subsided and was submerged, and the Permian deposits were laid down on this irregular surface.

At the close of the Permian epoch the whole region was uplifted with comparatively little folding, and apparently it remained a land area through Triassic and Jurassic time, the surface being reduced by erosion to a low-lying, comparatively level plain in which hard and soft rocks alike were removed and brought to one general level. At the beginning of the Cretaceous period this broad flat plain was tilted toward the southeast and the Cretaceous sea advanced upon it, spreading its deposits of sand, shale, and limestone over what had formerly been land. As the southeastern part of the plain subsided the northwestern part of it rose, and when conditions of stability were restored and erosion continued to act upon that part of the surface which remained above the ocean, the softer rocks of the ancient plain were reduced to lower levels, leaving the harder rocks, such as those that form the Arbuckle uplift, rising above the newly formed surface and preserving in their flat summits the former base-level. Erosion continued until a new plain was formed, and this plain is the notable feature of the present physiography of the greater part of Oklahoma. Over the surface of this plain rivers deposited thin sheets of gravel, and it is stated by Taff[1] that these gravel deposits, which lie in terraces along the courses of the present rivers, may be traced southeastward into the Tertiary area, where they merge with the Tertiary gravels of the Coastal Plain, showing that the gravel deposits and the ancient plain on which they were formed are probably of Tertiary age. The correlation of the gravel deposit of the plain with those of the coastal sediments may, however, be open to question, and the formation of the plain may be more recent than Tertiary. Since the formation of this plain a slight uplift of the region has occurred, and now the rivers are once more cutting their valleys below the plain which they formerly made. This cycle of erosion has not progressed far, and the new base-level that is slowly being formed is represented only by the flood plains of the larger streams.

INFORMATION AFFORDED BY WELL LOGS AND METHODS OF FIELD WORK.

In an oil field like that of Healdton, in which exposures of rock are very few, the outline of the structure must be determined in large measure from the data afforded by the logs of the wells drilled in the field. A clear appreciation of the nature of the data afforded by well logs is necessary in order to understand the degree of accuracy of the statements which follow and of the structure as outlined on the accompanying map.

In deep wells depths as usually measured are, because of the stretching of the drilling cable, accurate only within 5 or 6 feet. The change from shale to sandstone is not necessarily abrupt, and the sandstone may not be recognized until it has been penetrated for several feet. Very fine grained sandstone is easily mistaken for shale by one who is not accustomed to distinguish between the two, and certain drillers habitually call fine-grained sandstone shale or slate. Hard sandstone may be referred to as "lime," and limestone, if it is oil bearing, is sometimes mistaken for sandstone. Alternating beds of sandstone and shale may be regarded as unbroken sandstone. Certain drillers note only those sandstones that carry water, oil, or gas, and, as a consequence, the thicknesses of sandstone beds are often underestimated. In these circumstances

[1] Taff, J. A., op. cit., p. 17.

accurate correlations between the strata recorded in the logs of adjacent wells are difficult, and sometimes impossible, but by a careful comparison of all the logs available in a given field, it is usually possible to determine what beds are continuous over the area and to decide which of the records are inaccurate. Where exact correlation between wells is impossible, the geologist must rely on his judgment in representing the form of structure that is most likely to exist, and his results are of course subject to error.

In the field work the locations and elevations of all wells in the field were determined by means of a plane table and telescopic alidade.

INTERPRETATION OF STRUCTURE CONTOURS.

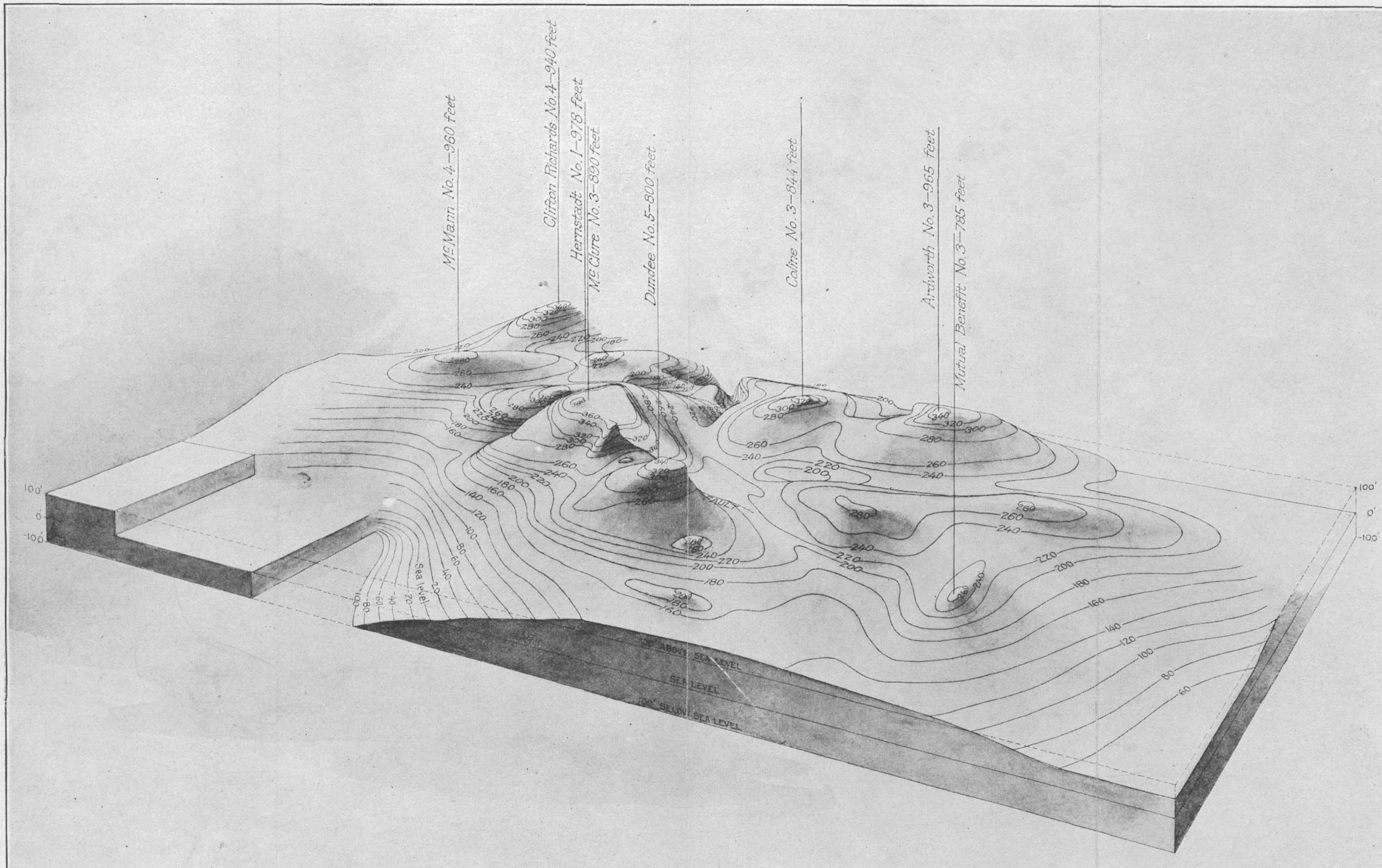
The structure contours given on Plate III are drawn on the surface of the first main oil sand below the gas sand (B, Pl. IV) and represent the shape of the folded surface of that bed (see also Pl. V). Every point along any one line is at the same elevation above or below sea level, the lines being drawn at intervals of 20 feet. To one unfamiliar with the interpretation of contours the following somewhat fanciful conception may be of assistance:

Were it possible to remove all the overlying strata and to walk about on the surface of the oil sand, the course followed by one who endeavored to walk always at an elevation of 200 feet above the sea, never stepping up or down, would be that indicated by the 200-foot contour on the map. When the pedestrian came to a knoll or jutting point, he would be compelled, if he did not wish to ascend, to walk around its side. When he crossed the valley which lay between this knoll and the next he would be compelled, if he did not wish to descend, to walk up the valley to a point where its floor was level with that of the hillside which he had just left. In other words, his course were it represented by a line, would outline the form of the hills and valleys, or their contour.

A series of contour lines drawn at regular intervals above sea level reveals very clearly, to one accustomed to reading contours, the form of the surface which they represent. On the map (Pl. III) the surface indicated by the contour lines is that of oil sand B of the columnar sections. To calculate the approximate depth to this sand at any point in the field it is only necessary to obtain the elevation above sea level of the land surface at that point and to subtract from it the elevation of sand B at the same point as shown on the map.

STRUCTURE.

The accumulation of oil at Healdton is situated on an irregular structural dome or anticline about 4½ miles in length by 2 miles in breadth, the long axis trending N. 62° W. (See Pls. III and V.)



STEREOGRAM OF THE HEALDTON OIL FIELD, OKLAHOMA.

The presence of the dome is not indicated by the topography. Superimposed on the fold are twelve or thirteen minor folds, the long axes of which appear to trend in general at right angles to the trend of the major fold. In the east half of the dome there are among the minor folds at least two oval depressions, which may be considered to be the reverse of the minor dome structures.

The extreme difference of elevation in the main dome, indicated by the altitude of the oil sands on its flanks and on the highest of the minor domes, amounts to about 400 feet, but the height of the entire dome, could it be measured at a greater distance from its central part, is probably considerably more than this. The amount of dip in different parts of the field varies greatly, ranging from 100 to 400 feet in a mile.

Near the corner of secs. 4, 5, 8, and 9, T. 4 S., R. 3 W., a fault trending in general parallel to the long axis of the major dome appears to be present. Its downthrow is to the north. It is possible that this structure may be an abrupt fold rather than a fault, but from the relations of the strata recorded in wells on both sides of it, as well as from the presence of the dry hole in the SE. $\frac{1}{4}$ SW. $\frac{1}{4}$ SE. $\frac{1}{4}$ sec. 5, the presence of a true fault is regarded as very probable. The abrupt fold shown in the south-central part of sec. 32 may be a fault rather than a fold and this probability is strengthened by the presence of two dry holes in the NW. $\frac{1}{4}$ NE. $\frac{1}{4}$ sec. 5.

As has already been stated, the Healdton pool lies about 12 miles southwest of the west end of the Arbuckle Mountain uplift. At a distance of 65 miles N. 72° W. from the Arbuckle Mountains lies the Wichita Mountain uplift, which is believed to be of the same age. Between these two uplifts the Permian beds are bent into a broad, low arch which is outlined on its north side by an escarpment of sandstone. This escarpment may be traced from a point north of Foster post office, which is northwest of the Arbuckle Mountains, to the Duncan gas field, thence north of the town of Duncan in a northwesterly direction to the north flank of the Wichita Mountains. The position of the south limb of the low arch between the two mountain uplifts has never been determined, as the rock exposures in the broad plains of this region are very few.

About 10 miles northwest of the Healdton dome is the Loco gas field, and 15 miles north and a little west of Loco is the gas field known as the Duncan field, which lies 10 miles northeast of the town of Duncan. (See fig. 3.) The three fields lie along a curve which appears to encircle the west end of the Arbuckle Mountains, forming, so to speak, a cross fold to the low arch which lies between the Arbuckle and Wichita uplifts. It is not meant to imply that the Healdton, Loco, and Duncan fields are situated on one long anticline. They are in fact three separate domes, but they lie in such a relation to one another as to suggest that they are more intimately connected in origin with the Arbuckle uplift than with the Wichita. The Duncan field lies north of the low arch between the two mountain uplifts, and the Loco and Healdton fields lie south of it.

Midway between the Healdton field and the Arbuckle Mountains is the dome or anticline on which is situated the Wheeler oil field, the axis of which appears to parallel that of the Healdton dome.[1] About 30 miles west and 8 miles south of the Healdton dome is an anticline exposed in the east bank of Red River, about 6 miles southwest of Waurika.[2] This structure is in alignment with the Devol anticline mapped and described by Munn [3] in the Grandfield district, farther west. The axis of this fold lies about 30 miles south of the Wichita Mountains and is in general parallel to the axis of that uplift. South of the line of the Devol anticline and the anticline which lies southwest of Waurika are the Burkburnett and Petrolia oil and gas fields, which are situated on domal or anticlinal structures.

It is apparent, therefore, on considering the structure of this general region as a whole, that the Permian beds have been thrown into a series of waves or undulations such as might have been caused by stresses acting between the rigid mass of the Arbuckle and Wichita mountains and the strata of the plains region. That subsequent stresses have acted in directions oblique or at right angles to those which produced the major folds is indicated by the relations of the axes of minor domes, such as those which occur in the Healdton field, to the axes of the larger structures on which they are superimposed. It is possible that the time of the formation of the folds that are now occupied by oil and gas pools was coincident with the uplift of the region which followed the formation of the supposed Tertiary plain. (See p. 21.) In Cotton County, southwest of the Healdton field, the adjustment of the minor streams to folds is very exact, and it is probable that the time of folding has been comparatively recent.[4]

OCCURRENCE OF OIL AND GAS.

Oil and gas in the Healdton field are found in many sandstone strata of the "Red Beds," but the principal deposits from which they are obtained lie in three or more sandstone beds which form, together with the interbedded shale, an oil-bearing zone about 250 feet in thickness. The top of this zone is found from 600 to 950 feet below the surface. In general the highest of the sandstone beds (A, Pl. IV) is the gas-bearing sand, although gas occurs in considerable amount

[1] Snider, L. C., Petroleum and natural gas in Oklahoma, p. 144, 1913.

[2] Wegemann, C. H., Anticlinal structure in parts of Cotton and Jefferson counties, Okla.: U. S. Geol. Survey Bull. 602, pl. 5, 1915.

[3] Munn, M. J., Reconnaissance of the Grandfield district, Okla.: U. S. Geol. Survey Bull. 547, 1914.

[4] Wegemann, C. H., op. cit., p. 34.

in the lower sands, and the gas sand in certain wells produces a considerable amount of oil. From this sand also, on the flanks of the fold, below the oil and gas horizon, salt water is reported. The next sand below the gas sand (B, Pl. IV) is that on the surface of which the structure contours of Plate III are drawn. The oil in this sand is often, though not invariably, lighter than that of the lowest sand (C, Pl. IV). This lowest oil sand is not reached in all the wells but appears to be as rich in oil as sand B. Certain wells that have been drilled to considerable depths have encountered below this sand thick beds of limestone which alternate with dark shale, and which are probably of Pennsylvanian age.

Oil, when found in the beds above the principal oil and gas zone, is of high specific gravity, containing considerable amounts of asphalt. Salt water is rarely, if ever, recorded from the strata above the principal oil-bearing zone, but it is found in the strata of that zone on the flanks of the fold below the oil pool, and in some wells—as, for example, Woodward No. 4 of the 1911 Oil Co., in sec. 32, T. 3 S., R. 3 W.—it is reported from strata below those which carry the oil.

The lower limit of the oil pool is by no means at the same elevation with reference to sea level on all sides of the dome. In the SE. $\frac{1}{4}$ SE. $\frac{1}{4}$ sec. 36, T. 3 S., R. 4 W., oil is encountered at sea level, and in the SE. $\frac{1}{4}$ SE. $\frac{1}{4}$ sec. 6, T. 4 S., R. 3 W., the oil-bearing zone was found barren at 190 feet above sea level. In the shallowest part of the Healdton pool, on the crest of the dome, oil is obtained at 380 feet above sea level, or 600 feet below the surface. The wells which show the greatest quantity of gas are, as a rule, situated on the crests of the minor domes (Pl. III). This does not appear to be true of the wells just northeast of the center of sec. 5, as shown on Plate III. It should be stated, however, that logs of the Wrightsman and Foster wells, just northeast of the wells mentioned, were not obtained, so that the details of the structure in this particular area are not known and the mapping may be somewhat inaccurate.

The general character and fractional composition of the Healdton crude oils are indicated in the accompanying tables, which are extracted from a report on "Conditions in the Healdton oil field," submitted by Jos. E. Davies, Commissioner of Corporations, to the Secretary of the Department of Commerce, March 15, and published by the department under that date. According to this report the Healdton oils range in gravity from 29.27° to 33.93° Baumé. The variation does not appear to have any direct relation to the structure. Oils of different gravity that are obtained from adjacent wells come, as a rule, from different sands. In general, the oil in the Healdton pool is darker in color than oil of the same gravity in other fields.

The analyses made by G. Y. Williams and C. K. Francis show gasoline, and those made by M. C. Whitaker show naphtha.

The two samples examined by Mr. Whitaker for the Bureau of Mines (see pp. 103–107 of the report cited) were subjected to fractional analyses by four methods, with corresponding variation in the results, as shown in the second table. These samples were taken at the localities indicated below:

1470. Lease, Silsanny Jones Allot—Dept. lease: Sec. 4, T. 4 S., R. 3 W., Carter County, Okla.; owner, Coline Oil Co., Ardmore, Okla.; well No. 1. Sampled by Irving C. Allen, May 23, 1914.

1464. Million & Thomas farm: Sec. 5, T. 4 S., R. 3 W., Carter County, Okla.; owner, Crystal Oil Co., Ardmore, Okla.; well No. 3 at extreme southeast corner of S. ½ SE. ¼. Sampled by Irving C. Allen, May 23, 1914.

Concerning these results Mr. Whitaker adds:

A comparison of the results obtained shows a wide discrepancy in amounts of the various products obtained by the several methods of analysis, and this difference is especially great in the case of the "naphtha." On sample No. 1464 about one and three-fourths times as much "naphtha" is obtained by the Engler method as by the Regnault method, whereas in sample No. 1470 the "naphtha" obtained by the Nawratil method is less than one-third that obtained by the Engler method. The variations shown in the analysis of your oils by the different methods are directly in accord with our previous experience, extending over a number of years. We do not consider any of the existing methods as dependable. It is doubtful if any of these methods will give results even approximating those attained in practical distillation.

Information as to laboratory barrel-still tests, as to sulphur content, and as to products, etc., will be found in the report of the Commissioner of Corporations.

The largest production from single wells, amounting in one well to 5,700 barrels a day, is obtained on the minor dome in the N. ½ sec. 6, T. 4 S., R. 3 W. This dome is not the highest one in the field, but it appears to be one of the most regular, and the question may here arise as to whether the more intense folding that has taken place in certain parts of the Healdton dome has tended to close the pores between the sand grains, making the sands less porous and reducing their capacity to hold oil. The two dry holes in the NW. ¼ NE. ¼ sec. 5, T. 4 S., R. 3 W., may perhaps be accounted for in this manner or on the possibility of a fault existing at this locality. (See p. 23.) The dry hole in the SW. ¼ SE. ¼ sec. 5 is probably due to the presence of the fault indicated on Plate III. A fault of this nature may interrupt an oil-bearing bed, causing an accumulation on one side of the fault, whereas the beds on the opposite side are left barren of oil.

SOURCE OF THE OIL.

The oil in the Healdton field has probably been derived from the Pennsylvanian rocks underlying the Permian, near the base of which the oil is found. There is, however, no direct proof of this assump-

Laboratory distilling flask analyses made to determine the refining qualities of Healdton crude oil.[a]

Test made by—	Where test was made.	Date.	Quantity tested.	Gravity of crude oil.	Sulphur content of crude oil by weight.	Paraffin content by weight.	Asphalt content by weight.	Product.															
								Naphtha.		Gasoline.		Kerosene.		Total naphtha, gasoline, and kerosene.	Gas oil.		Lubricating oils.		Residuum.		Coke.	Loss.	Total.
								Gravity.	Per cent.	Gravity.	Per cent.	Gravity.	Per cent.		Gravity.	Per cent.	Gravity.	Per cent.	Gravity.	Per cent.			
G. Y. Williams:		1914.	*C. c.*[b]	*° Baumé.*	*Per cent.*	*Per cent.*	*Per cent.*	*° Baumé.*		*° Baumé.*		*° Baumé.*		*Per cent.*	*° Baumé.*		*° Baumé.*		*° Baumé.*		*Per ct.*	*Per ct.*	*Per ct.*
No. 1	Norman, Okla.	Apr. 12	100	31.80	0.66	0.67	0.71			62.4	12.0	42.0	35.0	47.0					32.5	48.0	5.0	(c)	100
No. 2	do	do	100	31.80	.55	.67	.70			62.4	11.7	42.0	34.6	46.3					32.5	48.2	5.5	(c)	100
No. 3	Oklahoma City, Okla.	May 1	100		.72					62.4	12.9	42.0	34.0	46.9					32.5	47.0	6.1	(c)	100
No. 4	do	do	500		.73					62.4	11.6	42.0	34.5	46.1					20.4	53.9		(d)	100
C. K. Francis:																							
No. 1	Stillwater, Okla.	Mar. 23	300–500	33.70			(e)			61.6	14.5	f 41.9	40.8	55.3			35.0	7.0	20.2	37.2		0.5	100
No. 2	do	do	300–500	30.40			(e)			54.6	10.3	f 39.1	32.0	42.3			34.2	16.0	20.6	41.7		.0	100
L. Kirschbraun	Chicago, Ill.	Apr. 18		31.80						64.9	15.0	42.2	25.0	40.0	32.7	15.0	26.4	12.5	15.2	32.5		(d)	100
M. C. Whitaker:																							
Sample 1470—																							
No. 1 g	New York, N. Y.	June 5	100	30.30				57.5	9.3			41.4	32.7	42.0			28.0	52.9			3.5	1.6	100
No. 2 h	do	do	100	30.30				57.0	5.2			43.6	32.3	37.5			29.1	56.0			4.8	1.7	100
No. 3 i	do	do	100	30.30				57.7	3.7			43.7	34.8	38.5			29.8	56.0			3.9	1.6	100
No. 4 j	do	do	100	30.30				55.3	2.8			44.2	34.0	36.8			29.1	57.5			4.0	1.7	100
Sample 1464—																							
No. 1 g	do	do	100	32.75				60.2	16.7			40.5	28.3	45.0			27.7	50.5			2.6	1.9	100
No. 2 h	do	do	100	32.75				62.7	11.5			43.3	30.8	42.3			28.7	53.5			3.1	1.1	100
No. 3 i	do	do	100	32.75				62.1	9.5			43.3	31.2	40.7			29.2	53.5			2.7	3.1	100
No. 4 j	do	do	100	32.75				59.9	11.1			43.2	30.2	41.3			30.8	52.5			4.8	1.4	100
Bureau of Mines, average of 20 tests.	Pittsburgh, Pa.			31.57	.70	(k)	(e)			57.7	7.0	42.2	30.7	37.7			29.9	29.4		32.9		(d)	100

[a] All results are based on the percentages by volume.
[b] 100 c. c. equals 3.38 fluid ounces.
[c] Loss included in coke.
[d] Loss included in residuum.
[e] Presence of asphalt stated in testimony, but amount not given.
[f] Weighted average. Original table shows kerosene fraction, 44.8 gravity, 27.5 per cent; illuminating oils, 36.0 gravity, 13.3 per cent for test No. 1. Kerosene fraction, 40.0 gravity, 25.0 per cent; illuminating oils, 36.1 gravity, 7.0 per cent for test No. 2.
[g] Engler method.
[h] Ubbelohde method.
[i] Regnault method.
[j] Nawratil method.
[k] From the lubricating distillates from 8.5 to 1.5 per cent of paraffin wax can be obtained. (Testimony of I. C. Allen at Corporation Commission hearing of June 9, 1914.)

Temperature (° C.).	Engler method.				Ubbelohde method.				Regnault method.				Nawratil method.			
	Sample 1470.		Sample 1464.		Sample 1470.		Sample 1464.		Sample 1470.		Sample 1464.		Sample 1470.		Sample 1464.	
	Volume (per cent).	Specific gravity at 60° F.	Volume (per cent).	Specific gravity at 60° F.	Volume (per cent).	Specific gravity at 60° F.	Volume (per cent).	Specific gravity at 60° F.	Volume (per cent).	Specific gravity at 60° F.	Volume (per cent).	Specific gravity at 60° F.	Volume (per cent).	Specific gravity at 60° F.	Volume (per cent.)	Specific gravity at 60° F.
Below 150	9.3	0.7467	16.7	0.7361	5.2	0.7486	11.5	0.7265	3.7	0.7458	9.5	0.7289	2.8	0.7556	11.1	0.7372
150 to 200	9.0	.7815	8.2	.7931	10.2	.7750	10.7	.7747	10.4	.7726	9.6	.7745	11.5	.7750	8.6	.7774
200 to 250	11.0	.8173	9.0	.8206	11.0	.8092	9.7	.8130	12.0	.8053	10.3	.8083	11.3	.8049	10.5	.8059
250 to 300	12.7	.8413	11.1	.8421	11.1	.8331	10.4	.8369	12.4	.8345	11.3	.8354	11.2	.8322	11.1	.8351
Above 300	52.9	.8861	50.5	.8877	56.0	.8798	53.5	.8822	56.0	.8762	53.5	.8794	57.5	.8798	52.5	.8705
Coke	3.5		2.6		4.8		3.1		3.9		2.7		4.0		4.8	
Loss (gases, etc.)	1.6		1.9		1.7		1.1		1.6		3.1		1.7		1.4	

Engler method: Sample 1470, specific gravity 0.8734 at 60° F., first drop at end of flask at 70° C.; sample 1464, specific gravity 0.8608 at 60° F., first drop at end of flask at 50° C.
Ubbelohde method: Sample 1470, first drop at end of flask at 60° C.; sample 1464, first drop at end of flask at 53° C.
Regnault method: Sample 1470, first drop at end of condenser at 110° C.; sample 1464, first drop at end of condenser at 90° C.
Nawratil method: Sample 1470, first drop at end of retort at 90° C.; sample 1464, first drop at end of retort at 75° C.

Chemists usually report the fraction distilling over below 150° C. as "naphtha"; the combined fractions distilling between 150° and 300° C. as "illuminating oils;" that distilling above 300° C. as "lubricating oil." In the following table the analyses have been grouped in the customary manner. Bracketed items have been inserted by the Bureau of Corporations in order to secure completeness of presentation.

	Sample 1470.				Sample 1464.			
	Engler.	Ubbelohde.	Regnault.	Nawratil.	Engler.	Ubbelohde.	Regnault.	Nawratil.
	Per cent.	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
"Naphtha"	9.3	5.2	3.7	2.8	16.7	11.5	9.5	11.1
"Illuminating oil"	32.7	32.3	34.8	34.0	28.3	30.8	31.2	30.2
"Lubricating oil"	52.9	56.0	56.0	57.5	50.5	53.5	53.5	52.5
Coke	3.5	4.8	3.9	4.0	2.6	3.1	2.7	4.8
Loss	1.6	1.7	1.6	1.7	1.9	1.1	3.1	1.4
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

tion. It is usually admitted that the Pennsylvanian beds, which contain more plant and animal remains than the beds of the Permian are the more probable source of oil, and in the great fields of northern Oklahoma the oil is obtained from Pennsylvanian strata. It is therefore usually assumed that oil found in the beds of the Permian has been derived from the underlying Pennsylvanian.

East of the Arbuckle Mountains beds of Ordovician age are known to be asphalt bearing in the vicinity of Atoka.[1] The asphalt deposits formerly mined near Woodford, 10 miles northeast of the Healdton field, however, occur in Carboniferous strata. It seems probable that the limestones underlying the Permian in the Healdton field are of Pennsylvanian age, inasmuch as the strata occupying a similar position in the Loco field have yielded Pennsylvanian fossils in the drill cuttings from the gas wells; yet there is a remote possibility that the limestone beds in the Healdton field may be older than Pennsylvanian and perhaps Ordovician.

If, as is believed by some authorities, the formation of petroleum from plant or animal remains is due to the action of bacteria, it is evident that the transformation to petroleum must take place soon after the deposition of the sediment. If the folding which produced such structure as that of the Healdton dome has taken place in comparatively recent time, it is evident that the oil, the accumulation of which is undoubtedly due to the presence of the rock folds, has been collected in its present position since the folding, or at a time long after the formation of the oil. It must then have existed through the ages as minute globules scattered through the Pennsylvanian rocks, or collected in some fold of the Pennsylvanian from which, after subsequent erosion, deposition of the overlying beds, and folding, it migrated into the strata of the Permian.

To the writers it seems more probable that the organic compounds, whether of vegetable or animal origin, from which the oil was eventually formed, existed as minute particles in shale or limestone. Recent microscopic studies by Davis[2] have demonstrated the presence in the "oil shales" of Colorado of the remains of algæ in great numbers, and there appears to be little doubt that the compounds in this shale, which on distillation give petroleum, are derived, in part at least, from these algal remains. The shales of the Carboniferous were probably not so highly impregnated with organic material capable of producing oil as the typical oil shales, yet their mass is so great that even with a comparatively low percentage of organic material they might be capable, under proper conditions of temperature and pressure, of generating vast stores of petroleum. Such conditions

[1] Taff, J. A., Grahamite deposits of southeastern Oklahoma: U. S. Geol. Survey Bull. 380, p. 296, 1909.

[2] Davis, C. A., On the fossil algæ of the petroleum-yielding shales of the Green River formation: Science, new ser., vol. 41, No. 1059, Apr. 16, 1915.

may well have been supplied by the earth movements that produced the folds in which the oil accumulated, the organic material in the shale undergoing slow distillation under conditions of high pressure and of the temperatures induced by the pressure. The product of such distillation may have been petroleum, or it may have been gas from which on condensation petroleum was formed. Gas passes through rock pores with little friction as compared with oil, and many accumulations of petroleum which are accounted for with difficulty on the supposition that petroleum as such migrated for considerable distances through the rock strata are easily explained by supposing that the petroleum reached its place of accumulation in the form of gas, which later condensed to petroleum. Whatever the method of formation of the oil and the conditions under which it was collected into pools, it is certain that in such fields as that of Healdton the presence of domal or anticlinal structure in the rock beds has been the controlling factor in determining the place of accumulation.

FUTURE DEVELOPMENT IN THE HEALDTON FIELD.

The productive area of the Healdton oil field has already been defined in a general way by the drill, but there still remains much undeveloped territory to be explored. The drilling already done shows that the oil sands are productive in practically all parts of the dome above the 200-foot contour—that is, within the area encircled by it, as shown on Plate III. In this area only one dry hole has been drilled. This was located on the line of a probable fault, and it may reasonably be inferred that when fully explored the entire area outlined by the 200-foot contour will be found productive. Greater gas pressure and consequently higher initial production will probably be encountered near the crests of the subsidiary domes, as shown on Plate III, than in the depressions between them.

A most promising place for an extension of the producing territory is in the NW. ¼ SE. ¼ sec. 31, T. 3 S., R. 3 W. A well has already been drilled in the southwest quarter of this 40-acre tract, but the axis of the subsidiary dome on which it is situated extends from the well in a northeasterly direction—how far has not yet been determined.

Similar conditions exist on the subsidiary dome whose highest part lies just north of the center of sec. 6, T. 4 S., R. 3 W., and on which some of the best wells in the field have been put down. The axis of this dome, as shown on Plate III, extends in a southwesterly direction from a point just north of the center of sec. 6, but the extent of the structure to the southwest has not been determined. The fact that dry holes were put down in the SE. ¼ SE. ¼ sec. 6 and the SE. ¼ NW. ¼ sec. 7 should not condemn the territory along the axis of this dome southwest of the center of sec. 6. In testing this territory, as well as that in sec. 31, T. 3 S., R. 3 W., wells should be drilled on the anticlinal axis at intervals of one-eighth of a mile, beginning near the productive wells.

Some areas outside of the 200-foot contour, as shown on Plate III, have already been proved to be productive territory. The dry hole near the center of the SE. ¼ SE. ¼ sec. 36, T. 3 S., R. 4 W., tends to condemn the territory beyond the productive wells at the northwest end of the pool, but the area east of these wells, although it is outside of the 200-foot contour, will probably prove to be oil producing.

Wells drilled near the east quarter corner of sec. 10, T. 4 S., R. 3 W., are not large but appear to indicate an extension of the pool in that direction, and the territory between them and the main dome to the west probably contains oil.

An extension of the productive territory is to be expected south of the small dome in the SW. ¼ NW. ¼ sec. 10, T. 4 S., R. 3 W., in line with its axis, and this territory may extend as far south as the productive well already drilled in the SW. ¼ SE. ¼ sec. 15. Recent development in the vicinity of this well, however, shows high gas pressure, which may indicate the presence of a subsidiary or separate dome. Should such a dome be present at this distance from the main dome there is a possibility that an oil pool accumulated in it is entirely separate from that of the main dome, in which case part of the territory between it and the main dome is probably barren.

A producing well is located near the northeast corner of sec. 16, T. 4 S., R. 3 W., and the territory between it and the small dome half a mile to the northwest appears promising.

At other places around the dome the limits of the oil pool are at present fairly well defined by dry holes. The producing territory will probably be extended for very short distances at many places, but prospecting should be done cautiously by wells drilled comparatively near those already producing.

The oil and gas development in the southern part of sec. 15, T. 4 S., R. 3 W., suggests the possibility of finding other oil pools in the vicinity of the Healdton pool. To judge by the steep dip to the southwest in the S. ½ sec. 8, T. 4 S., R. 3 W., and the dry holes which have been drilled in this locality, the chances of finding oil immediately southwest of the Healdton pool seem to be poor. The territory between the Healdton pool and the asphalt deposits in sec. 32, T. 3 S., R. 4 W., has been by many operators considered as favorable ground for oil prospecting, but the fact that dry holes have been put down in secs. 32 and 36 is against this view. The surface rocks between the northwest end of the Healdton field and the asphalt deposits belong to the sandy series which overlies the beds exposed on the Healdton dome, and the structure in this area is therefore probably synclinal and not favorable to oil accumulation. Except for the possible extension of producing territory in sec. 31, T. 3 S., R. 3 W., the area immediately north of the Healdton field does not appear promising.

In the vicinity of the Healdton field the best chances for the extension of the producing territory or the discovery of new domes appear to be in the areas mentioned above and in the Permian area for a distance of 4 or 5 miles east and southeast of the field. About 8 miles east of the field the older Paleozoic rocks reach the surface and the oil-bearing beds at Healdton are not present, having been removed by erosion.