STATE GEOLOGICAL SURVEY OF KANSAS

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GEOLOGY OF THE ELDORADO OIL AND GAS FIELD

BUTLER COUNTY, KANSAS

BY
A. E. FATH

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GEOLOGY OF THE ELDORADO OIL AND GAS FIELD, BUTLER COUNTY, KANSAS.

By A. E. Fath.

INTRODUCTION.

THE first attempt to develop petroleum in the Midcontinent field dates back to 1860, when several shallow wells were drilled in the vicinity of Paola, Miami county, Kansas. In one of these wells, located about a mile east of Paola, good showings of oil were encountered but no commercial production was obtained. With the outbreak of the Civil War, in the following year, further attempts at finding oil were abandoned, and not until 1873 was another forward step made in the development of the oil and gas industry of this region, when gas from the Acers mineral well at Iola, Allen county, Kansas, was piped to a neighboring sanitarium and used as an illuminant. No further development occurred until 1882, when commercial quantities of gas were encountered in several wells near Paola, being piped into the town two years later. At about the same time and in the same general region small oil wells were also occasionally found. Through these later commercial developments near Paola, Kansas bears the distinction of being the earliest gas and oil producing state in the entire region lying between the Appalachian belt and California.

The oil and gas industry in Kansas made no marked strides during its earliest years, and until 1916, with the exception of the years 1898 and 1904, the annual production of gas exceeded in value that of oil. The year 1904 was also the first year in which the state's oil production exceeded one million barrels, and from this time on, to and including 1915, the annual output of oil fluctuated between one and five million barrels. The year 1915, however, marked the end of the fluctuating period, for after that the production increased at a remarkable rate. From 2,823,487 barrels in 1915, the production rose to 8,783,077 barrels in 1916, to 36,536,125 barrels in 1917, to 45,451,017 barrels in 1918, to 29,683,972 barrels in 1919, and to 33,919,772 barrels (estimated) in 1920. This greatly increased production came principally from newly discovered fields in Butler county, and of these the Eldorado field, which is the subject of this report, was by far the leading one. The relationship of the production of the Eldorado field to that of the state of Kansas is graphically represented in plate II.

The importance of the Eldorado field deserves additional emphasis. Discovered late in 1915, it soon became the greatest field ever developed in Kansas. Its importance, however, was not to be confined to state lines, for by its 1918 output, 28,807,680 barrels (which was more than that of the entire Appalachian field), with a value of about $63,000,000, the Eldorado field proclaimed itself the leading field, not only in the Mid-continent region, but in the entire United States. Its importance may be further emphasized in pointing out that the value of its oil production in 1917 was 6.8 per cent, and in 1918, 8.9 per cent, of all the oil produced in the United States.

In still another and at the same time wholly different respect the Eldorado field has shown itself a very striking example, and that is in the measure in which geological knowledge was applied to its development by the discovering company, the Empire Gas and Fuel Company. Of the 34 square miles of territory which the company's geologists, from their study of the surface rocks prior to the drilling of the discovery well, outlined as the most promising in the main part of the field (not including the Wilson and Robinson domes)[1] only 7 square miles have since proven barren of oil. Outside of this area outlined as most promising, only 3½ square miles have since proven productive. With this advance information the company was able to acquire about two-thirds (19¾ of the 30½ square miles) of the territory that has since proven productive, and through these large holdings it has been by far the leading producer in the field.

The importance of the Eldorado field led to its selection as the subject of a coöperative investigation by the State Geological Survey of Kansas and the United States Geological Survey, in the hope that a public report of the geological conditions present in this field would lead to a better understanding of the underlying and governing features of oil and gas accumulation, and in addition would be a benefit and incentive to the discovery and development of other fields, especially within the state of Kansas. The funds necessary for the field work were divided equally between the two surveys.

1. McDowell, J. C.; Geology in its relation to the oil industry: Proc. Amer. Mng. Congress, vol. 19, map on p. 296, 1917.

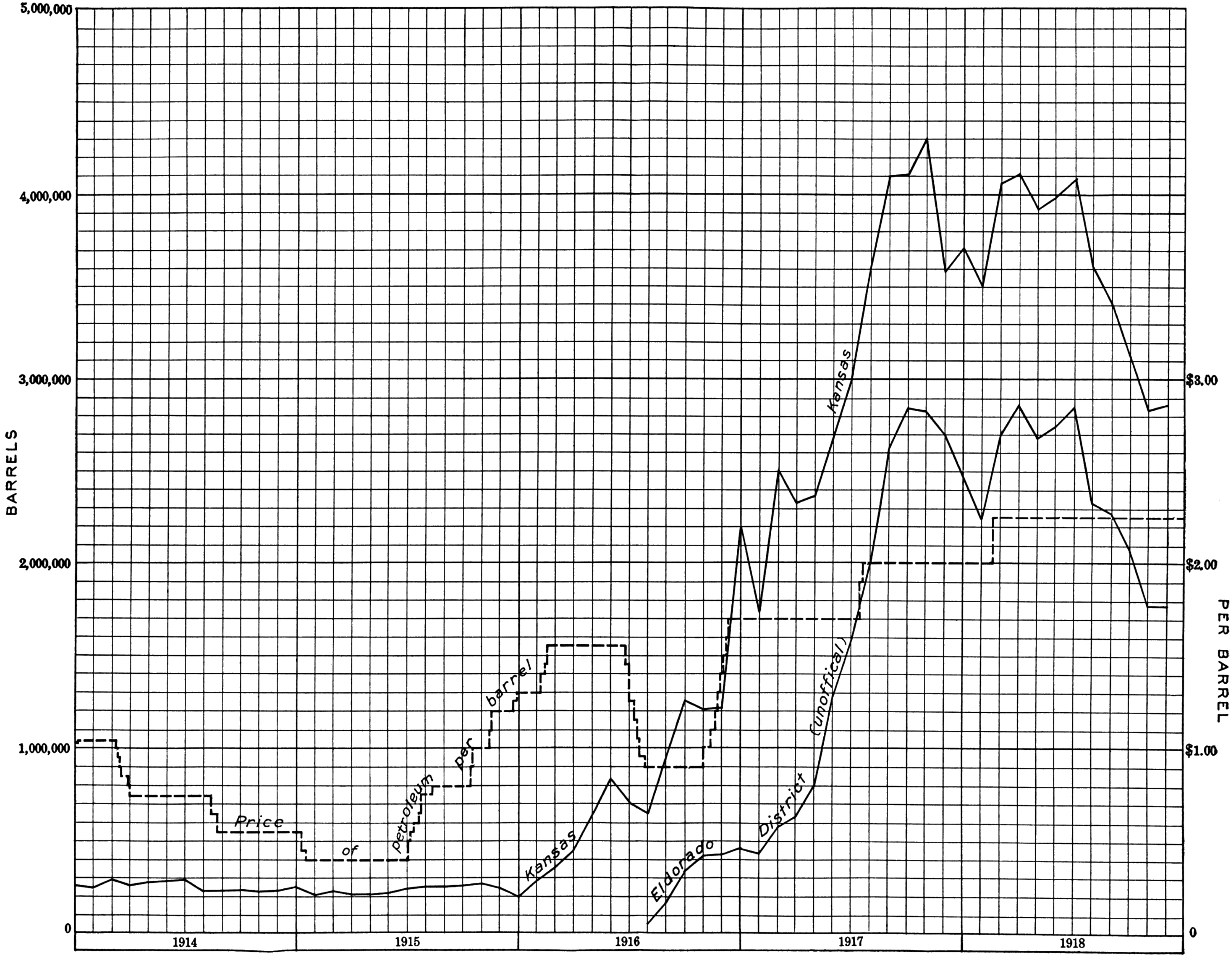


Plate II.—Graphs showing the petroleum production of the state of Kansas by months, and the proportion contributed by the Eldorado field.

SCOPE OF REPORT.

The present report gives a short historical account of the field's development and a brief sketch of its geographic setting. Its principal aim, however, is a detailed description of the geology, which embraces both stratigraphy and structure. Under stratigraphy, consideration is given to the rocks extending from the pre-Cambrian basement through the entire unexposed Paleozoic succession to the Permian limestones and shales which outcrop at the surface. This stratigraphic consideration includes not only a description of the strata, but also their historical significance. Under structure is described the structure of the surface rocks and of the various oil and gas pay sands, in the consideration of which the relationship in structure between the various horizons is emphasized. The relationship between production and the structure in each sand is also considered. Emphasis is given to the origin of the structural features and a theory is advanced explaining the mode of formation. The character and utilization of the oil and gas is discussed and the technological features of producing and handling of the oil and gas are briefly described.

Two features embodied in this report present new conclusions concerning the geology of the region. One of these is a stratigraphic problem, for which evidence is presented to consider the deep or Stapleton oil zone to be of Mississippian age, a conclusion which at first may seem radical in view of the fact that this oil zone lies at a considerably higher altitude than the Mississippian rocks in the neighboring region to the east. The other is a structural problem, for which evidence is presented to indicate that the anticlines and domes of the general region were not caused by horizontal thrust as is generally conceived, but were formed through vertical movements originating along ancient tectonic lines developed in the pre-Cambrian basement rocks. This structural problem has been anticipated by an earlier dissertation,[2] which in this report is considerably amplified.

FIELD WORK.

The investigation on which this report is based consisted of geologic field mapping and study and the collecting of large quantities of drilling and production data. It began on Sep-

2. The origin of the faults, anticlines and buried "granite ridge" of the northern part of the Midcontinent oil and gas field: U. S. Geol. Survey, Professional Paper 128-C, 1920.

tember 17, 1917, and continued with a few short interruptions until May 15, 1918. Of the 200 days in this period given to the Eldorado investigation, 127 were spent in actual field work, mapping and studying the geology, and the remaining 73 days in collecting well logs and other data from the operating companies.

The field work consisted of mapping in detail with a plane table, telescopic alidade, and stadia, the outcropping formations as differentiated on plate I, and in determining the elevations of all the wells. The latter part of the work was very greatly assisted by the well elevations supplied by several of the operating companies. In addition to the purely geologic mapping, an accurate road and stream map was made, which in itself required several weeks of the 127 days spent in field work. Every stream meander, even those of the small drainage channels, was located and tied to the land lines, and the locations of all permanent roads and streets were determined. It is believed that these features, as shown on the map (plate I) represent a correct road and stream map as for the spring of 1918.

ACKNOWLEDGMENTS.

In the field mapping Mr. Ray P. Walters operated the plane table from the beginning of the work until the end of January, 1918, when he resigned to resume his studies at the University of Kansas at the beginning of the second semester. For the remainder of the season Mrs. A. E. Fath took over this phase of the work. For the conscientious and painstaking work of both these individuals the writer is deeply indebted.

The Empire Gas and Fuel Company was exceedingly generous in assisting the investigation. Field maps, well logs, well elevations for the entire field, water analyses, gas-production data and sand samples were supplied without restrictions. The officials to whom especially grateful acknowledgment is made for these courtesies are Everett C. Carpenter, chief geologist; A. W. McCoy, research geologist; Everett C. Parker, resident geologist at Eldorado; and Mr. McCune, superintendent of gas production, who also were very free in discussing the problems involved, and thereby added greatly to the usefulness of the information collected.

The Gypsy Oil Company was also very generous in furnishing a list of well elevations, field maps, and logs of all its wells.

For these courtesies thanks are due to Mr. A. F. Smith and Mr. J. V. Howell, geologists for the company, and to Mr. W. T. Hartman, formerly production superintendent for the Kansas district.

Field maps and individual lease maps in addition to well logs were liberally supplied by the Carter Oil Company, through Mr. T. M. Newman, chief geologist, and in like manner field maps and well logs were furnished by the Sinclair Oil Company, for which considerations grateful acknowledgment is made. Well logs were very generously supplied by all operators, and for these and many other courtesies thanks are due to the following companies and individuals: Atlantic Petroleum Corporation, Bodarc Oil and Gas Company, Mr. R. H. Bradford, British-American Oil Company, Cassoday Oil and Gas Company, Central West Petroleum Company, Messrs. Chapman & McFarlin, Cosden Oil and Gas Company, Mr. J. T. Davis, Mr. A. L. Derby, Eldorado Oil and Gas Company, Eldorado Refining Company, Eureka Oil Company, Forrest Drilling Company, Foster Oil Company, Mr. O. E. Foulke, Mr. R. E. Frazier, Messrs. Galbraith & Compton, J. W. Gilliland Oil Company, Great Plains Oil and Gas Company, Great West Oil and Gas Company, Haverhill Petroleum Company, Hickman & Kennedy Drilling Company, Hickory Oil and Gas Company, Mr. F. W. Higgins, Hilty Drilling Company, Mr. L. V. Hites, Iron Mountain Oil Company, Leonard Petroleum Company, Mr. Deering Marshall, McK Oil Company, Melroot Oil Company, Mid-Co Oil Company, Midland Refining Company, Monitor Oil and Gas Company, National Refining Company, Oil and Gas Company of Eldorado, Oklahoma Petroleum and Gasoline Company, Page-Lewis Oil Company, Mr. H. H. Patton, Phillips Petroleum Company, Prairie Oil and Gas Company, Ramsey Oil and Gas Company, Ramsey Petroleum Company, Selby Oil Company, Mr. J. G. Shelden, Sharp Bros. Construction Company, Messrs. Skelly & Bole, Southwestern Petroleum Company, Standard Oil Company of Indiana, The Texas Company, Theta Oil Company, Tidal Oil Company, Towanda Oil and Gas Company, Union Oil Company of Wichita, Wichita Crude Oil Company, Mr. Winthers, and Mr. C. J. Wrightsman.

GEOGRAPHY.

CULTURE.

The Eldorado district, as treated in this report, is an irregularly rectangular area embracing about 137 square miles in Butler county, Kansas (see plate III), and includes not only the main Eldorado oil-field development and its two subsidiaries on the Wilson and Robinson domes to the north, but also the smaller Smock and Sluss pools lying to the southeast. (These subdivisions are differentiated on plate I.) It is traversed from north to south by the Florence branch of the Atchison, Topeka & Santa Fe, and from east to west by the Missouri Pacific railway. The Missouri Pacific also has a branch line running northwest from Eldorado to Newton.

Eldorado is the county seat of Butler county and its principal town. Previous to the development of the oil field Eldorado was a town typical of an agricultural district and possessed a population of about 3,000. With the development of the oil field the town boomed, and within one and a half years grew to a city with a population of 10,000 to 15,000. The streets are well paved and the town has tried to keep its civic improvements abreast of its growth. Towanda lies six miles west of Eldorado on the Missouri Pacific, and is a thriving small town of about 1,000 inhabitants, also enjoying the oil boom. Oil Hill, one and one-half miles northwest of Eldorado, is a busy oil-field settlement built by the Empire Gas and Fuel Company for its employees. Vanora and Ramsey are siding stations on the Atchison, Topeka & Santa Fe.

The public highways are clay roads which suffer the same vicissitudes as clay roads in other regions, only more so, because of the heavy oil-field traffic. The established roads follow the land lines, with but small modifications caused by grading difficulties presented by local surface features. It is believed that every permanent road or street which was established by the spring of 1918 is correctly shown on the map (plate I). Temporary field roads and short cuts are not represented.

PHYSIOGRAPHY.

The Eldorado district ranges in altitude from 1,225 to 1,450 feet above mean sea level, and lies principally on the prairie upland between the Walnut river, which crosses its south-

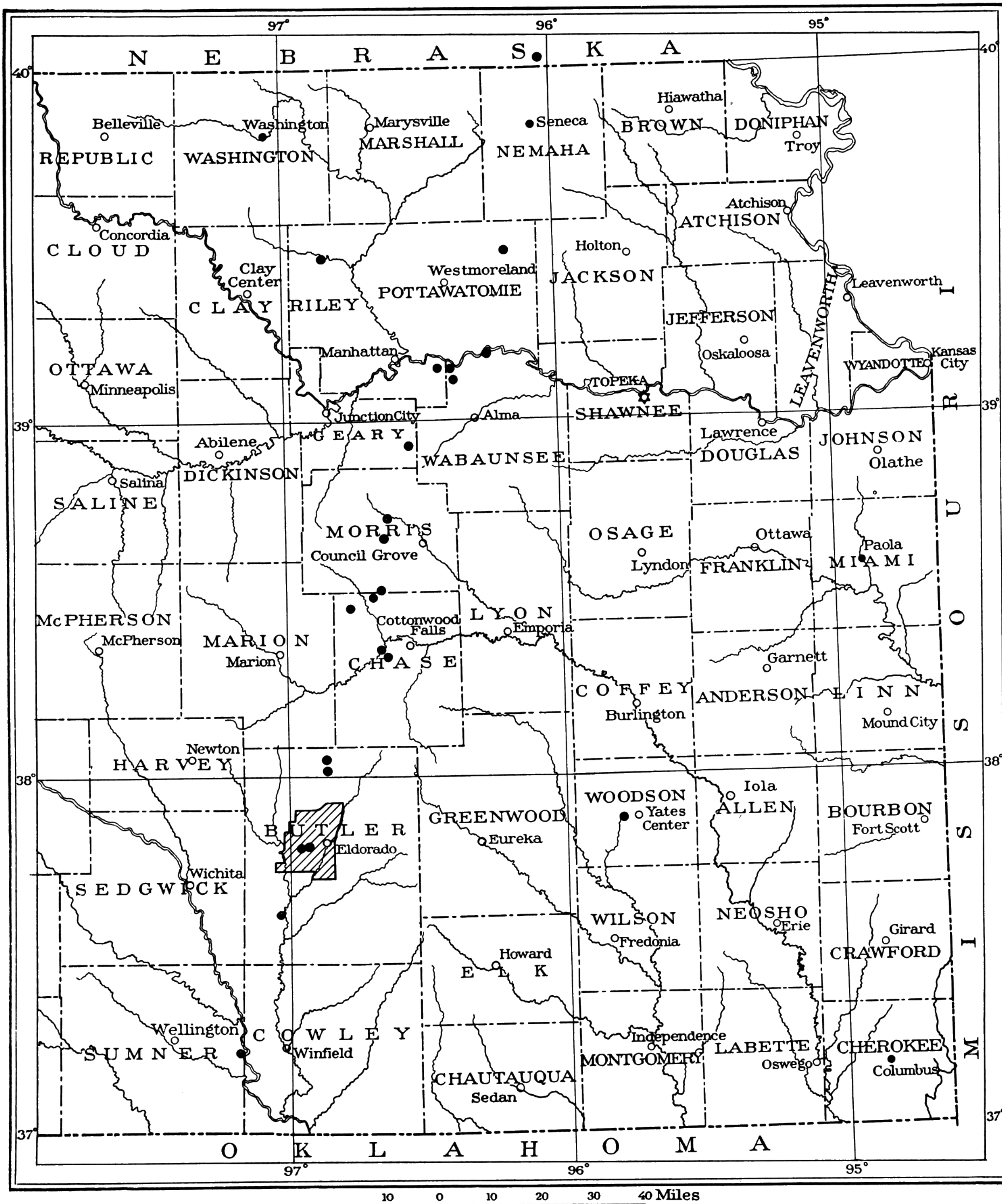


PLATE III.—Index map of eastern Kansas, showing the location of the Eldorado field and the locations of the "granite wells."

eastern part, and Whitewater river, which forms part of its western boundary. Since the district is located thus on the divide, it may be noted that the topography conforms rather closely to the anticlinal structure of the rocks. The ground surface is diverse in character; in some places it is rolling, in other places marked by long, gentle slopes (dip slopes), and in still other places is broken by low escarpments. The rolling portion is on the truncated axis of the anticline, while the long dip slopes developed on the top of the Fort Riley limestone lie principally on the west flank of the anticline and in the Smock pool and the Sluss pool localities. The principal escarpment, which starts on the northeast side and runs around the field to the north, northwest, west and southwest, is caused by the Winfield limestone. The Herington (?) and Towanda limestones also form, here and there, low and less pronounced escarpments. If the Fort Riley and Florence limestones were so exposed that a soft formation outcropped below them, they would also form an escarpment, but in the Eldorado district they are the lowermost rocks present, and therefore have no opportunity to form escarpments. However, where dissected by streams they form rock-walled valleys, as along Turkey creek and several other tributaries of Walnut river. The major valleys have pronounced alluvial plains, in which the streams have developed meandering courses. The alluvial flats range in general between ten and forty times the width of the streams.

The width of the alluvial plains varies quite notably, and, contrary to the general rule, the narrower constrictions are downstream and the wide portions upstream. In the vicinity of Eldorado the plain of the Walnut river is nearly a mile wide, and at two points—four and seven miles, respectively, downstream—it is less than one-fourth mile wide. Similarly the plain of the West branch is in general between one-fourth and three-eighths mile wide, but in the vicinity of its mouth, at the town of Eldorado, it narrows to about one-sixteenth of a mile in width. No satisfactory explanation of these constrictions can be offered. There is no apparent greater resistance to erosion of the bedrock at these points, and a recent local differential deformation at these places can hardly be called into account. The only factor which can be suggested is that at these places there was a possible greater underground drainage, which lessened the eroding power of the surface streams and thereby prevented the development of as wide a valley as at other points.

DRAINAGE.

The Walnut and Whitewater rivers are intermittent streams, flowing only during rainy periods. They both, however, have a considerable subsurface flow, especially the main Walnut river and in its west branch, in which the ground water is sufficiently high to maintain large ponds of water in the deeper depressions throughout the year.

Throughout much of the area, and outside of the stream valleys where the Fort Riley limestone and Florence flint form the surface rock, there is a great deal of subsurface drainage, and consequently surface drainage in such places has been eliminated. These places are usually marked by the presence of a great many sink holes. The subsurface drainage is probably the source of the ponded water in the deeper depressions of Walnut river. It also is the factor controlling most of the large springs, of which there are several in the river valleys. One of the peculiar results of this subsurface drainage is that many shallow-water wells and several of the springs which obtain their water from these rocks have turned to salt-water wells and salt-water springs since the development of the oil field higher on the anticline, the salt water being the waste material from the oil wells which is permitted to enter the underground drainage. At least one such well, located in Towanda, not only turned to salt water, but was reported in the daily press to have later turned into an oil well, the oil being waste material which escaped and entered the subsurface drainage in the Fort Riley limestone and Florence flint.

WATER SUPPLY.

Previous to the discovery of the oil field the municipal water supply of Eldorado was obtained from the natural and artificial ponding of the Walnut river within the confines of the city. Most of the drinking and much of the domestic supply, however, was obtained from shallow driven wells which tapped the water-bearing Fort Riley limestone and Florence flint. With the development of the oil field and its attendant influx of people, not only was the demand for water for boiler and domestic use increased, but the waste salt water obtained from the oil wells entered the underground drainage from which much of the domestic and most of the drinking supply was obtained, and polluted it. One interesting feature with respect to this pollution is to be noted in the position of Eldorado with respect to the rock structure and the location of Walnut river. To the east of Eldorado the underground drainage in the Fort Riley limestone and Florence flint is westward, but Walnut river has cut through these rocks, except to the northeast, and hence little or none of the water in the Fort Riley and Florence limestones in Eldorado is obtained from the drainage to the east, but rather from the oil-field region on the anticline to the west. The supply of drinking water was alleviated by boiling and by importing bottled water, and the increased demand for oil-field developments was in part supplied by making use of the naturally ponded water for many miles along the stream courses. Many times even this ponded water was inadequate, and drilling operations were greatly curtailed and at times almost suspended. To relieve their own deficiency of water the Empire Gas and Fuel Company made use of their twelve-inch gas pipe line to Wichita by pumping through it water obtained from Arkansas river near Valley Center, thirty-five miles away.

The problem at Eldorado in obtaining an adequate supply of good domestic water is serious. The source of the water must be so located that the oil field will not pollute it, and at the same time the supply must be sufficient for a city of 20,000 or more inhabitants. It is patent that the source must be north of the present developments in T. 25 S., R. 5 E., and also that it probably should be beyond the Chelsea dome, which further explorations may prove productive. On the basis of the geology of the Eldorado district, but without any detailed knowledge of the region beyond, the water supply should be obtained either from the territory lying east of Walnut river or in the valley of Walnut river beyond its confluence with Cole creek in sec. 33, T. 24 S., R. 6 E.

HISTORY.

Shallow gas wells drilled in the vicinity of Augusta as early if not earlier than 1906 represent the first developments in Butler county. The gas obtained was in sufficient quantities to supply the town of Augusta "years before oil was discovered,"[3] which was in June, 1914. The presence of gas at Augusta inspired the city of Eldorado to look for gas in its vicinity, and accordingly the city drilled a well late in 1909 or early in 1910 on the Holderman tract in the SW¼, sec. 3, T. 26 S., R. 5 E. A depth of 1,557 feet was reached without encountering any showings, and the well was abandoned. Not daunted by this failure, a second municipal well was drilled during the fall of 1910 or early in 1911, in the city park on the east bank of the Walnut river. After reaching a depth of 1,695 feet this too was abandoned as a failure.

Several years elapsed before interest was again aroused, and then the revival was due to the discovery of oil at Augusta, in June, 1914. This time the city of Eldorado consulted Dr. Erasmus Haworth, then state geologist, and employed him to make a field examination of the surrounding vicinity and to suggest a location for a third test well. As a result the Eldorado anticline was found, and, upon the recommendations of Doctor Haworth, leases were obtained on 790 acres of land in sec. 36, T. 25 S., R. 4 E., secs. 31 and 32, T. 25 S., R. 5 E., and sec. 1, T. 26 S., R. 4 E., high on this structural feature, and a well was drilled near the center of the NW¼ SE¼, sec. 1, T. 26 S., R 4 E., on the Fowler lease. A depth of about 2,650 feet was reached by August, 1915, without finding commercial production, and the well was abandoned.

Located high on the Eldorado anticline, in the heart of what has since developed into the Eldorado field, the failure of this well is difficult to explain. Wells to the west and north, only a location removed, have since come in with initial productions of several hundred barrels, but it is also to be noted that to the northeast and east at least three additional dry holes have been drilled on the immediately adjacent lease, forming an unbroken row of four dry holes. In the absence of detailed logs of all these wells their failure can be explained only by a local barren condition of the otherwise productive rock zone of this locality.

During the drilling of the city well on the Fowler lease (1915) the Wichita Natural Gas Company (now the Empire Gas and Fuel Company) made a detailed geologic examination of the region and leased many thousands of acres. Immedi-

3. Haworth, Erasmus; Historical outline of the oil and gas industry in Kansas: Oil and Gas Resources of Kansas, chapter I, Kansas State Geol. Survey Bull. 3, pp. 19-24; 1917.

ately after the abandonment of the Fowler well the Wichita Natural Gas Company negotiated with the city and acquired for $800 cash, plus certain stipulations, the city's 790 acres of leases. Among other considerations in these stipulations it was agreed that the company should drill a well to a depth of at least 3,000 feet on one of their own leases, and if this came in dry to drill a second well on one of the original city leases. If paying quantities of oil and gas were obtained the city was to be reimbursed its entire expense in drilling the Fowler dry hole, amounting to about $15,000. In accordance with their contract, the Wichita Natural Gas Company immediately started operations for a well on the Stapleton land on the SE¼, sec. 29, T. 25 S., R. 5 E. A location (center of NE¼ SE¼) was made on September 1, a standard rig was started on September 9, and drilling commenced on September 29, 1915. Within a week a good showing of oil was encountered in a sand at a depth of 549-557 feet (a few wells produce oil from this sand), and commercial production, estimated at 50 to 200 barrels per day, was found in a sand at a depth of 660-678 feet. This discovery marks the opening of the Eldorado field. The 660-foot sand in the discovery well was mudded off in order to make a deep test, but meanwhile other wells were soon started with portable rigs to develop this shallow sand, and for some time 100-barrel wells in this sand were common. At least seven wells were completed in the 660-foot sand before the close of 1915. During the deeper drilling of the discovery well, Stapleton No. 1, several showings of oil and gas were encountered, but no further commercial production was found until in December, when the Stapleton pay zone[4] was reached at a depth of 2,465 feet. This was penetrated 46 feet and a production of about 175 barrels was finally developed. The log of this well is graphically shown in plate VI.

Though operations at first centered principally around the discovery well, a 50-barrel pumper in the 660-foot sand was completed in December on the Linn lease in the W½ NW¼, Sec. 5, T. 26 S., R. 5 E., which extended the field two miles to the southwest. Following shortly upon this extension the Sunflower Oil Company (since sold to the Sinclair Oil Company)

4. This pay is here termed a zone, inasmuch as it is not a stratigraphic unit. See pp. 59-73.

developed in February, 1916, a 100-barrel producer in the 660-foot sand on the Adams farm in the SE¼, sec. 31, T. 25 S., R. 5 E. This company proceeded to develop its property at a rapid rate, completing about fifty shallow wells and one Stapleton pay-zone well within the following six months.

After the southwest extension of the field was proved, the

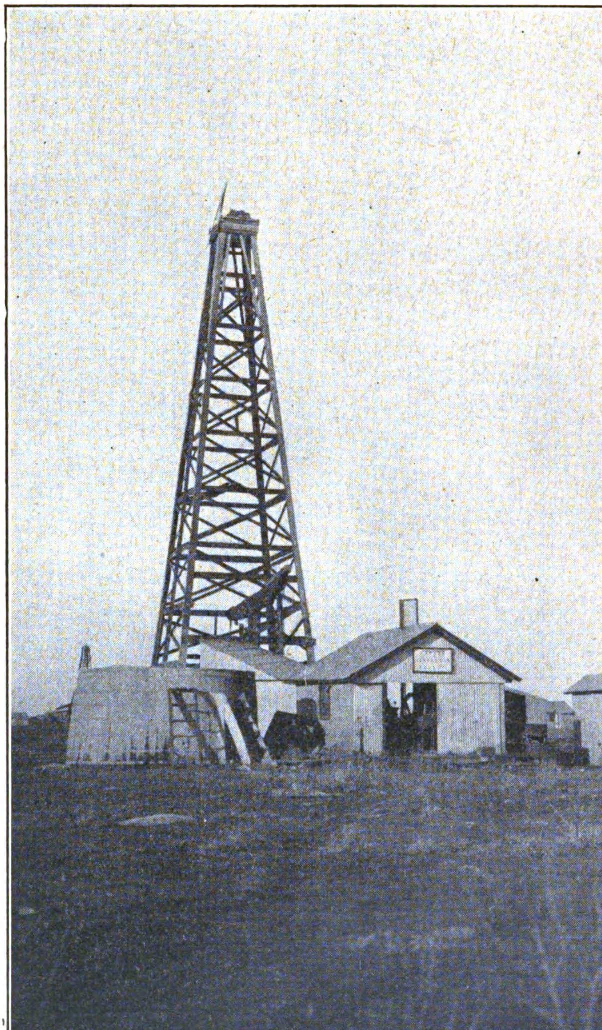


PLATE IV.—Stapleton well No. 1, the discovery well of the Eldorado field.

next development of interest took place on the Wilson farm in the E½, sec. 27, T. 25 S., R. 5 E., two and one-half miles east of the discovery well. Here, during April and May, A. L. Derby *et al.*, in their well No. 1 (southeast corner NW¼ NE¼), encountered a sand at 2,650 feet, nearly 200 feet deeper than the Stapleton pay zone in the Stapleton well. A production of between 500 and 1,000 barrels per day was developed in this Wilson well. The greater depth of the Wilson farm pay appeared to indicate a producing zone deeper than the Stapleton, but, as will appear later, it is believed that they are the same. A deep test well on the Adams farm, location No. 3 (center of east side NE¼ SE¼, sec. 31, T. 25 S., R. 5 E.), was completed in the Stapleton oil zone a few weeks later, with an initial production similar to that of the Wilson well.

Other developments rapidly extended the field. Gas in paying quantities was discovered in porous limestones, not in definitely recognized sands, at several localities at depths ranging from 850 to 1,450 feet. A two-mile southward extension of the field was made in July by the bringing in of a 150-barrel well in a new oil "sand" at a depth of about 1,650 feet, the Boyer "sand" on the Boyer lease (location No. 1 in center of NW¼ NE¼, sec. 17, T. 26 S., R. 5 E.). The year 1916 closed with about 600 producing wells and a daily output estimated at more than 12,000 barrels. Most of these were drilled to the shallow sand only, and were located within two and one-half miles of the discovery well. No wells whatever had been brought in in T. 26 S., R. 4 E. (Towanda township), nor in the S½ of T. 26 S., R. 5 E., nor on the Wilson and Robinson domes in the northern part of T. 25 S., R. 5 E. It remained for the following year to develop these localities.

Development in the Eldorado field in 1917 was exceedingly spectacular, and T. 26 S., R. 4 E. (Towanda township), led in this respect. Before any startling events took place in this township, however, the first well on the Wilson dome (center of NW¼ SE¼, sec. 8, T. 25 S., R. 5 E.) proved late in February that the 660-foot sand was productive on this structural feature. On March 23 the Stapleton pay zone was reached and a production of 350 barrels developed. This was the opening of the Wilson dome pool, which has since been shown to be separated from the main field by a narrow strip of barren territory. To return to Towanda township: In March the Alpine

Oil Company obtained a 250-barrel well from the Stapleton pay zone in the northeast corner SE¼, sec. 10, on the Ralston lease. Well No. 2 on this lease (southeast corner NE¼ SE¼, sec. 10) was reported to be worth about 500 barrels. At about the same time the Trapshooter Oil Company (later sold to the Eureka Oil Company) on the Williams & Walker lease, which offsets to the northeast, in section 11, the Alpine Oil Company's lease, brought in a Stapleton pay-zone well (southwest corner location in the NW¼) with a production about the same as that of Ralston No. 2. It remained, however, for the second Williams & Walker lease well (location No. 3 in the southeast corner SW¼ NW¼), completed early in June, to be the first Eldorado gusher. Because tankage adequate only for an average well had been provided, the initial production of this gusher could only be estimated. These estimates range from 6,000 to 24,000 barrels per day, of which probably those near 14,000 barrels are nearest the real output. Even so, this production placed this well as one of the largest ever discovered in the Mid-continent field.

Contrary to the usual condition in similar large wells in other fields, the oil did not gush, in the popular sense of that word, *i. e.*, it did not pour forth in a stream shooting high into the air. This absence of gushing is due, it seems, to a lack of dissolved gas, and in this 14,000 (?) barrel well the flow of oil did not run wild (out of control), but instead flowed a gentle, continuous stream that offered no difficulties whatever in controlling it. (See plate V, B.)

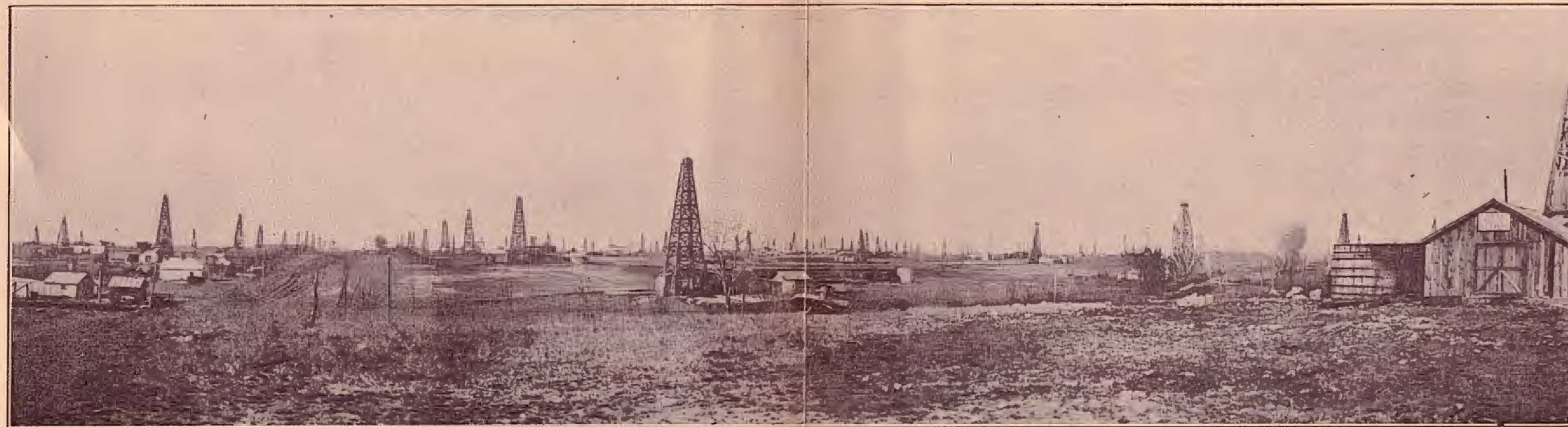
Following this first prolific well, developments in T. 26 S., R. 4 E., became intense, and numerous gusher wells, all producing from the Stapleton pay zone, were brought in, most of them located in section 11. An analysis of the initial productions of large wells drilled previous to 1919, and based on information believed to be reliable, is given in the following table.

Initial daily production capacities of Eldorado gusher wells drilled in 1917 and 1918.

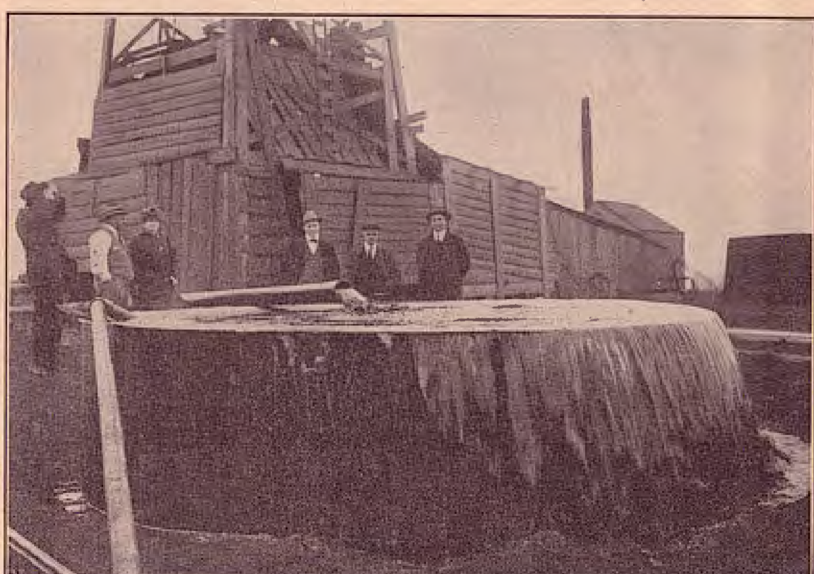
5 wells had initial daily capacities of more than 15,000 bbls.
4 wells had initial daily capacities of less than 15,000 but more than 10,000 bbls.
4 wells had initial daily capacities of less than 10,000 but more than 5,000 bbls.
31 wells had initial daily capacities of less than 5,000 but more than 2,000 bbls.
57 wells had initial daily capacities of less than 2,000 but more than 1,000 bbls.
104 wells had initial daily capacities of less than 1,000 but more than 500 bbls.

The general decline of most of these large wells is comparatively rapid. One noteworthy exception, however, deserves

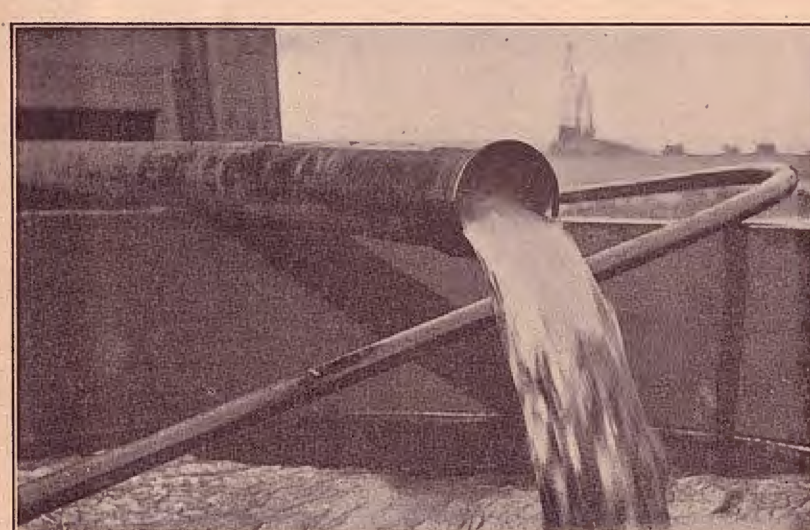
PLATE V.



A. Panorama of developments in sections 10 and 11 of Towanda township.



B. Trapshooter Oil Company's first gusher well.



C. Gypsy Oil Company's Shumway well No. 5.

especial mention. The Gypsy Oil Company's well No. 5 on the Shumway lease (center location along west side of SW¼ NE¼, sec. 11, T. 26 S., R. 4 E.) was not only the most prolific well in the Eldorado pool, but probably produced more oil than any other well ever drilled in the Midcontinent field. Completed on September 7, 1917, and with the tools in the hole, the production for the first twenty-four hours was estimated by the company to be 12,000 barrels, and for the second twenty-four hours 14,000 barrels. On September 10 the flow was gauged for one hour, and amounted to 800 barrels, or at a rate for this hour of about 19,000 barrels per day. The tools remained in the hole until about Christmas, by which time the daily production had gradually declined to about 10,000 barrels. The removal of the tools at this time increased the daily production to about 14,000 barrels, after which it declined gradually until it amounted to 8,500 barrels on April 8, 1918. This was the day when well No. 13, located about 650 feet to the northeast, was brought in with a daily initial production of 17,000 barrels. The production of No. 5 seemed not to be affected by No. 13 for the first two days, but then a rapid decline set in and six days later its production was but 5,800 barrels, and after a few more days had ceased entirely. It is probable that during the 222 days of its flowing life its total production amounted to about 2,500,000 barrels.

In contrast to this long-lived gusher is the history of the Empire Gas and Fuel Company's Shriver farm well No. 3 (northeast corner NW¼, sec. 14, T. 26 S., R. 4 E.), which when brought in, early in October, 1917, was reported to have flowed 144 barrels in nine minutes, or at the rate of about 23,000 barrels per day. The lack of available tankage caused the management to close in the well, but a few days later, when storage was available and the well opened, salt water instead of oil poured forth. A small production was later obtained.

The Smock pool, which is distinct from the main Eldorado field, was discovered early in March by the Haverhill Petroleum Company bringing in a 500-barrel well on the Smock farm (southwest corner location in NE¼, sec. 2, T. 27 S., R. 5 E.). The pay was found at a depth of 2,642 - 2,657 feet, and probably is in the Stapleton zone. The subsequent drilling in this vicinity has since developed a pool more than one and one-half miles long and hardly more than one-fourth mile wide.

Early in May the main Eldorado field was again extended, this time about two miles to the south, by the Page-Lewis Oil Company bringing in Koogler farm well No. 1 (northwest corner NE¼, sec. 30, T. 26 S., R. 5 E.), drilled to the Stapleton pay zone, found at a depth of 2,605 feet. The initial production obtained in the top of the pay zone was small, but on drilling deeper, late in August, the production increased to 500 barrels.

The next extension of importance was toward the northeast on the Robinson dome and took place early in August. It was the Theta Oil Company's L. W. Robinson farm well No. 1 (center location, along south line SW¼ NE¼, sec. 3, T. 25 S., R. 5 E.), which was reported to be good for 1,900 barrels, in the Stapleton pay zone. The producing area on this dome has been demonstrated to be separated from both the main field and the Wilson domes by barren territory.

The Sluss pool, located principally on the Sluss farm, in secs. 25 and 26, T. 26 S., R. 5 E., lying about one and one-half miles north of the Smock pool, was opened early in August by Messrs. Patton, Dingee & Davis, who drilled a well in the southeast corner NE¼ SE¼, sec. 26, finding a pay zone at a depth of 2,688-2,785 feet, which probably should also be correlated with the Stapleton pay zone. The initial daily production of this well was about 100 barrels. Like the Smock pool, it too is structurally unrelated to production from the Eldorado anticline.

On August 26, 1917, in the main field a further extension to the south was proved by the bringing in by the McK Oil Company of an 800-barrel Stapleton pay-zone well in the northeast corner of sec. 31, T. 26 S., R. 5 E., on the Nuttle lease.

The year 1917 was principally a year of extensions. The limits of production were largely although not completely defined by the end of 1917. With the extensive developments of the prolific Stapleton pay zone during 1917, the production of the Eldorado field increased in proportion, and during a part of September exceeded 100,000 barrels per day.

An eastward extension of the production on the Robinson dome was developed in the W½, sec. 2, T. 25 S., R. 5 E., in 1918, and proved this territory to be richly productive. In contrast to 1917, the year 1918 was a period of intensive de-

STATE GEOLOGICAL SURVEY OF KANSAS
IN COOPERATION WITH
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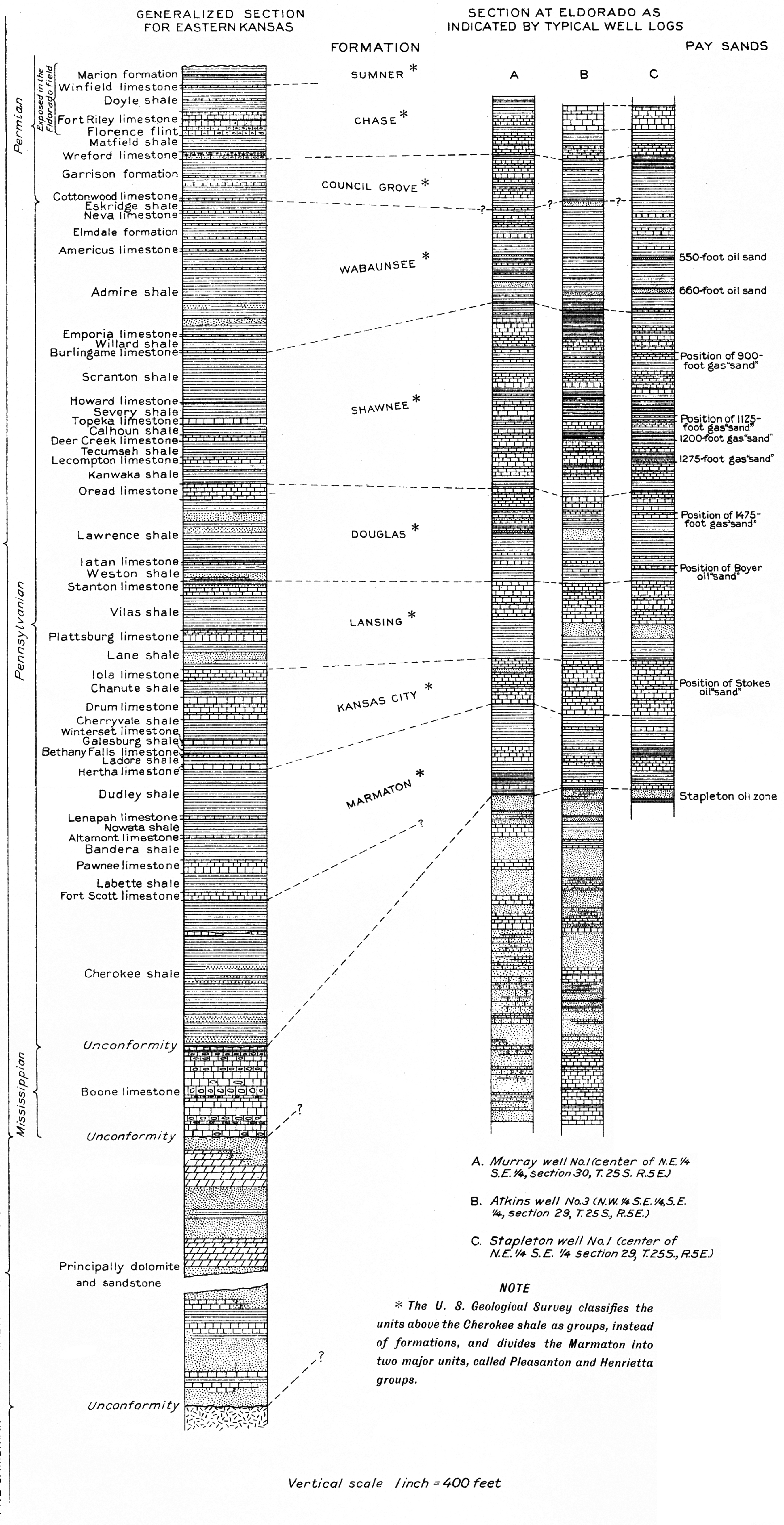
PLATE VI.



COLUMNAR STRATIGRAPHIC SECTIONS OF EASTERN KANSAS AND THE ELDORADO DISTRICT

velopment, the drilling being principally on territory proved productive during 1917, *i. e.,* inside drilling. With the great increase in number of wells, almost all of which were drilled to the Stapleton pay zone, a high production was maintained from March to September (see plate II), and as a result the total production of 1918 nearly doubled that of 1917.

STRATIGRAPHY.

GENERAL FEATURES.

The stratigraphy of eastern Kansas in comparison to that of most regions is simple, the various formations being remarkably uniform in character throughout the state. The rocks range in age from pre-Cambrian to Permian, and their sequence and relative thicknesses, as compiled from measurements made on the outcrops of the various formations, are graphically represented in plate VI. This section, which is typical for eastern Kansas, will be compared with the Eldorado section as determined from surface and drill-record study, which is shown in plate VI.[5]

In the following discussion it must be borne in mind that much of the evidence has been obtained from well records, and as the use of well records in correlating strata from place to place in the Midcontinent field is uncertain even at its best, the discussion must contain possibilities of error. This is more particularly true in the correlation of the formations encountered by drilling in the Eldorado field with the outcropping rocks to the east, because access was not had to all the information that could be desired. Nevertheless it is considered that the evidence and discussion which follow are close approximations of the facts.

UNEXPOSED ROCKS.

PRE-CAMBRIAN ROCKS.

Rocks of undoubted pre-Cambrian age, such as granites and quartzites, crop out at numerous places around the borders of the Midcontinent oil and gas field—in the St. Francis mountains of southeastern Missouri; the Arbuckle and Wichita mountains of southern Oklahoma; the Rocky Mountains of

5. The 900-foot, 1,485-foot, Boyer and Stokes "sands" are not recorded in the three logs shown on plate VI, hence their stratigraphic locations are indicated at the right by the words "position of——."

New Mexico, Colorado, and Wyoming; the Black Hills in southwestern South Dakota; and in the Sioux quartzite area of southeastern South Dakota, southwestern Minnesota, and northwestern Iowa. These outcrops probably do not represent rocks of precisely the same age, but they all represent ancient basement rocks upon which all the Paleozoic stratified rocks of the Midcontinent region were deposited. Similar crystalline rocks are known in Kansas, but unlike the localities mentioned above, their presence is known only through wells drilled for oil, which were located principally on a belt of anticlines regarded as favorable for oil.[6] (See plate III.) It is to be noted that one of these wells is located in the Eldorado field. With the single exception of the Eldorado field, all the so-called "granite well" localities have been proved barren of oil.

The "granite wells" on this belt of anticlines are located intermittently from southern Nebraska, south-southwestward across two-thirds of Kansas, and into the Eldorado field. The folding continues beyond the Eldorado field and includes the anticlines of the Augusta [7] and Douglas fields, which probably extend as far as, if not into, Cowley county.

The crystalline basement thus encountered is much shallower than had previously been thought possible. The depths at which these wells entered the crystalline rocks range from 500 feet (575 feet above sea level) in the Bern well in Pawnee county, southern Nebraska, to 2,715 feet on the Shumway lease in the NE¼, sec. 11, T. 26 S., R. 4 E., of the Eldorado field.[8] The rocks overlying the granite in the wells north of the Eldorado field are probably of Pennsylvanian age, whereas those in the Eldorado field are of Mississippian or even earlier age, as will be indicated further on. To the east of this linear series of "granite wells" other drill holes of greater depth did not encounter the crystalline rocks, indicating that the pre-

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6. Taylor, Charles H.; The granites of Kansas: Bull. Southwestern Assoc. Petroleum Geologists, vol. 1, pp. 111-126; Feb., 1917.
Powers, Sidney; Granite in Kansas: Amer. Jour. Sci., 4th series, vol. 44, pp. 146-150; Aug., 1917.
Wright, Park; Granite in Kansas wells: Bull. Amer. Inst. Min. Eng., No. 128, pp. 1113-1120; Aug., 1917.
Moore, Raymond C., and Haynes, Winthrop P.; The crystalline rocks of Kansas: Oil and Gas Resources of Kansas; Kan. State Geol. Survey, Bull. 3, pp. 140-173; 1917.
Moore, Raymond C.; Geologic history of the crystalline rocks of Kansas: Amer. Assoc. Petroleum Geologists, Bull. II, pp. 98-113; 1918.

7. McDowell, J. C.; Geology in its relation to the oil industry: Proc. Am. Mng. Congress, vol. XIX, map on p. 294; 1917.

8. Personal communication to the U. S. Geological Survey from Mr. Geo. C. Matson, chief geologist for the Gypsy Oil Company.

Cambrian in this bordering region lies much deeper. There is reason to believe that the same condition applies also to the west side of this series of wells, although one well near Winkler, in Riley county, Kansas, penetrated the crystalline rocks at a depth of 2,385 feet. These conditions taken together point to a buried crystalline mountain range extending from Pawnee county, Nebraska, southward into Butler county, Kansas, which has been termed the Nemaha mountains.[9] The relation in origin between this buried "granite ridge" and the belt of anticlines associated with it, which extends farther south across the state and includes those of the Eldorado and Augusta fields, is of considerable practical and theoretical importance, the nature of which is brought out more fully on pages 148-166. It may be mentioned, however, that the "granite ridge" probably continues south-southwestward beyond the Eldorado field, in which direction it should lie at increasingly greater depths beneath the belt of anticlinal folding. The crystalline-rock well near Winkler, in northern Riley county, may indicate another range to the west of the Nemaha range, with a valley between.

Crystalline rocks have also been encountered in the eastern part of the state, near Paola and Yates Center, but there appears to be no evidence indicating these occurrences to represent buried mountain ranges, but rather that they represent the normal pre-Cambrian basement on which the Paleozoic sediments were deposited.

CAMBRIAN AND ORDOVICIAN ROCKS.

The rocks of Cambrian and Ordovician age outcropping in southwestern Missouri consist of a thick series, 1,000-2,200 feet, of massive dolomites and sandstones. These extend westward and pass beneath the surface into Kansas, where they are known only through well records. It is probable that these strata are, at least in part, represented by the deeper known rocks encountered by drilling in the Eldorado field. Their differentiation here, however, is not clear.

Beneath the limestone portion of the Stapleton oil zone, which is of Mississippian (Boone) age, is a thick and apparently massive series of sandstones, which on the Shumway lease, in sec. 11, T. 26 S., R. 4 E., as before mentioned, was

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9. Moore, Raymond C., and Haynes, Winthrop P.; Oil and gas resources of Kansas: State Geol. Survey of Kansas, Bull. 3, pp. 141-145; 1917.

penetrated and the granite encountered at a depth of but 2,715 feet. Only three or four miles away, however, in secs. 29 and 30, T. 25 S., R. 5 E., wells have penetrated this series for more than 1,000 feet, to a depth of 3,700 feet (2,300 feet below sea level), without reaching the granite. (See Eldorado well logs in plate VI.) Drill records report limestone for a part of this, but the writer has been informed that[1] this is erroneous and that it is practically all sandstone.

This great thickness of sandstone is in large part, if not altogether, of pre-Mississippian age. If the upper part of it is Mississippian, the dividing line between the Mississippian and underlying strata is not clear. In view of this lack of differentiation it seems reasonable for present purposes tentatively to consider this great thickness of sandstone to be older than Mississippian and to correlate it with the Ordovician and Cambrian of the Missouri section.[2]

This sandstone series diminishes in thickness to the north-northeast of the Eldorado field in the direction of the "granite ridge" belt of folding, and very probably is not represented in the Covey "granite well" in sec. 26, T. 23 S., R. 5 E., only 6 miles north of the area described in this report. It should, however, extend northward both to the east and to the west of this buried ridge.

MISSISSIPPIAN ROCKS.

General Consideration.

The Mississippian rocks of the northern Midcontinent field have received a great deal of attention from the oil industry, since in this series lie the lowest known oil-producing horizons of this region.* Where higher formations are not oil bearing, the top of the Mississippian has usually been consid-

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* NOTE.—Recent subsurface studies and new information obtained in northern Oklahoma and southern Kansas indicate that producing horizons in these fields belong in part to the Ordovician. See Aurin, Clark and Trager, "Notes on the subsurface pre-Pennsylvanian stratigraphy of the northern Midcontinent oil fields," Am. Ass'n Petroleum Geologists, Bul., vol. 5, pp. 117-153, 1921. *State Geologist.*

1. Oral communication from Mr. A. W. McCoy, geologist for the Empire Gas and Fuel Company, who has had access to a very great number of drill cuttings.

2. Here and there in southwestern Missouri and northeastern Oklahoma the Devonian and Silurian rocks are only slightly developed. Their presence in Kansas, however, has not been well demonstrated, and hence no attempt has been made to correlate any part of the Eldorado section with these rock systems.

Another viewpoint of this thick sandstone series can be had by considering it to be of early Mississippian (pre-Boone) age. Its lithology on this basis could be accounted for through the relation of the Eldorado region to the buried "granite ridge" by postulating that the ridge existed prior to Boone times and that the material of this sandstone series which borders it was derived through its degradation by erosion. In this explanation, however, the ridge must have been greatly reduced in size by erosion and then partly submerged prior to the deposition of the Boone limestone.

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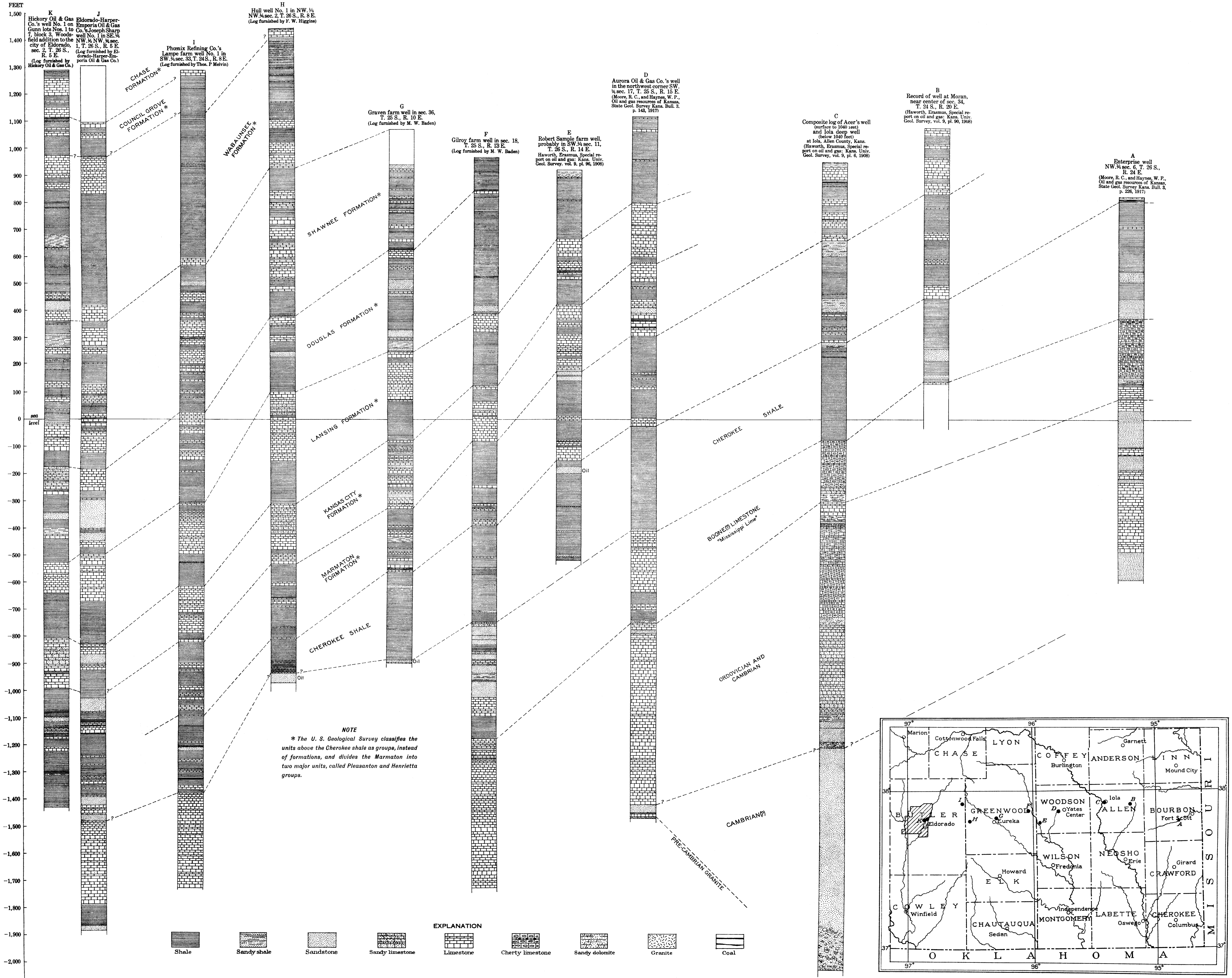
PLATE VII.



CORRELATED COLUMNAR SECTIONS BETWEEN BOURBON COUNTY AND THE ELDORADO DISTRICT, SOUTHEASTERN KANSAS

(Based on well-log information)

ered the last chance for obtaining production, and where this too is barren, deeper drilling is generally abandoned.

The Mississippian rocks crop out in Missouri, the southeastern corner of Kansas, and northeastern Oklahoma, and consist of 300 to 350 feet of cherty limestone, which has been termed the Boone limestone. Drillers and oil operators, however, often speak of it as the "Mississippi lime" or the Boone chert.

By the use of well records after the manner shown in plate VII, the Boone formation has been traced westward as far as Butler county and its surface through eastern Kansas contoured with considerable accuracy by Moore and Haynes.[3] The westernmost contours of Moore and Haynes' map extend into the Eldorado region and indicate the top of the Mississippian to lie about 1,800 feet below sea level, or at a depth of about 3,200 feet. These westernmost contours are probably extrapolations which were based principally on the apparent regular westerly dip prevalent to the east of the Eldorado district, and which took no account of the flexure in the deep-lying Mississippian rocks in this field, that raises these rocks hundreds of feet nearer to the surface. Only a part of this rise is apparent in the less strongly folded surface rocks, and the remainder is accounted for by a local thinning of the formations overlying the Mississippian on the crest of the anticline. This will be pointed out on a later page from the evidence presented by well logs.

In the Eldorado field the prolific oil-producing Stapleton pay zone lies at the top of a thick series of rocks, principally sandstones, below a shale which is the lowest shale in this general locality. This relation is similar to that of the Boone limestone in Greenwood and Woodson counties to the east (logs *D* to *H* in plate VII), where its presence is sufficiently well known so that the top of the Boone and the thickness of the overlying Cherokee shale can be contoured.[4] Well-record correlations between these areas and the Eldorado field indicate the Stapleton pay zone, as shown at the right in plate VI, to be at the top of the pre-Pennsylvanian rocks, or in the same relative position as the Boone. A study of plate VII and the sections *G* and *H*

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3 Moore, Raymond C., and Haynes, Winthrop P.; Oil and gas resources of Kansas: State Geol. Survey of Kansas, Bull. 3, pl. XXV; 1917.

4 Moore and Haynes; op. cit., plate XXV. Berger, Walter R.; The relation of the Fort Scott formation to the Boone chert in southeastern Kansas and northeastern Oklahoma: Jour. Geol., vol. XXVI, pp. 618-21; 1918.

of plate VIII, which are a direct continuation thereof, brings this relation out very clearly. In addition to this stratigraphic relation the Stapleton is largely a cherty limestone (see description on pp. 30-36), the same as the Boone, and this lithologic similarity, together with its similarity in stratigraphic position, seems to the writer to constitute sufficient evidence for correlating the limestone portion of the Stapleton with the Boone. If this correlation be correct the configuration of the upper surface of the Mississippian rocks in the Eldorado field is the same as that of the top of the Stapleton oil zone as given on plate I. The thickness of the Mississippian rocks in the Eldorado region will be brought out in the discussions of the Stapleton oil zone.

Stapleton Oil Zone.

The deep and productive Stapleton oil zone of the Eldorado field, which obtains its name from the Stapleton lease in sec. 29, T. 25 S., R. 5 E., where it was discovered, is believed by the writer to be a special phase of the pre-Pennsylvanian rocks (it may include more than the Mississippian), which, because of its importance in the production of oil, deserves special consideration. Further, its lithology differs so from place to place that an interpretation based on this variation must be made.

The mineral character of this pay varies greatly, from cherty dolomitic limestone through shale to sandstone composed of well-rounded quartz grains. The shale beds, which probably lie interbedded with the limestone, are in general thin, and their distribution is dependent upon the extent to which the post-Mississippian erosion period affected them. The diversity in composition of the Stapleton pay zone is indicated by the following detailed descriptions of drill cuttings, obtained from wells rather widely scattered in the Eldorado field:

Empire Gas and Fuel Company's Cardey Well No. 7.

(Northeast corner location in NW¼ SE¼, sec. 11, T. 26 S., R. 4 E.)

Top of sand at 2,333 feet.

Depth of sample, feet.	Material of sample.	Interpretation of sample.
2,329–2,330	Shale, light to dark gray; calcareous.	Shale, gray, calcareous.
2,330–2,346	No samples.	
2,346–2,352	Limestone, tan to gray in color, dolomitic; and shale, black.	Limestone, tan to gray in color, dolomitic; with a few interbedded thin shales, dark gray.
2,352–2,355	Limestone, tan to gray in color, dolomitic; with a little shale, dark gray.	
2,355–2,356	Limestone, tan to gray in color, dolomitic; with a little shale, dark gray.	
2,356–2,360	Limestone, gray, dolomitic; with considerable shale, dark gray.	Limestone, gray, dolomitic; with a few interbedded thin shales, dark gray.
2,360–2,363	Limestone, gray, dolomitic; with considerable shale, dark gray.	
2,363–2,366	Limestone, gray, dolomitic; with considerable shale, dark gray.	
2,366–2,368	Limestone, gray, dolomitic; with some shale, dark gray.	
2,368–2,370	No sample.	
2,370–2,372	Limestone, gray, dolomitic; with but very little shale.	Limestone, gray, dolomitic, slightly cherty; and a few interbedded thin shales, dark gray.
2,372–2,375	Limestone, light gray, dolomitic.	
2,375–2,377	Limestone, light gray, dolomitic; with some shale, black; and a very little chert.	

Empire Gas and Fuel Company's Paulson Well No. 3.

(Center location along north line of NW¼ NE¼, sec. 2, T. 26 S., R. 4 E.)

Top of sand at 2,350 feet.

Depth of sample, feet.	Material of sample.	Interpretation of sample.
2,348–2,350	Shale, dark gray in color; and limestone, dolomitic, gray; with considerable chert.	Shale, dark gray.
2,350–2,357	Principally chert, but also limestone, dolomitic, gray; and some shale, dark gray.	Limestone, very cherty, gray; with a few interbedded thin shales, dark gray.
2,357–2,363	Principally chert; with a little limestone, dolomitic, gray colored; and some shale, dark gray.	
2,363–2,368	Limestone, dolomitic, tan; with some chert.	Limestone, dolomitic, cherty, tan to gray.
2,368–2,374	Limestone, dolomitic, gray.	
2,374–2,381	Limestone, dolomitic, tan; with some chert.	
2,381–2,387	Limestone, dolomitic, gray; with some chert.	
2,387–2,392	Limestone, dolomitic, gray; with some chert.	
2,392–2,398	Limestone, dolomitic, tan.	
2,398–2,402	Limestone, dolomitic, tan; with a little chert.	
2,402–2,406	Limestone, dolomitic, tan; with a little chert, and some shale, dark gray.	Limestone, dolomitic, cherty, tan; with a few interbedded thin shales, dark gray.
2,406–2,407	Limestone, dolomitic, tan; with a little chert, and some shale, dark gray.	
2,407–2,409	Limestone, dolomitic, tan; with a little chert.	Limestone, dolomitic, cherty, gray to tan.
2,409–2,411	Limestone, dolomitic, gray; with much chert.	
2,411–2,414	Limestone, dolomitic, gray; with some chert.	
2,414–2,418	Limestone, dolomitic, gray; with some chert.	

Empire Gas and Fuel Company's Tague Well No. 1.

(Northeast corner location SE¼ NE¼, sec. 13, T. 26 S., R. 4 E.)

Top sand at 2,448 feet.

Depth of sample, feet.	Material of sample.	Interpretation of sample.
(?)–2,448	Shale, bluish gray; and limestone, light gray, with some chert.	Shale, bluish-gray; with gray cherty limestone at base.
2,448–2,457	No sample.	
2,457–2,464	Quartz sand, fine grained, fairly well rounded.	Sandstone, medium grained. (2,457–2,488)
2,464–2,469	Quartz sand, fine grained, fairly well rounded.	
2,469–2,474	Quartz sand, medium grained, grains well rounded.	
2,474–2,480	Quartz sand, medium grained, grains well rounded.	
2,480–2,483	Quartz sand, medium grained, grains well rounded.	
2,483–2,488	Quartz sand, medium grained, grains well rounded.	
2,488–2,492	Quartzitic sand, medium grained; with considerable shale, dark gray.	Sandstone, with a few interbedded thin shales, dark gray. (2,488–2,497)
2,492–2,497	Quartzitic sand, medium grained; with considerable shale, dark gray.	

Empire Gas and Fuel Company's Huston Well No. 1.

(Southeast corner location in SW¼, sec. 19, T. 26 S., R. 5 E.)

Top sand at 2,610 feet.

Depth of sample, feet.	Material of sample.	Interpretation of sample.
2,605–2,610	Shale, dark gray; but principally limestone, dolomitic, tan.	Shale, dark gray; with limestone, dolomitic, gray at base.
2,610–2,615	Limestone, dolomitic, gray.	Limestone, dolomitic, gray. (2,610–2,625)
2,615–2,619	Limestone, dolomitic, gray.	
2,619–2,625	Limestone, dolomitic, gray; with a little quartzitic sand.	
2,625–2,630	Quartzitic sand, medium grained; with a little limestone, dolomitic, gray.	Quartzitic sandstone, medium grained. (2,625–2,640)
2,630–2,635	Quartzitic sand, medium grained, grains well rounded.	
2,635–2,640	Quartzitic sand, medium grained, grains well rounded.	

Empire Gas and Fuel Company's Barnhill Well No. 9.

(Southeast corner location NW¼, sec. 6, T. 26 S., R. 5 E.)

Top of sand at 2,449 feet.

Depth of sample, feet.	Material of sample.	Interpretation of sample.
2,449–2,451	Principally chert; with limestone, dolomitic, gray; and some shale, dark gray.	Limestone, dolomitic, cherty, gray.
2,451–2,455	Limestone, dolomitic, gray; with considerable chert.	
2,455–2,461	Limestone, dolomitic, gray; with a little chert.	
2,461–2,466	Limestone, dolomitic, gray.	
2,466–2,471	Limestone, dolomitic, gray; with a little chert.	
2,471–2,476	Limestone, gray.	
2,476–2,482	Limestone, dolomitic, gray.	

Empire Gas and Fuel Company's Fulkerson Well No. 6.

(Northeast corner location NW¼, sec. 4, T. 26 S., R. 5 E.)

Top of sand at 2,523 feet.

Depth of sample, feet.	Material of sample.	Interpretation of sample.
2,523–2,528	Limestone, dolomitic, tan.	Limestone, slightly cherty, tan to gray in color.
2,528–2,533	Limestone, dolomitic, tan; with a little shale and a trace of chert.	
2,533–2,538	Limestone, tan; with a trace of chert.	
2,538–2,548	Limestone, tan; and a little quartzitic sand, grains well rounded.	Sandstone.
2,548–2,554	Quartzitic sand, medium grained; grains well rounded.	

Empire Gas and Fuel Company's Knox Well No. 22.

(Center location along south line of SE¼ NW¼, sec. 15, T. 25 S., R. 5 E.)

Top of sand at 2,507 feet.

Depth of sample, feet.	Material of sample.	Interpretation of sample.
2,507–2,523 (?)	No sample.	
2,523 (?)–2,526	Limestone, dolomitic, tan; with a little black shale.	Limestone, dolomitic, gray; with a few interbedded thin shales, dark gray.
2,526–2,527	Limestone, dolomitic, tan; with considerable shale, dark gray.	
2,527–2,530	Limestone, dolomitic, gray to tan; with some shale, dark gray.	
2,530–2,535	Limestone, dolomitic, gray to tan.	
2,535–2,540	Limestone, dolomitic, gray to tan; with some shale, dark gray.	
2,540–2,544	Limestone, dolomitic, gray to tan.	Limestone, dolomitic, gray.
2,544–2,549	Limestone, dolomitic, gray to tan.	

Empire Gas and Fuel Company's Wilson Well No. 55.

(Southeast corner location NE¼ NW¼, sec. 8, T. 25 S., R. 5 E.)

Top of sand at 2,443 feet.

Depth of sample, feet.	Material of sample.	Interpretation of sample.
2,334–2,445	Shale, gray to black; with considerable quartzitic sand and some cherty conglomeratic pebbles.	Shale, gray to black.
2,445–2,448	Shale, gray to black; and sand, medium grained.	
2,448–2,453	Quartzitic sand; and shale, dark gray.	Sandstone, medium grained; interbedded with several thin beds of shale, dark gray.
2,453–2,458	Quartzitic sand; with some shale and a little chert.	
2,458–2,463	Quartzitic sand, medium grained, grains well rounded; with a little shale, dark gray.	
2,463–2,468	Quartzitic sand, medium grained, grains well rounded.	

Empire Gas and Fuel Company's Wilson Well No. 60.

(Center location along north side of NE¼, sec. 8, T. 25 S., R. 5 E.)

Top of sand at 2,475 feet.

Depth of sample, feet.	Material of sample.	Interpretation of sample.
(?)–2,475	Shale, dark bluish-gray; with a little limestone, dolomitic, gray to tan.	Shale, dark gray.
2,475–2,481	Limestone, tan; with some shale, dark gray.	Limestone, dolomitic, slightly cherty, interbedded with a few thin shales, dark gray.
2,481–2,487	Limestone, tan; with some shale, dark gray.	
2,487–2,493	Limestone, dolomitic, tan; with a very little chert.	
2,493–2,499	Limestone, dolomitic, gray to tan; with much shale, dark gray.	

The variation in composition from cherty limestone, through shale, to sandstone is both horizontal and vertical, or geographic and stratigraphic. Drill cuttings of the Stapleton oil zone were obtained from forty-nine wells scattered rather widely over the field, but on detailed examination it was found that this number was insufficient from which to make any definite statement concerning the geographic and stratigraphic distribution of the limestone, shale and sandstone composing it. It seems, however, that the oil zone over much of the Koogler nose is composed principally of well-rounded quartz sand, whereas over much of the remaining part of the field it alternates more between limestone and sand, with the limestone predominating.

This variation in composition may possibly be due to purely geographic distribution of material in the same stratigraphic interval, as believed by some, but the author believes that a more plausible interpretation may be found in considering the Stapleton oil zone to be not a stratigraphic unit, but the dissected upper portion of the pre-Pennsylvanian rocks which suffered a period of erosion prior to the deposition of the Pennsylvanian sediments. This interpretation of the Stapleton zone is diagrammatically illustrated in figure 1. The top of this zone in the Eldorado field would thus be a peneplained surface with little relief, which since its dissection in post-Mississippian times has been warped into the attitude of an anticline. The limestone portions of the Stapleton zone may, therefore, be interpreted as remnants of the Boone limestone, and the sandstone portions as rocks of pre-Boone age. The thickness of the Mississippian rocks, on this basis, is indicated in the developed part of the field by the thickness of the limestone portions of the Stapleton oil zone. Where both limestone and sandstone are recorded in the well logs the limestone overlies the sandstone, in full agreement with this interpretation. Information pertaining to the thickness of the limestone in the area bordering the field proper was available from but one well log, shown graphically as *J* on plate VII. In the absence of drill cuttings from this well it is impossible to judge whether the limestone begins at 2,711 or at 2,806 feet; and depending on this, the Boone, according to the log, is either 402 or 307 feet thick, for at 3,113 feet the drill is reported to have passed from limestone into a soft formation logged as shale, and after 82 feet of this into sand for 18 feet. Drilling continued beyond this depth, 3,213 feet, but the log below this point was not available.

In the hope that fossil evidence would assist in establishing the age of the Stapleton zone, a microscopic examination was made of its drill cuttings from several wells for remains of microscopic organisms, but no determinable forms were found.

The Stapleton oil zone, according to the above interpretation of the author, and the interpretation which will be implied throughout the text, is not a stratigraphic unit, but instead is merely that portion of the Mississippian, and possibly pre-Mississippian, strata which is or might be oil-bearing. For this reason the term "sand," which is usually interpreted as an oil-bearing stratigraphic unit, has been substituted by "zone," a term which is more accurately descriptive.

Inasmuch as the author does not consider the Stapleton oil zone to be a stratigraphic unit, the concept of its thickness must be limited to the thickness of the pay rock where it is oil-bearing. Where not oil-bearing the Stapleton zone must be regarded simply as the upper part of the older rocks. The thickness of the oil-bearing portion probably varies greatly from place to place in the field, in some parts of the field within very short distances, especially where the oil follows some definite porous bed, and this bed dips at an angle with the top of the eroded Stapleton surface. The entire thickness of the

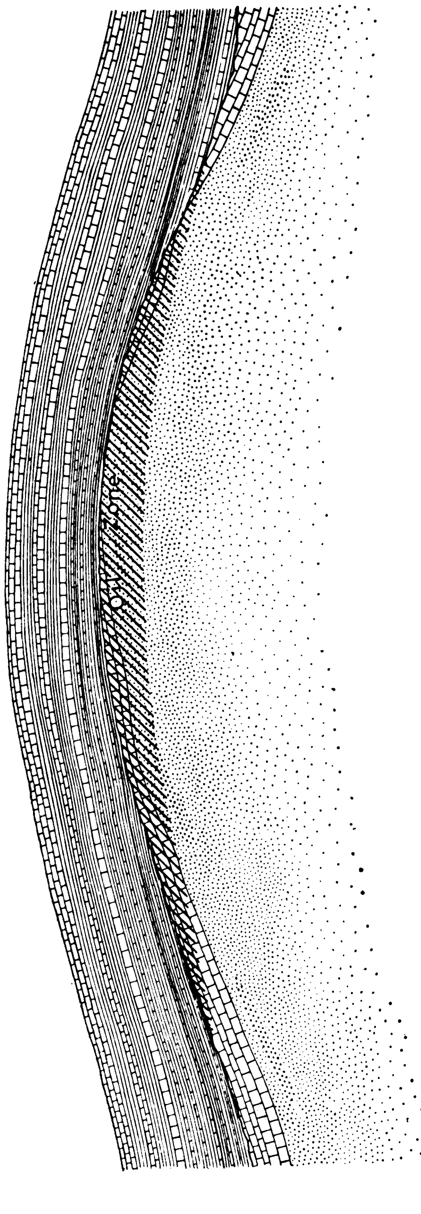


FIGURE 1.—Diagrammatic sketch showing an oil zone which crosses the bedding of the rocks in which it is contained.

Stapleton zone can be determined in but few places, since in wells the drilling is almost invariably stopped before passing through the oil zone. The thickness, therefore, cannot in general be determined closer than by the number of feet the oil zone is penetrated. Interest in the thickness of the oil-bearing zone centers principally in ascertaining the thickness of the reservoir rocks. On the Shumway dome the penetration of the Stapleton oil zone ranges in general from 35 to 65 feet. A few wells have penetrated as much as 90 feet, whereas others entered the Stapleton zone as little as 4 or 5 feet. The amount of penetration appears to be determined principally by the depth where the greatest flow of oil can be obtained. As an example, the Gypsy Oil Company's Shumway well No. 13, which was drilled in with a 17,000-barrel production, penetrated the Stapleton zone only 6 feet (see log on pp. 103-104), whereas the Carter Oil Company's Orban well No. 1, less than 2,000 feet distant, penetrated 60 feet before its production reached 10,000 barrels.

On the Boyer dome the penetration is in general greater, ranging principally between 50 and 80 feet, with exceptional ones reaching more than 100 feet. On the Koogler nose of this structure, where quartz sand appears to constitute most of the pay rock, the penetration in general ranges between 10 and 25 feet. On the Oil Hill dome the range averaged between 20 and 50 feet, with a few penetrating more than 80 feet into the sand. The range of penetration on the Chesney dome is greater, from 20 to 80 feet; and on the Wilson dome from 20 to 40 feet. The Robinson dome in this respect is very similar to the Wilson dome, most of the wells being drilled into the sand between 15 and 40 feet. The amount of penetration in certain areas is graphically shown on plate VIII.

PENNSYLVANIAN ROCKS.

Cherokee Shale[5] *and Marmaton Formation.**

Overlying the Stapleton oil zone and in the interval between it and the Kansas City formation, which in eastern Kansas is occupied by the Cherokee shale and the Marmaton formation, is a variable thickness of shale with interbedded thin lime-

* The divisions of the Pennsylvanian and Permian referred to in this report as "formations," in accordance with the usage of the Kansas Geological Survey in its reports, are at present considered as stratigraphic "groups" by the United States Geological Survey where applied to rocks in Kansas.

5. Named after Cherokee county, Kansas. Haworth, Erasmus, and Kirk, M. Z.; The Neosho river section: Kan. Univ. Quart., vol. 2, p. 105; 1894.

stones. On the crest of the Eldorado anticline this shale and limestone series measures about 250 feet, but on the flank it thickens rapidly, in one place to as much as 650 feet. (See the graphic Eldorado logs on plate VI, and sections on plate VIII.) Its thickness probably increases to beyond this amount, but the drilling information is not sufficiently satisfactory for accurate determinations. This variation in thickness from place to place is probably due to the early Pennsylvanian sediments in this region overlapping a previously formed anticlinal ridge in the Mississippian rocks.

In eastern Kansas the oldest formation of Pennsylvanian age is the Cherokee shale, which contains many of the oil sands of the northern Midcontinent field. Berger [6] has shown by his study of well records and drill cuttings that this formation thins in going west from Labette county to Butler county, and that because of the thinning and probable elimination of the Fort Scott limestone in eastern Butler county it so merges with the rocks of the overlying Marmaton formation that the two cannot be accurately differentiated farther west. This undoubtedly is the condition as the Eldorado field is approached. If the Cherokee shale continues to thin in Butler county at about the same rate as it does to the east of it, as shown by Berger,[7] it should be about 200 feet thick in the region immediately east of the Eldorado anticline. Whether it pinches out on reaching the flanks of the anticline, or whether it continues on over the crest by a relatively greater thinning in conjunction with a thinning of the overlying Marmaton formation, cannot, it is obvious, be ascertained from well-record information only. At any rate, the Cherokee probably reaches the Eldorado region in the Walnut syncline, where, as on the flanks of the anticline, it forms a part of the interval between the Stapleton oil zone and the Kansas City formation. It may be entirely absent on the crest of the anticline, and if present it must be thin.

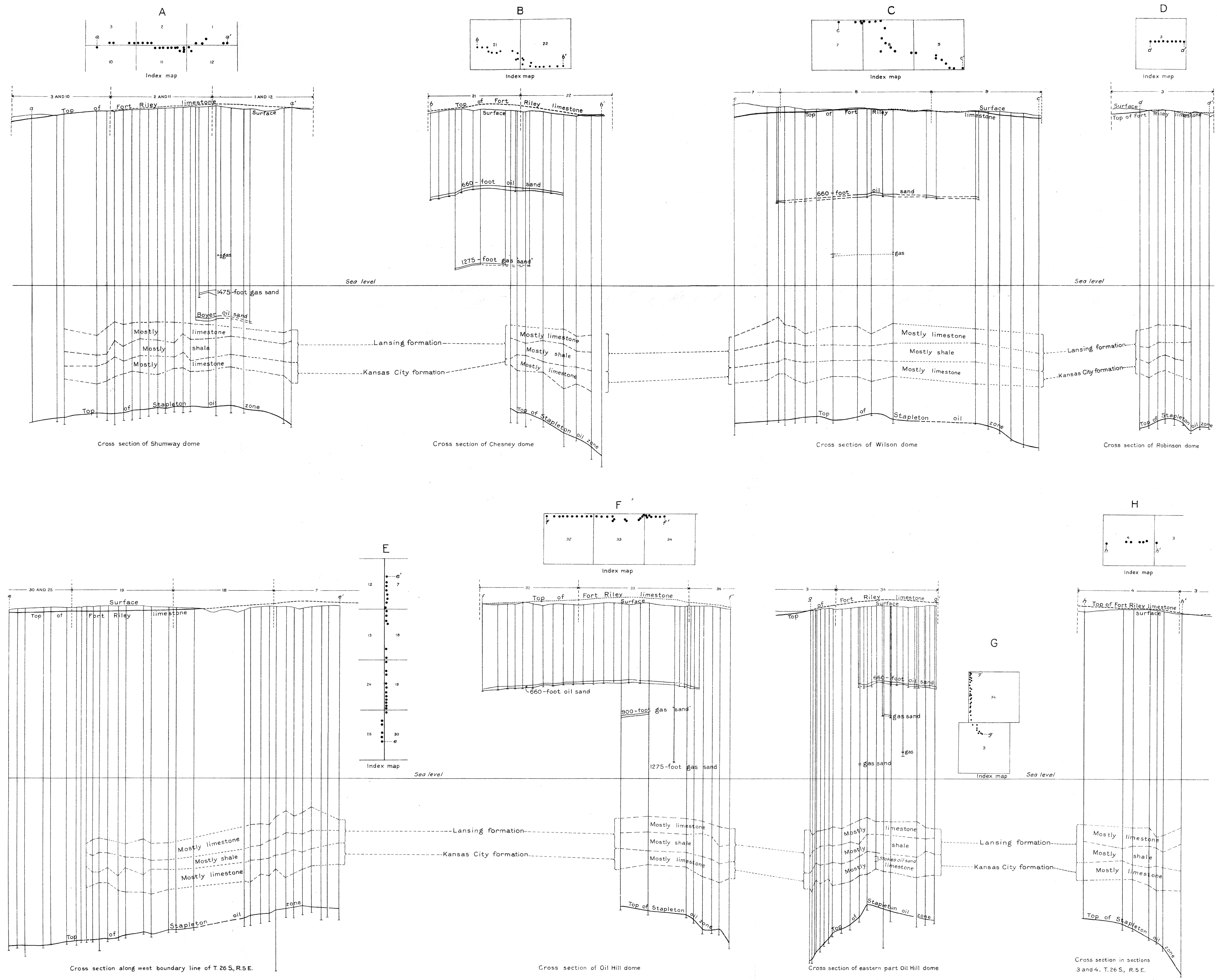
The Marmaton formation in its outcropping area in eastern Kansas is composed of several distinct limestone and shale members. To the west these members gradually lose their identify, and by the time they reach the Eldorado field they

6. Berger, Walter H.; The relation of the Fort Scott formation to the Boone chert in southeastern Kansas and northeastern Oklahoma: Jour. Geol., vol. XXVI, pp. 618-621; 1918.

7. Op. cit.

STATE GEOLOGICAL SURVEY OF KANSAS
IN COOPERATION WITH
U. S. GEOLOGICAL SURVEY

PLATE VIII.



STRATIGRAPHIC SECTIONS IN PARTS OF THE ELDORADO FIELD, KANSAS

(Sections based on information obtained from well-logs. The locations of the wells shown in the sections are indicated on the accompanying index maps without differentiation as to whether they are oil, gas, or dry wells.)

can no longer be differentiated. It is apparent that over the crest of the Eldorado anticline the thickness of the Marmaton is thinner than at the outcrop, even though it embraces most of the 250 feet of shale and thin limestone overlying the Stapleton oil zone on the crest of the anticline.

Kansas City Formation.[8]

The strata overlying the Marmaton formation can be correlated somewhat more readily by means of well records with their outcropping equivalents in eastern Kansas. Although the formations as a whole can be differentiated with considerable accuracy, the individual members have changed sufficiently and merged with each other to such an extent that they do not, as a rule, stand out as distinct units in the well records. Probably the most uniformly recorded beds in all the Eldorado well logs are two thick limestones separated by a thick shale, which altogether comprise about 500 feet of rocks lying approximately between 1,700 and 2,300 feet below the top of the Fort Riley limestone. These lithologic units which comprise the Kansas City and Lansing formations are differentiated in plate VI and the cross sections on plate VIII. The lowermost of these three lithologic units is believed to be the local representative of the Kansas City formation, which here, as well as in Greenwood county, as represented by the logs in plate VII, is less subdivided than in the region of its outcrop, as shown in plate VI—a feature which probably indicates that the Eldorado and Greenwood county localities were nearer the center of the depositional basin in which these strata were formed. In this connection it may be pointed out that the deep portion of the Cherokee basin, as interpreted by Berger,[9] lies along a line from Labette county, Kansas, to Rogers county, Oklahoma. In like manner the thickest portion of the overlying Fort Scott limestone of the Marmaton formation lies farther west, in northeastern Osage county, Oklahoma, and southeastern Chautauqua county, Kansas, or west of the deeper portion of the Cherokee basin. The more calcareous nature of the Kansas City formation in the Greenwood county and Eldorado localities, which lie still farther west, suggests a

8. Named after Kansas City, Mo. Hinds, Henry, and Greene, F. C.: The stratigraphy of the Pennsylvanian series in Missouri: Mo. Bur. Geol. and Mines, vol. 13, 2d series, p. 23; 1915.

9. Berger, op. cit.

continued westward shifting of the successive depositional basins.

It is to be noted that the Stokes "sand," which is producing pay in three wells near the east quarter corner, sec. 33, T. 25 S., R. 5 E. (marked as miscellaneous wells on plate I), and found at a depth of about 2,000 feet is a part of the limestone here correlated with the Kansas City formation. No drill cuttings of this "sand" were obtained; hence the driller's interpretation which designates it "sand" represents the only information concerning its lithology which can be supplied in this report.

Lansing Formation.[1]

Overlying the beds correlated with the Kansas City formation in most of the logs of the Eldorado wells is a comparatively thick shale, followed by another limestone similar in thickness to the limestone representing the Kansas City formation. Some few logs record "sand" between the shale and limestone, as in plate VI, but in general this is not mentioned. The shale probably is the equivalent of the Lane shale and the limestone the equivalent of the Plattsburg, Vilas and Stanton members, all of which belong to the Lansing formation.

The Kansas City formation as previously mentioned, is more calcareous in the Greenwood county and Eldorado localities than in the region of its outcrop, and so also is the Lansing formation, indicating that the Lansing basin was equally as far west as the earlier Kansas City depositional basin.

Douglas Formation.[2]

Overlying the thick shale and two limestones representing the Lansing and Kansas City formations are 200 to 250 feet of shale with a few thin limestone and sandstone members. These are correlated with the Douglas formation. The Oread limestone, at the top of the Douglas, is not positively identified, but the limestones in the Eldorado section (plate VI), lying between 1,395 and 1,490 feet below the top of the Fort Riley limestone are considered by the writer to be its approximate equivalent. These are the limestones that contain the 1,475-foot gas "sand." The Boyer "sand," which lithologically is a

1. Named after Lansing, Leavenworth county, Kansas. Hinds, Henry, and Greene, F. C.; Stratigraphy of the Pennsylvanian series in Missouri: Mo. Bur. Geol. and Mines, vol. 13, 2d series, p. 28; 1915.

2. Named after Douglas county, Kansas. Haworth, Erasmus: Stratigraphy of the Kansas Coal Measures: Kan. Univ. Geol. Survey, vol. 3, p. 93; 1898.

limestone, occurs in the lower part of the Douglas formation and may be considered to belong to the Weston shale.

Shawnee Formation.[3]

The overlying rocks in the Eldorado field that are correlated with the Shawnee formation consist of a thick series of interbedded limestones and shales, with the limestones predominating. The shale at the top of this division is believed to be the Scranton shale. The rocks as a whole are more calcareous than the Shawnee at its outcrop, and in addition are also more calcareous than in Greenwood county, a feature which is brought out by comparing the well records in plates VI and VII. This westward increase in the quantity of limestone in the rocks of this interval indicates that the Eldorado region was nearer to the center of the general Shawnee depositional basin than the area to the east. This would seem to indicate a still farther westward migration of the depositional basin since Kansas City time.

This suggested westward shifting of the depositional basins for the successive groups indicates a gradual elevation in some center lying to the east, probably the Ozark uplift. It further indicates that concurrent with the deposition of these Pennsylvanian rocks slight deformational movements occurred, a feature which will be taken into consideration in explaining, on pp. 160-163, the greater flexing of the deeper rocks than the surface formations in the Eldorado field.

The Shawnee formations contains the 900-foot, 1,125-foot, 1,200-foot and 1,275-foot gas "sands," but since the various formations cannot be differentiated, no close correlations can be made for the different producing "pays."

Wabaunsee Formation.[4]

Immediately above the Scranton (?) shale is a thin limestone, which is believed to be the Burlingame limestone, at the base of the Wabaunsee formation. This is followed by about 210 feet of shale, which probably represents the Willard and Admire shales, the intervening Emporia limestone not being recognized in the well records. The importance of this thick

3. Named after Shawnee county, Kansas. Haworth, Erasmus; op. cit., pp. 93-94; 1898.

4. Named after Wabaunsee county, Kansas. Prosser, C. S.; The classification of the upper Paleozoic rocks of central Kansas: Jour. Geol., vol. 3, pp. 682-705 and 764-800; 1895.

shale lies in the fact that it contains the two shallow oil sands of the Eldorado field. Following this shale are several limestones and shales which probably are the equivalents of the Americus limestone, Elmdale formation, Neva limestone, and Eskridge shale, the latter forming the top of the Wabaunsee formation, and probably the top of the Pennsylvanian in eastern Kansas.

PERMIAN ROCKS.

Council Grove Formation.[5]

There is no stratigraphic break between the Pennsylvanian and Permian systems in this part of Kansas; deposition appears to have been continuous from one period to the other. Because of the transitional nature of the upper Pennsylvanian and the lower Permian strata, the dividing line between the two is difficult to determine. According to the present classification of the United States and Kansas Geological surveys the line is drawn at the base of the Cottonwood limestone, the basal member of the Council Grove formation and a well-defined bed which has been mapped across the entire state of Kansas.[6]

A limestone, apparently persistent in the Eldorado field, is found about 400 feet below the top of the Fort Riley limestone, but according to the writer's interpretation this is more likely to be the Neva limestone, which is near the top of the underlying Wabaunsee formation. Besides the Cottonwood limestone, the Council Grove formation includes the Garrison member, a comparatively thick calcareous shale containing numerous thin limestone beds. Because of its "shelly" nature, its interpretation by drillers varies from limestone, through "shells," to shale.

Chase Formation.[7]

The next higher subdivision of the Permian is the Chase formation, the two basal members of which—the Wreford limestone[8] and the Matfield shale—are not exposed in the

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5. Named after Council Grove, Morris county, Kansas. Prosser, C. S.; Revised classification of the upper Paleozoic formations of Kansas: Jour. Geol., vol. 10, p. 716; 1902.

6. Haworth, Erasmus; Special report on oil and gas: Univ. Geol. Survey of Kan., vol. IX, pls. VII, *a, b, c;* 1908.

7. Named after Chase county, Kansas. Prosser, C. S.; Revised classification of the upper Paleozoic formations of Kansas: Jour. Geol., vol. 10, pp. 713-714; 1902.

8. Named after Wreford, Geary county, Kansas. Hay, Robert; Geology and mineral resources of Kansas: Kan. State Board of Agric., 8th Biennial Report, 1891-1892; 1893.

Eldorado field. The Wreford is a persistent stratigraphic unit very generally recorded in the well records. In many records this limestone is masqued by its flinty character, which because of its cutting effect on the bit, and water-bearing character, appears to have been interpreted by many drillers as sand.

In the Flint Hills escarpment and along the Missouri Pacific right of way, about 16 miles east of Eldorado, the Wreford forms a rather conspicuous ledge. It consists for the most part of cherty limestone and thin calcareous shales, which, as measured by the writer, total about 28 feet in thickness.[9]

The Matfield shale [1] is the highest unexposed stratigraphic unit in the Eldorado field. Really its upper portion, although not seen, may be present beneath a cover of soil and detritus washed down from the overlying rocks in the bottoms of the deeper valleys in secs. 20 and 17, T. 26 S., R. 5 E. Its outcrop, however, may be observed in the Flint Hills escarpment about 16 miles east of Eldorado and along the Missouri Pacific right of way, where it consists of maroon, bluish and yellowish calcareous shales and a few thin light-gray limestone beds, having a total thickness of about 57 feet.[2] In the well logs of the Eldorado field the Matfield is not always recorded with any great degree of uniformity. It is usually logged as "shale," and the thickness recorded varies from 45 to 75 feet.

EXPOSED ROCKS.

INTRODUCTORY STATEMENT.

But two classes of rock—limestone and shale, together with their intergradations—comprise the exposed rocks in the Eldorado field, and of these nine distinct stratigraphic units were recognized and mapped. As shown in plate VI, they all belong to but two formations—the Chase and Marion, of the Permian system. Those at the bottom, up to and including the Winfield, belong in the Chase formation, and the higher ones belong in the Marion formation. Several of these units, because they are difficult to erode, are prominent in the surface topography of the region.

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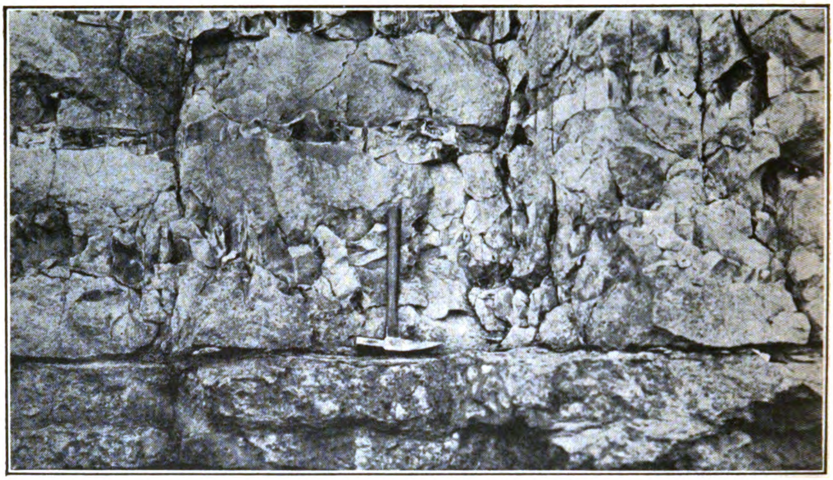
9. For a more detailed description see Beede, J. H., and Sellards, E. H.; Stratigraphy of the eastern outcrop of the Kansas Permian: Amer. Geol., vol. XXXVI, pp. 83-111; 1905.

1. Named after Matfield, Chase county, Kansas. Prosser, C. S., and Beede, J. W. Revised classification of the upper Paleozoic formations of Kansas: Jour. Geol., vol. 10, p. 718, diagram; 1902.

2. For a more detailed description see Beede, J. H., and Sellards, E. H.; op. cit., pp. 96-100.

PLATE IX.



A. Exposure of the Florence flint, showing its chert-bearing character.

B. Boulderlike outcrop of the top of the Fort Riley limestone.

PERMIAN ROCKS.

Chase Formation.

FLORENCE FLINT.[3] The lower part of the exposed Eldorado section consists of a limestone which measures 80 to 90 or more feet in thickness. The lower part of this limestone is characterized by its abundant content of chert, and thereby differs noticeably from the upper portion which contains no chert whatever. This two-fold character is uniformly persistent over wide areas and has permitted a division of the limestone into two distinct units—the lower flinty or chert-bearing portion, being appropriately termed the Florence flint; and the upper, more calcareous portion, the Fort Riley limestone.

The maximum exposed thickness of the Florence flint in the Eldorado field is in the south bank of the creek near the center of sec. 20, T. 26 S., R. 5 E., where it measures 35 feet. Its base was not observed in the Eldorado district, but its complete thickness probably does not greatly exceed 35 feet. This thickness is greater by 7 or more feet than at the type locality at Florence, 35 miles north of Eldorado, where its complete thickness, 27 feet, is shown in the face of a quarry about half a mile northeast of the town, along the McPherson branch of the Santa Fe railroad.

The upper boundary of the Florence flint is not marked by any topographic feature in the Eldorado district, but is defined merely by the upper limit of the chert. The dominant character of the Florence member is its flint, or as it may be termed preferably, its chert content, which comprises about 20 per cent of the rock and occurs as chert beds and bands of chert nodules rather uniformly interbedded with the limestone. The chert beds have characteristic nodular surfaces (see plate IX, *A*), and commonly range from 2 to 6 or 8 inches in thickness. The chert weathers to a rusty color, and on such surfaces it generally shows in relief innumerable fragmentary fossil remains, principally Bryozoa.

Because of its greater resistance to weathering, the chert is present as residual material in many places where there are no exposures of the Florence. By this evidence the areal distribution of the Florence is indicated in many localities. Where the chert is not noticeable on the surface of the ground

3. Named after Florence, Marion county, Kansas. Prosser, C. S.; The classification of the upper Paleozoic rocks of central Kansas: Jour. Geol., vol. 3, p. 773; 1895.

it is buried in the soil, and digging will generally disclose its presence. Pipe-line ditches and sludge pits or other excavations were thus of great help in disclosing the distribution of the Florence, and not only was its general areal extent indicated, but by noting where the chert ceased it was possible without natural exposures to determine closely the contact between the Florence flint and the overlying Fort Riley limestone.

The limestone of the Florence is nearly white and appears slightly granular in texture, although some layers, particularly near the bottom, are light gray and compact. The weathered surface is usually more or less gray. On the whole, however, there is no general distinctive difference between any parts of the Florence, either in the character of limestone or of the chert, or even in the distribution of the chert within the limestone. There is no color distinction between the limestone of the Florence and the lower part of the Fort Riley. The fauna of the Florence flint, according to Dr. George H. Girty, is clearly not distinctive. In a few places thin layers were observed which were made up largely of the coral *Lonsdaleia ?* n. sp. The following list is a representative collection of forms gathered from several places throughout the field and identified by Doctor Girty:

Productus calhounianus ?
Productus cora ?
Lonsdaleia ? n. sp.
Myalina wyomingensis ?
Deltopecten occidentalis.

FORT RILEY LIMESTONE.[4] The Fort Riley limestone is in several respects the most important stratigraphic unit in the Eldorado field. It is the surface rock throughout much of the producing area, and in many places the ground surface conforms closely to the top of this formation. It is thus more intimately related than any other unit to the determination of the structure, and because of this close relationship its upper surface is the key horizon used in this report for representing the structure of the outcropping rocks.

The Fort Riley as a whole is well exposed in but few places, though good exposures of its various divisions can be found at numerous places. It shows variations both in character and

4. Named after Fort Riley, Geary county, Kansas. Swallow, G. C.; Preliminary report, Geological Survey of Kansas, p. 14; 1866.

thickness, and ranges from whitish through yellowish-white to bluish-gray. In thickness it ranges from 44 feet along the Walnut river in sec. 8, T. 25, R. 6, to 55 or 56 feet in the SE¼, sec. 22, T. 26, R. 5. Throughout most of the field a threefold division in character is recognizable—a lower massively bedded portion; a middle thinly bedded or shaly portion; and an upper massively bedded portion. The characteristics of these subdivisions are indicated in the following generalized section:

Generalized section of the Fort Riley limestone in the Eldorado field.

	Thickness, feet.
Doyle shale.	
Fort Riley limestone.	
Upper, massively bedded division.	
Limestone, massively bedded; whitish to light gray; ranging from oölitic, through a characteristic minutely honeycombed, to a compact texture; weathering on level surfaces to boulder-like masses; fossiliferous	0–25
Middle thinly bedded division.	
Limestone, thin-bedded, light gray to bluish-gray; in most cases compact; interbedded with shale, calcareous; greenish gray to gray; fossiliferous	15–25
Lower massively bedded division.	
Limestone, massively bedded; spotted or granular, to finely compact in texture; light to dark gray; fossiliferous	10–21
Florence flint.	

As the formation varies in thickness, so each of the three divisions also vary in thickness, the upper heavy-bedded portion more than the two lower divisions. This upper portion is practically if not entirely absent in the northeast corner of the Eldorado district. It, as well as the lower massively bedded portions, each have their individual characteristics, and hence it is, in general, readily possible to determine to what part of the formation any isolated exposure may belong. These differences in character were of great value, especially in locating the contact with the underlying Florence flint at such places where exposures were poor and meager, particularly in pipeline or other excavations which but slightly uncovered the soil-buried rocks.

The base of the Fort Riley is placed just above the uppermost chert-bearing bed which represents the top of the Florence flint. The top of the Fort Riley is at the contact with the overlying Doyle shale. The lower part of this shale is in some places very limy, and may be called shaly limestone, but in such localities the topmost massively bedded limestone, with its individual characteristics, as described below, is considered the top of the Fort Riley.

The lower massive portion of the Fort Riley, which varies in thickness from 10 to 20 or more feet, is characterized by its content of small, indistinct, globular masses, which in places give it a spotted or faintly pisolitic appearance, especially on a freshly broken surface. In places these globular masses are more resistant than the embedding material, and give the rock a rough, etched appearance. The globular masses where weathered are more white or chalky than the embedding limestone, and range in size from minute grains to small masses one-fourth or one-third of an inch in diameter. In places they comprise practically the entire mass of the rock, while in other portions of the rock they are more scattered. Taken as a whole, however, the spotted or faintly pisolitic appearance is characteristic. This character is not confined exclusively to the lower part of the Fort Riley, but extends also slightly down into the chert-bearing Florence, and in such places the presence or absence of chert determines whether the rock belongs to the Fort Riley or Florence division. Because of their indistinct nature, it is rather uncertain whether the globular masses are concretionary grains or unknown organisms.

The middle division of the Fort Riley, which varies from 15 to 25 feet in thickness, is characterized by its thin and more argillaceous beds. In places limy shales form a part of this division. Because of this more argillaceous nature the exposures of this part are fewer and poorer than the overlying and underlying massively bedded parts. It is this contrast in exposure and character that so readily permits a subdivision of the Fort Riley.

The upper massively bedded division is more picturesque in its outcrops than the lower divisions. This is indicated by plates IX, *B*, and X, which show its pitted boulderlike outcrop and sink-hole-forming character. These boulders cover areas hundred of acres in extent in some places, and where the ground surface is nearly horizontal they are accompanied by sink holes. Even though these major features are not present, the rock itself is characterized by its porous nature, which may be described as minutely honeycombed or finely spongelike. The cause of the porous texture was not ascertained. This honeycomb structure is not uniformly present throughout the upper part of the Fort Riley, but it is its dominant individual character. The bouldery aspect of the outcrop, so typical of the upper Fort Riley, is a weathering phenomenon in which the joint planes play an important rôle, permitting readier circulation for dissolving waters. As the individual blocks become

Plate X.—Two views showing sink-hole development in upper division of the Fort Riley limestone.

smaller through solution the remnants become more isolated and the surface of the ground acquires a boulder-strewn appearance. Because this upper part is so soluble, sink holes have formed in it, especially where the surface is nearly level, for the rainfall, instead of running off, soaks through the soil into the porous limestone and through solution develops an efficient underground drainage. The depth of the sinks is probably controlled by the thickness of the upper member.

The three divisions of the Fort Riley limestone are well differentiated in the following section west of the Sluss pool:

Section of Fort Riley limestone exposed in north bank of small creek in the SE¼, sec. 22, T. 26 S., R. 5 E.

Doyle shale	
Fort Riley limestone.	
Upper division.	*Thickness, feet.*
Limestone, massive, whitish to light gray, forms 3 ledges. At places on the top of the lowermost bench a great many weathered-out fossils are present. (See fossil list on p. 53)	25
Middle division.	
Limestone, thinly bedded, light gray, more argillaceous than overlying and underlying divisions, probably interbedded with several thin beds of shale. Poorly exposed	20
Lower division.	
Limestone, massive, light gray, finely spotted and slightly pisolitic appearing	10
Florence flint.	

The upper division of the Fort Riley, as previously mentioned, is entirely absent in the northeastern part of the district. This is due apparently to a thinning eastward and northward, which culminates in the valley crossing the northeastern part of section 6 and the northwestern part of sec. 5, T. 25 S., R. 6 E. The thinning is evident also in the section given below, which is exposed in the face of the Dolese Brothers' quarry, about two miles east of Eldorado and a short distance east of the area embraced by the map (plate I). The threefold division so typically exhibited throughout most of the field is not well represented in this section. The topmost bed is a part of the boulder-forming upper massive division, and may be its only representative here. Beneath this are 18 feet of the thinly bedded middle division, which is underlain by a massive bed, 6 feet 7 inches in thickness, of very fine-grained, compact limestone, which was not observed at any other place. This lower 21 feet represents the lower division.

Section of Fort Riley limestone exposed in east face of Dolese Brothers' quarry, two miles east of Eldorado, Kan. (a short distance east of the area embraced by the map, plate I).

Fort Riley limestone.	*Thickness.* *ft.*	*in.*
Limestone, light gray, weathering boulderlike masses, complete thickness not shown	2 +	
Shale, poorly exposed, thickness not shown	1 +	
Limestone, thin bedded, fossiliferous	4	
Limestone, argillaceous, gray, with a few very thin shale bands	1	6
Limestone, gray, fossiliferous		9
Shale, very calcareous, changing horizontally to argillaceous limestone, thickness 1 ft. 6 in., to	2	
Limestone, argillaceous, light gray, containing a few very thin shaly layers,	1	10
Limestone, light gray, very fossiliferous	1	4
Limestone, thin bedded, light gray	1	
Shale, calcareous, greenish gray		5
Limestone, thin bedded, light gray	2	11
Shale, greenish gray		7
Limestone, light gray	2	
Limestone, very fine grained, breaks in places with conchoidal fracture, light gray, streaked with dark bands, slightly fossiliferous	6	7
Shale, calcareous, dark gray		3
Limestone, granular in appearance on account of its content of some inorganic or organic growth, gray to dark gray	20	10
Florence flint.		

The individual limestone layers in the above section are not constant in material, color or thickness, even within distances so small as 100 feet. In a few places shale replaces limestone and limestone replaces shale.

Besides the small globular masses that characterize the lower division, and which may be of a concretionary origin or may represent unknown organisms, the fauna of the Fort Riley, according to Doctor Girty, includes the following forms from the upper division:

Meekella striaticostata.
Meekella n. sp.
Composita subtilita.
Deltopecten ? sp.
Bellerophon (*Bucanopsis?*) sp.

DOYLE SHALE.[5] The rocks of eastern Kansas between the Fort Riley limestone below and the Winfield limestone above have been termed the Doyle shale. In the Eldorado district

5. Named after Doyle creek, Marion county, Kansas. Prosser, Chas. S., and Beede, J. W.; Revised classification of the upper Paleozoic formations of Kansas: Jour. Geol., vol. 10, p. 718, diagram; 1902.

the rocks of this interval include three stratigraphic units—a lower shale (in places shaly limestone), a middle limestone, and an upper shale—all three of which are shown on plate I. In this report they will be designated as the lower shale bed, the Towanda limestone bed, and the upper shale bed.

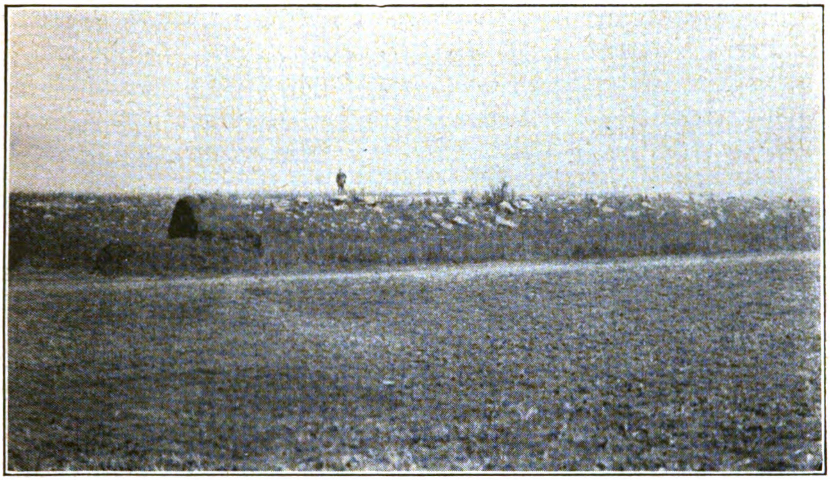
Lower shale bed. The lower shale bed varies little from 35 feet in thickness. It is poorly resistant to erosion, in contrast to the underlying Fort Riley limestone, and therefore is generally represented on the surface by a grassy slope back from the boulderlike upper limit of that division. Its character is shown in but few exposures, and in these considerable variation appears. Along the east side of the area mapped, the lower 20 to 25 feet is made up of light-colored calcareous shale, with several thin beds of argillaceous limestone, while the upper 10 to 15 feet is greenish shale. In contrast to this, its character in the western part of the field is much more limy. In places the lower 20 to 25 feet is altogether thin-bedded, shaly limestone with overlying shale, while in one locality along the creek crossing the SW¼, sec. 26, and the SE¼, sec. 27-25-4, this thin-bedded limestone appears to comprise the entire thickness of the lower portion of the Doyle shale.

Along the east side of the region the lower portion of the lower shale bed is partly exposed along the small stream in the W½ SE¼, sec. 18-25-6, and the overlying greenish shale is exposed below the Towanda limestone escarpment near the center of NE¼, sec. 32-24-6. No fossils were observed in this part of the stratigraphic section.

Towanda limestone bed. This limestone is bluish-gray, slabby in character, and measures from 5 to 9½ feet in thickness. It is named after Towanda, where it is well exposed in the escarpment along the northwest side of this town and for a mile or more to the north. In places it crops out as a prominent ledge and forms low escarpments (see plate XI, *A*), as at its type locality, but throughout much of the field it is poorly exposed and its presence is indicated merely by small, thin, smooth-faced residual slabs or plates of drab-colored limestone. Its areal distribution, therefore, is not everywhere clearly defined, and this difference in definition of outcrop from place to place is roughly indicated on plate I by different symbols—a solid line where clearly defined and a dashed line where its boundary is uncertain.

The dominant characteristics of the Towanda limestone are its bluish-gray or drab color and its thin-bedded, platy or slabby nature. (See plate XI, *B*.) Weathering, as indicated by residual material, gives the broken fragments smooth, rounded surfaces.

PLATE XI.



A. Escarpment formed by Towanda limestone.

B. Outcrop of Towanda limestone, showing its thin-bedded, stratiform nature.

This limestone is well exposed at numerous localities besides the Towanda neighborhood. Some of the better of these exposures are near the S¼ corner, sec. 21, T. 26, R. 4; in the south bank of the creek, one-quarter mile south of N¼ corner, sec. 33, T. 26, R. 4; in the SE¼, sec. 14, T. 25, R. 5; sec. 17, T. 25, R. 5; and sec. 32, T. 24, R. 6. At a few places a small, indeterminable gastropod is represented by numerous individuals, covering the surface of Towanda limestone slabs.

Upper shale bed. The upper portion of the Doyle shale is truly shale, and in the Eldorado field varies from 50 to 60 feet in thickness. It is variegated in color, with greenish to yellowish-gray predominating, but containing also, in its lower part, several maroon and dark-gray bands. The upper few feet are transitional in nature, becoming more and more calcareous, until they merge into the Winfield limestone. These upper few feet of calcareous shale contain in places a large number of fossil remains, particularly of the brachiopod *Derbya multistriata,* which, where conditions are favorable, weather out in large quantities and may be picked up easily by the handful. This is particularly true in the railroad cut at the north side of sec. 19, T. 25 S., R. 5 E.

The best exposure in the Eldorado district of the upper shale bed of the Doyle is below the Winfield escarpment in the S½, sec. 28, T. 26 S., R. 4 E. The upper part of the shale is exposed at several places beneath the Winfield at the S½ corner, sec. 24, T. 25, R. 4; in the road east of W¼ corner, sec. 18, T. 25, R. 6; and along the creek in the NW¼, sec. 5, T. 25, R. 5.

The transitional beds at the top of the Doyle yielded the following fauna, as identified by Doctor Girty:

Echinocrinus edgarensis.
Spirorbis sp.
Leioclema ? sp.
Septopora gracilis ?
Rhombopora lepidodendroides.
Derbya multistriata.
Productus calhounianus.
Composita subtilita.
Myalina wyomingensis ?

This list, which includes all the species found in the immediately overlying Winfield limestone, should, perhaps, because of its intimate relation to the Winfield, be considered a Winfield fauna, or at least a phase of it.

Winfield Limestone.[6] The Winfield is the most prominent ledge-forming bed in the Eldorado field, and its influence on the topography is to be seen in the mild escarpments which

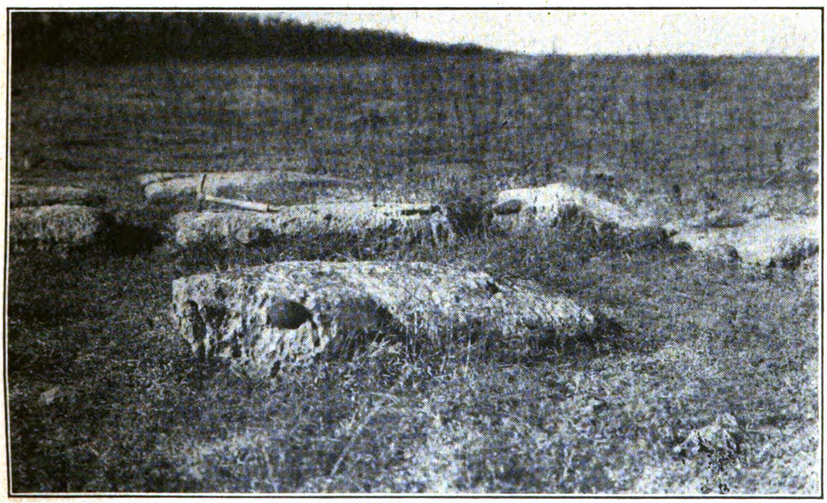
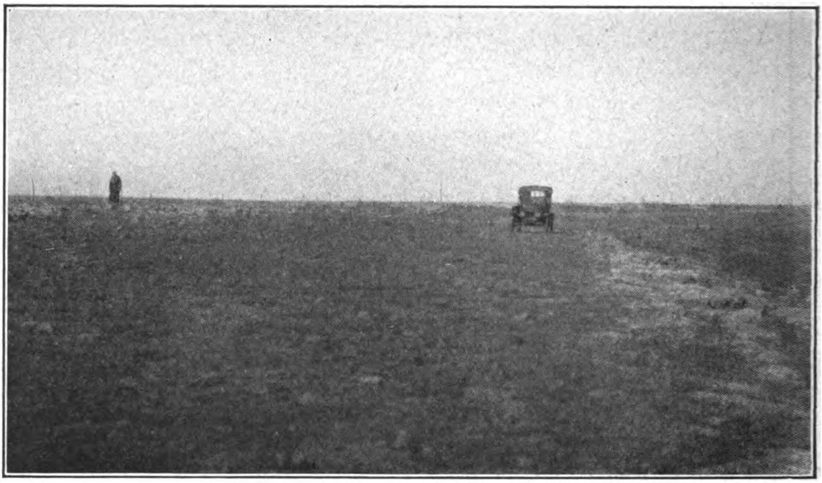


Plate XII.—Two outcrops of Winfield limestone, showing its concretion-bearing nature.

6. Named after Winfield, Cowley County, Kansas, by Prosser, C. S.; Revised classification of the upper Paleozoic formations of Kansas: Jour. Geol., vol. 10, p. 715; 1902.

border the field, beginning on the northeast side and swinging around to the north, west and southwest. The position of the Winfield escarpment may be noted by the position of its outcrop as shown in plate I. The escarpment-forming quality of the Winfield lies in its relatively greater resistance to erosion as compared with the immediately underlying and overlying shales.

PLATE XIII.



A. Outcrop of Winfield limestone, forming a double bench.

B. Exposure of Herington (?) limestone.

The Winfield member in the Eldorado district is represented by a single heavy-bedded limestone from 8 to 9½ feet in thickness, in contrast to a threefold limestone and shale division in the Cottonwood Falls quadrangle[7] and some other districts. Most of this thickness is formed by two beds, which in many exposures form a double bench. (See plate XIII, *A*.) The limestone is light gray to whitish in color and it contains abundant fossil remains, mostly fragmentary. On the weathered surface these fragmentary fossils stand out in relief and give the rocks a rough or highly etched appearance—its most characteristic feature. The presence of irregularly rounded reddish-brown concretions in several places is a local feature. (See plate XII.) In most places these concretions are exceedingly abundant, and in some places, because of their greater resistance, they form what may be termed a residual mantle on the slope beneath the Winfield. The concretions appear to be masses of fragmentary fossil remains embedded in a ferruginous and calcareous matrix. Reddish-brown is their weathered color, while the fresh surface is a mottled dark gray. The concretionary character is developed principally in the following three localities: Secs. 25 and 36, T. 24 S., R. 5 E.; secs. 30 and 31, T. 24 S., R. 6 E.; N½, sec. 13, T. 25 S., R. 5 E.; and the west side of sec. 24, T. 25 S., R. 4 E., and for a mile or so to the southwest.

The fauna of the Winfield in the Eldorado district includes the following forms, identified by Doctor Girty:

Septopora gracilis?
Derbya multistriata.
Productus calhounianus?
Myalina wyomingensis?

Marion Formation.[8]

GENERAL STATEMENT. In the Eldorado field the Marion formation is represented by 65 to 80 feet of shale and limestone, which contains three mappable members: (1) A lower shale and soft, nonresistant limestone, aggregating 45 to 50 feet in thickness, tentatively correlated with the Enterprise shale member; (2) a middle ledge-forming limestone, 3 feet thick, which is believed to represent the Herington limestone

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7. Prosser, C. S., and Beede, J. W.; Cottonwood Falls Folio, No. 109, U. S. Geological Survey, pp. 4, 5; 1904.

8. Named after Marion county, Kansas. Prosser, Chas. S.; The classification of the upper Paleozoic rocks of central Kansas: Jour. Geology, vol. 3, 786; 1895.

member; and (3) an upper shale, 15 feet thick, which is tentatively correlated with the Pearl shale member. The correlation of these beds with the recognized members of the Marion in its type locality 30 miles to the north is tentative, and hence the uncertainty is indicated throughout the report by the use of question marks.

The type localities of these three members of the Marion formation are in Dickinson and Marion counties, where the section of the Marion formation has been differentiated as follows:[9]

Subdivisions of the Marion formation.

	Thickness ft.	in.
Pearl shale, thickness estimated	70	
Herington limestone	9	
Enterprise shale	35	8
Luta limestone	30	

The Luta limestone member, if present, is not exposed in the Eldorado section, hence the lower shale and shaly limestone division as recognized in the Eldorado district is tentatively correlated with the Enterprise shale. The Herington limestone member, which follows, is described at the type locality as a buff, massive, very fossiliferous bed, with a thickness of 9 feet, which is quite in contrast with the bed in the Eldorado field that is provisionally correlated with it. The principal reason for the correlation is the similarity in stratigraphic position with respect to the Winfield limestone. In the Eldorado section the first ledge-making limestone above the Winfield is separated from the latter by a considerable thickness of shale, and soft, nonresistant limestone.

ENTERPRISE (?) SHALE.[1] The lower 45 to 50 feet of the Marion is generally represented by a smooth, grass-covered surface, on which in places there is scattered a large amount of residual chert. Since chert is so invariably, and apparently necessarily, associated with limy material, the supposition—which is borne out by a few small, unsatisfactory and scattered exposures—is that this residual chert indicates that some of the Enterprise shale member in the Eldorado field consists of

9. Beede, J. W.; Formations of the Marion stage of the Kansas Permian: Kansas Acad. Sci. Trans., vol. 22, pp. 251-255; 1908. It appears from recent investigations by members of the State Geological Survey of Kansas in Dickinson, Marion and Harvey counties that the subdivision Abilene conglomerate, which has been included at the top of the Marion formation, is not a Permian deposit. The upper limit of the Marion is marked by thin limestone beds at the top of the Pearl shale division.

1. Named after Enterprise, Dickinson county, Kansas. Beede, J. W.; Formations of the Marion stage of the Kansas Permian: Kan. Acad. Sci. Trans., vol. 22, p. 253; 1908.

limestone, which, because of the absence of exposures, is probably soft and nonresistant. At a few places gray calcareous shale was also observed. As already stated, these beds are only tentatively correlated with the Enterprise shale member of the Marion as developed to the north.

HERINGTON (?) LIMESTONE.[2] The middle division of the Marion formation in the Eldorado field is limestone, dull bluish-gray in color, with a thickness which varies little from three feet. Its resistance to erosion is generally sufficient to form ledges, and in a few places it even produces low escarpments. On the whole, however, its outcrop is inconspicuous. Its general character is well illustrated by the following section and the photograph of this section (plate XIII—*B*):

Section of the Herington (?) limestone member exposed in small quarry near center N½, sec. 34, T. 26, R. 4.

	Thickness. Ft.	In.
Limestone, light yellowish-gray, single bed; contains numerous small calcite geodes and small cauliflower-like chalcedony concretions; upper surface partly incrusted with gray chert..	0	11
Limestone, light gray, shaly or limy shale....................		2
Limestone, light gray, thin bedded	2	0
Total	3	1

At one place only, in the SE¼, sec. 12, T. 25, R. 4, were any fossil remains observed in this limestone, and these consisted of a single species identified by Doctor Girty as *Pseudomonotis hawni.*

PEARL (?) SHALE.[3] Probably not more than 15 to 30 feet of the upper portion of the Marion formation above its Herington (?) limestone member is present in the Eldorado field, and no exposure of it was observed. Residual chert is present on the surface in some places, but other than the nonresistance of the strata to erosion there is no indication as to the material of which they are composed. Probably they are shale and soft limestone. If the correlation of the underlying limestone with the Herington limestone member is correct the correlation of the upper part of the Marion in the Eldorado field with the Pearl shale member is beyond question.

QUATERNARY DEPOSITS.

Covering the broad valleys of Walnut and Whitewater rivers and their larger tributaries are accumulations of muds, gravels and sands of comparatively recent geological age, deposited

2. Named after Herington, Dickinson county, Kansas: Beede, J. W., op. cit.
3. Named after Peal, Dickinson county, Kansas. Beede, J. W., op. cit., p. 255.

during the period since the rivers cut to grade and while they have been broadening their valleys by lateral planation. The materials were derived from the higher valley reaches and were brought to their present location principally during flood periods.

The valley alluvium in the Eldorado region contains but little common quartz sand because of the meagerness of siliceous bed rocks in the drainage area from which sand could be derived. Stream action on the broken limestone fragments reduces the rock to pebbles and to sandlike particles, but these small grains are relatively unstable because of weathering and their relative lack of resistance to solution in the ground waters. Hence calcareous sands, as such, do not form large quantities of the valley alluvium. The coarser materials—that is, the gravels and rubble—are in large part limestone fragments. The clays of the alluvium consist principally of the transported clays and shales of the shale formations, and in part of the weathering products of the limestones.

STRUCTURE.

REGIONAL STRUCTURE.

The dominating structural feature of the northern Mid-continent oil field is the Ozark uplift, a widespread regional elevation with maximum development in southwestern Missouri. This dominating uplift is the result of diastrophic activities which principally took place in two periods—the first in late Mississippian or earliest Pennsylvanian time, and the second in post-Paleozoic time.[4] The first deformation involved the Cambrian, Ordovician and Mississippian strata and resulted in an extensive emergence, followed by a long period of erosion which affected principally the Mississippian rocks. This erosional interval is recognized in eastern Kansas through a widespread unconformity between the Mississippian and the overlying Pennsylvanian rocks—an unconformity which is marked, not by any notable angular divergence of the beds, except locally, as in the Eldorado field, but rather through the irregular eroded surface of the Mississippian strata, and the

4. Diastrophic movements in the Ozark region and in eastern Kansas before the Mississippian are clearly indicated by the stratigraphic relations of the Silurian, Devonian and Mississippian strata about the Ozark highland, and the subsurface studies in east central Kansas conducted by the Kansas Geological Survey.—Raymond C. Moore.

absence of lower Pennsylvanian strata such as are found in regions to the south.

The Pennsylvanian and Permian rock series deposited on the eroded Mississippian were not notably deformed until the second phase in the development of the Ozark uplift, which took place in post-Paleozoic times. This phase of the Ozark uplift consisted principally of a regional elevation, with its maximum development in the Ozark mountain region of Missouri. In all directions away from this central region the uplift extended with diminishing elevation, and throughout eastern Kansas and other bordering regions the rocks were only very gently tilted. In eastern Kansas the inclination of the strata due to the regional elevation is westward and amounts to between 15 and 25 feet to the mile. This inclination is indicated in a highly exaggerated form in plate VII.

Because eastern Kansas and the adjacent areas are not located in the heart of the Ozark uplift, the westward inclination of the rocks in these regions, although directly due to the uplift, is generally spoken of, not as a part of the Ozark uplift itself, but instead as the Prairie Plains monocline. Erosion has removed much of the Paleozoic sediments involved in the Ozark uplift, and in places in the center of the uplift the pre-Cambrian is exposed. In eastern Kansas on the flanks of this regional uplift the westward-tilted strata were beveled, and are now exposed in broad parallel belts trending north-northeastward across the state.

The oldest rocks exposed in Kansas are of Mississippian age and are located in the southeast corner of the state. To the west-northwest follow the outcropping belts of the successively higher formation belonging to the Pennsylvanian and Permian divisions, which dip gently westward. This westward dipping attitude of the strata in eastern Kansas, the Prairie Plains monocline, is spoken of as the regional structure, and it is upon this that the local and minor irregularities, such as the anticlines, domes and synclines of the Eldorado field are developed.

The structural features of the Eldorado field will be described in considerable detail, but before doing so it seems pertinent to discuss briefly the relation which the structure of the surface rocks bears to the accumulation of oil and gas.

RELATIONSHIP OF SURFACE STRUCTURE TO OIL AND GAS ACCUMULATION.

The oil and gas in the Midcontinental field is almost invariably, if not always, associated with water, and where present in considerable amounts the oil and gas will tend to accumulate in the tops of the folds or arches into which the oil-bearing strata are flexed, in case they are uniform in thickness and porosity, and the water will lie beneath in the lower levels. This situation will obtain though the folds in the exposed beds are not parallel or identical with those in the sands. It is, however, the rule that in most oil and gas regions the underground structure of the oil- and gas-bearing rocks is reflected in the surface **rocks** by similar structural features; in other words, the surface rocks very generally lie in such positions that they closely parallel the underground rocks.

Obviously the structural geologic study of an oil and gas region is for the purpose of determining as accurately as possible the structure—that is, the position and magnitude of the folds—of the oil- and gas-bearing beds. It is also obvious that because of the impossibility of observations underground, the structure of the oil- and gas-bearing "sands" cannot be determined in detail previous to drilling. Therefore, while this information is unavailable the geologist must resort to the best accessible indications as to this underground structure, and from these draw his conclusions.

The best indications of the underground structure, *i. e.*, the best symptoms upon which a diagnosis can be made—are to be found in the structural features of the outcropping rocks which so generally closely parallel the underground rocks. It is because the structure of the outcropping rocks furnish the best accessible surface indications of the subsurface structure that geologists give so much attention to the structure of the surface rocks. It is not a matter of choice, but of necessity.

The use of surface structure is not limited to the outlining of favorable acreage in advance of considerable drilling developments; it is of inestimable value in the further development of partly drilled fields, where to secure best results it is used in conjunction with the underground structural and "sand" information revealed locally by the preliminary drilling. Surface structure is of use in the active development of any field until the limits of the producing territory have been clearly defined by drilling. Thereafter, during the inside or intensive development of a field, it is of little value provided all the information that should be gathered as the drilling proceeds is accessible.

The study of surface structure is of value other than in the development of a field. The examination of its relationship, even in its details, to the underground structure and to the distribution of accumulated oil and gas as revealed in developed fields, leads to generalizations which should apply to other localities and should lead to the discovery of other oil and gas fields. If applied to prospective fields in the same general region, their economic and scientific development should be greatly advanced and expedited. It is expected that such will be the principal result of this detailed investigation of the Eldorado field, where the relationships of surface structure to underground structure and to occurrence of oil accumulation are rather clearly defined. For instance, the relationship between the surface structure and the location of the oil in the developed portions of the Eldorado field is advanced on pp. 143-147 of this report as a reason for believing that one of the Eldorado field domes, the Chelsea, which up to April, 1920, has failed to yield oil, has not been adequately tested.

The use to which a knowledge of the origin of oil-field structure may be put will be discussed farther on under the heading, "Origin of the Eldorado anticline and of other types of structure found in the northern part of the Midcontinent oil and gas field."

STRUCTURE OF THE ELDORADO DISTRICT.

STRUCTURE OF THE SURFACE ROCKS.

ELDORADO ANTICLINE AND WALNUT SYNCLINE. The structure of the exposed beds in the Eldorado field, which consists of minor and local modifications of the regional monoclinal structure, was ascertained by determining, with a plane table, telescopic alidade, and stadia, the distribution of the various strata and their altitude at more than 1,600 points scattered rather uniformly over the field. With this horizontal and vertical control the altitude of the top of the Fort Riley limestone was determined throughout the field; where below the surface by subtracting the thickness of the intervening rocks, and where eroded by adding the known thickness of the rocks removed. These elevations were then used in drawing the structure contours given on plate I, which indicate the attitude or lay of the surface beds.

One major fold, the Eldorado anticline, extends in a somewhat sinuous line and in a southwesterly direction across the entire area embraced in this report, from the southeast corner of T. 24 S., R. 5 E., to beyond the southwest corner of T. 26 S., R. 5 E. According to the map published by McDowell,[5] the southward extension of the Eldorado anticline continues into T. 27 S., R. 4 E., to near the town of Augusta; and it is further possible that to the north it extends beyond the northern limits of the Eldorado district as mapped on plate I, in which case the Lincoln syncline is but a minor cross fold separating the Chelsea dome from the dome next beyond. The Eldorado anticline is marked by alternating minor domes and minor cross synclines, and at its southwest end is forked, with the Shumway dome and Whitewater nose forming one branch and the Boyer dome and Koogler nose forming the other. On several of the domes which modify its crest, erosion has exposed the lowermost strata of the district, the Florence flint, which crops out in irregular-shaped areas surrounded by the Fort Riley limestone. The Eldorado anticline is limited on the east by the pronounced Walnut syncline, which is located in the main valley and west branch of Walnut river, after which it is named. This syncline is a rather straight trough extending from beyond the south border of the Eldorado district to the east-central part of T. 25 S., R. 5 E. Here it terminates in a slightly accentuated depression from which minor synclines radiate to the northwest and east. The maximum vertical difference between the crest of the Eldorado anticline and the trough of the Walnut syncline is about 180 feet. Because of its location in the valleys of Walnut river and its west branch, the rocks exposed in the Walnut syncline belong, for the most part, to the lower portion of the exposed stratigraphic section, and in but one locality, that of the accentuated depression in the east-central part of T. 25 S., R. 5 E., are rocks as high as the Towanda limestone and the Winfield limestone present. The minor domes and minor synclines which modify the Eldorado anticline are several in number, and to facilitate discussion they will be designated by names. The names as given below are taken either from local

5. Geology in its relation to the oil industry: Proc. Amer. Mng. Congress, Vol. XIX, map on p. 294; 1917.

features or from the more prominent leases located on them. They may be classified as follows:

Minor domes:	*Minor synclines:*
Shumway dome with Whitewater nose extension.	Hammond syncline.
Boyer dome with Koogler nose extension.	Bishop syncline.
Oil Hill dome.	Fowler syncline.
Chesney dome.	Bancroft syncline.
Wilson dome.	Hegberg syncline.
Robinson dome.	Dunkle syncline.
Chelsea dome.	Ramsey syncline.
	Theta syncline.
	Lincoln syncline.

SHUMWAY DOME. This dome is located principally in the northeast corner of T. 26 S., R. 4 E. (Towanda township), where the Fort Riley limestone outcrops over most of its crest. It is slightly elongated in a northeasterly direction, extending from the SW¼, sec. 31, T. 25 S., R. 5 E., on the northeast, to sec. 14, T. 26 S., R. 4 E., on the southwest, a distance of about three miles. Its width ranges from 1½ to about 2 miles. Because of the lack of well-defined rock exposures, the exact location of its apex is not clearly indicated. It seems, however, to lie near the northeast corner of section 11, which also is the northeast corner of the prolific Shumway lease, after which the dome is named. The elevation of the apex, referred to the top of the Fort Riley limestone, is over 1,420 feet above tide and its closure amounts to about 30 feet. A plunging anticlinal nose, apparently related to the Shumway dome, from which it offshoots to the south, is located in secs. 22, 27 and 33, T. 26 S., R. 4 E. This plunging fold is called the Whitewater nose, after Whitewater river, which is located on its west flank.

The most prolific production of the entire field, almost altogether from the Stapleton pay zone, has been developed on the Shumway dome in section 11, a short distance southwest of the crest. Production from this pay is continuous across the shallow Fowler syncline to the east, and to the south and west the limit of production is roughly marked by the 1,340-foot contour (plate I), which is about 80 feet below the crest. To the northwest the limit of the producing area on this dome rises gradually, and in sec. 35, T. 25 S., R. 4 E., it lies within the 1,360-foot structure contour. It is to be noted that the 1,600-foot or Boyer "sand," which has been developed over a part of this dome, is productive only on the crest of the dome, and that this is the only locality where the 1,475-foot gas "sand" has been exploited commercially. The 900-foot gas "sand" is productive at the north end of the Shumway dome and a few scattered 1,125-foot and 1,200-foot "sand" gas wells have also been obtained.

In the above discussion the distribution of the oil and gas has been described with reference to the contours on plate I, which show the structure of the surface rocks. In the chapter describing the oil and gas sands, structure contours on the 660-foot oil sand and the Stapleton oil zone, given on plate XIV, will be referred to in connection with those and other sands. It will be noted in these later discussions that the production from the Stapleton pay zone will receive the principal attention, its relation being considered of greater significance to the development of other fields in the surrounding region.

BOYER DOME. The Boyer dome is a quadrilateral-shaped area centering along the boundary of sections 8 and 17 of T. 26 S., R. 5 E., near the Boyer lease, and covering most of sections 7, 8 and 17, and extending into sections 5, 6, 9, 16 and 18 of the same township. Its crest at the surface is developed in a rather broad expanse of the Florence flint. Its apex, as indicated on plate I, which refers to the top of the Fort Riley limestone, has an altitude of about 1,440 feet. This is about 20 feet higher than the Shumway dome. Its closure also is correspondingly greater, amounting to about 50 feet.

At the time the field work was completed developments had not clearly defined the limits of the oil and gas production on this dome. The Stapleton pay zone production is continuous with the Shumway and Oil Hill domes to the west and north, and extends far down on the nose in the direction of the southeast corner of the township. On the south and west sides of this nose, which will be referred to as the Koogler nose, after the principal lease on which it is located, production is found as low as the 1,310-foot contour. To the east of the dome proper, along the north side of section 9, and down on the flanks of the anticline, Stapleton oil production has been obtained as low as the 1,360-foot contour, but farther south in section 16 it appears to be considerably higher. It is to be noted that the 1,600-foot or Boyer "sand" production and the gas production from the 900-foot, 1,125-foot, 1,200-foot and 1,275-foot "sands" are limited to the crest of the dome.

OIL HILL DOME. The Oil Hill dome is slightly elongated in a northwesterly direction and centers in the north-central part of sec. 33, T. 25 S., R. 5 E., near Oil Hill. Its crest at the surface is developed in the Florence flint, which crops out over most of section 33 and small parts of neighboring sections. The Oil Hill dome is separated by the Bancroft syncline from both the Boyer and Shumway domes and its apex lies at the same elevation as that of the Boyer dome, about 1,440 feet above sea level. Its closure amounts to over 25 feet.

The 660-foot Stokes and Stapleton oil pays and several of the gas "sands" are productive on this dome. The extent of the producing area in the Stapleton oil zone is peculiar, in that at the southeast it extends down to the 1,330-foot contour, while in the northern part of sec. 34, T. 25 S., R. 5 E., it is about 30 feet higher, or near the 1,360-foot contour. To the west and northwest it is still higher, although its limits in this direction were not definitely outlined at the time this report was written. The lower extension of the oil on the east side is a condition prevailing also on the Wilson and Robinson domes farther north, and probably also on the Chesney dome. The oil production in the 660-foot sand is rather symmetrically distributed structurally, being limited in general by the 1,380-foot contour. The gas production is practically confined to the area outlined by the 1,400-foot contour. The development of the Stokes "sand" as given on plate I is confined to a few wells near the east quarter corner of sec. 33, T. 25 S., R. 5 E., and it is to be noted that this is the only locality in the field where this sand was exploited.

CHESNEY DOME. This dome is nearly quaquaversal in shape. It centers in the SE¼, sec. 21, T. 25 S., R. 5 E., on the Chesney lease and extends into the adjacent quarter sections. The shallow Hegberg syncline separates it from the Oil Hill dome. The crest of the dome is surfaced by the Florence flint. The closure of the Chesney dome probably does not exceed 20 feet, and the elevation of its apex, referred to the Fort Riley limestone, lies about 1,430 feet above tide, which is 10 feet lower than that of the Oil Hill dome.

The 660-foot and Stapleton oil pays and the 1,275-foot gas pays are productive on this dome. The Stapleton zone has not been thoroughly exploited in this dome; but even so, its extent down on the east flank is noteworthy, where it is found at about

1,330-foot contour, which is 100 feet below the apex. On the other hand, the shallow or 660-foot sand has been almost completely developed and in it the oil shows a unique distribution. Near the south quarter corner of section 22 it is limited by the 1,360-foot contour; but to the north, in the NW¼ of this same section, it rises to the 1,380-foot contour, and still farther north it drops rapidly to the 1,360- and 1,350-foot contours in sections 15 and 16. On the west side it rises from north to south from the 1,360-foot contour in section 16 to about 1,385 feet in the southwest corner of section 21. The gas which is produced from the 1,275-foot "sand" is confined to the area within the 1,390-foot contour.

WILSON DOME. This dome is elongated with a west-northwesterly trend, and although centering in sec. 8, T. 25 S., R. 5 E., includes also parts of sections 4, 5, 6, 7, 9, 16 and 17 of the same township. Its crest is considerably lower than those of the domes to the south, and as a result the surface rocks on this feature are principally the Doyle shale, with the top of the Fort Riley exposed only in small areas. Its apex referred to the top of the Fort Riley limestone has an altitude of more than 1,385 feet and its closure probably exceeds 40 feet. It produces oil from both the 660 foot and Stapleton pays and gas from the 1,200- and 1,275-foot "sands."

The distribution of the oil in the Stapleton zone is to be noted. To the southeast it is as low as the 1,320-foot contour. Near the north quarter corner of section 9 it is at about 1,355 feet, and in the southeast corner of section 6 it is about 1,360 feet. This lower position of the oil on the southeast side is similar to that pointed out for the Oil Hill dome and will also be pointed out for the Robinson dome to the east. This same peculiar distribution does not apply for the oil in the shallow sand, whose limits have not been fully exploited, and therefore cannot be definitely outlined. The gas which has been developed lies well within the area outlined by the 1,370-foot contour, or within 15 feet vertically of the apex.

ROBINSON DOME. This low northeasterly trending structural feature is surfaced by the Fort Riley limestone and Doyle shale, and is located almost entirely in sec. 3, T. 25 S., R. 5 E. The altitude of its apex is about 1,375 feet, the lowest of the Eldorado domes, and its closure is probably less than 25 feet. The Stapleton oil zone is the only pay on this dome. The outstanding feature of the distribution of the productive area is that its western limit is less than 10 feet below and less than one-eighth mile distant from the apex of the dome, whereas to the east it persists for at least a mile into and beyond the Ramsey syncline and lies a short distance up on the southwestern extension of the Chelsea dome. The structure of the outcropping rocks does not suggest this great eastward extent of production which was developed since the completion of the field studies. It is possible that the structure of the Stapleton sand controls this distribution, but, unfortunately, there is no detailed underground information available for this report by which this can be determined.

CHELSEA DOME. This elongated structure may be termed a minor anticline, but for reasons of uniformity it is classed as a dome. Its surface development is principally in the lower member of the Doyle shale, although tongues of the Fort Riley limestone indicate the configuration of its southeast and northwest ends. The Towanda limestone crops out on its south flank, and this limestone in conjunction with the Winfield limestone determines its north flank. The long axis of the dome extends from the center of sec. 35, T. 24 S., R. 5 E., to the center of sec. 8, T. 25 S., R. 6 E., a distance of about three and one-half miles. It includes all or parts of secs. 35 and 36, T. 24 S., R. 5 E.; sec. 31, T. 24 S., R. 6 E.; secs. 1 and 2, T. 25 S., R. 5 E.; and secs. 5, 6, 7 and 8, T. 25 S., R. 6 E. The altitude of its crest, referred to the top of the Fort Riley limestone, exceeds 1,390 feet and its closure amounts to more than 40 feet.

No oil has been found in the Chelsea dome except as noted in the discussion of the Robinson dome. Three dry holes have been drilled on it in widely scattered places, none of which, according to the opinion of the writer, were located in the most favorable place. One of these dry holes is in the NW¼ NW¼, sec. 1, T. 25 S., R. 5 E., another in the SE¼ SE¼, sec. 36, T. 24 S., R. 5 E., and the third in the southeast corner of the SE¼, sec. 1, T. 25 S., R. 5 E. The inadequacy of these tests will receive special consideration (pp. 143-148) after the relation of the oil with reference to the structure of the Stapleton pay zone has been discussed.

HAMMOND SYNCLINE. Outside of the Walnut syncline, which is the major depression marking the eastern limit of the Eldorado anticline, the most prominent feature of this type is the Hammond syncline, a deep local depression, much deeper than the Walnut syncline, named after the Hammond lease which it crosses. This depression centers in sec. 34, T. 26 S., R. 4 E., and its southeastward extension, according to McDowell,[6] separates the south extension of the Eldorado anticline from the North Augusta anticline of the Augusta field. The Herington (?) member of the Marion formation is the key horizon indicating the depth of this depression, and the Winfield limestone outlines its flanks. The top of the Fort Riley limestone in the trough is certainly below an altitude of 1,140 feet, and may be as low as 1,120 feet or even less. The sharpness of this depression has resulted in a marked reversal of dip on the west, producing there a plunging anticlinal flexure, the Whitewater nose, which is a southwesterly offshoot from the Shumway dome.

BISHOP SYNCLINE. Located in a direct line with the axis of the Hammond syncline, and also possibly genetically related to it, is another depression extending across the Bishop lease in sec. 23, and into SW¼, sec. 13, T. 26 S., R. 4 E. This depression permits the Winfield to crop out in the vicinity of the southwest corner of section 13, and the elevation of the Fort Riley in the lowest portion of the trough is below 1,265 feet. This depression is sufficiently developed to exclude the presence of oil in its trough.

FOWLER SYNCLINE. Still farther north, and located in line with the Hammond and Bishop synclines, to which it appears to be genetically related, is the Fowler syncline, extending from the Fowler lease in sec. 1, T. 26 S., R. 4 E., into section 13 of the same township, and into sec. 6, T. 26 S., R. 5 E. The Fowler syncline separates the Shumway and Boyer domes and in its trough is a small outcrop of the Doyle shale, which is exposed along the railroad in sec. 1, T. 26 S., R. 4 E. Production is continuous across this shallow depression from the Shumway to the Boyer domes.

BANCROFT SYNCLINE. This shallow downfold, trending northwesterly from sec. 4, T. 26 S., R. 5 E., to sec. 30, T. 25 S., R. 5 E., crosses the Bancroft lease and separates the Shumway and Boyer domes from the Oil Hill dome. Due to its slight development it appears to have had little or no effect in controlling the accumulation of the oil, production being contin-

6. Op. cit., p. 294.

uous from the Oil Hill dome on the north to the Boyer and Shumway domes to the south and southwest.

HEGBERG SYNCLINE. This depression, located on the Hegberg lease, separates the Oil Hill and Chesney domes. It is very shallow and apparently has had no appreciable effect in controlling the oil accumulation.

THETA SYNCLINE. A pronounced depression, indicated principally by the Towanda limestone member, crosses leases of the Theta Oil Company in secs. 16 and 17, T. 25 S., R. 5 E., and separates the Chesney dome from the Wilson dome. It is a westward extension of the deep basin of the Walnut syncline in the east-central part of this township and is sufficiently developed to separate in both the shallow and Stapleton zones the production of the Chesney and Wilson domes.

DUNKLE SNYCLINE. Starting on the Dunkle lease in sec. 4, T. 25 S., R. 5 E., this depression trends southeastward across section 9 to the Walnut syncline and separates the Wilson and Robinson domes. Like the Theta syncline, the Dunkle syncline also separates the production of the domes flanking it.

RAMSEY SYNCLINE. Located north of the Ramsey station on the Atchison, Topeka & Santa Fe railway is a shallow depression separating the Robinson and Chelsea domes. Lying in the valley of the west branch of Walnut river, where rock outcrops are absent, its configuration along the line between sections 2 and 3 is not discernible. Although a syncline, much production has come from it, while wells located higher structurally, according to the surface rocks, on the as yet unproductive Chelsea dome to the east failed to find production. This development of oil in the Ramsey saddle could probably be explained were all the information available, but as this development took place after the completion of the field work, no explanation is here presented.

LINCOLN SYNCLINE. Marking the north and northeastern boundaries of the Chelsea dome is a syncline, well indicated by good exposures of the Winfield limestone. It is located principally in Lincoln (political) township, which extends across sec. 25, T. 24 S., R. 5 E., and secs. 30, 31, 32 and 29, T. 24 S., R. 6 E. The region to the north was not examined, but it is possible that the Eldorado anticline continues in this direction.

STRUCTURE OF UNDERGROUND ROCKS.

The structural relation of the underground rocks to those outcropping at the surface, as previously pointed out, is of foremost importance in understanding the conditions which control the accumulation of oil and gas into oil pools. To recapitulate briefly, it is patent that to cause the accumulation of oil in anticlines and domes, these structures must be found in the oil- and gas-bearing rocks, and it is only where anticlines and domes developed in the oil- and gas-bearing rocks affect also the surface rocks that structural investigations in advance of developments are of use in directing exploratory work. That these conditions prevail over so much of the oil and gas regions explains the apparent ease with which geology has in the past assisted the oil industry in the locating and developing of oil and gas pools. If the structure in the oil sands always conformed to that of the surface rocks, and if the surface rocks were also of such character as to lend themselves to structural studies, geologists would have little trouble in locating all oil and gas pools in which folding was the factor causing the oil accumulation. In many places, however, these simple conditions do not prevail, and herein lie the difficulties which must be surmounted by much painstaking work and the accumulation of many details of fact.

The study of the underground structural conditions in the Eldorado field was undertaken to show what relation the structure of the surface rocks bears to the structure of the buried rocks, principally the oil- and gas-bearing beds. The condition prevailing at Eldorado should shed light on what may be expected in other localities of the same general region. As a result of the studies it is evident that the structure of the underground rocks is similar to that in the surface rocks, but that the relation between the two structures is not ideally simple. Further, the conditions prevailing in the Eldorado field are found to indicate, as will be demonstrated, that the number of localities where the development of new oil pools may be expected is greater than has in the past generally been considered probable.

Sufficient drilling information was obtained to determine the structure of the oil- and gas-bearing beds in a portion only of the producing area. The results obtained are graphically shown on the structure contour maps given on plate XIV and figures 3 and 4. The discussion of their structure, however, instead of being given at this point, is presented under the next general heading as a means of simplifying the general treatment of the sands.[7]

OIL AND GAS SANDS.

GENERAL STATEMENT.

The oil- and gas-bearing beds in the Eldorado field probably number fifteen to twenty, but in many of these only "showings" are reported. Some of the latter appear to be but local porous areas in limestone, and may be considered erratic. Up to July 1, 1918, ten only of the beds had been found to contain sufficient quantities of oil and gas to sustain commercial production, and of these five produced oil and five produced gas. (See plate VI.)

The productive beds may be divided into three groups—a shallow oil series lying at depths generally less than 700 feet, an intermediate gas series between 800 and 1,550 feet in depth, and a deep oil series lying below 1,550 feet. Of the two productive sands in the shallow oil series, the 660-foot sand only was extensively exploited, whereas the other, the 550-foot sand, was productive in but two or three wells. Of the five productive sands in the intermediate gas-bearing series, the 900- and 1,275-foot pays were the most productive, and therefore the principal ones tapped. The other three are not as consistently productive, and hence were less exploited. Of the three productive sands in the deep oil series, the Stapleton is the prolific pay which yielded the gusher wells that made the Eldorado field famous. The Boyer and Stokes "sands" in July, 1918, were the producing beds in probably not over a dozen wells, but since then press reports indicate that the Boyer "sand" has been more generally exploited, especially on the Shumway dome.

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7. The structure of the underground rocks is described as follows:

660-foot oil sand .... pp. 77 to 78.
1,275-foot gas "sand" .... p. 81.
900-foot gas "sand" .... pp. 81 to 83.
Stapleton oil zone .... pp. 99 to 132.
Smock-Sluss pool .... pp. 138 to 139.
Origin of structural features .... pp. 148 to 166.

SHALLOW OIL SANDS.

GENERAL CONSIDERATION.

The shallow sands lie between 500 and 700 feet below the top of the Fort Riley limestone and probably within the Willard and Admire shales of the Wabaunsee formation. They are two in number—an upper sand about 550 feet below the top of the Fort Riley, and a lower sand about 660 feet below the Fort Riley, which produces practically all the shallow oil. It was the development of this 660-foot sand which was the principal feature in the Eldorado field during 1916. In addition to these sands a third and unproductive one lying about 20 feet above the 660-foot sand is often indicated in the well logs as a "stray sand."

550-FOOT SAND.

The highest pay sand is found about 550 feet below the Fort Riley limestone, and although representing the first of the shallow sands, its content of oil is so meager that but few wells obtain a profitable supply from it. Since this sandstone is not generally productive, most drillers make no effort to determine and record its presence in well logs. Where recorded, it appears to be coextensive with that of the shallow sand production; that is, on the Wilson, Chesney and Oil Hill domes. Its further extent is also possible, but through the lack of trustworthy well-log information, its limits cannot be more accurately defined. The reported thickness ranges from 1 to 22 feet, but generally it averages between 5 and 7 feet.

So far as the writer could ascertain, but two wells had been drilled to the 550-foot sand prior to July, 1918, for the purpose of extracting its oil. Both of these are in sec. 28, T. 25 S., R. 5 E., and their initial productions were reported to be 15 and 50 barrels, respectively. A few of the logs of the 660-foot-sand wells report gas in this more shallow sand, and for one well in sec. 21, T. 25 S., R. 5 E., an estimate of 500,000 cubic feet per day open-flow volume was given. Since most of the shallow wells were drilled to produce from the more prolific 660-foot sand, the oil in the 550-foot sand was greatly neglected. According to present information it would seem possible to increase the production from this sand, not only by drilling additional wells, but perhaps, if invading water does not prevent, by raising the casing in the 660-foot-sand wells after the production in the deeper pay becomes so low as to be unprofitable.

660-FOOT SAND.

GENERAL STATEMENT. Samples of the 660-foot sands were obtained from but two wells, and these showed it to be formed of rather pure and rather well-rounded, comparatively fine quartz grains with a calcareous cement. These characters probably are uniform throughout its extent in the field.

AREAL DISTRIBUTION. The sand extends over considerable territory outside of its producing area, as shown by the distribution of shallow sand wells on plates I and XIV, but because it does not produce throughout its extent, drillers generally ignore its presence and do not record it in their logs. The logs, therefore, are not sufficient for tracing its full extent. Numerous wells drilled expressly for production from this sand report "no sand." This condition may not always be the case, however, for its "absence" may be due to the absence of oil in these localities, which with many drillers is the only criterion used to determine the presence of a sand.

THICKNESS. Over much of the productive area the 660-foot sand averages about 10 to 20 feet in thickness. Locally it is thicker or thinner, and, as mentioned before, in several places it is recorded as entirely absent.

In some places it is interpreted by the writer that the thinning is compensated by a corresponding thickening of the underlying shale; that is, the lower part of the sand present in some places is missing at other places. In still other places the lower part of the bed seems persistent, but the sand thins through the absence of the upper part, whose place is occupied by a thickened portion of the overlying shale. The latter condition has apparently produced some small irregularities in the contours drawn on the top of the sand, as shown on plate XIV, which may be interpreted as minor domes and synclines. If these features have been correctly interpreted, the domes and synclines resulting from them must not be considered structural features, but depositional features instead. One locality, where the thinning of the sand appears to cause an irregularity in the structure contours, is in the north part of sec. 21, T. 25 S., R. 5 E. This detail is to be observed in contours drawn on the top of the 660-foot sand on plate XIV, where the reëntrant syncline on the north side of the Chesney dome is probably due to such a thinning, causing a secondary dome at the south quarter corner of section 16. A similar slight thinning probably causes the double apex on the Oil Hill dome. A third thinning, and possible elimination (some wells report "no sand"), extends across sec. 31, T. 25 S., R. 4 E. A fourth thinning and complete elimination of this sand causes the marked reëntrant in the structure contours near the south quarter corner, sec. 32, T. 25 S., R. 5 E. Another such thinning and probable elimination causes the "dome" present in sec. 6, T. 26 S., R. 5 E.

These above-mentioned minor irregularities in the structure contours, which are shown on plate XIV, represent the attitude of the top of the sand and are probably in large part due to its variation in thickness.

STRUCTURE. Outside of the minor irregularities of surface due to thinning, the general structure of the sand is similar to the structure of the surface rocks. On the Wilson dome the folding of the 660-foot sand is remarkably parallel to that of the surface rocks. One feature, and an important one, as will be discussed later, is the apparently greater amount of folding in the 660-foot sand than in the surface rocks. The closure in the 660-foot sand certainly exceeds 50 feet, and if accurate information were available would probably exceed 60 feet. This is in contrast to the 40- to 50-foot closure in the surface rocks.

The Chesney dome is modified by thinning as previously discussed. If it were not for this the contours drawn on its top would be very similar to those of the surface rocks. The closure in the 660-foot sand is practically 40 feet; here also in excess of the closure of the surface rocks, about 20 feet.

The Oil Hill dome in the 660-foot sand is modified by some local thinning, producing a secondary apex near the east quarter corner, section 33, which may be present in the surface rocks, but because of the absence of mappable horizons in the latter at this immediate point it is not apparent. The closure in the 660-foot sand amounts to 42 feet (not fully indicated by contours), which here also is greater than that in the surface rocks, which probably (not certainly) is but slightly greater than 25 feet.

As discussed above, there is what appears to be an anticline near the northeast corner, sec. 6, T. 26 S., R. 5 E. This is not due to structure, as such, but to the attitude of the top of the sand caused by a pinching out of the bed to the southwest. This conclusion is supported, but not proved, by the fact that no similar structure is present in the surface rocks. Near the northeast corner, sec. 19, T. 25 S., R. 5 E., which is outside of the principal producing areas, is a small area where the 660-foot sand is producing under irregular conditions. The top of the sand does not have the same attitude as the surface rocks, nor is its structural relation to the shallow sand on the Wilson and Chesney domes apparent.

PRODUCTION. The 660-foot sand produces oil only. A few wells encountered some gas in the top of the sand, but not in sufficiently large quantities to make profitable gas wells.

During the early development of this sand the initial productions of the wells generally ranged from 40 to 80 barrels, although several wells were brought in with productions of 100 barrels or more. Some of these flowed for a short time, but the rapid decline soon necessitated pumping. After the early flush production was passed the initial production of new wells declined until in 1918 they averaged about 20 barrels. Up to this time very few wells had been drilled to this sand whose initial capacity was less than 10 barrels. The productivity of the wells bears a slight but not marked relation to their locations on the domes; that is, the initial productivity of wells on the apexes of the domes is usually slightly larger than those one-half to three-quarters of the way down on the flanks. At the margin of the productive areas, however, and in the localities where the sand is thin, there is a corresponding lower initial production. It is here that the low yields—five to ten barrels—are met, and, too, it is in these wells that the ingress of water was first noticeable.

GAS "SANDS."

DISTRIBUTION OF THE "SANDS."

The strata of the Eldorado field which are reported in well records to contain gas number ten to fifteen, and possibly more, but up to the spring of 1918 those which were proven to contain commercial quantities numbered but five. Named according to their approximate stratigraphic distance below the top of the Fort Riley limestone, they are the 900-, 1,125-, 1,200-, 1,275- and 1,475-foot "sands." In places the distinction of the middle three is not sharply defined; and where this is the case they are grouped and spoken of as the 1,200-foot sand. In the stratigraphic section given in plate VI it may be seen that all five gas "sands" are included in the Shawnee and Douglas formations. The strata from which the gas is obtained are in practice termed "sands," but so far as the writer could ascertain this is for the most part a misnomer; they probably are porous layers in limestone. The locations of the more or less productive gas areas are usually found in drilling oil wells, and from the locations thus determined the gas is then later exploited by drilling special wells. This indicates a more or less pockety distribution, due, no doubt, to the locations of the more porous parts of the gas-bearing strata. Although the nature of the limestones determines the locations of the gas occurrences,

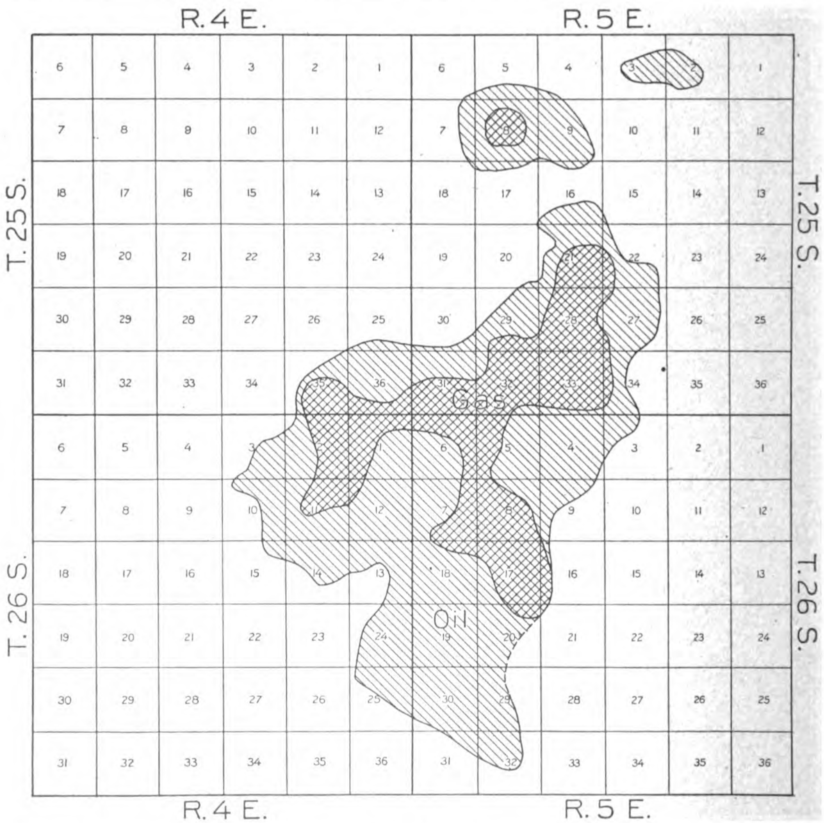

FIG. 2.—Map of the El Dorado field, showing extent of the gas-producing territory in comparison to that of the oil-producing territory.

it is only where this feature is high on the domes that the gas is found. Its distribution is much more confined to the apexes of the domes than the oil in either the 660-foot sand or the Stapleton zone. In fact, its areal distribution is about one-third that of the oil, as shown in figure 2. The controlling feature in the accumulation of the gas appears to be a combination of the structure and the relative position of the more porous portions of the gas-bearing limestones. It is to be noted that no gas wells are located on the Robinson dome or the Koogler nose.

Discontinuity of the various "sands"—or perhaps, more correctly, their porous parts—is indicated in the distribution of the wells obtaining their supply from the different horizons as indicated in the following table, which shows the principal productive localities for each "sand."

Table showing distribution of production from the various gas sands.

"Sand."	Shumway dome.	Boyer dome.	Koogler nose.	Bancroft syncline.	Oil Hill dome.	Chesney dome.	Wilson dome.	Robinson dome.
900 ft.	+	+	....	....	+	....	....	....
1,125 ft.	+	+	....	....	+	....	....	....
1,200 ft.	+	+	....	+	+	....	+	....
1,275 ft.	....	+	....	+	+	+	+	....
1,475 ft.	+	....	....	....	....	....	....	....

The 900-foot "sand" produces principally on the Oil Hill and Boyer domes and in the north part of the elongated Shumway dome. But few wells obtain their gas supply from the 1,125-foot "sand," and these are scattered over the same folds as the 900-foot "sand." The 1,200-foot "sand" is the producing bed in a few more wells than the 1,125-foot "sand," and also is more widely scattered, being productive on the Wilson, Oil Hill, Boyer and Shumway domes and the minor Bancroft syncline. The 1,275-foot "sand" is productive principally on the Wilson, Chesney, northeastern part of the Oil Hill and the northern part of the Boyer domes. It is to be noted that this is the only "sand" thus far productive on the Chesney dome. The deep "sand" found at 1,475 feet beneath the top of the Fort Riley limestone is more restricted in its productivity than the others. It is confined almost altogether to the Shumway dome.

STRUCTURE.

In a few localities sufficient wells have been drilled to the gas "sands" so that these productive zones can be contoured and their structure studied. This was possible for the 1,275-foot gas "sand" on the Chesney dome and the 900-foot gas "sand" on the Boyer dome. The structure of the 1,275-foot "sand" on the Chesney dome, as given in figure 3, is very similar to the folding of the 660-foot oil sand. The amount of closure is equally as great as, and possibly greater than, that of the 660-foot sand, indicating an increase in the amount of apparent folding of the beds with depth on this structural feature—a feature which was pointed out in the discussion of the 660-foot "sand" in relation to the surface rocks.

The structure of the 900-foot gas "sand" on the Boyer dome is shown in figure 4. It is not so readily determinable as that of the 1,275-foot "sand," described above, since it does not conform closely to the structure of the surface rocks nor to

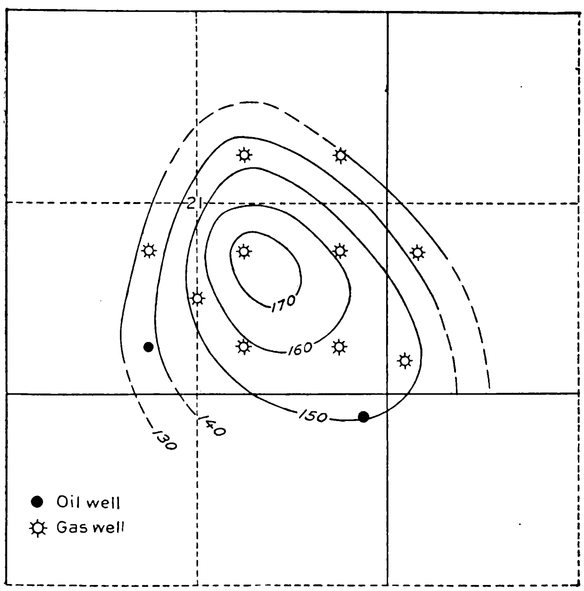

FIG. 3.—Contour map of the Chesney dome, showing structure of the 1,275-foot gas "sand."

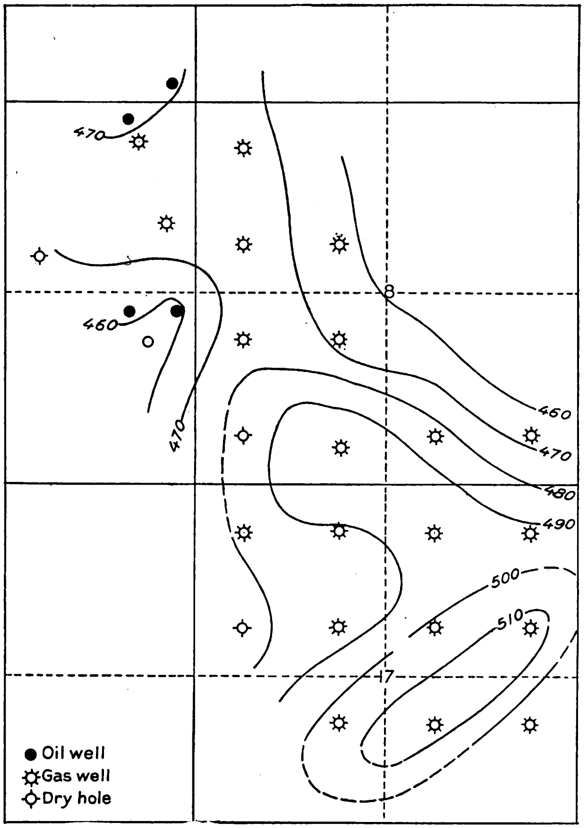

FIG. 4.—Contour map of the Boyer dome, showing structure of the 900-foot gas "sand."

that of the Stapleton sand. A northeasterly trending minor fold is suggested crossing the southeast quarter of section 17, which is not indicated in the structure of the surface rocks (see plate I), nor in that of the Stapleton pay zone (see plate XIV). As will be pointed out in the discussion of the Stapleton pay zone, the Boyer dome represents the poorest exhibition of conformity between the structure of the surface and underground rocks, and it would seem that the 900-foot gas "sand" accords well with this fact.

PRODUCTION.

Total Field Production. Much of the gas produced in the Eldorado field during 1916 and 1917, and practically all of it produced since then, is used for development purposes, principally under boilers and in gas engines which pump the oil wells.

The gas used on many of the leases where it originates is not metered, and for this reason gas-production data for the entire field cannot be determined accurately. Production data covering the gas wells owned by the Empire Gas and Fuel Company, which represent approximately three-fourths of the gas wells of the field, are graphically indicated in figure 5, which gives the total and average well production per month, for the period from May, 1916, to March, 1918. The total production of these 69 gas wells during this period amounted to 6,660,276,000 cubic feet, and if this be considered as three-fourths of the production for the entire field, then the Eldorado field produced a total of 8,880,356,000 cubic feet prior to April, 1918.

A rough estimate was made of the proportion which this total production bore to the original total gas content of the field. This was obtained by determining how much the average original rock pressure for all the "sands" had been reduced by the total production. The determination of the original rock pressure for each "sand" was first obtained by assuming it to be the initial closed rock pressure of the first well tapping it where this pressure was not exceeded in some later well. If this first well did not have the highest initial closed rock pressure, then an average was taken of the pressure of the first well and the highest closed rock pressure of any later-drilled well. The pressure thus obtained for each "sand" was as follows:

900-foot "sand"	332.5 lbs. per sq. in.
1,125-foot "sand"	460.0 lbs. per sq. in.
1,200-foot "sand"	450.0 lbs. per sq. in.
1,275-foot "sand"	462.5 lbs. per sq. in.
1,475-foot "sand"	382.5 lbs. per sq. in.

The relative extent or capacity of the reservoirs of these "sands" for this field was considered by the writer to be roughly indicated by the number of wells drilled to each; hence to obtain an average for the original closed rock pressure for the field the above "original pressures" for the various "sands" were weighted according to the number of wells drilled to each, and the resulting average was calculated to be 393 pounds.

If this pressure of 393 pounds per square inch is considered to be the average original rock pressure for all the gas "sands"

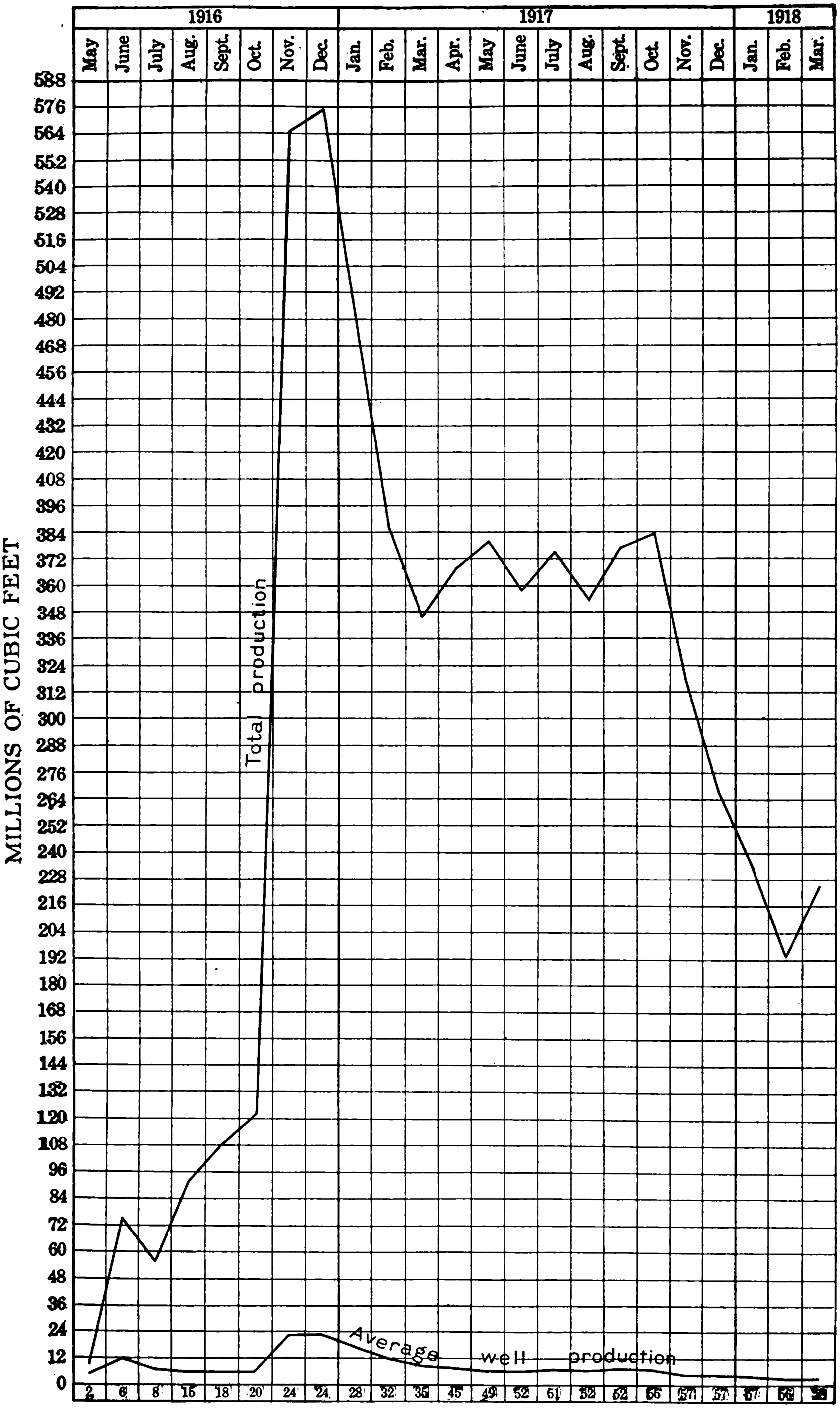

Fig. 5—Graph showing total gas production and average well production per month of 69 gas wells over a period of 23 months.

in the Eldorado field, and a production of 8,880,356,000 cubic feet reduced this pressure to 108 pounds[8] by March, 1918, then the total production, 8,880,356,000 cubic feet, is to the total amount of gas originally in the field as the decrease in the rock pressure, 285 pounds, is to the original rock pressure, 393 pounds. The solution of this proportion gives the total amount of gas originally in the field as about 12,245,000,000 cubic feet, of which the production up to March, 1918, represented 73 per cent. This, of course, represents but a rough approximation. The possibility that encroaching water under high pressure is keeping up the gas pressure, thereby making the above calculated original volume too large, or that there is a lag in the rock pressure due to friction in passing through the pay sand, which diminishes the pressure at the well, thereby causing the calculated volume to be too small, were not taken into consideration. In the absence of porosity determinations for the various sands—a feature whose average would be quite difficult to ascertain, inasmuch as the rock is a porous limestone with a probable varying porosity—no attempt was made to determine the original amount of gas in the field by estimating the amount of pore space in conjunction with the average original rock pressure.

The graph in figure 5 shows that from May to October, 1916, but a small part of the potential production was taken from the wells, but that during the following cold months, when much of the gas was supplied to the town of Eldorado for domestic use, the wells were drawn on for a large part of their available production. The high production maintained during most of 1917 was used for field development by a constantly increasing number of wells drilled. During the winter of 1917-'18 but little if any gas was sold for domestic use, and the marked slump during this period may be accounted for by the great curtailment of drilling operations caused by the severe cold weather. Assuming that the graph in figure 5 represents but three-fourths of the total production for the field, the average daily production (reduced from the monthly production of the graph) reached a maximum of 25,572,800 cubic feet during December, 1916; and that in March, 1918, the last month for which production figures are given, was 10,005,244 cubic feet.

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8. One hundred and eight pounds is the average as shown by the curve in figure 6, whereas 98 pounds was the average determination.

INITIAL OPEN-FLOW CAPACITIES. The productivity of the wells when drilled in varies greatly. Of seventy-nine wells whose records were accessible, the largest open-flow volume measured 21 million cubic feet per day. Three others had open-flow capacities of 10 million or more, and those with capacities of 5 million or more but less than 10 million numbered eleven. The remaining sixty-three had initial open-flow volumes of less than 5 million cubic feet. The 1,275-foot "sand" leads in the initial size of its wells, four wells with capacities of 10 or more million obtaining their supply from this "sand." The 900-foot "sand" yielded five wells with open flows greater than 5 million but less than 10 million, and the 1,475-foot "sand" furnished four similarly sized wells. This information is summarized in the following table. It is to be noted that the information here given differs slightly from that given on figure 7, which referred to but sixty-eight wells.

Table showing initial open-flow volumes of 79 wells whose records were available.

	"Sands"—				
	900-foot.	1,125-foot.	1,200-foot.	1,275-foot.	1,475-foot.
Number of wells with volumes of 10 million or more cubic feet	......	......	......	4	......
Number of wells with volumes of 5 million or more, but less than 10 million cubic feet	5	......	......	2	4
Number of wells with volumes of 1 million or more, but less than 5 million cubic feet	31	5	5	8	8
Number of wells with volumes less than 1 million cubic feet	......	2	3	1	1
Total wells	36	7	8	15	13
Average initial volume in millions of cubic feet per day	2.8	1.6	1.1	6.2	3.4

DECLINE IN ROCK PRESSURE AND OPEN-FLOW VOLUME. The large initial productions of these wells is exceedingly short-lived. The withdrawing of gas lowers the rock pressure, and the productivity, which is largely dependent on the rock pressure, declines at nearly the same rate. The decline in productivity varies for the different sands. Also, those with large initial open-flow volumes decrease most rapidly, which is to be expected, since it is the large wells which are drawn upon most generously, and those with small initial open-flow volumes decrease more slowly.

The decline in productivity is generally studied in the decline of rock pressure, upon which the productivity is in large part dependent. When first "drilled in," the closed rock pressures of those wells whose records were available varied from 110 to 510 pounds per square inch. That the rock pressures vary also for the wells producing from the different "sands" has previously been pointed out.

Consideration will first be directed to the decline in rock pressures of seven wells on the Chesney dome which produce from the 1,275-foot "sand." The bimonthly determinations of their closed rock pressures during a period of about two years are graphically shown in plate XV. It is to be noted that these wells were completed within a period of three months, and that except for wells F and G the decline has been very uniform. The reason for the exceedingly slow decline in well G is not apparent. It is possible that it was not drawn upon as much as the other wells.

The initial pressures of wells F and G, in that they are lower than the earlier completed wells, closely coincide with the principle formulated by Rogers,[9] that in any gas pool the initial pressures of wells correspond closely to the existing pressures of the wells already producing. The apparent low initial pressure in curve *a* of plate XV is due to some cause, possibly insufficient penetration of the "sand," but this is compensated later by an increase when the full rock pressure in the sand became effective in this well.

The decline in sixteen wells (lettered *a* to *p* in the order of their completion) producing from the 900-foot "sand" on the Boyer dome is given in plate XVI. The heavy line which connects the initial rock pressures of the successively completed wells shows that wells *j, k, l, m, n* and *o* closely follow the principle of declining initial pressures formulated by Rogers, but wells *i* and *p* are specially marked discrepancies. It is possible that these discrepancies indicate some local sand condition, possibly lack of free access of gas throughout the porous reservoir. This may be due to the discontinuity of the porous gas-bearing layers, such as is to be expected more or less in limy strata.

A comparison of plates XV and XVI shows that the gas in the 1,275-foot "sand" on the Chesney dome originally had a much higher rock pressure—about 500 pounds—than the 900-foot "sand" in the Boyer dome, with its average pressure of

9. Rogers, G. Sherburne; The Cleveland gas field, Cuyahoga county, Ohio, with a study of rock pressure: U. S. Geol. Survey Bull. 661, p. 37.

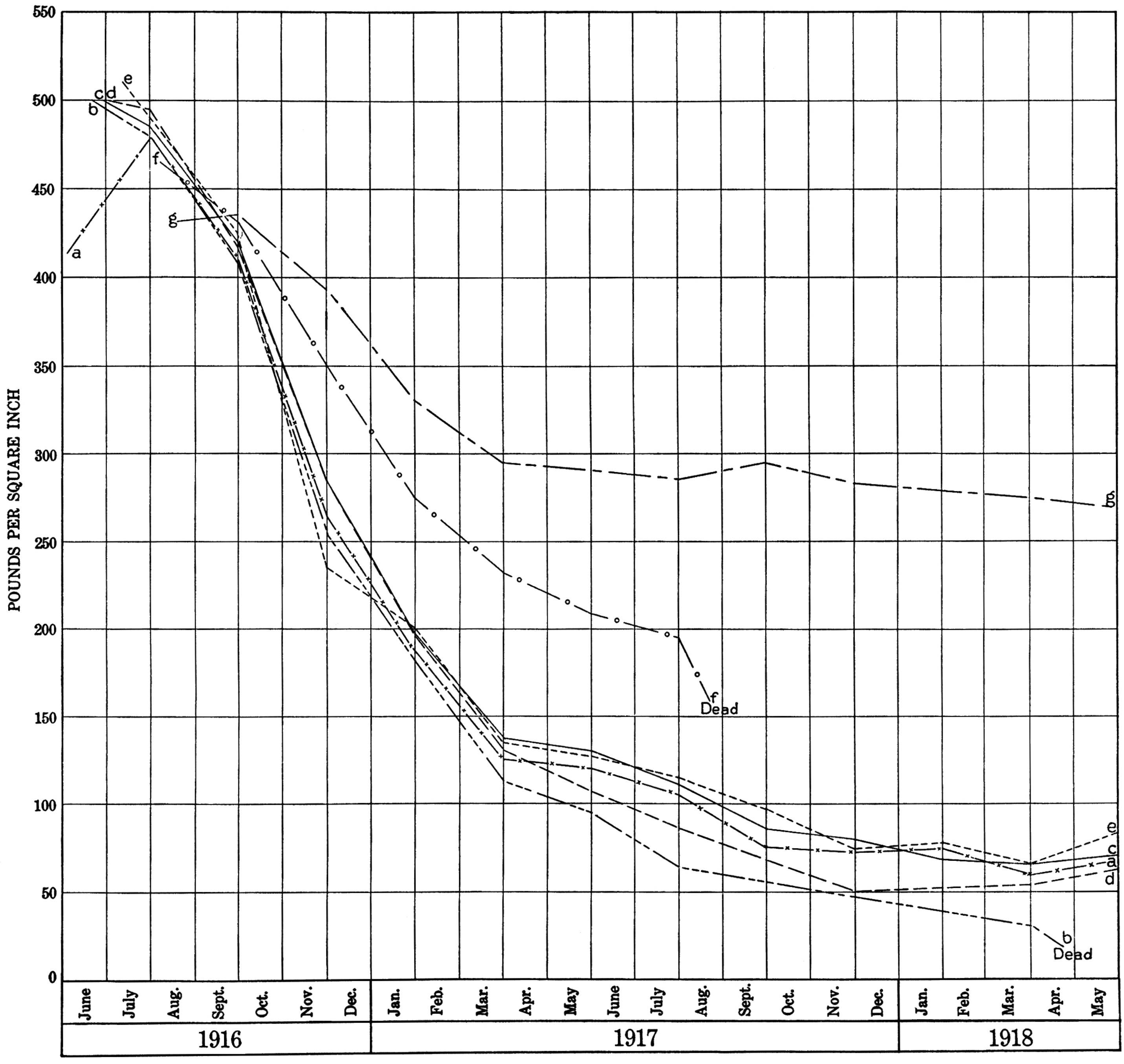


PLATE XV.—Graphs showing declines in closed rock pressure of seven 1,275-foot "sand" gas wells on the Chesney dome.

about 340 pounds. It is to be noted that at the end of May, 1918, the 1,275-foot "sand," with its higher initial rock pressure, retained its lead over the 900-foot "sand" by about 50 per cent. This difference in the rock pressures of wells producing from different "sands" is graphically shown in figure 6, which gives the averages of the wells producing from each "sand."

Although the 1,475-foot "sand" has the highest initial average closed rock pressure, its decline is more rapid than that of the 1,125-foot "sand." Similarly, the 1,275-foot "sand" has a higher average initial closed rock pressure than either the 1,125- or 1,200-foot "sands," but its decline is more rapid. By noting the number of wells from which the decline information was obtained, indicated by figures at the sides of the bimonthly determinations for each "sand," several interesting features may be deduced. The rapid decline of one 1,475-foot-"sand"

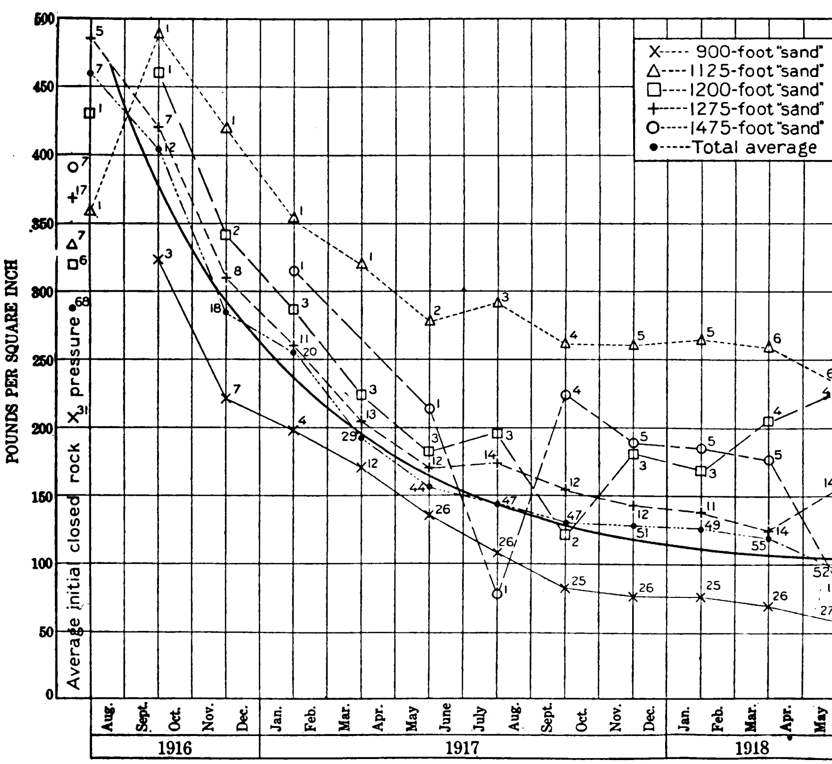


FIG. 6.—Decline curve of closed rock pressures based on the records of 68 wells grouped according to the "sands" from which they produce.

well from January to July, 1917, is noteworthy, and the increase thereafter in the average closed rock pressures of wells producing from this "sand" is due solely to the drilling of additional wells.

That the rock pressure does not completely govern the open-flow volume is illustrated by comparing the rock-pressure curve (figure 6) with the open-flow volume curve (figure 7). It will be noted that, whereas the 1,125-foot "sand" has the highest initial average closed rock pressure, the open-flow volume of its wells is less than that of the other "sands," with the exception of the 1,200-foot "sand." On the other hand, the 900-foot "sand" has the lowest rock-pressure-decline curve, but its decrease in open-flow volume is greater than that of all the other "sands." The 1,475-foot "sand," whose decline in closed rock pressure was noted as specially rapid, is even more marked in its rapid decline in open-flow volume. One of its wells—the sole producer from this "sand" between January and July, 1917—completed on January 3, 1917, with an open-flow volume of 11,000,000 cubic feet, declined by the end of the month, when the first determination shown on the graph was made, to 4,500,000 cubic feet, and by July had reached the low figure of 280,000 cubic feet. The increase thereafter in the open-flow-volume determinations for this "sand" is due solely to the bringing in of new wells.

LIFE OF GAS PRODUCTION. A study of figures 6 and 7 would seem to indicate that the 1,475-foot "sand" wells cannot be relied upon to furnish any considerable part of the future gas supply. Its excessively rapid decline in open-flow volume, which necessitated the abandonment of four wells in February, 1918, after a life of less than six months, clearly shows the greater pockety nature of this "sand" in comparison to the more shallow "sands." The other "sands" show a more uniform decline in their production, and hence will continue to supply gas for at least a short time to come.

If, as roughly estimated on page 86, but 27 per cent of the original gas supply remained in the ground, the end of the Eldorado field as a producer of gas is not far distant. The time when the drilling of new gas wells will cease at Eldorado will probably not be before the average daily open-flow volume becomes less than 100,000 cubic feet.

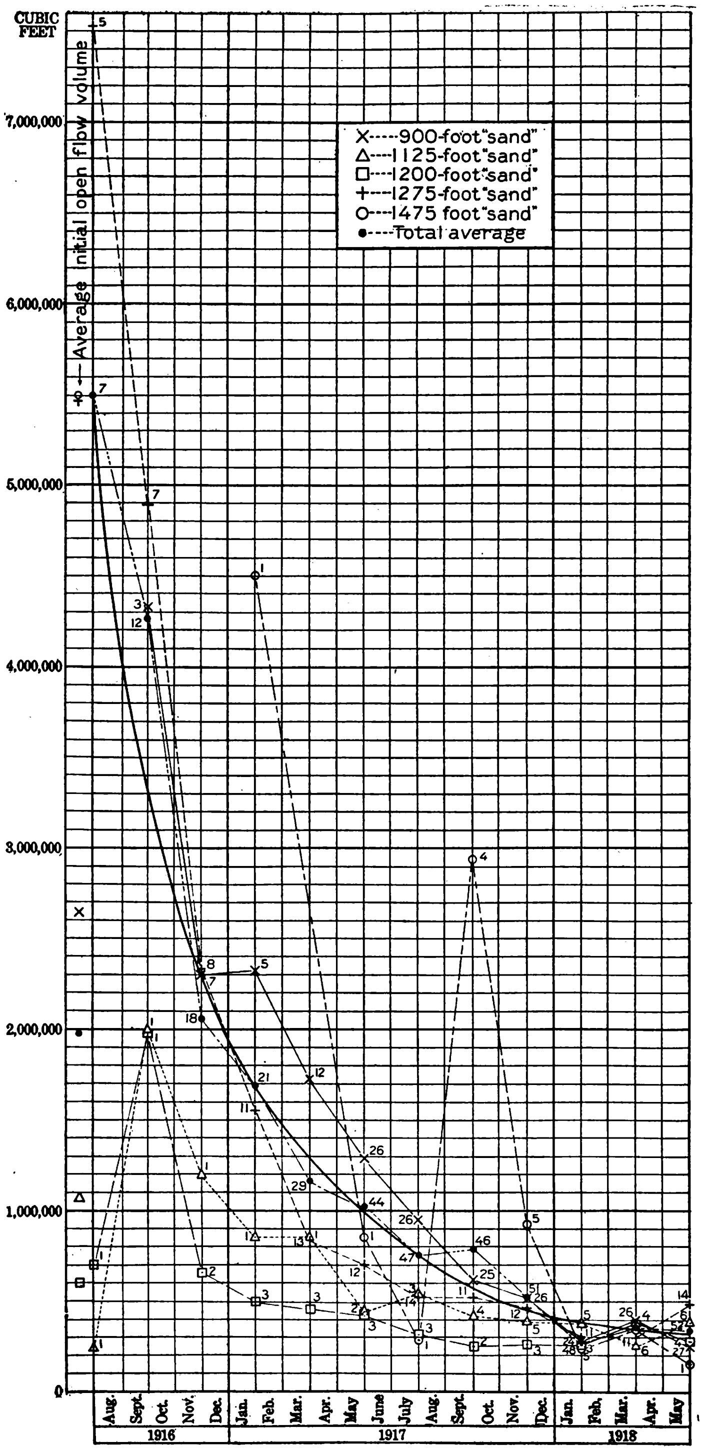


Fig. 7.—Decline curve of daily open-flow volumes based on the records of 68 wells grouped according to the "sands" from which they produce.

DEEP OIL "SANDS."

BOYER "SAND."

The Boyer "sand," which is located in the lower part of the Douglas formation about 1,700 feet below the top of the Fort Riley limestone, was discovered on the Boyer lease in sec. 17, T. 26 S., R. 5 E., after which it is named. The discovery well had an initial daily production reported to have been 150 barrels. The productive portion of the "sand" in this vicinity is very limited, and although the discovery of the "sand" was made in July, 1916, but one additional well was completed in it in the immediate locality prior to 1919.

An oil-bearing "sand" at about the same stratigraphic position—which in this report will be considered the same—was found about two miles to the northwest on the Shumway dome in the Empire Gas and Fuel Company's Enyart well No. 10 (northwest corner location, sec. 12, T. 26 S., R. 4 E.), and Paulson well No. 2 (center location, NE¼ SE¼, sec. 2, T. 26 S., R. 4 E.), which were completed during November, 1917, with initial productions of about 100 barrels. Further attempts to develop this "sand" on the Shumway dome were not made until late in 1918 and 1919, when, according to press reports, numerous wells were drilled to exploit the oil contained in it.

The Boyer "sand," according to drilling logs, is rather uniformly oil-bearing over the northern part of the Shumway dome; that is, in sec. 35, T. 25 S., R. 4 E., and in secs. 1, 2, 10, 11 and 12 of T. 26 S., R. 4 E. It has also been reported in the logs of a few wells on the Oil Hill dome. Even though rather widely oil-bearing over a part of the Shumway dome, the oil seems to be present in commercial quantities only along the crest of this fold.

Drill cuttings from the Boyer "sand" in Paulson well No. 2, previously cited, show that the oil is contained in a calcareous limestone, and a few well logs record the "sand" as limestone, from which evidence it seems reasonable to infer that the Boyer oil zone is contained in a calcareous limestone.

Most of the Boyer "sand" development on the Shumway dome was done after the completion of the field work on which this report is based, and hence the information here presented must of necessity be very meager. Following are the logs of the original Boyer "sand" well and of a Boyer "sand" well on the Shumway dome:

Log of Empire Gas and Fuel Company's Fee Well No. 1.

Location, center of NW¼ NE¼, sec. 17, T. 26 S., R. 5 E. Drilled April 25 to June 30, 1916. Elevation of well mouth, 1,377 feet, which is about 60 feet below top of Fort Riley limestone. Initial production, 100 barrels. Casing record: 15½-inch, 100 feet; 12½-inch, 670 feet; 10-inch, 920 feet; 8¼-inch, 1,590 feet; 2-inch, 1,670 feet. Log furnished by Empire Gas and Fuel Company.

Drillers' record.	Thickness in feet.	Depth in feet.	Geological correlations by the writer.
Lime	34	34	Florence flint.
Lime	6	40	
Shale	17	57	
Lime	8	65	
Shale	15	80	
Lime	20	100	
Shale	3	103	
Lime	7	110	
Lime	20	130	
Shale	5	135	
Lime	15	150	
Shale	55	205	
Lime	5	210	
Shale	20	230	
Shale	10	240	
Lime	20	260	
Shale	15	275	
Lime	25	300	
Shale	100	400	
Shale	15	415	
Lime	8	423	
Shale	6	429	
Lime	4	433	
Shale	17	450	
Shale	15	465	
Lime	20	485	
Shale	5	490	
Lime	10	500	
Shale	20	520	
Mud	8	528	
Lime	4	532	
Red bed	5	537	
Mud	2	539	
Lime	2	541	
Shale	5	546	
Lime	9	555	
Shale	3	558	
Lime	4	562	
Lime-flint	5	567	
Shale	3	570	
Shale	6	576	
Lime	9	585	
Shale	2	587	
Lime	2	589	
Lime	6	595	
Shale	3	598	
Lime	14	612	
Shale	8	620	
Shale	8	628	
Lime	4	632	

Drillers' record.	Thickness in feet.	Depth in feet.	Geological correlations by the writer.
Shale	8	640	
Lime	4	644	
Shale	2	646	
Lime	4	650	
Lime	4	654	
Shale	12	666	
Shale	2	668	
Lime	5	673	
Shale	23	696	
Lime	8	704	
Shale	10	714	
Lime	15	729	
Shale	25	754	
Lime	40	794	
Shale	15	809	
Lime	3	812	
Shale	3	815	
Shale	55	870	
Shale	6	876	
Sand	6	882	
Shale	15	897	
Lime, gas	3	900	900-foot gas "sand."
Shale	5	905	
Shale	15	920	
Lime	5	925	
Shale	25	950	
Shale	82	1,032	
Lime	33	1,065	
Lime	40	1,105	
Break	5	1,110	
Lime	50	1,160	
Shale	4	1,164	
Shale	3	1,167	
Gas sand	3	1,170	
Sand	15	1,185	
Sand	10	1,195	
Lime	49	1,244	
Lime	61	1,305	
Lime	65	1,370	
Shale	5	1,375	
Shale	20	1,395	
Lime	25	1,420	
Shale	50	1,470	
Sand	15	1,485	
Shale	80	1,565	
Shale	20	1,585	
Shale	2	1,587	
Lime	30	1,617	
Shale	20	1,637	
Lime	8	1,645	
Lime	8	1,653	
Sand; oil	25	1,678	Boyer "sand."

Log of Empire Gas and Fuel Company's Paulson Farm Well No. 2.

Location, center of NE¼ SE¼, sec. 2, T. 26 S., R. 4 E. Drilled September 5 to November 4, 1917. Elevation of well mouth, 1,395 feet, which is about 15 feet below top of Fort Riley limestone. Initial production, 100 barrels. Casing record: 12½-inch, 14 feet; 8¼-inch, 825 feet; 6⅝-inch, 1,300 feet; 5$\frac{3}{16}$-inch, 1,644 feet; 2-inch tubing, 1,688 feet. Log furnished by Empire Gas and Fuel Company.

Drillers' record.	Thickness in feet.	Depth in feet.	Geological correlations by the writer.
Soil	5	5	
Lime, white, firm	75	80	Fort Riley limestone and Florence flint.
Shale, white, soft	15	95	
Lime, gray, hard	35	130	
Shale, blue, soft	20	150	
Lime, gray, hard	25	175	
Red rock, red, soft	10	185	
Shale, white, soft	20	205	
Lime, gray, hard	15	220	
Shale, white, soft	70	290	
Lime, gray, hard	35	325	
Shale, blue, soft	25	350	
Lime, gray, hard	15	365	
Shale, dark, soft	10	375	
Lime, gray, firm	55	430	
Shale, white, soft	25	455	
Lime, gray, hard	10	465	
Shale, dark, soft	15	480	
Shale, white, soft	15	495	
Lime, gray, hard	10	505	
Shale, blue, soft	25	530	
Lime, white, firm	15	545	
Red rock, red, soft	15	560	
Shale, dark, soft	10	570	
Lime, gray, firm	10	580	
Shale, white soft	40	620	
Shale, blue, soft	30	650	
Lime, white, firm	15	665	
Shale, dark, soft	20	685	
Shale, white, soft	55	740	
Lime, gray, hard	50	790	
Sand, white, soft; water	10	800	
Lime, sandy, gray, firm	20	820	
Shale, white, soft	10	830	
Lime, gray, hard	5	835	
Shale, white, soft	60	895	
Sand, white, soft; 3,000,000 cu. ft. of gas; water	25	920	900-foot gas "sand."
Lime, sandy, gray, firm	30	950	
Lime, gray, hard	30	980	
Shale, dark, soft	25	1,005	
Sand, white, soft; water	10	1,015	
Shale, dark, soft	10	1,025	
Sand, white, soft	5	1,030	
Sand, dark, firm	10	1,040	
Shale, white, soft	40	1,080	
Lime, gray, hard	30	1,110	
Shale, dark, soft	10	1,120	
Shale, white, soft	10	1,130	

Drillers' record.	Thickness in feet.	Depth in feet.	Geological correlations by the writer.
Lime, gray, hard	15	1,145	
Shale, dark, soft	5	1,150	
Lime, white, firm; 500,000 cu. ft. of gas	55	1,205	
Shale, dark, soft	10	1,215	
Lime, gray, hard	25	1,240	
Shale, dark, soft	10	1,250	
Lime, gray, firm	73	1,323	
Lime, white, soft	7	1,330	
Shale, dark, soft	45	1,375	
Lime, gray, hard	20	1,395	
Shale, white, soft; 200,000 cu. ft. of gas	25	1,420	
Shale, dark, soft	15	1,435	
Lime, sandy, gray, soft	10	1,445	
Sand, gray, firm	60	1,505	
Lime, sandy, gray, firm	40	1,545	
Shale, dark, soft	40	1,585	
Lime, gray, hard	35	1,620	
Shale, dark, soft	24	1,644	
Lime, gray, hard	2	1,646	
Lime, sandy, gray, firm	3	1,649	
Oil sand, gray, firm	28	1,677	Boyer "sand."

STOKES "SAND."

The Stokes "sand," which lies about 2,000 feet below the top of the Fort Riley limestone, was discovered on the Stokes lease near the east quarter corner of sec. 33, T. 25 S., R. 5 E., from which it obtains its name. From the discovery of commercial production in this "sand," during March, 1917, and up until the end of that year, but two additional wells located in the immediate vicinity of the discovery well were completed to this pay in the entire field. It would appear also from the information given in press reports for 1918 that no additional Stokes "sand" wells were completed during this year. The initial daily capacities of these three wells were reported as ranging from 100 to 300 barrels. As pointed out in the discussion on stratigraphy, the Stokes "sand" belongs to the Kansas City formation, as differentiated in plate VI, which is there indicated as consisting principally of limestone. The mineralogical composition of the Stokes "sand," as recorded in the logs of the wells which obtain their oil from it, is reported as "broken sandy lime" in one, and "sand" in the other two. In the logs of other wells scattered rather widely in the field, and which also record this "sand," it is generally referred to as "sand," but a few specifically record it as "lime." Since most drillers call any oil-bearing rock a "sand," without reference to its mineralogical composition, it may be that the few who specify this oil-bearing rock as "lime" more truthfully indicate its mineralogical character.

The Stokes "sand" is slightly oil-bearing over a larger area than the Boyer "sand," but the extent of the area in which its content of oil is present in commercial quantities, as indicated by the two wells producing from it, is much more limited. Its presence, according to logs of oil wells, is recognized on the Robinson, Wilson, Chesney, Oil Hill and Shumway domes and at the north extremity of the Boyer dome. Following is a log of a Stokes "sand" well:

Log of Union Oil Company of Wichita's Hill Farm Deep Well No. 2.

Location, center of west line, NW¼ SW¼, sec. 34, T. 25 S., R. 5 E. Drilled April 3 to (?), 1917. Elevation of well mouth, 1,368 feet, which is about 50 feet below top of Fort Riley limestone. Initial production, 300 barrels. Log furnished by the Union Oil Company of Wichita.

Drillers' record.	Thickness in feet.	Depth in feet.	Geological correlations by the writer.
Lime, white, hard	50	50	Florence flint.
Slate, black, soft	10	60	Matfield shale.
Slate, white, soft	20	80	
Lime, white, hard	10	90	
Slate, white, soft	30	120	
Red rock, red, soft	5	125	
Lime, white, hard	15	140	Wreford limestone.
Sand, white, soft	20	160	
Slate, black, soft	60	220	
Lime, white, hard	15	235	
Shale, white, soft	30	265	
Lime, white, hard	10	275	
Slate, white, soft	20	295	
Lime, white, hard	15	310	
Slate, black, soft	5	315	
Lime, white, hard	5	320	
Slate, black, soft	5	325	
Shale, white, soft	15	340	
Slate, black, soft	10	350	
Lime, white, hard	5	355	
Slate, black, soft	20	375	
Slate, white, soft	40	415	
Slate, black, soft	5	420	
Slate, white, soft	10	430	
Slate, black, soft	10	440	
Lime, white, hard	5	445	
Slate, black, soft	5	450	
Lime, white, hard	10	460	
Slate, white, soft	10	470	
Slate, black, soft	5	475	
Slate, white, soft	10	485	
Lime, gray, hard	5	490	
Slate, black, soft	30	520	
Slate, white, soft	10	530	
Slate, black, soft	5	535	

Drillers' record.	Thickness in feet.	Depth in feet.	Geological correlations by the writer.
Lime, gray, hard; 3 bailers water per hour	5	540	
Slate, black, soft	5	545	
Slate, white, soft	10	555	
Shale, white, soft	15	570	
Slate, black soft	15	585	
Slate, white, soft	10	595	
Sand, white, soft; oil	15	610	660-foot oil sand.
Slate, black, soft	20	630	
Slate, white, soft	20	650	
Slate, black, soft	55	705	
Slate, white, soft	20	725	
Lime, white, hard	25	750	
Slate, white, soft	15	765	
Lime, white, hard; 2 bailers of water per hour	40	805	
Slate, black, soft	57	862	
Sand, white, soft; gas	2	864	
Slate, black, soft	6	870	
Sand, white, soft; hole full of water	25	895	
Slate, black, soft	65	960	
Lime, white, hard	10	970	
Slate, black, soft	70	1,040	
Lime, white, hard	20	1,060	
Slate, black, soft	15	1,075	
Lime, white, hard	25	1,100	
Slate, black, soft	25	1,125	
Sand, white, hard; gas at 1,140	18	1,143	
Slate, white, soft	10	1,153	
Lime, white, hard; water at 1,160	30	1,183	
Slate, black, soft	10	1,193	
Lime, brown, hard	42	1,235	
Sand, white, hard; 3,000,000 cu. ft. of gas at 1,240	30	1,265	
Lime, white, hard	20	1,285	
Slate, black, soft	15	1,300	
Lime, gray, hard	20	1,320	
Slate, black, soft	10	1,330	
Lime, white, hard	25	1,355	
Slate, black, soft	10	1,365	
Lime, gray, hard	10	1,375	
Slate, black, soft	10	1,385	
Lime, white, soft	15	1,400	
Slate, black, soft	150	1,550	
Lime, gray, hard; 2 bailers of water per hour	20	1,570	
Slate, black, soft	30	1,600	
Lime, white, hard	40	1,640	
Sand, white, hard; oil showing at 1,650	30	1,670	
Slate, dark, soft	35	1,705	
Lime, white, hard	105	1,810	Lansing formation.
Slate, white, soft	140	1,950	
Sand, white, hard; first oil at 1,985 and second oil at 2,015,	132	2,082	Kansas City formation containing Stokes "sand."

STAPLETON OIL ZONE.

Résumé of Stratigraphic Relations.

In a preceding chapter the Stapleton oil zone is described as lying below the pre-Cherokee peneplained erosion surface. This erosion surface, as discussed there, bevels the Boone (?) limestone and in places completely eliminates it, bringing the underlying sandstone in unconformable contact with the superposed Pennsylvanian rocks. The erosion surface, so far as can be ascertained, possessed a very low and gentle relief. It is the writer's opinion, which is amplified on a later page, that diastrophic forces gently bowed up this surface in early Pennsylvanian time, prior to the deposition of the Cherokee shale and the Marmaton formation. It is the upper portion of this eroded terrain which now contains the deep-lying oil of the Eldorado district, and is called the Stapleton oil zone. The present attitude of the surface of this unconformity, as modified by additional folding during Pennsylvanian, Permian, and even later time, has been determined from well-record data, and is shown by contours on plate XIV.

The agreement of the general features of folding in the Stapleton oil zone with those of the surface rocks and the 660-foot oil sand is quite striking. It is more intricately folded and differs from them principally in the intensity of the folding, the deep-lying Stapleton being more strongly flexed. This greater intensity of folding, as discussed on pages 155-164, the author believes is due largely to the fact that the older rocks were subjected to flexing prior to the deposition of the later rocks. Therefore, the contours drawn on top of the Stapleton oil zone show several local details of flexing not present in the surface rocks and the 660-foot oil sand, because the movement which caused them was not repeated after the later beds were deposited, and the inequalities of the Stapleton surface were filled by later sediments.

Structure.

SHUMWAY DOME. The dome in the Stapleton zone covers essentially the identical area as in the outcropping Fort Riley limestone, extending from sec. 14, T. 26 S., R. 4 E., to sec. 36, T. 25 S., R. 4 E. Its crest line follows in general the elongated crest in the Fort Riley but its crest area is not as regular in the Stapleton as in the Fort Riley, being slightly wrinkled with several low upfolds and a few shallow depressions.

The Shumway dome in the Stapeton zone is limited on the east by the same features as the dome in the surface rocks, the Bishop and Fowler synclines. The Bishop syncline, however, is so sharply developed that it appears to approach a fault and may in reality be one, which for lack of sufficient drilling information cannot be indicated as such on plate XIV. The Fowler syncline, too, is strongly developed, so much so that it might be termed a pit. In addition to these features there is another in sec. 31, T. 25 S., R. 5 E., not represented in the surface rocks, which starts in the southwest corner of sec. 31, T. 25 S., R. 5 E., and runs northeasterly until it joins the northwest extension of the Bancroft syncline near the northeast corner of the section.

So far as the information at hand indicates, production in the Stapleton zone is continuous across this depression and also the Fowler syncline. A few dry holes, including the original well drilled by the city of Eldorado, are present here on the east flank between the center and east quarter corner of sec. 1, T. 26 S., R. 4 E. This series of dry holes is noteworthy. They all lie above the 1,030-foot contour on plate XIV, whereas a short distance to the south production has been developed as far down as the —1,100-foot contour. The writer has no information from which he can obtain a specific explanation for this local barrenness of the Stapleton. The lower limit of production varies considerably. To the southeast, in section 13, it appears to be limited at about the —1,030-foot elevation, but farther west, near the center of section 14, it extends below the —1,050-foot contour. Northwest of this point the production limit rises somewhat, but drops again at the north side of section 10 and in section 3 to below the —1,075-foot contour. In sec. 35, T. 25 S., R. 4 E., good wells have been obtained as low as the —1,060-foot contour and in section 25 of the same township almost down to the —1,090-foot contour. A range of about 60 feet in elevation is thus indicated in the margin of the oil limits in the Stapleton oil zone on the Shumway dome.

The Shumway dome is the most productive portion of the Eldorado field, the largest wells ever drilled in the Midcontinent field, several of which initially produced more than 15,000

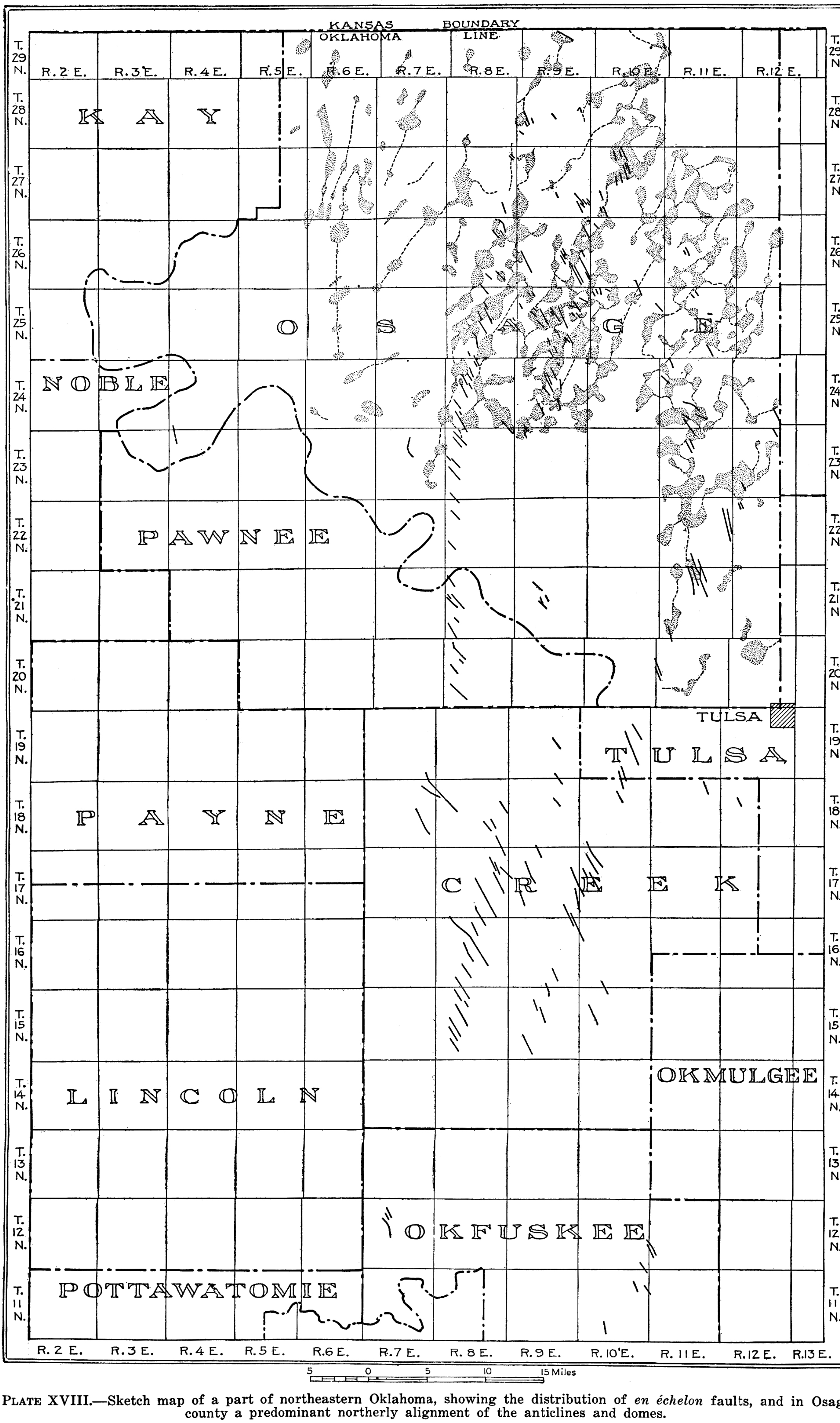


PLATE XVIII.—Sketch map of a part of northeastern Oklahoma, showing the distribution of *en échelon* faults, and in Osage county a predominant northerly alignment of the anticlines and domes.

barrels per day, being located on this structure. During the early development of the Shumway dome, wells with initial daily capacities of more than 1,000 barrels were common, and from this figure they ranged up to 15,000 barrels, and even better. These wells of high yield follow rather closely the crest of the structure, with their greatest concentration in sec. 11, T. 26, R. 4. A few wells with initial productions of 500 to 3,000 barrels are located east of the crest, but instead of being in the deep Fowler or Bishop synclines they are located on the ridgelike fold between these depressions, which extends eastward across the SE¼, sec. 12, T. 26 S., R. 5 E., and into sec. 7, T. 26 S., R. 5 E. The distribution of these prolific wells, graded according to size, is shown on plate XVII. The logs of the original gusher well and of the Shumway well No. 5 follow:

Log of Eureka Oil Company's Williams & Walker Farm Well No. 3 (Trapshooters Oil Company's Well No. 2).

Location, southeast corner, W½ NW¼, sec. 11, T. 26 S., R. 4 E. Drilled April 19 to June 2, 1917. Elevation of well mouth, 1,369 feet, which is about 10 feet below top of Fort Riley limestone. Initial production estimated to have been between 6,000 and 24,000 barrels. Log furnished by Eureka Oil Company.

Drillers' record.	Thickness in feet.	Depth in feet.	Geological correlations by the writer.
Lime	65	65	Fort Riley limestone and Florence flint.
Slate	15	80	Matfield shale.
Sand	20	100	
Slate	25	125	
Lime	10	135	Wreford limestone.
Slate	15	150	
Sand	10	160	
Slate	10	170	
Lime	20	190	
Slate	10	200	
Lime	50	250	
Slate	15	265	
Lime	58	323	
Slate	22	345	
Slate and shell	305	650	
Lime	5	655	
Red rock	8	663	
Lime	12	675	
Slate and shell	25	700	
Red rock	5	705	
Lime	15	720	
Slate and shell	45	765	
Lime	15	780	
Slate and shell	32	812	
Lime	20	832	
Slate and shell	118	950	
Lime	15	965	

Drillers' record.	Thickness in feet.	Depth in feet.	Geological correlations by the writer.
Slate	38	1,008	
Sand	12	1,020	
Slate	30	1,050	
Lime	40	1,090	
Slate	20	1,110	
Lime	10	1,120	
Slate; gas	20	1,140	
Lime	85	1,225	
Slate	10	1,235	
Lime	25	1,260	
Slate	7	1,267	
Lime	53	1,320	
Slate	30	1,350	
Lime; gas	40	1,390	
Slate	10	1,400	
Lime	15	1,415	
Slate	35	1,450	
Lime	25	1,475	
Slate	5	1,480	
Lime	38	1,518	
Slate	17	1,535	
Lime	5	1,540	
Slate	40	1,580	
Lime	10	1,590	
Slate	35	1,625	
Lime	13	1,638	
Slate	22	1,660	
Lime	170	1,830	Lansing formation.
Slate	106	1,945	
Lime; oil at 1,955	145	2,090	Kansas City formation.
Slate	5	2,095	Marmaton formation, with possibly some Cherokee shale at bottom.
Lime	10	2,105	
Black slate	51	2,156	
Lime	4	2,160	
Black slate	30	2,190	
White slate	85	2,275	
Lime	25	2,300	
Black slate	46	2,346	
Sand; oil at 2,360	...	....	Stapleton oil zone.

Log of Gypsy Oil Company's Shumway Farm Well No. 5.

Location, center of west line, SW¼ NE¼, sec. 11, T. 26 S., R. 4 E. Drilled July 25 to September 7, 1917. Elevation of well mouth, 1,372 feet, which is about 25 feet below top of Fort Riley limestone. With tools in the hole the production for one hour on September 10 gauged 800 barrels per hour. Casing record: 12½-inch, 1,053 feet; 10-inch, 1,519 feet; 8¼-inch, 1,803 feet; 6⅝-inch, 2,278 feet. Log furnished by Gypsy Oil Company.

Drillers' record.	Thickness in feet.	Depth in feet.	Geological correlations by the writer.
Soil, black, soft	5	5	
Red rock, soft	10	15	
Lime, white, hard	20	35	
Shale, black, soft	45	80	
Lime, white, hard	55	135	
Lime, white, hard	10	145	
Shale, white, soft	55	200	
Shale, white, soft	40	240	

Drillers' record.	Thickness in feet.	Depth in feet.	Geological correlations by the writer.
Lime, white, soft	10	250	
Shale, white, soft	20	270	
Lime, white, hard	10	280	
Shale, white, soft	70	350	
Lime, white, hard	10	360	
Shale, dark, soft	40	400	
Lime, white, hard	10	410	
Shale, black, soft	40	450	
Lime, white, hard	15	465	
Shale, black, soft	35	500	
Red rock, soft	10	510	
Shale, black, soft	90	600	
Water sand, white, soft	10	610	
Shale, brown, soft	70	680	
Shale, white	35	715	
Lime, white, hard	15	730	
Shale, brown, soft	20	750	
Lime, white, hard	30	780	
Sandy lime, white, soft	30	810	
Shale, brown, soft	30	840	
Shale, brown, soft	60	900	
Lime, white, hard	20	920	
Shale, brown	40	960	
Sand, white, soft	20	980	
Shale, soft	40	1,020	
Lime, soft	10	1,030	
Lime, hard	25	1,055	
Lime, hard	25	1,080	
Shale, white, hard	10	1,090	
Lime, white, hard	80	1,170	
Shale, brown, soft	20	1,190	
Lime, white	70	1,260	
Shale, white, soft	10	1,270	
Shale, white, soft	15	1,285	
Lime, white, soft	85	1,370	
Lime, white, hard	70	1,440	
Gas sand, white, soft	30	1,470	
Water sand, white	50	1,520	
Shale, brown, soft	55	1,575	
Broken lime, white, soft	25	1,600	
Lime, white	80	1,680	
Lime, white	30	1,710	
Water sand, white	20	1,730	Lansing formation.
Lime, white, hard	70	1,800	
Shale, brown, soft	100	1,900	
Lime, white	50	1,950	Kansas City formation, containing Stokes "sand."
Oil sand	20	1,970	
Lime, white, hard	80	2,050	
Sand, white	20	2,070	
Lime	10	2,080	
Shale, black, soft	120	2,200	Marmaton formation, and possibly some Cherokee shale at bottom.
Shale, black, soft	77	2,277	
Lime, white	13	2,290	
Broken lime	30	2,320	
Unrecorded	10	2,330	
Top of first pay	..	2,330	Stapleton oil zone.
Thickness, one screw	..	2,335	
Limestone break, few feet	..	....	
Second pay	..	....	
Total depth	..	2,340	

While the wells of highest yield are in general located on the highest portion of the structure, in accordance with the generally accepted interpretation of the influence of anticlinal structure, there is no apparent structural reason why the Shumway dome, rather than the other domes of the field, should have in such a large measure the preponderance of high-yield wells. This coincidence must be explained by a local condition in the pay rock.

The pay rock, as described on pages 30-37, is not uniform in character, but varies from good quartz sand to cherty, dolomitic limestone. The fact that on the Shumway dome it is principally cherty, dolomitic limestone makes an explanation easier. Limestone is naturally not a porous rock, and hence when it contains oil it cannot generally be considered that the oil is contained in natural pore spaces such as prevail in sandstones. Secondary features must, instead, be brought under consideration. Of such secondary features for cherty limestone the following are the most common:

Joint cracks;
Solution cavities and channels;
Fault fissures and brecciation;
Minute and small crevices due to—
- crystalline growth of minerals,
- chemical changes in mineral composition,
- dolomitization,
- different brittleness and strength of chert and limestone subjected to deformational forces; and
- possible other causes.

Where the production is more normal it would seem that joint cracks and the small and variously formed crevices could account for much of the pore space, but it is difficult to conceive how these alone could account for the exceptional and prolific yield of wells concentrated principally on the Shumway dome. To the writer it seems necessary that large and open spaces be present, and especially must this be true in this field, where there is no apparent great gas pressure behind the oil. So small is this pressure that when the Gypsy Oil Company's Shumway well No. 5 (center location in west line of SW¼ NE¼, sec. 11, T. 26 S., R. 4 E.) came in at better than 15,000 barrels, the column of oil rose but about 6 feet above the 6-inch casing before breaking and falling back to the derrick floor.

The behavior of some wells has demonstrated flow channels between them, as when the Shumway No. 5 ceased flowing soon after well No. 13 (the adjacent well to the northeast) was drilled in with a flush production of 17,000 barrels. Solution channels or open fissures can probably best account for such a condition. Additional evidence of such open spaces is found in the drilling in of the Denny well No. 18 (southwest corner location in SE¼, sec. 12, T. 26 S., R. 4 E., belonging to the Union Oil Company of Wichita), in which it was reported that an open space was found, the top of which was at 2,450 feet and the bottom 39 feet deeper, at 2,489.

Less direct evidence of open channels in the pay rock is to be found in the disparity in size of adjacent wells; *e. g.*, the Gypsy Oil Company's well No. 5 (center location along west side, SW¼ NE¼, sec. 11, T. 26 S., R. 4 E.), with an initial production of 15,000 plus barrels, which is offset to the north by an 800-barrel well, Shumway No. 7. The Empire Gas and Fuel Company's Cardey well No. 6 (southwest corner location in NW¼ SE¼, sec. 11, T. 26 S., R. 4 E.), with a production reported by the company to have been 20,000 barrels, is offset to the south by the 100-barrel Cardey well No. 9. On the same lease, Cardey well No. 17 (center location along south side, NE¼ SE¼, sec. 11, T. 26 S., R. 4 E.), with a reported initial production of 12,000 barrels, is offset to the north by a 300-barrel well, Cardey No. 21. In section 12, T. 26 S., R. 4 E., the Empire Gas and Fuel Company's Enyart well No. 22 (northwest corner location in NE¼ NW½) was drilled in with a 10,800-barrel production, and this is offset to the north by a previously completed 320-barrel well, Abraham well No. 4. In sec. 2, T. 26 S., R. 4 E., the Carter Oil Company's Porter well No. 35, an 8,000-barrel starter, was drilled in after the completion of its offsetting wells to the east, south and west, which had flush productions of 200, 600 and 450 barrels, respectively.

If the interpretation that the top of the Stapleton zone represents the dissected upper surface of the Mississippian rock series is correct, then the possible porous and cavernous nature of this pay rock and its absence locally can be readily understood as being largely due to the effects of erosion and solution by surface waters during the time it was subjected to subaërial agencies.

BISHOP SYNCLINE. The Bishop syncline in the outcropping rocks is comparatively a shallow structure, being more of a synclinal reëntrant in line with the still smaller Fowler syncline, and, with it, separating the Shumway and Boyer domes. Sufficient drilling information is not at hand to show the details of the structure, but a strongly developed syncline is indicated in the Stapleton zone. So strongly is it developed that a fault is suggested, and because of the possibility that a fault may be present, the doubtful area was left blank on plate XIV.

The influence of the Bishop syncline on production is quite marked. It apparently is the controlling feature in cutting off production on the west side of the Koogler nose, which here follows a line almost parallel with the dip rather than the strike. This abrupt termination of production is evidence supporting the previously stated inference that the flexing here may have been so intense that fracturing and faulting have taken place.

FOWLER SYNCLINE. This structure in the Fort Riley limestone is but a shallow trough about 40 feet in depth separating the Shumway and Boyer domes. In the deep-lying Stapleton it is represented by a downfold which suggests a pit, the base of which lies near the southeast corner of sec. 1, T. 26, R. 4. The bottom of this depression is about 190 feet below the apex of the Shumway dome, which is quite in contrast to the 40-foot trough in the Fort Riley limestone at the surface.

Production has been found on the southwest slope of this downfold, but whether it continues uninterruptedly across it had not been demonstrated prior to 1919.

BOYER DOME. This structure, which is well developed in the surface rocks, cannot be identified as such in the Stapleton zone, and represents the greatest lack of conformity between underground and surface structure in the Eldorado field. There is no Boyer dome, as such—that is, a minor bulge on top of the major Eldorado anticline—but simply a comparatively large area of low relief, more or less isolated by the deep Fowler pit, and occupying much of sections 7, 8, and a part of 17, T. 26 S., R. 5 E. A lack of drilling on the east and south flanks, in sections 9, 16 and 17, leaves unknown the configuration of the Stapleton surface in these sections. It is believed, however, that the east flank of the Boyer dome, or rather the east flank of the Eldorado anticline, is strongly developed. This probability should largely compensate for the minor development of the Boyer dome as a feature distinct from the Shumway dome. The minor development of the crest of the Boyer dome may in part be explained by considering the Stapleton surface in this locality to have been a topographic depression in pre-Cherokee times, and that the later folding was not sufficient to reverse the attitude of this surface. The wells located on the Boyer dome are quite ordinary in size, 100 to 300 barrels initial daily production being the average. But one well, Opperman No. 2, in the northeast corner, SE¼ NE¼, sec. 7, T. 26 S., R. 5 E., had a reported initial daily production as high as 500 barrels. This generally low yield may in part be explained by the absence of strong folding in the Stapleton pay.

Following is a log of a Stapleton zone well located on the Boyer dome:

Log of Empire Gas & Fuel Company's Gussman Farm Well No. 3.

Location, northeast corner, NW¼ NW¼, sec. 17, T. 26 S., R. 5 E. Drilled March 10 to May 22, 1917. Elevation of well mouth, 1,376 feet, which is 55 or more feet below top of Fort Riley limestone. Initial production, 125 barrels. Log furnished by Empire Gas and Fuel Company.

Drillers' record.	Thickness in feet.	Depth in feet.	Geological correlations by the writer.
Mud, soft	8	8	
Lime, white, hard	20	28	Florence flint.
Slate, blue, soft	10	38	
Lime, gray, hard	20	58	
Slate, blue, soft	30	88	
Lime, gray, hard	12	100	
Lime, gray, hard	30	130	
Shale, blue, soft	10	140	
Red bed, red, soft	7	147	
Lime, gray, hard	3	150	
Shale, blue, soft	10	160	
Lime, white, hard	65	225	
Shale, blue, soft	20	245	
Lime, gray, hard	20	265	
Shale, blue, soft	8	273	
Red bed, red, soft	7	280	
Lime, white, hard	30	310	
Shale, blue, soft	15	325	
Lime, white, hard	15	340	
Shale, dark, soft	20	360	
Lime, white, hard	70	430	
Shale, blue, soft	60	490	
Sand, light, soft; water	10	500	
Shale, light, soft	15	515	
Lime, white, hard	5	520	
Shale, blue, soft	5	525	
Lime, white, hard	35	560	
Shale, blue, soft	17	577	
Slate, dark, soft	20	597	
Sand, white, soft; water	33	630	

Drillers' record.	Thickness in feet.	Depth in feet.	Geological correlations by the writer.
Shale, dark, soft	12	642	
Shale, light, soft	60	702	
Lime, white, hard	40	742	
Shale, dark, soft	10	752	
Lime, white, hard	50	802	
Shale, blue, soft	94	896	
Sand, gray, soft; gas	10	906	
Lime, gray, hard	64	970	
Shale, blue, soft	50	1,020	
Lime, white, hard	70	1,090	
Shale, blue, soft	10	1,100	
Lime, gray, hard	125	1,225	
Blue mud, blue, soft	100	1,325	
Lime, gray, hard	75	1,400	
Shale, blue, soft	70	1,470	
Sand, gray, soft; water	20	1,490	
Lime, gray, hard	10	1,500	
Shale, blue, soft	60	1,560	
Lime, white, hard	40	1,600	
Shale, blue, soft	60	1,660	
Sand, dark, soft; oil	10	1,670	Boyer "sand."
Lime, gray, hard	10	1,680	
Sand, white, soft; water	30	1,710	
Lime, white hard	40	1,750	Lansing formation.
Lime, gray, hard	75	1,825	
Shale, blue, soft	125	1,950	
Shale, blue, soft; oil	20	1,970	
Lime, gray, hard; water	70	2,040	Kansas City formation.
Lime, white, hard	85	2,125	
Lime, gray, hard	20	2,145	
Shale, blue, soft	70	2,215	Marmaton formation, with possibly some Cherokee shale at bottom.
Shale, blue, soft	25	2,240	
Shale, blue, soft	20	2,260	
Lime, white, hard	10	2,270	
Brake, black, soft	6	2,276	
Shale, blue, soft	15	2,291	
Lime, white, hard	11	2,302	
Shale, black, soft	78	2,380	
Shale, blue, soft	5	2,385	
Lime shell, black, hard	10	2,395	
Shale, blue, soft	10	2,405	
Sand, white, hard	4	2,409	Stapleton oil zone.
Sand, white, hard	4	2,413	
Sand, white, hard	37	2,350	
Sand, brown, soft; oil	12	2,462	
Sand, light, hard	3	2,465	

KOOGLER NOSE. The Koogler nose in the Stapleton zone, so far as information at hand indicates, conforms very closely to the area occupied by and to the configuration of the structure as developed in the surface formations. Its southwesterly slope is greater than that of the Fort Riley limestone in having a difference of elevation of 140 feet between the northeast corner of section 19 and the west quarter corner of sec. 30, T. 26, R. 5, whereas the Fort Riley difference is but 40 feet.

The east flank was not sufficiently drilled to supply much information concerning it. At only one place was any information available, and that in the vicinity of the south quarter corner of section 29. To the south of this corner the dip becomes very steep to the southeast, while to the north offsetting wells found their respective pays at depths which varied as much as 100 feet in elevation—a situation which may suggest the presence of a possible fault. The information, however, is too meager to permit definite statements. The presence of three dry holes in this same vicinity is perplexing. This situation adds weight to the possibility of faulting.

Production on the Koogler nose is irregularly distributed. To the west in the vicinity of the Bishop syncline—or possibly it is a fault—production is cut off without respect to height on the dip. It is possible that the Bishop syncline is replaced by a fault in the Stapleton. On the southwest flank of the nose, in the vicinity of the Bishop syncline, producing wells seem to be limited to about the —1,300-foot contour. To the southeast, where the Stapleton begins to dip southeasterly at a rapid rate, wells have been brought in as low as the —1,520-foot contour.

The wells when brought in have in general been rather uniform in size, ranging from 100 to 400 barrels, and in but two cases has an 800-barrel initial daily production been obtained. The first wells drilled in any one place on this structure had larger initial daily productions than the later wells, but in no case was the production of the first wells excessively large. The initial well on this structure, the Page-Lewis Oil Company's Koogler No. 1, in the northwest corner, NE¼, sec. 30, was a 500-barrel well, and No. 2, immediately adjacent to the east, was an 800-barrel well. The offsetting well to the northwest, the Empire Gas and Fuel Company's Huston No. 1, in the southeast corner, SW¼, sec. 19, was good for 550 barrels. Harmon well No. 7, in the southeast corner of section 24, owned by the Ramsey Petroleum Company, was reported to yield 700 barrels. The McK Oil Company's Nuttle well No. 1, in the northeast corner, section 31, came in at 800 barrels, and No. 2, immediately to the south, at 500 barrels. These represent the largest wells, and from these figures the later wells ranged down to 10 barrels, with a general average of about 200 barrels, prior to 1919. This greater uniformity in yield may be attributed in part to the character of the pay rock in this vicinity, which the available information indicates to be largely a quartz sand, a type of rock which generally has a more uniform porosity than limestone.

Four logs of scattered wells on the Koogler nose follow. The log of Koogler well No. 2 is representative of wells high along the crest line. The Hill farm well No. 1 is low on the south end, and the Kinney farm well No. 1 is one of those in which production was not obtained until about 100 feet below the normal depth. The Sargent farm well No. 2 is located on the west flank near the Bishop syncline.

Log of Page & Lewis Oil Company's Koogler Farm Well No. 2.

Location, near center of north line of NW¼ NE¼, sec. 30, T. 26 S., R. 5 E. Drilled May 24 to October 28, 1917. Elevation of well mouth, 1,349 feet, which is a few feet above the top of the Fort Riley limestone. Initial production, 800 barrels. Casing record: 12½-inch, 712 feet; 10-inch, 814 feet; 8¼-inch, 1,616 feet; 6⅝-inch, 2,365 feet; 5$\frac{3}{16}$-inch, 2,601 feet. Log furnished by Page & Lewis Oil Company.

Drillers' record.	Thickness in feet.	Depth in feet.	Geological correlation.
Lime	95	95	Fort Riley limestone and Florence flint.
Slate	20	105	Matfield shale.
Red rock	10	115	
Lime	10	125	
Slate	20	145	
Red rock	10	155	
Lime	30	185	Wreford limestone.
Slate	10	195	
Red rock	5	200	
Lime	20	220	
Slate	15	235	
Lime	10	245	
Slate	5	250	
Lime	20	270	
Slate	20	290	
Lime	5	295	
Slate	10	305	
Lime	20	325	
Slate	5	330	
Red rock	5	335	
Slate	10	345	
Lime	10	355	
Sand; water	5	360	
Shale	15	375	
Lime	10	385	
Slate	25	410	
Lime	10	420	
Slate	10	430	
Lime	10	440	
Slate	5	445	
Lime	5	450	
Slate	20	470	

Drillers' record.	Thickness in feet.	Depth in feet.	Geological correlation.
Lime	55	525	
Slate	15	540	
Lime	20	560	
Slate	5	565	
Lime	5	570	
Slate	60	630	
Lime	5	635	
Slate	10	645	
Sand; water	20	665	
Lime	10	675	
Slate	21	696	
Sand	9	705	
Lime	2	707	
Slate	3	710	
Lime	25	735	
Lime	10	745	
Slate	55	800	
Lime	30	830	
Slate	25	855	
Lime	150	1,005	
Slate	35	1,040	
Shell	10	1,050	
Slate	15	1,065	
Shale	20	1,085	
Slate	45	1,130	
Lime	5	1,135	
Slate	50	1,185	
Lime	5	1,190	
Slate	25	1,215	
Lime	10	1,225	
Slate	5	1,230	
Lime	5	1,235	
Slate	5	1,240	
Lime	10	1,250	
Slate	40	1,290	
Lime	35	1,325	
Shell	75	1,400	
Lime	5	1,405	
Slate	85	1,490	
Lime	10	1,500	
Slate	25	1,525	
Shell	5	1,530	
Slate	15	1,545	
Sand; water	25	1,570	
Slate	30	1,600	
Lime	60	1,660	
Lime	20	1,680	
Slate	5	1,685	
Lime	15	1,700	
Slate	20	1,720	
Slate	55	1,775	
Lime	165	1,940	Lansing formation.
Slate	135	2,075	
Lime	20	2,095	Kansas City formation.
Slate	5	2,100	
Lime	10	2,110	
Slate	15	2,125	
Lime	10	2,135	
Slate	30	2,165	

Drillers' record.	Thickness in feet.	Depth in feet.	Geological correlation.
Lime	5	2,170	
Slate	30	2,200	
Lime	10	2,210	
Slate	20	2,230	
Lime	5	2,235	Marmaton formation, with possibly some Cherokee shale at bottom.
White slate	15	2,250	
Lime	38	2,288	
Slate	17	2,305	
Lime	25	2,330	
Sand; water	5	2,335	
Slate	5	2,340	
Lime	20	2,360	
Sand	10	2,370	
Lime	10	2,380	
Slate	5	2,385	
Slate and lime shells	65	2,450	
Slate	10	2,460	
Lime	10	2,470	
Slate	10	2,480	
Lime	5	2,485	
Slate	15	2,500	
Lime	10	2,510	
Black slate	5	2,515	
Lime	5	2,520	
Red rock	10	2,530	
Brown slate	40	2,570	
Lime	7	2,577	
Black slate	23	2,600	
Cap rock	6	2,606	
Top of pay sand	20	2,626	Stapleton oil zone.

Log of Theta Oil Company's Hill Farm Well No. 1.

Location, northwest corner of sec. 32, T. 26 S., R. 5 E. Drilled November 17, 1917, to February 1, 1918. Elevation of well mouth, 1,323 feet, which is a few feet below top of Fort Riley limestone. Initial production, 150 barrels. Casing record: 15½-inch, 23 feet; 12½-inch, 710 feet; 10-inch, 1,314 feet; 8¼-inch, 2,077 feet; 6⅝-inch, 2,363 feet; 5³⁄₁₆-inch, 2,619 feet. Log furnished by Theta Oil Company.

Drillers' record.	Thickness in feet.	Depth in feet.	Geological correlation.
Mud formation	60	60	
Lime, white	15	75	
Slate, blue	30	105	
Lime, white	20	125	
Rock, red	10	135	
Lime, white	45	180	Wreford limestone.
Rock, red	10	190	
Lime, gray	10	200	
Slate, gray	50	250	
Lime, blue	50	300	
Slate, blue	50	350	
Slate, gray	25	375	
Sandy lime	10	385	
Slate, brown	50	435	
Slate, white	15	450	
Lime, gray	25	475	
Slate, black	65	540	

Drillers' record.	Thickness in feet.	Depth in feet.	Geological correlation.
Slate, white	60	600	
Lime, gray	60	660	
Sandy lime; hole full of water at 670 feet	10	670	
Broken lime	30	700	
Slate, black	50	750	
Hard lime	20	770	
Slate, blue	30	800	
Lime, gray	20	820	
Slate, blue	70	890	
Slate, brown	10	900	
Lime, white; 1 bailer of water per hour at 920 feet	20	920	
Lime, gray	80	1,000	
Sand	25	1,025	
Slate, gray	25	1,050	
Sand; 4 bailers of water per hour at 1,075 feet	25	1,075	
Slate, blue	25	1,100	
Lime, white	25	1,125	
Slate, black	75	1,200	
Slate, gray	35	1,235	
Lime, black	15	1,250	
Slate, white	25	1,275	
Sand; hole full of water	35	1,310	
Lime, broken	30	1,340	
Shale, black	190	1,530	
Lime, gray	30	1,560	
Slate, black	30	1,590	
Lime, white	20	1,610	
Slate, white	40	1,650	
Big lime	280	1,930	Lansing formation.
Slate, blue	50	1,980	
Lime, white	30	2,010	
Slate, white	50	2,060	
Slate, white	40	2,100	
Lime, gray	30	2,130	Kansas City formation.
Sandy lime; 6 bailers of water at 2,160 feet	30	2,160	
Slate, black	30	2,190	Marmaton formation, with possibly some Cherokee shale at bottom.
Slate, white	35	2,225	
Lime, blue	25	2,250	
Shale, blue	60	2,310	
Sand, white; hole full of water,	50	2,360	
Lime, broken	55	2,415	
Slate, white	30	2,445	
Sandy shale	20	2,465	
Slate, black	25	2,490	
Lime, white	35	2,525	
Slate, blue	25	2,550	
Slate, white	30	2,580	
Slate, black	39	2,619	
Top of oil sand	..	2,619	Stapleton oil zone.
First show of oil	..	2,619	
Filled up 400 feet with oil	..	2,629	
Filled up 1,500 feet with oil	..	2,639	
Total depth	..	2,639	

Log of Leonard Petroleum Company's Kinney Farm Well No. 1.

Location, center of west line of SE¼, sec. 29, T. 26 S., R. 5 E. Drilling completed January 2, 1918. Elevation of well mouth, 1,314 feet, which is about the same as the top of the Fort Riley limestone. Initial production, 300 barrels. Casing record: 15½-inch, 20 feet; 12½-inch, 750 feet; 10-inch, 1,450 feet; 8¼-inch, 2,152 feet; 6⅝-inch, 2,376 feet; 5³⁄₁₆-inch, 2,585 feet. Log furnished by Leonard Petroleum Company.

Drillers' record.	Thickness in feet.	Depth in feet.	Geological correlation.
Unrecorded	6	6	
Lime, white	80	86	Fort Riley limestone and Florence flint.
Slate, black	20	106	Matfield shale.
Lime, white	10	116	
Red rock	12	128	
Slate, black	20	148	
Sand, white	25	173	Wreford limestone
Slate, black	25	198	
Lime, white	10	208	
Slate, black	40	248	
Lime, white	12	260	
Slate, white	25	285	
Lime, white; 8 bailers of water at 300 feet	25	310	
Slate, white	40	350	
Lime, white	30	380	
Slate, white	45	425	
Lime, white; 20 bailers of water at 440 feet	25	450	
Slate, white	50	500	
Lime, white	60	560	
Slate, black	35	595	
Red rock	10	605	
Slate, white	10	615	
Lime, white	6	621	
Slate, white	85	706	
Lime, white	5	711	
Slate, white	65	776	
Lime, white	35	811	
Slate, white	25	836	
Lime, white	50	886	
Slate, white	5	891	
Lime, white	20	911	
Shale, brown	204	1,115	
Lime, gray	85	1,200	
Shale, brown	20	1,220	
Lime, white	175	1,395	
Slate	40	1,435	
Lime	5	1,440	
Shale, brown	10	1,450	
Sand, gray; puff of gas and dose of water at 1,455 to 1,460 feet	10	1,460	
Lime	70	1,530	
Sand	20	1,550	
Slate	10	1,560	
Shale, brown	40	1,600	
————	15	1,615	
Shale, brown	35	1,650	
Lime, white	15	1,665	
Shale	10	1,675	

Drillers' record.	Thickness in feet.	Depth in feet.	Geological correlation.
Lime; 3 bailers of water at 1,850 feet	225	1,900	Lansing formation.
Slate	10	1,910	
Shell	15	1,925	
Slate	140	2,065	
Lime, white; 10 bailers of water at 2,070 feet	140	2,205	Kansas City formation.
Shale, brown	10	2,215	
Lime, white	25	2,240	
Slate, black	40	2,280	
Slate, white; water at 2,310 feet	30	2,310	
Lime, soft	35	2,345	
Slate, white	120	2,465	
Lime	30	2,495	
Slate, white	35	2,530	
Sand	59	2,589	
Sand, brown	46	2,635	
Slate, black	45	2,680	
Lime	10	2,690	
Shale, brown	17	2,707	
Oil sand	12	2,719	

Log of Central West Petroleum Company's Sargent Farm Well No. 2.

Location, center of north line of SE¼ NW¼, sec. 24, T. 26 S., R. 4 E. Drilled January 2 to April 12, 1918. Elevation of well mouth, 1,349 feet, which is about 65 feet above top of Fort Riley limestone. Casing record: 15½-inch, 86 feet; 12½-inch, 755 feet; 10-inch, 1,206 feet; 8¼-inch, 1,783 feet; 6-inch, 2,630 feet. Log furnished by Central West Petroleum Company.

Drillers' record.	Thickness in feet.	Depth in feet.	Geological correlation.
Surface soil	10	10	
Slate, soft	25	35	Doyle shale.
Lime, soft	15	50	
Lime, hard, white	30	80	Fort Riley limestone.
Shale, soft, gray	15	95	
Lime, sandy; 1 bailer of water per hour at 125 feet	30	125	Florence flint.
Shale, soft, gray	63	188	Matfield shale.
Lime, hard, white; 1 bailer of water per hour at 225 feet,	42	230	Wreford limestone.
Shale, soft, red	15	245	
Lime, hard, gray	25	270	
Shale, soft, gray	5	275	
Lime, gray, hard	65	340	
Shale, dark	10	350	
Slate, soft, white	10	360	
Lime, hard, white	5	365	
Shale, soft, red	30	395	
Lime, hard, white	15	410	
Shale, soft, gray	15	425	
Lime, hard, gray	25	450	
Shale, gray	10	460	
Lime, hard, gray	30	490	
Lime shell; 7 bailers of water per hour at 545 feet	55	560	
Lime, hard, gray	15	560	
Shale, soft, gray	30	590	
Lime, hard, gray	10	600	

Drillers' record.	Thickness in feet.	Depth in feet.	Geological correlation.
Slate, soft, gray	15	675	
Shale, gray	15	690	
Water sand; hole full of water,	30	720	
Broken lime and sand	35	755	
Lime, hard, white	10	765	
Shale, soft, gray	20	785	
Lime, sandy	15	800	
Limestone, broken	35	835	
Lime, hard, gray	45	880	
Shale, soft, gray	10	890	
Lime, hard, gray	35	925	
Shale, soft, red	5	930	
Lime, hard, gray	10	940	
Slate, soft, blue	15	955	
Shale, soft, gray	35	990	
Water sand; hole full of water,	15	1,005	
Shale, soft	10	1,015	
Slate, soft, gray	45	1,060	
Lime, hard, white	12	1,072	
Shale, gray; considerable water between 1,100 and 1,185 feet	113	1,185	
Lime, hard, gray	40	1,225	
Slate, soft, gray	10	1,235	
Lime, hard, white	15	1,250	
Slate, soft, gray	20	1,270	
Lime, hard, gray	45	1,315	
Shale, soft, gray	75	1,390	
Lime, hard, gray	20	1,410	
Shale, dark	5	1,415	
Lime, hard, gray	60	1,475	
Shale, soft, gray; 2 bailers of water per hour at 1,480 feet,	20	1,495	
Lime, hard, gray	50	1,545	
Shale, soft, gray	65	1,610	
Lime, hard, gray	18	1,628	
Water sand; hole full of water,	17	1,645	
Slate, gray	30	1,675	
Shale, gray	20	1,695	
Lime, hard, gray	35	1,730	
Slate, gray	35	1,765	
Water sand; hole full of water,	10	1,775	
Lime, hard, white	25	1,800	Lansing formation.
Shale, gray	30	1,830	
Shale, dark	75	1,905	
Slate, gray	20	1,925	
Lime, hard, gray	89	2,014	Kansas City formation.
Shale, gray	26	2,040	
Lime, hard, white	303	2,343	
Shale, gray	27	2,370	
Lime, sandy; considerable water at 2,330 feet	20	2,390	Marmaton formation, with possibly some Cherokee shale at bottom.
Shale, gray	25	2,415	
Lime, hard, gray; oil showing at 2,445 feet	55	2,470	
Shale, brown	25	2,495	
Lime, sandy	10	2,505	
Shale, black	20	2,525	
Lime, sandy	50	2,575	
Shale, sandy	55	2,630	
Oil sand	12	2,642	Stapleton oil zone.

BANCROFT SYNCLINE. The presence of this minor syncline in the Stapleton oil zone in sec. 32, T. 25 S., R. 5 E., immediately beneath its counterparts in the 660-foot sand and the outcropping rocks, follows the apparently general rule, in that it is more strongly developed. The southeastward continuation of this down-fold in very close conformity to the configuration of the surface rocks, but more intensely developed, is quite noteworthy. The dip of the Stapleton zone relative to that of the surface strata in this locality will be touched upon in the description of the Oil Hill dome.

This minor syncline appears to have had little or no effect in the productivity of the wells drilled in its vicinity. One well with a reported production of more than 1,000 barrels is located in the center of the north line of the SW¼ NE¼, sec. 4, T. 25 S., R. 4 E., and the well immediately to the northwest came in at 500 barrels. Other wells in this depression averaged about 200 barrels.

OIL HILL DOME. The similarity in structure—but not, however, the similarity in intensity of folding—between the Stapleton zone, the 660-foot sand and the surface rocks on this dome is more than usually striking. The area covered by the domes in each of these horizons is very nearly the same, and their apexes are located at points almost identical. Following the general rule, the intensity of flexing increases with depth. In the area between the apex of the structure in each horizon and the saddle on the north and the saddle to the southwest, the increase of dip on the three horizons is as follows:

	Apex to saddle in sec. 28, T. 25 S., R. 5 E.	Apex to saddle in sec. 32, T. 25 S., R. 5 E.
Surface rocks	30	50
660-foot "sand"	40	50
Stapleton oil zone	50	80

This increased dip in the Stapleton zone is even more marked on the east and southeast flanks, as between the apexes and the east quarter corner of sec. 4, T. 26 S., R. 5 E., where the difference in elevation of the Stapleton zone is 500 feet and that of the surface rocks but 110 feet.

The east flank of the structure in the central part of sec. 34, T. 25 S., R. 5 E., is not sufficiently defined by drilling to indicate its general configuration. Along the north side of this section, however, and in the southeast quarter of section 27, to the north, the Stapleton dips very steeply. So steep is the dip in these two localities that in each place it appears to slope off to a fault in these deep-lying strata, forming the apparent terrace at the north side of section 34 and separating the production in the southwest quarter of section 27 from that in the east half. The dry holes in the area intervening between these last two localities and the few wells immediately south of the center of the section, which have odd depths, join in indicating the possible presence of a fault.

Production on the Oil Hill dome, as on others, is not symmetrically distributed on the structure. To the southeast producing wells are located as low as the —1,440-foot contour and in the Bancroft minor syncline as low as the —1,520-foot contour. Directly up the dip on the southeast nose of the dome are two dry holes, one located as high as the —1,180-foot contour. On the northwest flank, also, in sec. 30, T. 25 S., R. 5 E., is a dry hole as high as the —1,140-foot contour, and in sec. 29, T. 25 S., R. 5 E., is a dry hole as high as the —1,120-foot contour.

The discovery well of the field, as well as the first well to penetrate the Stapleton oil zone, is located on the northwest flank of this dome, in the center of the NE¼ SE¼, sec. 29. Although the first well to tap the Stapleton zone, its initial production was comparatively small, but 175 barrels. Later wells in this vicinity ranged as high as 700 barrels daily, and but one found the Stapleton zone unproductive. The extent of the barren area discovered by this well had not been demonstrated by drilling at the time this report was written. The principal development has taken place on the east and south flanks of the structure, where medium-sized wells—100 to 200 barrels—were the general rule prior to 1919. Exception to this rule is found in a few wells; *e. g.*, a 650-barrel well located near the center of the west line of the SW¼ of sec. 34, T. 25 S., R. 5 E., and several 500-barrel wells, one of which is located in the northwest corner of section 3. Another is the well immediately adjacent toward the east, and a third is in the northwest corner, NE¼ NE¼ NW¼ of the same section. The last three are far down on the flanks of the structure.

On the crest of the dome, where large wells might be expected, only normal-sized wells of 200 to 300 barrels daily production were obtained.

The logs of two Stapleton zone wells follow. The Stokes well is near the apex of the dome and the Kessler well is in the town-lot development and near the edge of production on the southeast side.

Log of Empire Gas and Fuel Company's Stokes Farm Well No. 3.

Location, center of NW¼ NE¼, sec. 33, T. 25 S., R. 5 E. Drilled May 5 to September 25, 1916. Elevation of well mouth, 1,386 feet, which is 50 or more feet below top of Fort Riley limestone. Initial production, 300 barrels. Casing record: 15½-inch, 18 feet; 12½-inch, 648 feet; 10-inch, 1,040 feet; 8¼-inch, 2,042 feet; 6½-inch, 2,420 feet; 3-inch tubing, 2,425 feet. Log furnished by Empire Gas and Fuel Company.

Drillers' record.	Thickness in feet.	Depth in feet.	Geological correlation.
Clay, yellow, soft	5	5	
Lime, white, hard	35	40	Florence flint.
Shale, black, soft	15	55	
Lime, white, hard	25	80	
Shale, white, soft	5	85	
Lime, white, hard	40	125	
Shale, white, soft	5	130	
Shale, pink, soft	5	135	
Lime, white, hard	30	165	
Shale, white, soft	25	190	
Lime, white, hard	15	205	
Shale, black, soft	10	215	
Lime, white, hard	5	220	
Shale, white, soft	40	260	
Shale, black, soft	5	265	
Lime, white, hard	8	273	
Shale, pink, soft; little gas	10	283	
Lime, white, hard; little water at 295 feet	27	310	
Shale, white, soft	85	395	
Shale, black, soft	20	415	
Lime, white, hard	5	420	
Shale, black, soft	15	435	
Lime, white, hard	4	439	
Shale, white, soft; little gas at 490 feet	106	545	
Shale, pink, soft	4	549	
Shale, white, soft	16	565	
Lime, white, soft	4	569	
Shale, white, soft	46	615	
Oil sand, white, soft; 2 bailers oil per hour	20	635	660-foot "sand."
Shale, white, soft	13	648	
Lime, white, hard	5	653	
Shale, white, soft	25	678	
Lime, white, hard	5	683	
Shale, black, soft	37	720	
Shale, white, soft	5	725	
Lime, white, hard; little water at 805 feet	85	810	
Shale, black, soft	20	830	
Shale, white, soft	20	850	
Lime, white, hard; 8,000,000 cu. ft. of gas	15	865	900-foot gas "sand."
Sand, gray, soft	15	880	
Shale, white, soft; 4,000,000 cu. ft. of gas	3	883	

Drillers' record.	Thickness in feet.	Depth in feet.	Geological correlation.
Sand, gray, soft; 5 bailers of water per hour	17	900	
Shale, black, soft	21	921	
Lime, white, hard	4	925	
Shale, white, soft	5	930	
Lime, white, hard	15	945	
Shale, white, soft	10	955	
Shale, black, soft	85	1,040	
Shale, black, soft	10	1,050	
Lime, white, hard	10	1,050	
Lime, white, hard	20	1,080	
Shale, dark, soft	10	1,090	
Sandy lime, dark, hard	25	1,115	
Sandy shale, dark, soft	15	1,130	
Lime, dark, hard	5	1,135	
Slate, white, hard	10	1,145	
Lime, white, soft	35	1,180	
Shale, dark, soft	10	1,190	
Lime, white, hard	20	1,210	
Slate, blue, hard	15	1,225	
Lime, white, hard	10	1,235	
Sandy lime, dark, soft; 1,000,000 cu. ft. of gas	5	1,240	
Lime, white, hard	35	1,275	
Lime, white, hard	15	1,290	
Slate, blue, hard	10	1,300	
Lime, dark, hard	5	1,305	
Shale, dark, soft	50	1,355	
Lime, sandy, dark, soft; 500,000 cu. ft. of gas	10	1,365	
Lime, white, medium	35	1,400	
Shale, dark, soft	5	1,405	
Lime, white, soft	35	1,440	
Sand, dark, soft	10	1,450	
Shale, dark, soft	35	1,485	
Shell, dark, hard	3	1,488	
Sand, white, soft	7	1,495	
Shale, dark, soft	20	1,515	
Lime, broken, dark, soft	25	1,540	
Lime, broken, dark, soft	10	1,550	
Shale, dark, soft	15	1,565	
Sandy lime, white, medium	10	1,575	
Slate, white, soft	20	1,595	
Sand, shale, red, soft	5	1,600	
Sand, white, soft; enough water for drilling	20	1,620	
Slate, dark, soft	15	1,635	
Shell, dark, hard	3	1,638	
Slate, white, soft	27	1,665	
Lime, white, hard	22	1,687	
Sand lime, white, hard; showing of oil	3	1,690	
Sandy lime, white, soft	15	1,705	
Lime, dark, hard	6	1,711	
Lime, light, soft	4	1,715	
Lime, white, soft	10	1,725	
Lime, white, soft	15	1,740	

Drillers' record.	Thickness in feet.	Depth in feet.	Geological correlation.
Lime, white, hard	10	1,750	Lansing formation.
Lime, white, hard	20	1,770	
Lime, white, hard	10	1,780	
Sandy lime, white, hard	20	1,800	
Sandy lime, white, soft	10	1,810	
Broken lime, white, soft	27	1,837	
Slate, white, hard	53	1,890	
Slate, white, hard	60	1,950	
Slate, white, hard	10	1,960	
Lime, white, hard	10	1,970	Kansas City formation.
Lime, white, soft; little gas	5	1,975	
Lime, white, hard	15	1,990	
Sandy lime, white, hard	25	2,015	
Lime, white, hard	51	2,066	
Shale, black, soft	3	2,069	Marmaton formation, possibly some Cherokee shale at bottom.
Sand, white, hard	12	2,081	
Broken lime, soft, black	11	2,092	
Lime, dark, hard	15	2,107	
Sandy lime, light, soft	8	2,115	
Lime, light, hard	10	2,125	
Slate, black, hard	35	2,160	
Sandy shale, blue, soft	10	2,170	
Slate, white, soft	20	2,190	
Slate, white, soft	10	2,200	
Lime, dark, hard	4	2,204	
Slate, white, soft	36	2,240	
Lime, white, hard	8	2,248	
Slate, black, hard	7	2,255	
Red rock, red, soft	2	2,257	
Lime, white, hard	8	2,265	
Slate, white, soft	13	2,278	
Lime, white, hard	12	2,290	
Slate, black, hard	8	2,298	
Lime, white, hard	15	2,313	
Shale, red, soft	8	2,321	
Slate, white, soft	15	2,336	
Lime, white, hard	3	2,339	
Sandy shale, dark, soft	7	2,346	
Shale, light, soft	24	2,370	
Lime, dark, hard	15	2,385	
Sandy shale, light, hard	10	2,395	
Sand, light, soft, carrying particles of iron	5	2,400	
Lime, white, hard	19	2,419	
Sand, white, hard	15	2,434	Stapleton oil zone.
Sand, brown, soft	6	2,440	
Sand, white, hard	25	2,465	
Sand, dark, hard	3	2,468	

Log of Hickory Oil and Gas Company's Kessler Lot Well No. 1.

Location, near center of SE¼ NE¼ NW¼, sec. 3, T. 26 S., R. 5 E. Elevation of well mouth, 1,328 feet, which is about the same elevation as the top of the Fort Riley limestone. Drilling record: 15½-inch, 89 feet; 12½-inch, 983 feet; 10-inch, 1,606 feet; 8¼-inch, 2,316 feet; 6⅝-inch, 2,572 feet; 5$\frac{3}{16}$-inch liner, 243 feet. Log furnished by Hickory Oil and Gas Company.

Drillers' record.	Thickness in feet.	Depth in feet.	Geological correlation.
Soil, soft	4	4	
Lime, white, hard	56	60	Fort Riley limestone and Florence flint.
Shale, blue, soft	23	83	
Lime, white, hard	2	85	
Shale, blue, soft	2	87	
Red rock, red, soft	25	112	
Lime, white, hard	14	126	
Lime, shells, white, hard	4	130	
Red rock, red, soft	16	146	
Shale, blue, soft	90	236	
Lime, white, hard	4	240	
Shale, blue, soft	136	376	
Lime, white, hard	16	392	
Red rock, red, soft	18	410	
Clay, blue, soft	30	440	
Lime, white, hard	25	465	
Red rock, red, soft	8	473	
Shale, blue, soft	20	493	
Red rock, red, soft	27	520	
Lime, white, hard	20	540	
Shale, gray, soft	45	585	
Slate, gray, hard	25	610	
Lime, white, hard	20	640	
Shale, blue, soft	40	680	
Lime, white, soft	10	690	
Sand, gray, soft	20	710	
Slate, gray, soft	10	720	
Lime, white, hard	15	735	
Slate, blue, soft	10	745	
Shale, black, soft	25	770	
Shale, blue, soft	13	783	
Shale, blue, soft	27	810	
Lime, white, hard	5	815	
Shale, black, soft	35	850	
Lime, white, hard	10	860	
Sand, gray, soft; 5 bailers of water per hour	15	875	
Lime, white, hard	11	886	
Shale, blue, soft	4	890	
Red rock, red, soft	2	892	
Shale, gray, soft	3	895	
Shale, black, soft	15	910	
Shale, gray, hard	35	945	
Lime, white, hard	15	960	
Sand, gray, soft	19	979	
Shale, blue, soft	4	983	
Lime, white, hard	57	1,040	
Shale, blue, soft	20	1,060	
Lime, white, hard	55	1,115	
Shale, gray, soft	125	1,240	
Lime, white, hard	3	1,243	
Sand, gray, soft; 3½ bailers of water per hour	22	1,265	
Lime, white, hard	5	1,270	
Slate, gray, soft	45	1,315	
Lime, white, hard; 3 bailers of water per hour	2	1,317	
Sand, gray, soft	20	1,337	
Lime, white, hard	13	1,350	

Drillers' record.	Thickness in feet.	Depth in feet.	Geological correlation.
Lime, white, soft	10	1,360	
Slate, blue, soft	45	1,405	
Lime, white, hard	50	1,455	
Shale, black, soft	32	1,487	
Slate, gray, hard	3	1,490	
Lime, white, hard	20	1,510	
Slate, blue, soft	5	1,515	
Lime, white, hard	25	1,540	
Shale, gray, soft	30	1,570	
Sand, gray, soft	35	1,605	
Lime, blue, hard	2	1,607	
Shale, gray, soft	63	1,670	
Lime, white, hard	5	1,675	
Slate, blue, hard	40	1,715	
Sand, gray, soft; showing of water	8	1,723	
Lime, white, hard	97	1,820	Lansing formation.
Lime, blue, very hard	5	1,825	
Sand, gray, soft; 4 bailers of water per hour	5	1,830	
Lime, white, hard	105	1,935	
Shale, blue, soft	5	1,940	
Lime, white, hard	10	1,950	
Shale, blue, soft	125	2,075	
Lime, white, hard	115	2,190	Kansas City formation.
Slate, gray, soft	15	2,205	Marmaton formation above and Cherokee shale below.
Lime, white, hard	30	2,235	
Shale, blue, soft	8	2,243	
Lime, white, hard	7	2,250	
Shale, black, soft	65	2,315	
Lime, white, hard	5	2,320	
Shale, gray, soft	40	2,360	
Lime, white, hard	10	2,370	
Shale, black, soft	20	2,390	
Lime, white, hard	10	2,400	
Shale, black, soft	25	2,425	
Shale, blue, soft	5	2,430	
Lime, white, hard	130	2,560	
Lime shells, white, soft	5	2,565	
Shale, black, soft	5	2,570	
Sand, gray, hard	113	2,683	
Shale, blue, soft	15	2,698	
Red rock, red, soft	10	2,708	
Green shale, green, soft	11	2,719	
Shale, black, soft	44	2,763	
Shale, brown, soft	9	2,772	
Sand, brown, hard; pay sand,	15	2,787	Stapleton oil zone.

HEGBERG SYNCLINE. This low minor fold in the surface rocks has its counterpart in the Stapleton zone, and, like other features of this field, is more intensely developed in the deep-lying strata. The flexing in the 660-foot sand is stronger than in the surface rocks and is still more strongly developed in the Stapleton zone. Production apparently continues uninterruptedly across this structural feature, which forms a saddle between the Oil Hill and Chesney domes.

CHESNEY DOME. The drilling of Stapleton zone wells on this structure has not progressed sufficiently to indicate the general configuration of the dome in this deep-lying pay. The deep drilling is confined principally to the east side of the structure, where, as on the other domes, the production extends far down on the flank. Production is obtained to the southeast in section 27 as low as the —1,410-foot contour, whereas a well to the north in the southeast corner of section 16, situated as high as the —1,080-foot contour, failed to find oil. The dip of the Stapleton along the south line of section 22 is two and one-half times as steep as the dip of the 660-foot sand and three and one-third to four times as steep as the dip of the surface rocks, bearing out the general condition that the deeper rocks are more sharply flexed than those at the surface.

In considering the productivity of the wells on this dome, those lying northeast of the possible fault in section 27 will be considered as belonging to the Chesney dome group. The wells in this group reflect an unusual sand condition. The first well, which is located in the southeast corner, NW¼ NE¼, sec. 27, was reported variously to yield from 800 to 1,500 barrels daily, and the second well in the northeast corner of this same 40-acre tract from 750 to 1,000 barrels. Other wells in this vicinity ranged from 30 to 500 barrels. The feature to be noted is that these comparatively large wells are very far down the dip, whereas those to the northwest, which are higher on the flanks of the dome and therefore theoretically more favorably located, but which were drilled considerably later, are much smaller producers, none of them being reported larger than 250 barrels. The log of one such well is given below:

Log of Empire Gas and Fuel Company's Chesney Farm Well No. 35.

Location, southeast corner of sec. 21, T. 25 S., R. 5 E. Drilled April 17 to June 21, 1917. Elevation of well mouth, 1,373 feet, which is 45 or more feet below the top of the Fort Riley limestone. Initial production, 250 barrels. Log furnished by Empire Gas and Fuel Company.

Drillers' record.	Thickness in feet.	Depth in feet.	Geological correlation.
Surface, brown, soft	3	3	
Lime, white, hard	15	18	Fort Riley limestone and Florence flint.
Shale, dark, soft	12	30	
Lime, white, hard	40	70	
Red Rock, red, soft	10	80	
Shale, dark, soft	20	100	
Sand, white, soft	20	120	
Shale, black, soft	60	180	

Drillers' record.	Thickness in feet.	Depth in feet.	Geological correlation.
Lime, white, hard	5	185	
Slate, blue, soft	55	240	
Sand, white, soft	15	255	
Shale, blue, soft	10	265	
Sand, white, soft; 3 bailers of water at 270 feet	10	275	
Lime, white, hard	40	315	
Red rock, red, soft	5	320	
Lime, white, hard	55	375	
Shale, gray, soft	15	390	
Sand, white, hard	8	398	
Shale, dark, soft	50	448	
Lime, white, hard	40	488	
Shale, dark, soft	2	490	
Sand, white, soft; oil at 498 feet	10	500	550-foot oil sand.
Shale, blue, soft	60	560	
Lime, white, hard	30	590	
Slate, light, soft	20	610	
Sand, white, soft; oil at 630 feet	30	640	660-foot oil sand.
Slate, dark, soft	20	660	
Lime, white, hard	5	665	
Shale, blue, soft	35	700	
Lime, white, hard	60	760	
Shale, dark, soft	15	775	
Lime, white, hard	10	785	
Slate, light, soft	35	820	
Lime, white, hard	15	835	
Shale, blue, soft	10	845	
Lime, white, hard	45	890	
Shale, blue, soft	40	930	
Sand, white, hard	20	950	
Lime, white, hard	40	990	
Shale, dark, soft	45	1,035	
Lime, white, hard	91	1,126	
Slate, light, soft	6	1,132	
Sand, white, soft; 2,000,000 cu. ft. of gas at 1,134 feet	13	1,145	
Slate, dark, soft	40	1,185	
Lime, white, hard	5	1,190	
Sand, white, soft; 2,000,000 cu. ft. of gas at 1,208 feet	60	1,250	
Lime, white, hard	30	1,280	
Slate, dark, soft; 1,000,000 cu. ft. of gas at 1,325 feet	50	1,330	
Lime, white, hard	40	1,370	
Shale, black, soft	5	1,375	
Lime, white, hard	25	1,400	
Shale, blue, soft	125	1,525	
Lime, white, hard	10	1,535	
Shale, blue, soft	95	1,630	
Lime, white, hard; oil at 1,674 feet	140	1,770	Lansing formation.
Shale, dark, soft	90	1,860	
Lime, white, hard	15	1,875	
Slate and shells, light, soft	25	1,900	
Slate, light, soft	10	1,910	
Slate and shells, light, soft	18	1,928	

Drillers' record.	Thickness in feet.	Depth in feet.	Geological correlation.
Lime, white, hard	160	2,088	Kansas City formation.
Slate, black, soft	7	2,095	Marmaton formation, with possibly some Cherokee shale at bottom.
Lime, white, hard	5	2,100	
Slate, dark, soft	85	2,185	
Slate, dark, soft	15	2,200	
Sand, white, soft; show of oil at 2,210 feet	15	2,215	
Slate, dark, soft	45	2,260	
Lime, white, hard, show of oil 2,270 feet	15	2,275	
Shale, blue, soft	95	2,360	
Lime, white, hard	15	2,375	
Shale, dark, soft	15	2,390	
Sand, light, hard; steel line measurement	88	2,481	Stapleton oil zone.

THETA SYNCLINE. This feature in the Stapleton zone has been but very slightly defined by drilling, it being indicated principally by the steep southeastward dip on the Wilson dome. From this dip it would appear that the Theta syncline is a strongly developed depression separating the Chesney and Wilson domes. Several dry holes have been drilled within it, indicating that in general no production may be obtained in its lower portions.

SEC. 15, T. 25 S., R. 5 E. Near the center of sec. 15, T. 25 S., R. 5 E., are a group of wells which, so far as available information indicates, are located on a strongly southeastward tilted portion of the Stapleton zone. It is possible that a small local dome is present immediately to the northwest and that they are situated on its southeast flanks, but this at present is merely an inference. The distribution of the three dry holes in the northeast quarter of the section is opposed to this interpretation, but instead suggests some unknown feature, not domal structure, which controls the oil in this locality.

The productivity of the wells also points to some peculiar sand condition. The initial well located in the southwest corner of the northeast quarter was reported as a 1,200-barrel producer, and this is offset to the north by a dry hole. The initial well is offset to the west by a 2,000-barrel producer. Four other wells were reported at 500 barrels or better, and the remainder below this. The log of the first well in this locality is given below:

Log of Derby Oil Company's Nuttle Farm Well No. 1.

Location, southwest corner of NE¼, sec. 15, T. 25 S., R. 5 E. Elevation of well mouth, 1,317 feet, which is about the same elevation as the top of the Fort Riley limestone. Casing record: 10-inch, 830 feet; 8-inch, 1,462 feet; 6⅝-inch, 2.050 feet; 5$\frac{3}{16}$-inch, 2,532 feet. Log furnished by the Empire Gas and Fuel Company.

Drillers' record.	Thickness in feet.	Depth in feet.	Geological correlation.
Soil, dark, soft	10	10	
Gravel, dark, soft	10	20	
Lime, light, hard; 12 bailers water at 80 feet	70	90	Fort Riley limestone and Florence flint.
Shale, light, soft	10	100	
Lime, light, hard	7	107	
Shale, light, soft	3	110	
Lime, light, hard	5	115	
Slate, dark, soft	10	125	
Red rock, red, soft	10	135	
Lime, hard, light	5	140	
Slate, dark, soft	20	160	
Lime, light, hard	15	175	
Red rock, red, soft	10	185	
Shale, light, soft	3	188	
Lime, light, hard	7	195	
Shale, light, soft	5	200	
Lime, light, hard	8	208	
Shale, light, soft	15	223	
Lime, light, hard	25	248	
Shale, light, soft	7	255	
Lime, light, hard	5	260	
Shale, light, soft	10	270	
Lime, light, hard	8	278	
Slate, dark, soft	10	288	
Lime, light, hard	8	296	
Slate and shells, dark, hard	24	320	
Slate, light, soft	10	330	
Lime, light, hard	7	337	
Sand, light, soft	18	355	
Slate, light, soft	5	360	
Lime, light, hard	10	370	
Shale, light, soft	8	378	
Lime, light, hard	12	390	
Slate, dark, soft	5	395	
Lime, light, hard	5	400	
Slate, dark, soft	10	410	
Sandy shale, light, soft	10	420	
Lime, light, hard	5	425	
Shale, light, soft	30	455	
Lime, light, hard	10	465	
Slate, light, soft	10	475	
Lime, dark, hard	5	480	
Shale, blue, soft	45	525	
Shale, light, soft	45	570	
Lime, light, hard	5	575	
Shale, light, soft	5	580	
Lime, light, hard	6	586	
Shale, light, soft	10	596	
Red rock, red, soft	5	601	
Shale, light, soft	4	605	
Lime, light, hard	3	608	
Shale, light, soft	12	620	
Lime, light, hard	5	625	
Slate, dark, soft	40	665	
Shale, brown, soft	5	670	

Drillers' record.	Thickness in feet.	Depth in feet.	Geological correlation.
Sand, light, soft; hole full of water at 675 feet	20	690	
Slate, dark, soft	15	705	
Sand, light, soft	5	710	
Slate, dark, soft	8	718	
Lime, light, hard	3	721	
Sand, light, soft	4	725	
Shale, light, soft	55	780	
Sand, light, soft; hole full water at 795 feet	25	805	
Sand, light, hard	10	815	
Slate, light, soft	10	825	
Lime, light, hard	30	855	
Shale, dark, soft	10	865	
Lime, light, hard	5	870	
Shale, light, soft	95	965	
Lime, light, hard	5	970	
Shale, dark, soft	10	980	
Lime, light, hard	10	990	
Shale, dark, soft	15	1,005	
Lime, light, hard	20	1,025	
Shale, light, soft	75	1,100	
Lime, light, hard	20	1,120	
Shale, dark, soft	12	1,132	
Lime, light, hard	20	1,152	
Shale, light, soft	15	1,167	
Lime, shells, hard	13	1,180	
Lime, light, hard	20	1,200	
Shale, light, soft	1,200	1,220	
Lime, light, hard	2	1,225	
Slate, dark, soft	10	1,235	
Sand, light, soft; 3 bailers of water per hour at 1,235 feet,	3	1,238	
Lime, light, hard	12	1,250	
Shale, dark, soft	5	1,255	
Lime, light, hard	5	1,260	
Shale, dark, soft	3	1,263	
Lime, light, hard	8	1,271	
Shale, dark, soft	6	1,277	
Lime, light, hard	10	1,287	
Shale, dark, soft	5	1,292	
Lime, light, hard	28	1,320	
Sand, light, soft; hole full of water at 1,325 feet	25	1,345	
Shale, light, soft	58	1,403	
Lime, light, hard	37	1,440	
Shale, dark, soft	10	1,450	
Lime, light, hard	15	1,465	
Slate, light, soft	85	1,550	
Sand, light, soft; little water at 1,558 feet	8	1,558	
Shale, dark, soft	67	1,625	
Lime, light, hard	25	1,650	
Slate, light, soft	25	1,675	
Slate, dark, soft	25	1,700	
Lime, light, hard	135	1,835	Lansing formation.
Shale, blue, soft	155	1,990	

Drillers' record.	Thickness in feet.	Depth in feet.	Geological correlation.
Lime, light, hard	10	2,000	Kansas City formation.
Sand, light, soft; hole full of water at 2,005 feet	5	2,005	
Lime, light, hard	10	2,015	
Sand, light, soft	5	2,020	
Lime, light, hard; hole full of water	105	2,125	
Sand, light, soft	8	2,133	
Lime, light, hard	17	2,150	
Slate, light, soft	90	2,240	Marmaton formation, with possibly some Cherokee shale at bottom.
Lime, light, hard	5	2,245	
Shale, light, soft	20	2,265	
Lime, light, hard	10	2,275	
Slate, dark, soft	30	2,305	
Lime, dark, hard; bad cave at 2,315 feet	33	2,338	
Slate, dark, soft	7	2,345	
Lime, dark, hard	5	2,350	
Slate, light, soft	80	2,430	
Lime, light, hard	5	2,435	
Slate	28	2,463	
Sand, dark, hard; steel line measurement at 2,470 feet	8	2,471	
Slate, white, soft	24	2,495	
Slate, dark, soft	31	2,526	
Oil sand	51	2,577	Stapleton oil zone.

WILSON DOME. The Wilson dome in the Stapleton covers essentially, so far as available drilling information is at hand, the same territory as that of the 660-foot sand and that of the surface rocks. Its configuration at its southeast end is more like that of the 660-foot sand than that of the still younger surface rocks, as is to be expected. The most pronounced difference between the flexing of the Stapleton and that of the higher rocks is found to the east and southeast, where the Stapleton dips relatively much stronger toward the Dunkle and Theta minor synclines than the outcropping rocks. Its slope here is between three and five times as steep. No comparison can be made with the 660-foot sand because of the lack of reliable depth measurements to this sand this far down on the flanks.

The dome in the Stapleton has a double crest caused by a small down-fold, one of the minor details which is not represented in the surface rocks, but is reflected in the 660-foot sand by a flattening. The configuration of the flanks of the dome to the northwest and south and into the troughs of the Dunkle and Theta synclines has not been sufficiently determined by drilling to permit comparisons with the structure of the surface formations.

The noteworthy feature to be observed here is the structural location of the wells. The wells in the east half of section 9 are far down on the east flank, as low as the —1,240-foot contour, whereas dry holes have been drilled on the south, west and northwest sides which are located respectively as high as the —1,060- and —1,080-foot contours. The wells on this dome have been rather uniform producers. The highest initial daily production reported for any well on this dome was 600 barrels, and this distinction was enjoyed by but two wells. Two others were reported as 500-barrel producers, and the others averaged about 200 to 300 barrels. The log of the initial Wilson dome well is given below:

Log of Empire Gas and Fuel Company's Wilson Farm Well No. 1.

Location, center of NW¼ SE¼, sec. 8, T. 25 S., R. 5 E. Drilled February 8 to March 23, 1917. Elevation of well mouth, 1,385 feet, which is about the same elevation as the top of the Fort Riley limestone. Initial production, 350 barrels. Casing record: 15½-inch, 193 feet; 12½-inch, 695 feet; 10-inch, 1,580 feet; 8¼-inch, 2,008 feet; 6⅝-inch, 2,440 feet; 3-inch, 2,462 feet. Log furnished by the Empire Gas and Fuel Company.

Drillers' record.	Thickness in feet.	Depth in feet.	Geological correlation.
Lime, white, hard; enough water to drill with at 75 feet,	75	75	Fort Riley limestone and Florence flint.
Sand, white, soft	10	85	
Lime, white, hard	45	130	
Shale, white, soft	10	140	
Lime, white, hard	10	150	
Shale, white, soft	5	155	
Lime, white, hard	45	200	
Shale, white, soft	10	210	
Lime, white, hard	25	235	
Shale, white, soft	5	240	
Lime, white, hard	30	270	
Shale, white, soft	5	275	
Lime, white, hard	25	300	
Shale, dark, soft	40	340	
Lime, white, hard	20	360	
Shale, dark, soft	5	365	
Lime, white, hard; enough water to drill with at 370 feet	15	380	
Shale, dark, soft	5	385	
Lime, white, hard	15	400	
Shale, dark, soft	45	445	
Lime, white, hard	10	455	
Shale, dark, soft	20	475	
Lime, white, hard	10	485	
Shale, white, soft	10	495	
Lime, white, hard	5	500	
Shale, white, soft	62	562	
Sand, gray, soft; small showing of oil at 562 to 567 feet,	5	567	550-foot oil sand.
Shale, white, soft	53	620	

Drillers' record.	Thickness in feet.	Depth in feet.	Geological correlation.
Sand, gray, soft	35	655	
Shale, white, soft	7	662	
Sand, gray, soft; 10 bbls. of oil; very good-looking sand and oil	23	685	660-foot oil sand.
Shale, gray, soft	17	702	
Lime, white, hard	3	705	
Shale, dark, soft	10	715	
Shale, white, soft	60	775	
Lime, white, hard	25	800	
Broken lime and shale, white, hard	35	835	
Lime, white, soft	30	865	
Shale, white, soft	80	945	
Lime, white, hard	25	970	
Shale, dark, soft	20	990	
Lime, white, hard	10	1,000	
Shale, dark, soft	30	1,030	
Lime, white, hard	5	1,035	
Shale, white, soft	35	1,070	
Lime, white, hard	40	1,110	
Shale, white, soft	10	1,120	
Lime, white, hard; about one-half million cu. ft. of gas at 1,120 feet in lime	25	1,145	
Shale, brown, soft	10	1,155	
Lime, white, hard	20	1,175	
Shale, white, soft	10	1,185	
Lime, white, hard	12	1,197	
Shale, brown, soft	10	1,207	
Lime, white, hard	23	1,230	
Shale, black, soft	5	1,235	
Lime, white, hard	5	1,240	
Shale, white, soft	7	1,247	
Lime, soft, white; small showing of oil at 1,250 feet in lime	6	1,253	
Shale, white, soft	12	1,265	
Lime, white, hard	10	1,275	
Lime, gray, hard	25	1,300	
Lime, gray, soft; 2 bailers of water at 1,317 feet in soft lime	17	1,317	
Shale, dark, soft; good showing of oil at 1,390 feet in lime	39	1,356	
Lime, white, hard; about one-half million cu. ft. of gas at 1,400 feet	44	1,400	
Shale, dark, soft	5	1,425	
Shale, dark, soft	25	1,450	
Lime, white, hard	9	1,459	
Shale, dark, soft	31	1,490	
Sand, brown, soft; 5 bailers of water per hour at 1,490 to 1,500 feet; 3 bailers of water per hour at 1,520 feet	45	1,535	
Shale, dark, soft	40	1,575	
Lime, white, hard	10	1,585	

Drillers' record.	Thickness in feet.	Depth in feet.	Geological correlation.
Shale, white, soft	35	1,620	
Lime, white, hard	5	1,625	
Shale, white, soft	55	1,680	
Lime, white, hard	155	1,835	Lansing formation.
Shale, white, soft	145	1,980	
Lime, white, hard	15	1,995	Kansas City formation, containing Stokes "sand."
Lime, white, hard; good show of oil at 1,995 to 2,010 feet in soft lime; hole filled over 300 feet first hour	15	2,010	
Lime, white, hard	40	2,050	
Sandy, lime, white, hard; 12 bailers of water at 2,050 feet to 2,085 feet; small show of oil at 2,085 feet in sandy lime	35	2,085	
Lime, white, hard	15	2,100	
Shale, dark, soft	110	2,210	Marmaton formation, with possibly some Cherokee shale at bottom.
Lime, gray, hard	3	2,213	
Shale, blue, soft	37	2,250	
Shale, blue, soft	45	2,295	
Lime, white, hard	33	2,328	
Shale, soft	47	2,375	
Shale, dark, soft	5	2,380	
Lime, white, hard	23	2,403	
Sand, white, hard	7	2,410	
Shale, blue, soft	28	2,438	
Lime, red, hard; top of sand 2,438 feet (steel line measurement)	3	2,438	Stapleton oil zone.
Sand, brown, soft	5	2,443	
Sand, brown, hard	5	2,448	
Sand, brown, soft	3	2,451	
Sand, brown, hard	10	2,461	
Sand, white, hard	4	2,465	
Sand, white, soft	2	2,467	

ROBINSON DOME. This flexure in the Stapleton zone is essentially similar, except in strength of development, to that in the outcropping Fort Riley limestone and Doyle shale. The flanks of the structure in the Stapleton are five or more times as steep. The principal difference between the Stapleton and surface rocks of this locality is a suggested second dome centered in section 2 to the east, with a southward plunging syncline between the two. This possible second dome has no similar fold in the surface rocks so far as was ascertained, but is represented by the broad and very shallow Ramsey syncline. The developments on this suggested second dome took place principally after the completion of the field work on which this report was based, and hence accurate well locations and drilling information are not at hand for further discussion.

If this suggested second dome in reality exists in the Stapleton zone, the presence of good oil wells in the trough separating it from the main dome in section 3 is at least worthy of attention. Oil wells in this trough are situated as low as the —1,160-foot contour, while to the west is a dry hole located as high as the —1,030-foot contour. This situation is similar to the distribution of the producing wells on the Wilson, Chesney and Oil Hill domes, and the situation suggests that structure alone is not the sole controlling feature in the distribution of the oil.

The productivity of the wells on the Robinson dome points to a rather open condition in the pay rock. The first well drilled here, located in the middle of the south line of SW¼ NE¼, sec. 3, and practically on the apex, came in with an initial daily production of about 1,900 barrels. The wells immediately adjacent came in at 750 to 1,000 barrels daily. These large wells rapidly lessened the pressure in the sand, and until late in 1918 the later wells averaged 100 to 300 barrels.

The wells located on the possible second dome to the east were all good producers, and up to the end of 1918 averaged about 400 barrels each in initial daily production, according to trade journal reports.

The logs of two wells on this dome are given below. The Robinson farm well is located high on the structure and its log is representative of most of the producing wells. The log of the Hewitt farm well, although a dry hole, is given because of its deep penetration into the rocks underlying the Stapleton zone.

Log of Theta Oil Company's Frank Robinson Farm Well No. 4.

Location, southeast corner, SW¼ NE¼, sec. 3, T. 25 S., R. 5 E. Drilled September 4 to October 25, 1917. Elevation of well mouth, 1,348 feet, which is about 7 feet below top of Fort Riley limestone. Initial production about 300 barrels. Log furnished by Theta Oil Company.

Drillers' record.	Thickness in feet.	Depth in feet.	Geological correlation.
Lime, white, hard; 8 bailers of water per hour	65	65	Fort Riley limestone and Florence flint.
Slate	50	115	Matfield shale.
Lime, white, hard	10	125	
Red rock, soft	5	130	
Lime shell, hard	4	134	
Slate	10	144	
Lime, hard	30	174	Wreford limestone.
Slate	6	180	Garrison limestone and shale.
Lime, hard	12	192	
Slate	6	198	
Lime	15	213	

Drillers' record.	Thickness in feet.	Depth in feet.	Geological correlation.
Slate	40	253	
Lime	5	258	
Slate	54	312	
Lime and sand, hard; 2 bailers of water per hour	18	330	
Slate	8	338	
Lime	15	353	
Slate	5	358	
Lime	12	370	
Slate	55	425	
Lime	15	440	
Slate	17	457	
Lime shell, hard	3	460	
Slate	165	625	
Lime	10	635	
Slate	85	720	
Lime	5	725	
Slate	10	735	
Lime	15	750	
Slate	30	780	
Lime	5	785	
Slate	12	797	
Lime	30	827	
Slate	48	875	
Lime	15	890	
Slate	70	960	
Lime	10	970	
Slate	30	1,000	
Lime	25	1,025	
Slate	75	1,100	
Lime, hard	25	1,125	
Slate	15	1,140	
Lime shell, hard	5	1,145	
Slate	35	1,180	
Lime, hard	30	1,210	
Slate	5	1,215	
Lime	30	1,245	
Slate	20	1,265	
Lime, broken, soft; 1 bailer of water per hour	20	1,285	
Slate	75	1,360	
Lime, hard	70	1,430	
Slate	45	1,475	
Lime	15	1,490	
Slate, soft, caving	15	1,505	
Lime shell	2	1,507	
Slate	93	1,600	
Lime	5	1,605	
Slate	65	1,670	
Lime, hard; 1 bailer of water per hour	130	1,800	Lansing formation.
Slate	5	1,805	
Lime	5	1,810	
Slate	134	1,944	
Lime, hard; oil showing at 1,955 feet; 4 bailers water per hour	176	2,120	Kansas City formation containing Stokes "sand."

Drillers' record.	Thickness in feet.	Depth in feet.	Geological correlation.
Slate	63	2,183	Marmaton formation, with possibly some Cherokee shale at bottom.
Lime shell, hard	2	2,185	
Slate, bad cave, white, soft	40	2,225	
Lime, white, hard	12	2,237	
Slate, cave, white, soft	18	2,255	
Lime, white, hard	45	2,300	
Slate, soft	65	2,365	
Lime, white, soft	5	2,370	
Slate, soft	58	2,428	
Oil sand, brown	25	2,453	Stapleton oil zone.

Log of Gypsy Oil Company's Hewitt Farm Well No. 1.

Location, northeast corner of the SE¼, SW¼, sec. 3, T. 25 S., R. 5 E. Elevation of well mouth, 1,363 feet, which is about 8 feet above top of Fort Riley limestone. Dry hole. The log is complete for the drilling up to February 12, 1918. Drilled deeper later on. Casing record: 12½-inch, 819 feet; 10-inch, 1,528 feet; 8-inch, 2,345 feet; 8-inch, 2,595 feet; 6⅝-inch, 3,345 feet. Log furnished by Gypsy Oil Company.

Drillers' record.	Thickness in feet.	Depth in feet.	Geological correlation.
Soil	15	15	
Lime; 1½ bailers of water per hour	110	125	
Blue shale	10	135	
Red rock	8	143	
White lime	7	150	Wreford limestone.
White lime	15	165	
White lime	20	185	
Blue shale	40	225	
Blue shale	20	245	
White lime	15	260	
Gray slate	15	275	
Gritty lime	65	340	
Lime	10	350	
Red rock	10	360	
Lime	40	400	
Lime	20	420	
Sandy lime; water	35	455	
Lime	10	465	
Blue lime	15	480	
Blue shale	20	500	
Blue shale	30	530	
Yellow lime	15	545	
Blue shale	25	570	
Blue shale	50	620	
Pink shale	8	628	
Brown shale	12	640	
Brown shale	30	670	
Gray shale	20	690	
White sand; water	8	698	
Gray shale	32	730	
Brown shale	20	750	
Brown shale	20	770	
Gray shale	35	805	
Dark lime; 2 bailers of water per hour	7	812	
Brown shale	7	819	

Driller's record.	Thickness in feet.	Depth in feet.	Geological correlation.
Gray shale	21	840	
Brown shale	10	850	
Light lime; water	35	885	
Gray shale	15	900	
Yellow lime; 2 bailers of water per hour	15	915	
Brown shale	15	930	
Blue shale	50	980	
Blue shale	25	1,005	
Gray lime	15	1,020	
Blue shale	10	1,030	
Yellow lime	10	1,040	
Shelly shale	40	1,080	
Brown shale	20	1,100	
Gray lime	15	1,115	
Gray shale	15	1,130	
Yellow lime	15	1,145	
Brown shale	10	1,155	
Dark lime	15	1,170	
Brown shale	5	1,175	
Unrecorded	25	1,200	
Blue lime	12	1,212	
Brown shale	18	1,230	
Brown lime	8	1,238	
Brown shale	7	1,245	
Yellow lime	25	1,270	
Soft shale	35	1,305	
Blue lime	15	1,320	
Blue lime; 2 bailers of water per hour	25	1,345	
White, sandy lime	15	1,360	
Brown shale	15	1,375	
Unrecorded	40	1,415	
White lime, hard	50	1,465	
Brown shale	5	1,470	
Hard lime	5	1,475	
White shale, soft	37	1,512	
Lime	8	1,520	
Blue gumbo	10	1,530	
White lime	10	1,540	
Brown shale	35	1,575	
Brown shale	60	1,635	
Light, hard lime	5	1,640	
Gray shale	25	1,665	
Gray lime	15	1,680	
Brown shale	30	1,710	
Gray shale	10	1,720	
Blue lime	30	1,750	
Yellow lime; 4 bailers of water per hour	10	1,760	
Yellow sand	25	1,785	
Brown shale	5	1,790	Lansing formation.
Sandy, yellow lime	80	1,870	Lansing formation.
Blue shale	70	1,940	Lansing formation.
Gray shale	50	1,990	Kansas City formation.
Hard, gray lime	100	2,090	

Driller's record.	Thickness in feet.	Depth in feet.	Geological correlation.
White lime; 2 bailers of water per hour	20	2,110	Marmaton formation, with possibly some Cherokee shale at bottom.
Dark, soft shale	7	2,117	
White lime	23	2,140	
Dark lime	15	2,155	
Broken sandy lime	15	2,170	
White lime	15	2,185	
Sandy brown shale; one-half bailer of oil per hour	75	2,260	
White sand	15	2,275	
Broken white sand	15	2,290	
White sand; water	15	2,305	
Broken blue shale	40	2,345	
Yellow lime	15	2,360	
Blue shale	10	2,370	
Broken slate and lime	20	2,390	
Blue shale	50	2,445	
Broken dark lime	20	2,465	Stapleton oil zone.
Dark sand and lime	25	2.490	
Brown shale	10	2,500	
Dark, sandy lime	20	2,520	
Brown shale	15	2,535	
Shell lime	3	2,538	
Soft, brown shale; salt water,	55	2,593	
White sand; water	81	2,674	
Blue shale	10	2,684	
Light sand	10	2,694	
Water sand	6	2,700	
Water	45	2,745	
Light lime; water	5	2,750	
Gritty sand	40	2,790	
Blue sand	30	2,820	
White, water sand	20	2,840	
White, gritty lime; water	100	2,940	
Gritty lime	100	3,040	
Sandy lime; water	60	3,100	
Shelly lime; water	50	3,150	
Shelly lime; water	50	3,200	
Lime, very sharp and hard	40	3,240	
Hard, shelly lime	25	3,265	
White water sand	40	3,305	
Gritty lime	30	3,335	
Blue shale	8	3,343	
Soft, gray sand	2	3,345	
Limestone	5	3,350	
Sandstone	5	3,355	
Limestone	40	3,395	

(Record incomplete.)

THE SMOCK AND SLUSS POOLS.

LOCATION AND EXTENT.

Located to the southeast and across the Walnut river from the main developed field lies a narrow strip of producing oil territory which constitutes the Smock and Sluss pools. This strip of developed territory extends from sec. 11, T. 27 S., R. 5 E., on the south, through sec. 2, T. 27 S., R. 5 E., secs. 35, 26, 25 and 24 of T. 26 S., R. 5 E., and into sec. 19, T. 26 S., R. 6 E. It is not only geographically but also structurally distinct from the main field, although probably genetically related. The development in this area started from two principal centers—one on the Smock farm, in sec. 2, T. 27 S., R. 5 E., where the discovery well was completed in March, 1917, with an initial daily production of about 500 barrels; and the other, one and three-fourths miles to the north, on the Sluss farm, in sec. 26, T. 26 S., R. 5 E., where the first well was brought in in August, 1917, with a production of 100 barrels daily.

Continued drilling in 1918 and 1919 has greatly diminished the distance separating these pools, until they have nearly coalesced. Since much of the drilling in the intervening area took place after the completion of the field work on which this report is based, accurate information concerning this development feature could not be obtained, and hence it is not shown on plates I and XIV. However, as the two pools are theoretically, if not practically, a unit, they will be treated together.

STRATIGRAPHY.

The general stratigraphy of the Smock-Sluss district is in practically every respect identical with that given in the main portion of this report, and hence there is no need for further general discussion.

Of interest, however, are the character and stratigraphic position of the single pay zone of this district. No drill cuttings of the pay rock were collected, and hence no information other than the drillers' interpretation, as given in well logs, can here be presented. Drillers report the pay rock as "sand," but so also is reported the Stapleton pay of the main field; hence it is possible, and to the writer it seems probable, that the Sluss and Smock "sands" may be similar in character to the Stapleton oil zone, which ranges from limestone to sandstone. And it seems further possible that the Sluss and Smock "sands" occupy the same stratigraphic position as the Stapleton; that is, the upper part of the eroded Mississippian rock series. While this cannot be readily demonstrated, the position of this pool to the east of the major anticline, together with the greater depth of the oil sand below the Fort Riley limestone, approximately 2,700 feet in comparison to the 2,460 feet of the Stapleton pay zone in Stapleton well No. 1, conforming closely to the thickness interpretation of the Cherokee and Marmaton formations in this locality as outlined on page 41, constitute evidence for such a correlation.

STRUCTURE.

SURFACE ROCKS. In mapping the surface rocks of the Smock-Sluss district more than usual care was exercised to find the presence of any flexing that might be present, but none could be detected. The pools lie on the regular westward dipping monocline characteristic of the region. It is possible, but not probable, that the dip here is slightly below normal, about twenty feet to the mile, but inasmuch as the region to the east has been mapped for only about a mile, the possibility cannot be well determined. The surface structure is not indicative of the presence of oil, and the discovery of this pool is due entirely to the efforts of the wildcat operator. In this respect these pools are quite different from the main Eldorado field. The smallness of these pools may be indicative of the size of pools which wildcat operations may be expected to discover in this general region.

OIL PAY. Sufficient evidence for the drawing of contours on the oil pay of the Sluss-Smock district was obtained only for the Smock end or southern part of this linear area. Here an underground anticline is well indicated, with its axis trending east of north and paralleling the trend of producing territory. (See plate XIV.) The distribution of the oil with respect to this arching shows it to be limited to the upper part of this underground anticline, and within the area where the sand is contoured it appears to be confined to an area which is within forty feet (vertically) of the crest of the fold. A similar structural situation appears to obtain in the Sluss neighborhood one and one-half miles to the north, and although the evidence at hand is insufficient for contouring, there seems reason for thinking that the probable fold is here simply the continuation of the Smock fold, and that this line of folding may extend both to the north and south; in other words, that this linear fold or zone of folding represents a tectonic line along which minor folding took place in pre-Permian time, and which has been concealed by the later-deposited Permian rocks now exposed at the surface. It probably is a fold initiated by a vertical movement along a fault plane, or shear zone, in the pre-Cambrian basement, as proposed on pages 155-164, and the outstanding difference between it and the larger Eldorado anticline is that no post-Permian deformation has taken place here to fold the rocks now exposed at the surface. This may indicate that the fold in the pay rock is of much smaller magnitude—a fact which is further evinced by the greater depth of the folded oil-bearing zone.

Logs of a Smock farm well and of a Sluss farm well are given below:

Log of J. S. Cosden's Smock Farm Well No. 1.

Location: Southeast corner NW¼, sec. 2, T. 27 S., R. 5 E. Drilled March 22 to June 13, 1917. Elevation of well mouth, 1,320 feet, which is about same elevation as top of Fort Riley limestone. Initial production, 232 barrels. Log furnished by Cosden Oil and Gas Company.

Drillers' record.	Thickness in feet.	Depth in feet.	Geological correlation.
Hard, gray lime	90	90	Fort Riley limestone and Florence flint.
Soft, red rock	15	105	
Hard, white rock	5	110	
Soft, blue slate	15	125	
Soft, red rock	10	135	
White, hard lime	55	190	
Soft, blue slate	40	230	
Hard, black shale	10	240	
Soft, blue slate	15	255	
Hard, blue lime	10	265	
Soft, blue shale	50	315	
Soft, white sand	15	330	
Hard, white lime	30	360	
Soft, blue shale	10	370	
Hard, white lime	5	375	
Soft, blue slate	5	380	
Hard, white lime	10	390	
Soft, blue shale	5	395	
Hard, white lime	15	410	
Soft, blue shale	15	425	
Hard, white lime	15	440	
Soft, blue slate	30	470	
Hard, white lime	25	495	
Soft, blue slate	10	505	
Hard, white lime	5	510	
Hard, white slate	20	530	
Hard, brown shale	20	550	
Soft, brown slate	40	590	

Drillers' record.	Thickness in feet.	Depth in feet.		Geological correlation.
Hard, blue lime	10	600		
Soft, red rock	10	610		
Hard, white lime	5	615		
Soft, blue shale	35	650		
Soft, white slate	50	700		
Hard, brown shale	25	725		
Soft, white sand; hole full of water	15	740		
Soft, white shale	60	800		
Soft, white slate	16	815		
Hard, white lime	35	850		
Soft, blue slate; water	10	860		
Hard, white lime	60	920		
Soft, white shale	90	1,010		
Hard, white sand	10	1,020		
Hard, white lime	55	1,075		
Soft, blue shale	35	1,110		
Hard, white lime	70	1,180		
Soft, blue shale	5	1,185		
Hard, white lime	75	1,260		
Soft, blue slate	10	1,270		
Hard, white lime	75	1,345		
Soft, blue slate	10	1,355		
Hard, white lime	20	1,375		
Soft, blue slate	3	1,378		
Hard, white lime	10	1,388		
Soft, blue slate	5	1,393		
Hard, white lime	42	1,435		
Soft, blue slate	35	1,470		
Hard, white lime	70	1,540		
Soft, blue slate	58	1,598		
Hard, blue lime	4	1,602		
Hard, white, sandy shale	40	1,642		
Hard, white lime	10	1,652		
Soft, blue slate	28	1,680		
Hard, white lime	25	1,705		
Soft, blue slate	90	1,795		
Hard, white lime	55	1,850		Lansing formation.
Hard, white sand	20	1,870		
Hard, white lime	120	1,990		
Soft, white slate	130	2,120		
Hard, blue lime; water	15	2,135		Kansas City formation.
Soft, blue slate	5	2,140		
Hard, blue lime	64	2,204		
Soft, blue slate	20	2,224		
Hard, white lime	46	2,270		
Soft, blue slate	20	2,290		
Hard, blue lime	10	2,300		
Soft, blue slate	5	2,305		
Hard, white lime	15	2,320		
Hard, blue shale	40	2,360		
Soft, white sand	20	2,380		
Soft, white slate	70	2,450		
Hard, white lime	20	2,470		
Soft, dark shale	120	2,590		
Hard, white lime	20	2,610		
Soft, brown shale	47	2,657		
Oil "sand," hard, green	24	2,681		
Oil "sand," soft, brown	20	2,701		
Soft, brown slate	3	2,704		Total depth.

Log of Houston-Dingee-Davis, Sluss Farm Well No. 1.

Location, southwest corner of NW¼ SW¼, sec. 25, T. 26 S., R. 5 E. Elevation of well mouth, 1,345 feet which is a few feet below top of Fort Riley limestone. Casing record: 12½-inch, 892 feet; 10-inch, 1,045 feet; 8¼-inch, 1,091 feet; 6⅝-inch, 2,432 feet. Log furnished by Cassaday Oil and Gas Company.

Drillers' record.	Thickness in feet.	Depth in feet.	Geological correlation.
Clay	4	4	
Lime	91	95	Fort Riley limestone and Florence flint.
Slate	15	110	
Red rock	5	115	
Lime	20	135	
Red rock	10	145	
Lime	60	205	
Slate	45	250	
Lime	8	258	
Slate	77	335	
Water sand	7	342	
Lime	8	350	
Slate	40	390	
Red rock	6	396	
Lime	4	400	
Slate	40	440	
Lime	8	448	
Slate	78	526	
Lime	8	534	
Shale	18	552	
Slate	18	570	
Lime	4	574	
Slate	52	626	
Red rock	8	634	
Slate	44	678	
Light sand	14	692	
Slate	25	717	
Lime	10	727	
Slate	40	767	
Light sand	10	777	
Black slate	13	790	
Gray slate	40	830	
Hard lime	45	875	
Lime	35	910	
Hard lime	12	922	
Black slate	12	934	
Gray slate	26	960	
Water sand	10	970	
Lime	26	996	
Slate	14	1,010	
Water sand	20	1,030	
Slate	10	1,040	
Lime	5	1,045	
Lime	2	1,047	
Slate	5	1,052	
Lime	26	1,078	
Slate	8	1,086	
Lime	4	1,090	
Slate	65	1,155	
White lime	50	1,205	
Hard lime	25	1,230	

Drillers' record.	Thickness in feet.	Depth in feet.	Geological correlation.
Gray, soft slate	30	1,260	
Lime	22	1,282	
Water sand	12	1,294	
Lime	10	1,304	
Slate	5	1,309	
Lime	51	1,360	
Light shale	6	1,366	
White lime	12	1,378	
Black slate	4	1,382	
White lime	20	1,402	
White lime	33	1,435	
Dark shale	10	1,445	
White lime	15	1,460	
Dark shale	15	1,475	
White lime	67	1,542	
Gray shale	18	1,560	
White lime	15	1,575	
Dark shale	15	1,590	
White lime	5	1,595	
Dark shale	35	1,630	
Gray shale	70	1,700	
Lime	66	1,766	
Slate	69	1,835	
Lime	66	1,901	Lansing formation.
Hard lime	17	1.918	
Lime	82	2,000	
Slate	97	2,097	
Shale	44	2,141	
Lime	159	2,300	Kansas City formation.
Slate	12	2,312	
Lime	9	2,321	
Slate	5	2,326	
Slate	74	2,400	
Water sand	16	2,416	
Sand	4	2,420	
Water sand	5	2,425	
Lime	7	2,432	
White, hard lime	3	2,435	
Soft shale	5	2,440	
Hard lime	10	2,450	
Lime	20	2,470	
Slate	24	2,494	
Lime	22	2,516	
Slate	6	2,522	
Lime	8	2,530	
Slate	10	2,540	
Lime	7	2,547	
Slate	45	2,592	
Lime	5	2,597	
Slate	18	2,615	
Unrecorded	5	2,620	
Oil "sand"	26	2,746	Total depth.

CHELSEA DOME: PROMISING OIL TERRITORY INADEQUATELY TESTED.

The Chelsea dome, which lies in the immediate vicinity of the Eldorado field, has not, in the judgment of the writer, been adequately tested for oil and gas. The inadequacy of the testing was pointed out in a preliminary statement issued to the public press on November 4, 1918, at a time when there was a crying need for increased production during the prosecution of the World War. Although the statement of November 4, 1918, was preliminary in nature and not based upon a thorough study of all the available evidence, the later more detailed studies have strengthened rather than diminished the writer's confidence in the original conclusions as expressed in the press notice.

At the time the preliminary statement was issued two dry holes had been drilled on the Chelsea anticline—one on its west side, about 20 to 25 feet below the crest as indicated by the surface rocks, in the southwest corner of the NW¼ NW¼, sec. 1, T. 25 S., R. 5 E.; and the other on the north slope, about 15 to 20 feet below the crest, in the SE¼ SE¼, sec. 36, T. 24 S., R. 5 E. Since then, according to trade journal reports, another dry hole has been drilled in the southwest corner of the SE¼, sec. 1, T. 25 S., R. 5 E., which is about 60 feet below the crest. None of these wells were located in the most favorable position for testing the structure, as will be pointed out, and for this reason it seems probable that some very promising oil territory still lies (April, 1920) undeveloped on the Chelsea anticline.

A study of the distribution of the Stapleton zone oil in relation to the structure shows that the oil lies much farther down on the east flanks of the anticlines and domes than on any other portion, and further, that in these positions it is present in relatively larger quantities. This is particularly true of the Wilson, Robinson, Chesney and Oil Hill domes, and this relation is not only in reference to the structure as developed in the surface rocks, but is even more marked in reference to the folds in the Stapleton pay. The proof of this relation is to be found on plate XIV, in the distribution of the Stapleton sand wells with reference to the contours, showing the structure of the top of the Stapleton zone. This relation, although pointed out in the structural discussions of the Stapleton sand, will again be summarized briefly.

On the Oil Hill dome production extends to the southeast as far down as the —1,440-foot contour and to the south as far down as the —1,520-foot contour, whereas to the west and northwest dry holes have been drilled at places as high as the —1,140- and —1,120-foot contours. Producing wells in section 27 have been brought in on the southeast flank of the Chesney dome as low as the —1,410-foot contour, whereas a well in the southeast corner of section 16 on the north flank, and as high as the —1,080-foot contour, was dry.

Similarly, on the Wilson dome oil has been found on the east side as far down as the —1,240-foot contour, whereas dry holes have been drilled on the southwest and northwest sides which were located as high as the —1,060- and —1,080-foot contours. On the Robinson dome dry holes were drilled on the west side as high as the —1,030-foot contour, and oil wells brought in on the east side as low as the —1,160-foot contour.

If these relations hold in the Stapleton pay zone for the Robinson, Wilson, Chesney and Oil Hill domes, it would seem that they should also hold for the Chelsea dome.

It is not only, however, on the relation of the oil to the structure in the Stapleton zone that the inadequacy of the testing of the Chelsea dome must be judged, but also by the location of the dry holes with respect to the structure of the surface rocks, which is the only evidence available pointing to the structure of the possible oil-bearing Stapleton zone, 2,500 feet or more below. The dry hole located on the southwest flank lies structurally about 60 feet below the crest of the dome. (See plate I.) On the Wilson dome, similarly located, dry holes lie but 30 to 50 feet below the crest, yet these had no value in determining whether that structural feature was productive. The dry hole located on the west slope of the Chelsea dome is 20 to 25 feet below its crest, which is considerably lower than a similarly located dry hole on the Robinson dome, which is only about 10 feet below the crest of that fold. In like manner, the dry hole on the northeast flank of the Chelsea dome is more than 15 feet below the crest, and because of the uncertainty in the exact location of contours here may be in excess of 20 feet. On the Robinson dome a similarly located dry hole lies about the same vertical distance structurally below the crest, and one to the north lies but 25 feet below the crest. The northeast flank of the Wilson dome has also been proven dry at a point but 30 feet below the crest. On the basis of such evidence it would seem that additional drilling must be done on the Chelsea dome before it can reasonably be concluded to be barren of oil.

In view of these inadequate tests, it is suggested that additional drilling be undertaken to test the structure more thoroughly. Since the prevailing tendency of oil in this region is to congregate on the southeast and east flanks in preference to other parts, it is suggested that the southeast flank presents the most favorable location for further testing, and the recommended locations as given in the press notice issued on November 4, 1918, are still considered good. The first location suggested was the center of sec. 6, T. 25 S., R. 6 E., which is on the southeast slope of the dome and about 5 to 15 feet below its crest. Should a test here prove unsuccessful it is suggested that two more test wells be drilled before the anticline is condemned as valueless. One about a quarter of a mile north of the southeast corner of section 6, farther down the southeast slope, and the other about a quarter of a mile south of the northwest corner of section 6, on the crest of the anticline.

The depth to the Stapleton pay rock may be deeper on the Chelsea dome than in the developed field to the southwest—a very possible condition, since the position of the Stapleton zone is probably determined by the variable depth of the eroded Mississippian series from place to place. The well drilled in the SE¼, sec. 36, T. 24 S., R. 5 E., according to its log as given below, probably entered the Stapleton at a depth of 2,640 feet, but as was shown for the east flanks of other domes the Stapleton slopes off much more rapidly than the surface rocks, and hence the depth to the Stapleton at two of the suggested drilling locations will probably be considerably in excess of 2,640 feet, and may even reach as high as 3,000 or more feet.

For the guidance of drillers, the log of the hole drilled on the northeast flank is given below:

Log of Empire Gas and Fuel Company's Pippig Farm Well No. 1.

Location, SE¼, sec. 36, T. 24 S., R. 5 E. Elevation of well mouth, 1,415 feet, which is about 40 feet above the Fort Riley limestone. Log furnished by Empire Gas and Fuel Company.

Drillers' record.	Thickness in feet.	Depth in feet.	Geological correlation.
Clay, red, soft	15	15	
Shale, yellow, soft	20	35	
Lime, white, hard	25	60	Fort Riley limestone.
Shale, yellow, hard	10	70	Fort Riley limestone.
Lime, gray, hard	30	100	Fort Riley limestone.
Fresh-water sand	30	130	Florence flint.
Shale, blue, soft	25	155	
Shale, blue, shaly	15	170	
Red rock, soft	5	175	
Lime, gray, hard	40	215	
Red rock, hard	20	235	
Lime, broken, blue, hard	90	325	
Shale, blue, hard	65	390	
Lime, gray, hard	20	410	
Shale, blue, hard	40	450	
Lime, gray, hard	20	470	
Shale, gritty, white	30	500	
Lime, blue, hard	30	530	
Shale, blue, soft	25	555	
Shale, white, soft	20	575	
Shale, shelly, blue	30	605	
Lime, white, hard	10	615	
Shale, blue, soft	25	640	
Lime, broken, soft	40	680	
Shale, blue, soft	7	687	
Shale, shelly, white, soft	16	703	
Shale, light, hard	12	715	
Water sand, soft	8	723	
Shale, blue, soft	52	775	
Water sand, hard	25	800	
Shale, blue, soft	35	835	
Lime, broken, blue, hard	55	890	
Shale, blue, hard	18	908	
Lime, white, hard	20	928	
Shale, blue, shelly	112	1,040	
Lime, white, hard	20	1,060	
Shale, blue, soft	15	1,075	
Lime, blue, hard	31	1,106	
Shale, brown, soft	14	1,120	
Lime, white, hard	23	1,143	
Shale, blue, soft	10	1,153	
Lime, gray, hard	33	1,186	
Shale, blue, soft	13	1,199	
Shale, brown, hard	10	1,209	
Lime, gray, hard	7	1,216	
Shale, blue, soft	10	1,226	
Shale, brown, soft	14	1,240	
Lime, gray, hard	10	1,250	
Lime, white, hard	37	1,287	
Lime, gray, hard	9	1,296	
Sand, broken, soft	7	1,303	
Shale, blue, soft	7	1,310	
Lime, gray, hard	17	1,327	

Driller's record.	Thickness in feet.	Depth in feet.	Geological correlation.
Shale, blue, soft	26	1,353	
Lime, white, hard	18	1,371	
Shale, black, soft	7	1,378	
Lime, gray, hard	19	1,397	
Shale, blue, soft	15	1,412	
Lime, gray, hard	6	1,418	
Sand, yellow, hard, dry	10	1,428	
Shale, blue, soft	48	1,476	
Lime, gray, hard	45	1,521	
Shale, blue, soft	12	1,533	
Lime, white, hard	15	1,548	
Shale, blue, soft	65	1,613	
Sand, water, soft	37	1,650	
Shale, blue, soft	50	1,700	
Lime, gray, hard	12	1,712	
Shale, blue, soft	88	1,800	
Lime, gray, hard	100	1,900	Lansing formation.
Sand, water, soft	27	1,927	
Lime, gray, hard	4	1,933	
Shale, broken, hard	12	1,945	
Shale, blue, soft	131	2,076	
Lime, blue, dark	34	2,110	Kansas City formation.
Lime, shelly, blue, hard	115	2,225	
Water sand, soft	35	2,260	
Shale, shelly, blue, soft	65	2,325	
Shale, white, soft	65	2,390	
Lime, gray, hard	10	2,400	
Shale, blue, soft	35	2,435	
Lime, gray, hard	10	2,445	
Broken lime, blue, soft	55	2,500	
Shale, blue, soft	144	2,644	
Lime, broken, soft	56	2,700	
Sand, soft	100	2,800	
Shale, blue, soft	6	2,806	
Sand, white, hard	40	2,846	
Shale, blue, soft	6	2,852	
Lime, gray, hard	20	2,872	
Slate, black, soft	80	2,952	
Sand, white, soft	38	2,990	

ORIGIN OF THE ELDORADO ANTICLINE

AND OF OTHER TYPES OF STRUCTURE FOUND IN THE NORTHERN PART OF THE MIDCONTINENT OIL AND GAS FIELDS.

INTRODUCTORY STATEMENT.

Anticlinal folding is usually attributed to a buckling of strata under horizontal or tangential compressive forces which operate at right angles to the axes of the folds. This explanation is based principally on observations made in regions adjacent to mountain ranges which were caused by great orogenic movements. That similar forces have operated in the northern part of the Midcontinent region to produce anticlines and domes, such as those in the Eldorado and other fields, seems to the writer very difficult to conceive, for the source of such forces in the near-by regions is not apparent, and, besides, the strata of this region, consisting predominantly of shale, are comparatively weak and could not transmit horizontal forces through any considerable distance, because the weak strata would yield by crumpling and thus relieve the stresses. This was impressed on the writer during his investigation of the Bristow quadrangle, Creek County, Oklahoma,[1] which led to the publication of a tentative solution of the problem in a paper entitled "The origin of the faults, anticlines and buried 'granite ridge' of the northern part of the Midcontinent oil and gas field."[2] The theory there advanced explains the folding as not caused by lateral thrust transmitted through the sediments of this region, but as in large part the surface expression of deep-seated readjustments along ancient faults or lines of weakness present in the pre-Cambrian basement rocks of the region.

The probable presence of such faults or lines of weakness in the basement rocks is suggested by (1) parallel belts of *en échelon* faults in the rocks exposed at the surface in northeastern Oklahoma, and (2) by the parallelism of these fault belts to many of the lines of anticlinal folding present through-

1. Preliminary report published in U. S. Geol. Survey Bull. 661-*b*, pp. 69-99, "Structure of the northern part of the Bristow quadrangle, Creek county, Oklahoma, with reference to petroleum and natural gas." 1917.

2. U. S. Geol. Survey, Professional Paper 128-C.

out the oil-and gas-producing region of the northern part of Midcontinent field. The Eldorado field supplies additional evidence in support of this theory, and in order to show the relation which this field bears to the hypothesis, it seems essential to present in this place most of the original argument.

ORIGIN OF THE EN ÉCHELON FAULTS.

En échelon faults in the rocks at the surface in northeastern Oklahoma furnish the most direct evidence for the contention that ancient faults or lines of weakness exist in the basement rocks. The *en échelon* faults lie in a broad, northward-trending zone known to extend from Okfuskee county to Osage county, and probably continuing into Hughes and Seminole counties on the south and into the state of Kansas on the north. (See plate XVIII.) These faults, which locally modify the general westward dip of the strata, are normal faults—*i. e.*, the hade lies in the direction of the downthrow—and are noteworthy not only because of the approximate parallelism of the individual faults, but also because of their grouping into belts or series which are parallel to one another but trend in a different direction from the individual faults. Most of the individual faults trend about No. 20° to 45° W., and lie *en échelon* to one another in such a manner that they form linear belts or series which trend from north to N. 25° E., or roughly at an angle of 45° with the trend of the faults. Some of these belts are 50 miles or more long. The faults are of minor magnitude both in vertical displacement and areal extent. One of the largest that the writer found has a stratigraphic throw of about 130 feet and a length of about 3¼ miles. Where they cut sandstone beds slickensided surfaces are developed, and these indicate that some of the fault planes dip southwest and some northeast, at angles which range between 50° and 65° from the horizontal.[3]

As mentioned above, the faults are normal—*i. e.*, the downthrow is in the direction of the hade—and hence the immediate forces that caused the individual fractures were probably tensional in nature and operated horizontally in a direction

3. Somewhat similar faults in southern Montana have been mapped and described by E. T. Hancock, in "Geology and oil and gas prospects of the Lake Basin field, Montana"; U. S. Geol. Survey Bull. 691-D, pp. 101-147; 1918. Dr. Rollin T. Chamberlin has recently advanced a well-founded explanation for them in a paper entitled "A peculiar belt of oblique faulting"; Jour. Geol. XXVII, pp. 602-613; 1919. Chamberlin's discussion on pages 610-613 of his paper is quite analogous to the arguments presented here and deserves more consideration in this report than it is possible to give to it, for want of time.

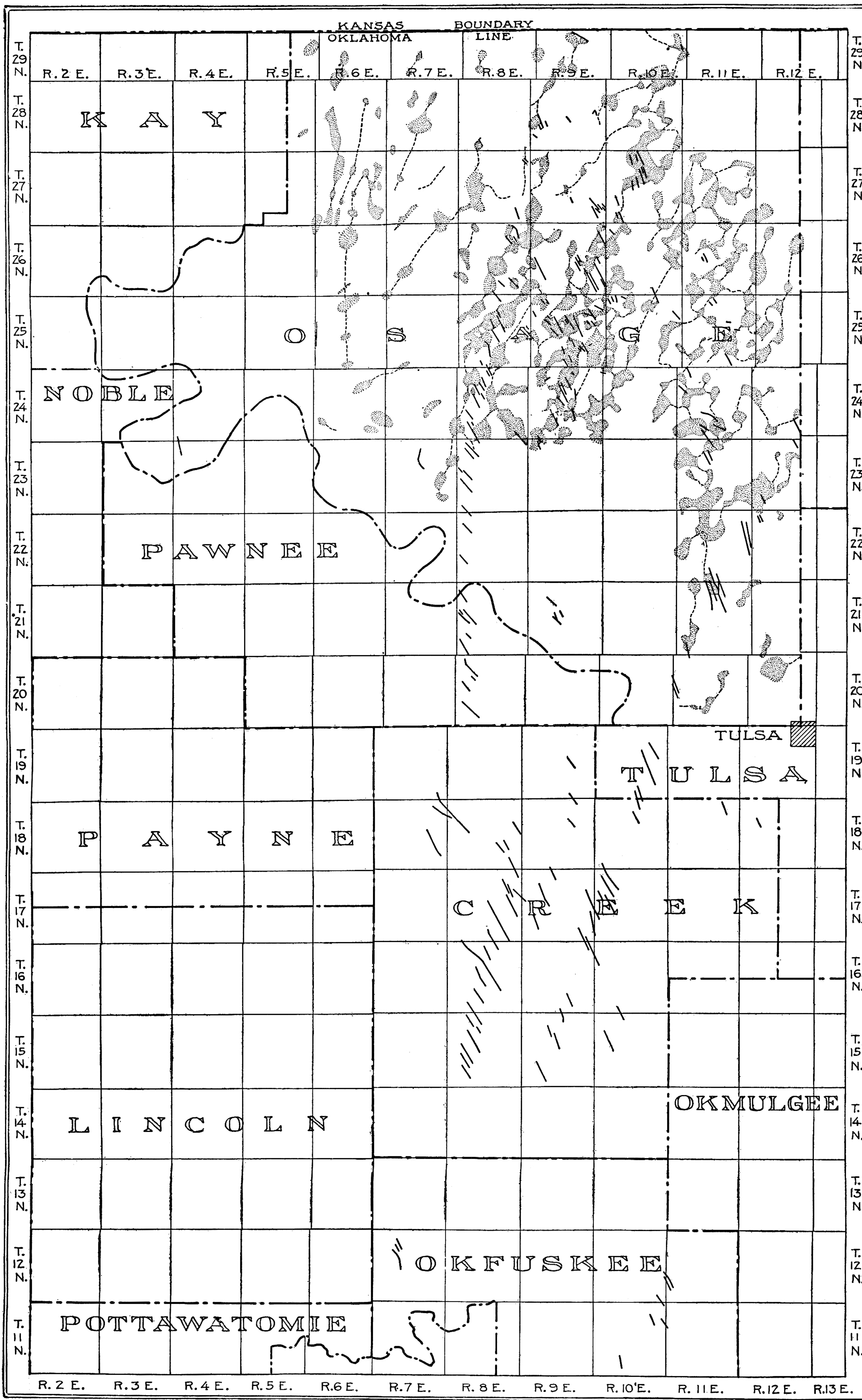


Plate XVIII.—Sketch map of a part of northeastern Oklahoma, showing the distribution of *en échelon* faults, and in Osage county a predominant northerly alignment of the anticlines and domes.

normal to their trend, or N. 45° to 70° E. On the other hand, the linear grouping of these fractures into belts and their general uniform development throughout each belt suggest, as the most simple explanation, that the faults of any one series were caused by horizontal forces which operated in a direction parallel to the trend of the series—*i. e.*, N. 0° to 25° E. The question at once arises, How can horizontal forces operate to produce belts 50 miles or more long of diagonal tensional faults in weak strata like the Pennsylvanian rocks of this region? The writer believes that the controlling forces were not transmitted by the weak Pennsylvanian strata, for the stresses would have been relieved by adjustment within the soft strata.

As the upper few thousand feet of strata in this region are too weak and incompetent to transmit such horizontal forces, some other agent must be sought. Lying at some unknown depth beneath the surface of this region there exist massive granites, quartzites and associated rocks which constitute the basement rocks, and above them there may be some massive limestones and sandstones such as are known in the St. Francis, Arbuckle, Wichita and other mountain ranges surrounding this region. A submerged "granitic ridge," which has previously been discussed under the head of stratigraphy, is known to underlie the Permian and Pennsylvanian strata in a part of eastern Kansas. These crystalline rocks are fully competent to transmit earth forces, and furthermore are more closely related to the deep-seated deformational movements of the earth than the higher beds. These competent crystalline rocks could transmit horizontal forces caused by movements along fault planes or shear zones in these older rocks through considerable distances in the overlying beds, especially if overlain by a heavy load of sediments. It is postulated, therefore, that the controlling or master forces that produced the long belts of faults at the surface operated in a direction parallel to those belts and were transmitted in a horizontal direction by the strong, massive, competent rocks which lie at considerable depth beneath the surface, and that the belts of parallel diagonal faults of the Midcontinent region are the natural surface expression in overlying weak rocks of such deep-seated horizontal movements.

Since the strata overlying the deep-seated beds are relatively weak and yielding, their deformation will differ from that of the hard beds. Instead of breaking or shearing sharply along a nearly vertical plane or zone parallel to the fracture or shear zone in the underlying granites along which a horizontal displacement has taken place, they will be bent and the parts will tend to be dragged apart, so that tension will be produced diagonal to the direction of movement. This action may be demonstrated by drawing a circle on the side of a rubber eraser or other flexible substance and distorting the eraser by a shearing force acting in the direction shown in figure 8, the ends of the eraser being held firmly. The circle on the eraser will be

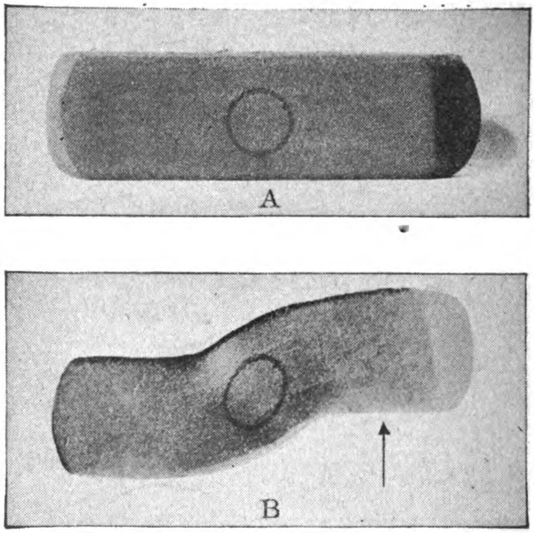
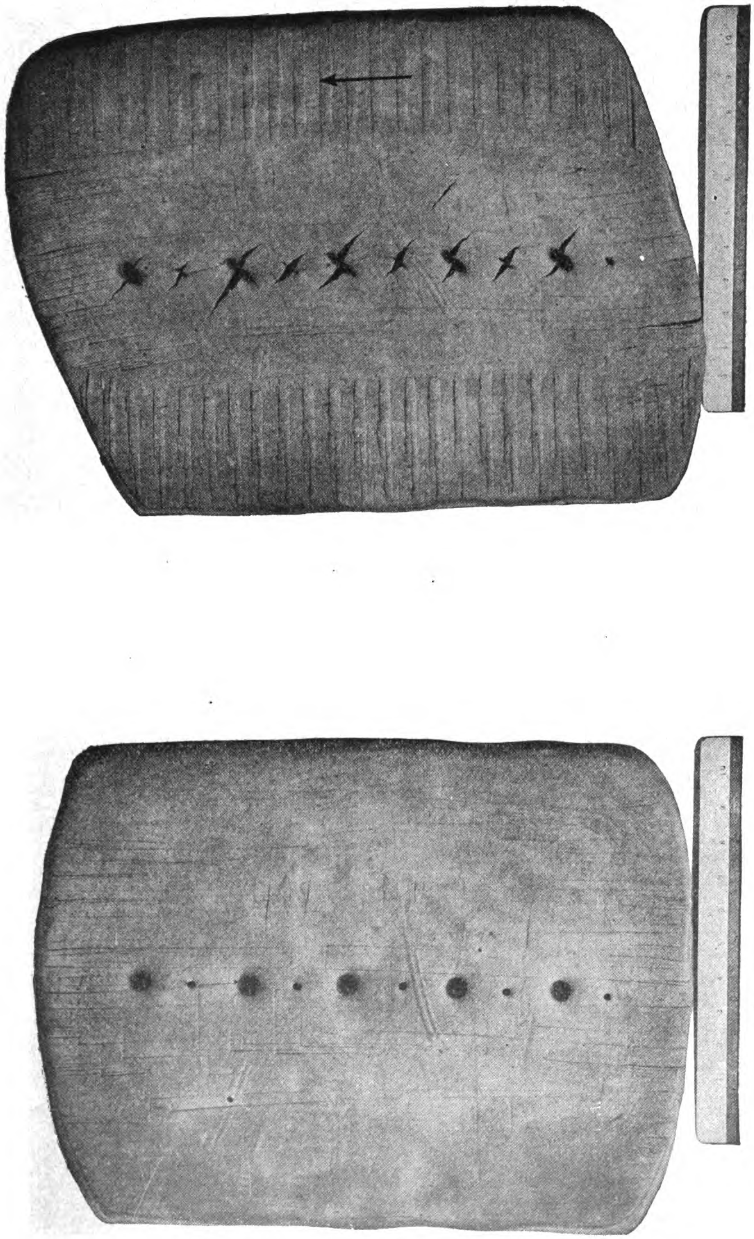


FIG. 8.—A circle on a rubber eraser, elongated by distorting the eraser.

distorted by being elongated in a diagonal direction. Contraction in a direction at right angles to the elongation may also be observed. The same effect accompanied by the production of fractures normal to the tension is pictured in plate XIX. In this illustration A is an undeformed flat piece of modeling clay partly pierced by several conical holes along a medial belt. B is the same piece of clay after being deformed by a force operating in the direction indicated by the arrow. The rounded holes have been elongated in the direction of tension, and fractures, which have been centralized by the weakening of the mass at the holes, have been produced at right angles to the



A. B.

PLATE XIX.—Clay model showing *en échelon* fractures. A flat mass of modeling clay pierced by several conical holes, before and after being deformed.

direction of elongation, and the adjacent walls pulled apart. Minor compression perpendicular to the direction of elongation is indicated by the contraction of the holes in that direction.

Under this explanation, the fractures produced in the rocks immediately overlying the harder rocks in which the horizontal displacement occurred would be open tears which would remain open fissures if it were not for adjustment which would immediately take place in the thick series of overlying soft formations. In this adjustment the fractures would be closed up by the slumping or giving way of the soft, yielding rocks on one side or the other, which would result in a small vertical displacement of the beds on opposite sides of the fissures—*i. e.*, there would be a normal fault. The fissuring itself would cause no displacement of the strata at the surface, but the after-adjustment does. While the deep-lying fractures may have been irregular tears, their upward extensions into the overlying, less-loaded material caused by the slumping would be straighter, and at the surface they would be represented by regular normal faults.

In applying this explanation to the faults in the Midcontinent field, the direction of the shearing movement in the hard, deep-lying, competent rocks must have been along the belts of faults, the territory on the east side of each fault belt having moved northward relative to the west side. Considering the faulted region as a whole, each unbroken strip on the east of a fault belt having moved northward relative to its respective strip on the west, the movement may be likened to a regional shearing, the belts of faults in the weak and yielding surface beds marking the location of the fault planes in the granite basement.

If the soft and yielding beds were sufficiently thick it is clear that faulting of this type would be gradually dissipated upwards and would not reach the surface. It is therefore probable that other such fault zones exist in the Pennsylvanian rocks beneath the surface which failed to reach the surface, because the movements which initiated them were not as great as those which produced the faults which now show at the surface, or which, as will be shown later, may have been formed previous to the deposition of the surface rocks. The possibility of such belts of deep-lying, diagonal faults which do not reach the surface is suggested in the Eldorado field by the supposed faulting of the Stapleton oil zone in sec. 27, T. 25 S., R. 5 E., as discussed on page 117. It is also slightly suggested by the anomalous production from the Stapleton zone in the central part of section 15 of the same township, and by the transverse-lying Bancroft and Dunkle synclines which, although but slightly developed in the surface rocks, are much more strongly developed in the Stapleton zone, and may with still greater depth be fractured and displaced.

ORIGIN OF THE ANTICLINAL AND SYNCLINAL FOLDS.

An extensive series of faults or shear zones in the pre-Cambrian basement rocks along which there was horizontal movement has been postulated to explain the belts of faults, but the movement along these ancient lines of weakness probably was not everywhere horizontal. Vertical movement would probably be even more common, and the effect in the overlying weak beds would be quite different from the belts of faults described above. It is a commonly recognized fact that faulting passes in distance into folding, and although the lowermost beds of overlying weak rocks would be faulted similarly to the hard rocks, this faulting would diminish in intensity away from the competent rocks, and at a sufficient distance would resolve itself into folding. It is the writer's opinion that many of the Midcontinent anticlines represent such folds, which are the effects in the soft formations outcropping at the surface of faults in the hard rocks of the pre-Cambrian basement.[4] It is also the writer's opinion that some of the anticlines of this region can be only partly explained in this manner, and that others were probably formed by entirely different causes.

In all the folds in the area that have come to the writer's attention, and which probably formed in this manner, the causal movement consisted of a relative lowering of the area to the east, which, however, may actually have been a rise of the area to the west.

4. Since this report was written, "The origin of the central Kansas domes," by Dr. Eliot Blackwelder, has appeared in Bull. Amer. Assoc. Petr. Geologists, pp. 89-94, vol. 4, No. 1; 1920. In this article mention is made of another paper on the same subject by Dr. M. G. Mehl, which was read at the St. Louis meeting of the American Association for the Advancement of Science, in December, 1919. The opinions of these able geologists are worthy of careful consideration; but for want of time, no discussion of their papers can be undertaken for inclusion in this report. It is to be noted, however, that the main endeavor of both these writers, like that of the author of this report, is to find some explanation other than horizontal compressive forces to account for the Midcontinent type of anticlinal folds.

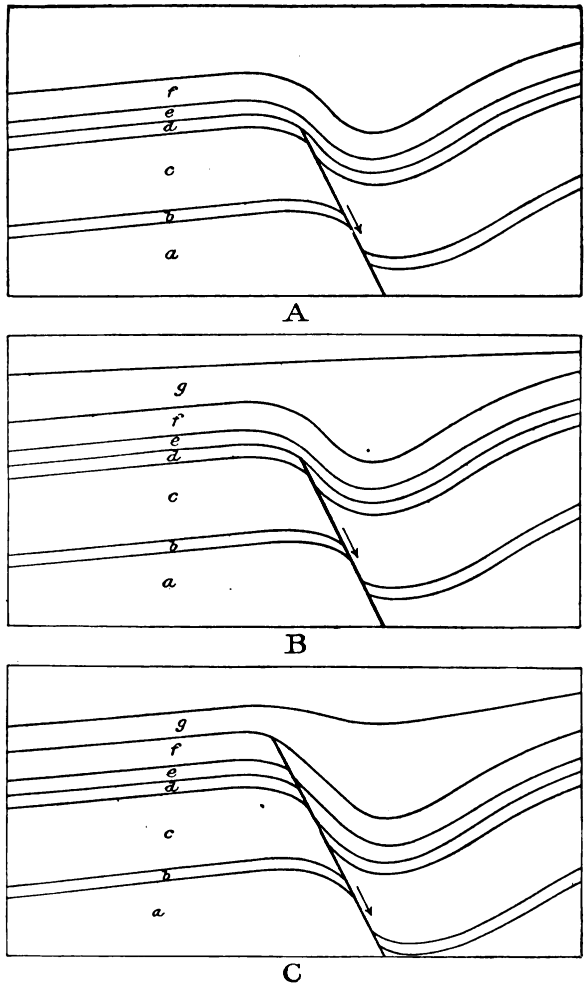


FIG. 9.—Diagrammatic sketches illustrating different stages in the upward dissipation of normal faults and their resolution into folding.

As discussed on page 105, there is some reason for thinking that the Stapleton zone is faulted in the Bishop syncline of the Eldorado field. The increase in the magnitude of the folding here between the surface rocks and the Stapleton is so great that if the Stapleton zone is not actually faulted the rocks a short distance below almost certainly must be. If the deeper rocks underlying the Bishop syncline are faulted there is good reason for thinking that the same rocks are more highly faulted beneath the more sharply folded Hammond syncline lying to the south, and if so, the faults extend higher up through the stratigraphic section than beneath the Bishop syncline. North of the Bishop syncline is the Fowler syncline, and in this structure the folding is less intense, but this also increases with depth. (See plate XIV.) If this finally gives place to a fault at greater depths, the fracture probably would not come so near to the surface as those in the Bishop syncline and Hammond syncline localities.

It is to be noted that the Hammond and Bishop and Fowler synclines lie in line with each other, as if related to some tectonic line or fault in the granitic basement. To produce these structures, according to the author's views, the displacement on the fault must have varied from place to place.

The possibility of faulting in the Stapleton zone on the southeast flank of the Koogler nose is also suggested by the evidence in hand. (See page 108.)

The steeply dipping east flanks of the Koogler nose and the Boyer, Oil Hill and Chesney domes, which form the west limb of the Walnut syncline, well shown by the surface rock structure, are in line with each other, and if continued farther north would about extend to the east flank of the Robinson dome. The same alignment is more marked in the Stapleton zone by the much steeper east dips on the above structures, which if continued northward would extend into the diminishing syncline in the E½, sec. 3, T. 25 S., R. 5 E., which separates the Robinson dome from the one possibly present in the Stapleton zone to the east. To the writer this alignment appears to represent another tectonic line whose expression increases with depth, and at depths greater than the Stapleton should be marked by a fault in the granitic basement.

Although the anticlines of the Eldorado field seem to the author to be intimately related to faults with vertical throw in the basement rocks, the general subject may receive a broader consideration. Carrying this reasoning further, the question arises, Do the anticlinal folds of the northern Mid-continent region as a whole indicate vertical displacements along extensive master faults or shear zones in the basement rocks comparable to those which, by horizontal movements, are believed to have produced the belts of *en échelon* faults of northeastern Oklahoma, some of which have lengths of 50 miles or more.

The "granite ridge" belt of folding, which includes at the south the anticlines of the Eldorado, Augusta and Douglas fields, reaches nearly across the state of Kansas. Other extensive lines of flexing have been mapped in Kay, Garfield, Noble, Creek and Osage counties, Oklahoma, and in Cowley county, Kansas, and their distribution and trend is shown on a single map in plate XIV, U. S. Geological Survey, Professional Paper 128-C; 1920. Extensive lines of flexing are also shown in Osage county, Oklahoma.[5] (See plate XVIII.) Some of these anticlines are not only in general parallel to the hypothetical deep-seated horizontal faults which caused the belts of *en échelon* surface faults, but are also equally extensive. This parallelism and coextensiveness point to a close, if not common, relation in origin. All the anticlines in the Midcontinent field cannot, however, be pointed out in support of this hypothesis, for many small ones, including many in Osage county, Oklahoma, do not lend themselves so readily to this explanation, and still others may be wholly due to other causes.

If some of the belts of folding are due to vertical displacements along master faults or shear zones in the basement rocks, the displacement along any such fault would probably not be of equal magnitude throughout its entire extent. The result in the surface rocks of such a deep-seated displacement would not be a single continuous and uniform anticline, but would probably be more or less local in extent. A 100-foot displacement at any one place might disappear within a short distance and the resulting anticline in the overlying beds would have definite termini. The length of such an anticline is a measure not of the extent of the fault or shear zone, but merely of the distance along its course through which noticeable vertical displacement has taken place. There may have been vertical displacements at intervals along these lines or zones of weakness, forming a long linear series of anticlines in the surface rocks, such as those in the beds overlying the buried "granite ridge," which extends practically, if not entirely, across the state of Kansas, and in the subparallel belts of short anticlines such as those of Osage county, Oklahoma. An excellent example in the Eldorado field is to be found in

5. Heald, K. C.: The oil and gas geology of the Foraker quadrangle, Osage county, Okla.: U. S. Geol. Survey Bull. 641, plate II, 1916; and Geologic structure of the northwestern part of the Pawhuska quadrangle, Oklahoma; U. S. Geol. Survey Bull. 691, pl. XIII, 1918. Heald, K. C., and others; Structure and oil and gas resources of the Osage Reservation; U. S. Geol. Survey Bull. 686. The plates of the various chapters which appeared prior to April 15, 1919.

the Hammond-Bishop-Fowler line of depression, where, although located along a single tectonic line, these features are each distinct, and appear to be of decreasing intensity, the Hammond syncline at the south being strongly developed, whereas the Fowler syncline at the north is but slightly developed, and the Bishop syncline lying between is intermediate in its development. It may be possible that where these displacements die out rapidly in both directions the resultant folding in the overlying sediments will not be elongated into an anticline, but will assume the more local form of a dome if buckling in the bedded rocks attended the vertical movement in the basement rocks. The domes on the major Eldorado anticline may be due to locally greater vertical displacements along these master faults in the basement rocks.

To form the extensive systems of anticlinal, synclinal and fault belts of the northern Midcontinent oil and gas field, it is believed by the author that a regional series of essentially parallel master faults or shear zones should be present in the basement rocks. Two such appear to be present in the Eldorado field, one of which, as previously mentioned, follows the east flank of the Shumway dome and its southward prolongation, the Whitewater nose. The other follows in general the east flanks of the Koogler nose, the Boyer, Oil Hill and Chesney domes (the Walnut syncline), and appears, according to the structure in the Stapleton zone, to terminate in the vicinity of the Robinson dome. The displacement may merely diminish here and farther north increase again. Other more local faults, probably trending in transverse directions, should be present to account for such features as the Chelsea and Wilson domes.

Such parallel faults or shear zones of regional extent and large displacement are not uncommon in the basement rocks exposed in the surrounding region. They were formed, however, only during great orogenic disturbances, and no deformation of this magnitude has taken place, so far as known since the beginning of Paleozoic time in the vicinity of the northern Midcontinent region, as evidenced by the rocks exposed in the surrounding region, so the faults or zones of weakness postulated as present in the basement rocks of this region probably originated in pre-Cambrian times. It is possible that these faults or shear zones were formed originally either by thrust faulting or normal faulting; but whatever their origin, it is believed that the later displacements along these ancient lines which caused the faulting and dip reversals in the Pennsylvanian and Permian strata of the northern Mid-continent region represent merely a renewed movement along these ancient fault planes.

As discussed on pages 81 and 82 and pages 85 and 86, slight deformational movements incident to the Ozark uplift occurred intermittently in this region since Mississippian times. If the parallel system of fault planes in the basement rocks existed throughout this time, these intermittent movements probably took place along these zones of weakness. The lower Pennsylvanian strata may therefore have been involved in movements, presumably along the faults, prior to the deposition of the overlying higher beds. If such movements occurred at repeated intervals, the lowermost beds would have been involved in numerous deformations and the successively higher beds in correspondingly fewer deformations. This would result in the lower beds being more folded or faulted than the higher beds, and it is therefore possible that folds and faults exist in the deeper Pennsylvanian strata which have no corresponding structure in the surface rocks, which were deposited after the particular movement took place. This theoretical condition is illustrated in B of figure 9, and examples of its existence are believed to be exhibited in the folded pay rock of the Smock and Sluss pools and in the following features in the Stapleton oil zone: the Ralston syncline in sec. 36, T. 25 S., R. 4 E.; the probable fault in sec. 27, T. 25 S., R. 5 E.; the syncline in sec. 3, T. 25 S., R. 5 E., and the possible dome in sec. 2, T. 25 S., R. 5 E.; the double apex on the Wilson dome, the wrinkled crest of the Shumway dome, and other features of lesser development.

As the kind of structure in the surface rocks is determined by the nature of the latest movement along the fault planes in the old rocks, which occurred since these surface rocks were deposited, according to the theory here presented, other types of structure may occur in deeper lying rocks along the same fault plane. Thus *en échelon* faults, due to horizontal displacements in early Pennsylvanian times, may exist in the deeper rocks, while a vertical movement in post-Permian times along the same fault would produce folding in the surface rocks. Of such a nature may be the faults in the Stapleton sand in secs.

27 and 34, T. 25 S., R. 5 E., as described on page 248. Further, a combination of horizontal and vertical displacements, whether of the same or of different age, may produce both faulting and folding. Numerous occurrences of such combined types of structure are known, such as the Catfish anticlines of the Bristow quadrangle, Oklahoma, and many others in Osage county of the same state.

Where several movements have occurred along a fault, some of these displacements may have been in opposite directions and compensated each other, with the result that a lower bed would show less displacement or folding than a higher bed. Such a reversal of movement along an otherwise normal fault is indicated in the faults near Paden, Okla.[6]

That slight and intermittent deformational movements occurred in this region since Mississippian times is quite clearly confirmed by the results of drilling in the oil and gas fields located on anticlinal folds. In the Eldorado field this is exceedingly well shown by comparing the spacing of the contours for the different horizons on plates I and XIV and figures 3 and 4. This increase of dip for the successively lower horizons is given below in tabular form.

The increase in amount of folding with depth, as shown in this table, is regular throughout the field with the exception of the Boyer dome. Here the amount of closure with depth decreases, but in this connection closure alone must not be considered as the only criterion. It is believed that the east dip in the Stapleton zone would, if sufficient drilling information were available, show ratios in dip to the surface rocks similar to those on the other domes. This condition obtains not only in the Eldorado field, but is also indicated in the Cushing oil field in Oklahoma,[7] where intervals of deformation are indicated through a 2,600-foot series of sediments. The following table, compiled from the structure maps of Beal's report, shows this increasing amount of folding from the surface downward to the Bartlesville sand. The greater folding with depth is extremely well shown with the exception of the discrepancy between the Wheeler and Layton sands on the Mount Pleasant

6. Fath, A. E., and Heald, K. C.: Faulted structure in the vicinity of the recent oil and gas development near Paden, Okla.: Oklahoma Geol. Survey Bull. 19, Pt. 2, pp. 358 and 359; 1917.

7. Beal, Carl H.; Geologic structure in the Cushing oil and gas field, Oklahoma, and its relation to the oil, gas and water: U. S. Geol. Survey Bull. 658, pp. 21-35; 1917.

Table showing by amount of closure in feet and relative increase in dip the increased amount of folding with depth in the Eldorado field.

	Shumway dome.		Boyer dome.	Koogler nose.	Oil Hill dome.		Chesney dome.		Wilson		Robinson dome.	
	Closure, feet.	Ratio of dip betwen crest near SW cor. sec. 1 to base of Fowler syncline.	Closure, feet.	Ratio of dip between NE cor. 19 and W¼ cor. sec. 30.	Closure, feet.	Ratio of dip between apex and E¼ cor. sec. 33.	Closure, feet.	Ratio of dip between SW cor. and the SE cor. SW¼SE¼ sec. 22.	Closure, feet.	Ratio of dip between center and SE cor. sec. 9.	Closure. feet.	Ratio of dip between center and E¼ cor. sec. 3.
Surface rocks	30	1	50	1	30	1	20	1	40	1	20	1
660-foot oil sand					50		40		60+			
900-foot gas "sand"			40									
1,275-foot "sand"							50+					
Stapleton oil zone	60*–140	4	10	3½	80	4½	80+	1 3-3	100+	4	70	5

*The Boyer dome is of neglible importance in the Stapleton zone, and hence 140 feet should be considered the closure on the Shumway in contrast to 80 feet on the Oil Hill dome.

and Shamrock domes. The cause of this discrepancy is not clear. A not altogether plausible explanation is a pre-Layton local reversing movement similar to but far more highly developed than that indicated at Paden.[8] The increase in amount of folding between the surface rocks and the Layton sand is most marked.

Table showing, by amount of closure in feet, the increased amount of folding with depth in Cushing oil and gas field.

	Dropright dome.	Drumright dome (as distinct from Mt. Pleasant dome).	Mt. Pleasant dome (as distinct from Shamrock dome).	Shamrock dome.
Surface rocks	75–100	15–25	50– 75	75–100
Layton sand (1,350 feet deep)	175–200	15–25	300–325	250–275
Wheeler sand (2,100 feet deep)	200–225	25–50	250–275	100–125
Bartlesville sand (2,550 feet deep)	200–250	50–75	275–300	175–200

This increased amount of folding with depth, and therefore the possibility that well-developed folds exist in oil-bearing sands without any corresponding flexure in the surface rocks, is of great economic significance. Oil and gas may accumulate in such places where there is little or no folding in the surface rocks—a condition which cannot be determined by structural geologic investigations in advance of prospecting, as in the Smock-Sluss pool and probably many other of the smaller Midcontinent pools in localities where the rocks at the surface show no favorable structure. It is to be pointed out, therefore, that the absence of anticlinal folding in the surface rocks does not absolutely condemn any locality for its oil and gas prospects.

The explanation of the origin of the anticlines and synclines of the northern Midcontinent oil and gas field given in the preceding pages does not account for all of their attendant phenomena, but it is believed, nevertheless, that for some it does account for a considerable part of the causes which formed them, while for others it may not apply to all. Some of the principal features which are not accounted for in this explanation are: (1) The distinct down buckling of the strata on the east sides of the postulated deep-lying faults instead of their simple dropping, and thereby the simple reversing of the

8. Fath, A. E., and Heald, K. C.: op. cit., pp. 358 and 359.

dip of the strata. (2) The apparent complete absence of evidence showing that any of the vertical displacements along the postulated deep-seated faults or shear zones were sufficiently large to break entirely through the sedimentary rocks and show at the surface as a fault. This is particularly striking along the "granite ridge" where the overlying sediments are comparatively thin, less than 1,000 feet in places, and in which the movement was sufficient to cause reversed dips for 200 feet or more vertically. (3) The divergence of some of the anticlinal and domal axes from the supposed direction of the governing deep-seated fault zone, such as the Wilson and Chelsea domes of the Eldorado field. (4) The secondary or east-west relation of many of the folds in Osage county, Oklahoma, shown on plate XVIII.

ORIGIN OF THE BURIED "GRANITE RIDGE" OF KANSAS.

As the "granite ridge," which is described on pages 25-27, parallels the general trend of the anticlinal folds and the belts of *en échelon* faults, and as the "granite ridge" is intimately related to one of the belts of folding, it would seem that this buried feature must have an origin similar to these surface features. It would appear to have been caused by a larger vertical movement along one of the hypothetical faults or lines of weakness in the basement rocks, which raised the block on one side of the fault sufficiently high to form an island during a portion of Pennsylvanian time when the seas covered most of the rest of this general region.

If the "granite ridge" was due to such vertical faulting, and if the flexing of the surface rocks of this region was similarly due to vertical movements along faults in the basement rocks, as postulated by the writer, then the anticlines in the Permian strata overlying the "granite ridge" indicates that slight vertical movement took place along these fault planes as late as post-Marion times of the Permian. Although this late movement is small, attention is here called to it to show that the "granite ridge" as now known was not due to a single movement, but has been in different stages of development for a long period of time. The initial and major movement in the formation of the "granite ridge" probably occurred in pre-Pennsylvanian time. The relation of the Pennsylvanian strata to the "ridge" clearly shows that it was an island during a portion of Pennsylvanian time. In the Eldorado field the relation of the Cherokee shale to the Stapleton oil zone indicates that there was some movement along the "granite ridge" belt of folding in pre-Cherokee times, and it is probable that this was merely a part of the intermittent later developments similar to the post-Marion development mentioned above.

The time interval between the Boone and the deposition of the Cherokee was an extensive period of erosion of considerable duration,[9] and it is possible that the major development of the "ridge" took place during this time. There is some evidence, however, that the ridge was slightly developed even in Mississippian times.

The general lack of clastic material in the Mississippian strata of eastern Kansas, although not positive evidence, nevertheless favors the contention of both R. C. Moore[1] and the writer[2] that the ridge was not an elevated land mass during Boone times. The presence, however, locally of clastic sediments, principally sand, in the pre-Boone rocks of the Eldorado region would appear to require the presence of a near-by land mass to supply a source for the material from which they are made. If such a land mass was the source of the material in the sandy pre-Boone strata of the Eldorado region, then the absence of similar material throughout eastern Kansas would indicate the land probably to have been both low in elevation and small in extent. From this evidence it would appear that the "granite ridge" may have been at least partly developed in pre-Boone times.

In résumé it may be stated that the age of the buried "granite ridge" of Kansas probably represents a mass of the granitic basement uplifted above its general level by faulting. Its formation probably took place not in a single major displacement at one time, but in small increments occurring intermittently during a long period, extending perhaps from pre-Mississippian to post-Permian times, with its greatest development during the post-Mississippian erosion interval.

The "granite well" in Riley county, Kansas, may indicate the presence of a second buried "granite ridge" which may parallel the one described above. Granite was also encountered in Woodson county, Kansas, at a depth of 2,585 feet,

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9. See Snider, L. C.; Geology of a portion of northeastern Oklahoma: Okla. Geol. Survey Bull. 24, pp. 26-51; 1915.

1. Geologic history of the crystalline rocks of Kansas: Am. Assoc. Petr. Geologists, Bull. 2, pp. 105, 106; 1918.

2. The origin of the faults, anticlines and buried "granite ridge" of the northern part of the Midcontinent oil and gas field: U. S. Geol. Survey, P. P. 128-C, p. 83; 1920.

which is 1,045 feet below the bottom of the Pennsylvanian rocks. See log D on plate VII. It is possible that the total thickness of Cambrian, Ordovician and Mississippian rocks in this general region is only 1,045 feet, or, if not, another buried granite ridge may be located here.

SUMMARY OF CONCLUSIONS AS TO ORIGIN OF MIDCONTINENT TYPES OF STRUCTURE.

The parallelism of the fault belts, anticlinal and synclinal folds and the buried "granite ridge" of the northern Midcontinent oil- and gas-field region points to a common relationship in origin. The faults, by their character and grouping, furnish the best evidence of this common cause by indicating definite lines of weakness and movement, not in the weak strata in which they are found, but probably in the strong rocks of the basement complex. Nearly horizontal movements along these lines of weakness in the deep-lying rocks, with the consequent drag of the overlying weak sediments, would tear the lower parts of these sediments along a narrow belt parallel to the movement, and short fractures would open which would trend diagonally with the direction of the deep-seated movements. The adjustment of the overlying weak strata to these fractures would result in the belts of short normal faults characteristic of the region.

Vertical displacement along these same lines of weakness in the basement rocks would produce folds in the overlying Paleozoic sediments parallel to the lines of faulting, and some of the anticlinal and synclinal folds of the Midcontinent field exhibit considerable evidence that they were so formed. Other folds cannot be so readily explained, and still others probably were wholly formed by other causes.

Of special economic importance is the fact that deeply buried oil- and gas-bearing sands are generally more flexed into anticlines, domes and synclines than are the surface rocks, and hence that in places the oil- and gas-bearing strata are folded and control the accumulation of oil and gas into pools without the surface rocks being noticeably deformed.

The buried "granite ridge" of Kansas may be similarly explained as a large vertical displacement which took place in intermittent increments extending from Mississippian to post-Permian times along one of the lines of weakness in the basement rocks.

ORIGINAL SOURCE OF OIL AND GAS.

The origin of the structural features which determine the location of the oil and gas in the Eldorado field has been tentatively explained. There was considerable evidence upon which the explanation rested. The origin of the hydrocarbons, however, and the location of their source is not so clear. No direct evidence for the solution of these problems has been obtained, but some indirect evidence is at hand, and this will be briefly summarized.

It is very generally believed among geologists that oil and gas are derived through the slow distillation of carbonaceous material in sediments, principally shales, subjected to high pressure beneath overlying rock formations. In the Eldorado section, given on plate VI, the apparent absence of shales below the Stapleton oil zone as a source of the oil in this zone is to be noted.

In the apparent absence of an original source or mother rock below the Stapleton, which is probably the most appropriate location to be expected, since any circulation of fluids is more generally surfaceward, the strata which overlap the flanks of the folded erosion surface are to be considered. Here, as indicated in the sections on plate VIII and in figure 1, are to be found the Cherokee shales in the lowermost parts of the Pennsylvanian series, which in the oil fields farther east in Kansas and in northeastern Oklahoma contain most of the oil-producing beds, and which possibly may even here represent the source of the Stapleton oil. The movement necessary for oil and gas formed in these beds to reach the Stapleton oil zone is principally lateral, but at the same time is slightly upward, as is not improbable in oil and gas migration.

The higher shales overlying the Stapleton pay rock, those of the Henrietta and Pleasanton groups, could also have been the source, possibly in part only, in which case the migration of the petroleum from these beds must have been in part stratigraphically downward—a less likely possibility.

The source of the oil and gas for the higher pays is more readily explained by the greater abundance of shales with which they are closely associated.

CHARACTER OF THE OIL.

The oil produced in the Eldorado field has a specific gravity which ranges in general from 0.870 to 0.833 (31.0° to 38.0° B.). Its distillation fractions are indicated in table A. A comparison of the analyses of oil from the 660-foot sand and Stapleton pay rocks shows them to be practically of the same grade. If any real difference exists, it would seem that the shallower oil is somewhat lighter. No distinction, however, is made in marketing the oil.

No samples were obtained of the oil from the Boyer and Stokes "sand."

The oil of the Smock-Sluss district is of slightly higher rank than that of the main Eldorado field. This is indicated in the analyses of the table, where the gravities of two samples are given as .834 (37.9° B.) and .845 (35.7° B.), respectively, or about 2 to 3 degrees Baumé higher than that of the oil from the main field. It differs also in its content of dissolved natural gas, of which in the spring of 1918 there was sufficient caught at the casing head to supply the gas engines used in pumping the wells.

The variety and percentage of refinery products derived from the Eldorado oil by skimming plants[3] is indicated in the following table, the figures for which were derived by lumping the quantities reported by several refineries obtaining all their crude oil from the Eldorado district.

Percentages of refinery products derived from Eldorado crude oil during the period, January 1 to November 30, 1919.[4]

Gasoline.	Kerosene.	Gas and fuel oils.	Distillates.	Losses.
27.2	11.3	58.0	1.2	2.3

EXPULSIVE FORCE IN GUSHER WELLS.

In considering the Eldorado oil it seems fitting in this place to discuss briefly the forces which expel it from the flowing wells, especially from the large-sized wells. As noted on pages 21 and 103, there is comparatively very little gas accompanying the oil. So small is the amount that in the Gypsy Oil Company's Shumway well No. 5 (center location west side of SW¼ NE¼, sec. 11, T. 26 S., R. 4 E., approximately 15,000 barrels a day) the column of oil issuing from the six-inch casing rose

3. So called because they distill off only the higher fractions of the crude oil.
4. Data obtained from Bureau of Mines.

TABLE A.—RESULTS OF DISTILLATION OF OIL FROM ELDORADO FIELD, BUTLER COUNTY, KANSAS.

(Distillation by Bureau of Mines in Hempel flask; ERNEST W. DEAN, chemist. Samples collected in April, 1918, distilled in July, 1918.)

	660-FOOT SAND.		STAPLETON OIL ZONE.							SLUSS SAND.	SMOCK SAND.
	1	2	3	4	5	6	7	8	9	10	11
Field No.	2	4	1	3	5	6	7	12	9	10	11
Laboratory No.	.00260	.00258	.00264	.00259	.00257	.00261	.00263	.00262	.00256	.00254	.00255
Size of sample	1 pint	1 pint	1 pint	1 pint	1 pint	1 pint	1 pint	1 pint	1 pint	1 pint	1 pint
Portion distilled (cubic centimeters)	200	200	200	200	200	200	200	200	200	200	200
Gravity at 15 (°C.): Specific	0.851	0.846	0.854	0.845	0.848	0.866	0.863	0.854	0.860	0.834	0.845
Baume (°)	34.5	35.5	33.9	35.7	35.1	31.7	32.2	33.9	32.8	37.9	35.7
Sulphur	0.17	0.15	0.13	0.13	0.18	0.18	0.12	0.13	0.18	0.17	0.17
Wax	Some	Some.	Appreciable amount	Some	Small amount	......	Some	Appreciable amount	Small amount	Appreciable amount	Small amount
Distillation: First drop (°C.)	24	22	28	24	27	28	30	25	32	24	26
Pressure (millimeters): Air	740	740	740	740	741	737	740	738	744	744	744
Pressure (millimeters): Vacuum	40	40	40	40	40	40	40	40	40	40	40

Fractions (°C)	1 Fraction (per cent)	1 Total (per cent)	1 Specific gravity of fractions	1 Vacuum Total (per cent)	2 Fraction (per cent)	2 Total (per cent)	2 Specific gravity of fractions	2 Vacuum Total (per cent)	3 Fraction (per cent)	3 Total (per cent)	3 Specific gravity of fractions	3 Vacuum Total (per cent)	4 Fraction (per cent)	4 Total (per cent)	4 Specific gravity of fractions	4 Vacuum Total (per cent)
Up to 50	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
50 to 75	.....	.....	.....	.....	3.0	3.0	.660	.....	.....	.....	.....	.....	3.6	3.6	.662	.....
75 to 100	5.9	5.9	.697	.....	4.8	7.8	.716	.....	5.6	5.6	.700	.....	4.7	8.3	.715	.....
100 to 125	6.7	12.6	.738	.....	6.2	14.0	.742	.....	5.4	11.0	.739	.....	7.3	15.6	.744	.....
125 to 150	6.7	19.3	.759	.....	6.0	20.0	.760	.....	6.8	17.8	.755	.....	7.4	23.0	.762	.....
150 to 175	6.4	25.7	.775	2.5	6.8	26.8	.779	1.0	6.9	24.7	.772	2.0	6.6	29.6	.782	.....
175 to 200	5.9	31.6	.795	8.5	6.2	33.0	.797	1.5	5.6	30.3	.794	4.0	5.9	35.5	.801	1.0
200 to 225	6.3	37.9	.812	15.0	6.3	39.3	.815	3.0	6.6	36.9	.812	10.0	5.9	41.4	.817	4.5
225 to 250	7.5	45.4	.827	20.0	6.5	45.8	.843	7.5	6.6	43.5	.828	16.0	6.5	47.9	.833	7.0
250 to 275	6.0	51.4	.843	25.0	9.6	61.7	.855	14.0	6.7	50.2	.841	21.0	6.0	60.4	.858	12.0
275 to 300	.....	.....	.....	31.0	.....	.....	.....	20.0	6.6	56.8	.857	26.0	.....	.....	.....	19.5

Fractions (°C)	5 Fraction (per cent)	5 Total (per cent)	5 Specific gravity of fractions	5 Vacuum Total (per cent)	6 Fraction (per cent)	6 Total (per cent)	6 Specific gravity of fractions	6 Vacuum Total (per cent)	7 Fraction (per cent)	7 Total (per cent)	7 Specific gravity of fractions	7 Vacuum Total (per cent)	8 Fraction (per cent)	8 Total (per cent)	8 Specific gravity of fractions	8 Vacuum Total (per cent)
Up to 50	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
50 to 75	3.1	3.1	.661	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
75 to 100	4.7	7.8	.717	.....	3.9	3.9	.702	.....	3.2	3.2	.696	.....	5.9	5.9	.692	.....
100 to 125	5.9	13.7	.743	.....	4.2	8.1	.738	.....	3.8	7.0	.735	.....	6.6	12.5	.740	.....
125 to 150	6.6	20.3	.764	.....	6.7	14.8	.761	.....	6.1	13.1	.753	.....	6.2	18.7	.758	.....
150 to 175	6.5	26.8	.778	.....	6.7	21.5	.780	.....	6.8	19.9	.775	2.0	6.4	25.1	.778	1.0
175 to 200	6.0	32.8	.797	3.5	5.7	27.2	.801	5.0	6.0	25.9	.794	6.0	5.9	31.0	.790	2.5
200 to 225	6.1	38.9	.813	8.5	6.5	33.7	.818	7.5	6.1	32.0	.815	15.0	6.3	37.3	.813	7.5
225 to 250	6.6	45.5	.830	12.5	7.8	41.5	.832	13.0	7.5	39.5	.830	20.0	6.4	43.7	.829	14.5
250 to 275	6.1	51.6	.842	16.5	7.0	48.5	.843	18.0	5.5	45.0	.842	25.0	6.6	50.3	.841	18.5
275 to 300	6.5	58.1	.856	22.5	6.6	55.1	.856	24.0	.....	.....	.....	31.0	7.6	57.9	.853	25.5

Fractions (°C)	9 Fraction (per cent)	9 Total (per cent)	9 Specific gravity of fractions	9 Vacuum Total (per cent)	10 Fraction (per cent)	10 Total (per cent)	10 Specific gravity of fractions	10 Vacuum Total (per cent)	11 Fraction (per cent)	11 Total (per cent)	11 Specific gravity of fractions	11 Vacuum Total (per cent)
Up to 50	.....	.....	.....	.....	3.0	3.0	.649	.....	3.4	3.4	.652	.....
50 to 75	.....	.....	.....	.....	2.5	5.5	.668	.....	3.2	6.6	.675	.....
75 to 100	3.0	3.0	.705	.....	5.2	10.7	.723	.....	5.6	12.2	.727	.....
100 to 125	4.1	7.1	.740	.....	5.1	15.8	.746	.....	5.5	17.7	.749	.....
125 to 150	6.0	13.1	.758	.....	5.6	21.4	.763	.....	5.7	23.4	.766	.....
150 to 175	6.6	19.7	.776	.....	5.5	26.9	.783	4.0	6.0	29.4	.787	1.5
175 to 200	6.5	26.2	.798	1.0	5.0	31.9	.801	6.0	5.4	34.8	.805	5.0
200 to 225	6.4	32.6	.817	5.5	5.3	37.2	.817	10.5	4.9	39.7	.821	10.0
225 to 250	7.5	40.1	.831	12.5	5.8	43.0	.832	15.5	6.4	46.1	.832	15.0
250 to 275	6.9	47.0	.847	18.0	5.1	48.1	.845	20.5	5.3	51.4	.848	20.5
275 to 300	7.9	54.9	.856	24.0	.....	.....	.....	28.5	.....	.....	.....	27.5

1. Empire Gas and Fuel Company's W. C. and C. D. Wilson farm well No. 2, sec. 8, T. 25 S., R. 5 E. Sample obtained directly from flow line.
2. Empire Gas and Fuel Company's Hegberg farm well No. 49, sec. 28, T. 25 S., R. 5 E. Sample obtained directly from flow line.
3. Theta Oil Company's F. W. Robison farm well No. 13, sec. 3, T. 25 S., R. 5 E. Sample obtained directly from flow line.
4. Empire Gas and Fuel Company's W. C. and C. D. Wilson farm well No. 1. Sample obtained directly from flow line.
5. Empire Gas and Fuel Company's Hegberg farm well No. 38, sec. 28, T. 25 S., R. 5 E. Sample obtained directly from flow line.
6. Gypsy Oil Company's Shumway farm well No. 13, sec. 11, T. 26 S., R. 4 E. Sample obtained directly from flow line while producing at rate of about 18,000 barrels per day.
7. Ramsey Petroleum Company's Harmon farm well No. 5, sec. 24, T. 26 S., R. 4 E. Sample obtained directly from flow line.
8. National City Oil Company's Beaumont well No. 2, sec. 3, T. 26 S., R. 5 E. Sample obtained directly from flow line.
9. Empire Gas and Fuel Company's Boyer farm well No. 4, sec. 8, T. 26 S., R. 5 E. Sample obtained directly from flow line.
10. Bole and Skelly's W. H. Sluss farm well No. 1, sec. 26, T. 26 S., R. 5 E. Sample obtained directly from flow line.
11. J. S. Cosden's Smock farm well No. 1, sec. 2, T. 27 S., R. 5 E. Sample obtained directly from flow line.

only about 6 feet before falling back to the ground. This lack of gushing is well indicated in plate V (B and C). A slightly different but equally illustrative intance, as reported to the writer by Mr. J. C. Jordan, treasurer of the company, was the Union Oil Company of Wichita's Denny well No. 18 (southwest corner location, SE¼, sec. 12, T. 26 S., R. 4 E.), cited on p. 103, which when drilled in did not actually flow of its own accord, but required the agitation of a swab. With the swab working at a depth of less than 600 feet, the well at one time produced as high as 400 barrels an hour. After such agitation with the swab the well would continue to flow for several hours, but at a decreasing rate. Once shortly after the well was brought in, and with the tools in the hole, and the swab hanging idle in the hole, the well flowed 300 barrels per hour for four hours after the swabbing ceased. It is to be noted that a production of 300 barrels per hour would be equivalent to 7,200 barrels per day.

From these instances it would appear that the small amounts of dissolved gases have but little effect in forcing the oil to the surface, except perhaps to a very small degree. With the dissolved gases apparently impotent, the pressure under which the oil and salt water exist in these subterranean reservoirs must be appealed to as the prime cause in forcing the oil to the surface. The cause for this pressure is not altogether clear, but at least is in part simple rock pressure, or the pressure produced by the weight of overlying rock under which the fluid is confined. If this were the only cause of the pressure, the salt water, if tapped by a well in the same reservoir, would flow equally as fast as the oil. While such may be the case, the writer has no definite information concerning it.

CHARACTER OF THE NATURAL GAS.

HEATING VALUE.

The natural gas of the Eldorado field is essentially a mixture of the two gases—methane, or marsh gas (CH_4), and ethane (C_2H_6)—of which the methane is present in much the larger quantity. With these are associated as adulterants other noninflammable gases, which decrease the heating ability of the natural gas, in which lies its principal value.

The heating value of natural gas from the Eldorado field is low in comparison to the natural gas of most fields, its average heating value being about 675 B. t. u. per cubic foot, whereas the average for natural gas in the United States is probably above 900 B. t. u. Many natural gases produce more that 1,200 B. t. u. per cubic foot. This relation may be more specifically noted by comparing the heating values given in the analyses of Eldorado gas in table B and those of other fields in table C.

The cause of the low heating value of Eldorado gas is to be found in its high content of noncombustibles, principally nitrogen, which in many analyses is given as "residue." The residue in the Eldorado gases averages about 35 per cent of the total weight of the gas. This high content of residue is coincident with a highly interesting feature of the Eldorado gas—its content of helium, brought out during the investigations instigated by the World War.

HELIUM CONTENT.

Helium is present in natural gas only in small quantities, generally less than 0.3 per cent, and in fields which have adequate supplies for commercial extraction the percentage is only about 1 per cent. The presence of helium in the noninflammable constituent of Eldorado gas was first brought out by the intensive search during the World War for a nonburning balloon gas, which would not only nullify enemy incendiary bullets in balloon warfare, but would also prove safe in lightning and ignition in case of accident. Although helium was discovered in natural gas as far back as 1905, by Professors Cady and McFarland, of the University of Kansas, its possible value other than as a scientific curiosity was not considered until the necessities of war brought it to the fore. Under the war impetus it was being produced (not in the Eldorado field) on a commercial scale, but failed to reach the battle front prior to the cessation of hostilities.

The geological results of the war investigations have been ably presented by G. S. Rogers, of the United States Geological Survey, in a paper entitled, "Helium-bearing natural gas."[5] A brief summary of Rogers' conclusions concerning the occurrence of helium in natural gas is as follows:

(*a*) The Midcontinent region of the United States contains the largest known accumulations of helium-bearing gas.

(*b*) Helium in noteworthy quantities occurs only in those natural gases which have a high nitrogen content (10 to 85 per cent N.).

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5. U. S. Geol. Survey, Professional Paper 121; 1920.

TABLE B.—COMPOSITION OF NATURAL GAS FROM THE ELDORADO FIELD.

Location. Section, township south, and range east.	Well.	"Sand."	Depth.	Constituents. Methane, marsh gas, (CH_4).	Ethane (C_2H_6).	Carbon dioxide (CO_2).	Oxygen (O).	Residue, principally nitrogen (N).	Higher hydro-carbons.	Helium.	Heating value.	Analyst.	Where published.	Remarks.
				Per cent.	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*B. t. u.*			
33-25-5	Stokes No. 51	900-foot	851- 858	54.46	4.31	0.24		40.99			600		Not published	Analysis made by Empire Gas & Fuel Co.
17-26-5	Koogler No. 1	900-foot	827- 840	56.38	4.34			39.65	2.09	*1.17	674	R. O. Neal	Not published	Analysis made by Empire Gas & Fuel Co.
17-26-5	Gussman No. 1	900-foot	885- 892	60.68	3.22	0.19		35.95		*1.24	642	R. O. Neal	Not published	Analysis made by Empire Gas & Fuel Co.
17-26-5	Nichelger No. 1	900-foot	875- 887	54.78	7.19	0.24		37.40	0.41	*0.91	663	E. E. Lyder	Not published	Analysis made by Empire Gas & Fuel Co.
17-26-5	Empire No. 7	900-foot	868- 880	55.24	7.12	0.12		37.52			657	E. E. Lyder	Not published	Analysis made by Empire Gas & Fuel Co.
21-25-5	Chesney No. 2	1,275-foot	1,218-1,228	58.42	9.15	0.05	0.10	32.28			722	E. E. Lyder	Not published	Analysis made by Empire Gas & Fuel Co.
21-25-5	Chesney No. 5	1,275-foot	1,220-1,229	59.53	6.44	0.19	0.24	33.60			691	E. E. Lyder	Not published	Analysis made by Empire Gas & Fuel Co.
21-25-5	Chesney No. 13	1,275-foot	1,230-1,240	62.62	5.00	0.53	0.54	31.15	0.12		710	E. E. Lyder	Not published	Analysis made by Empire Gas & Fuel Co.
36-25-4	Adsit No. 3	1,475-foot	1,482-1,493	31.36	12.78	0.12	0.12	55.64			524	D. B. Dow	Not published	Analysis made by Empire Gas & Fuel Co.
31-25-5	Robinson No. 23	1,475-foot	1,505-1,510	48.79	21.59	0.21		29.41			845	R. O. Neal	Not published	Analysis made by Empire Gas & Fuel Co.
12-26-5	Enyart No. 2	1,475-foot	1,440-1,465	51.55	12.38	1.36		34.50			715	D. B. Dow	Not published	Analysis made by Empire Gas & Fuel Co.
		900-foot								1.20			U. S. Geol. Survey Prof. Paper 121	Average of 19 samples.
		1,200-foot								1.01			U. S. Geol. Survey Prof. Paper 121	Average of 13 samples.

*Included in the residue. Determination made separately by the Bureau of Mines, and published in United States Geological Survey Professional Paper 121.

TABLE C.—COMPOSITION OF NATURAL GAS FROM VARIOUS MIDCONTINENT FIELDS.

Given for comparison with natural gas from the Eldorado field.

State and District.	Collected from—	Constituents. Methane or marsh gas (CH_4).	Ethane (C_2H_6).	Carbon dioxide (CO_2).	Oxygen (O).	Residue principally nitrogen (N).	Other constituents.	Helium.	Heating value.	Analyst.	Where published.	Remarks.
Kansas:												
Butler county:		*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*B. t. u.*			
North Augusta field	Representative analyses	63.92	5.67	0.07	0.19	29.96	Higher hydrocarbons, 0.19	1.09	719	H. C. Allen	U. S. Geol. Survey Prof. Paper 121	Depth, 1,200 to 1,400 feet. The helium is included in the residue and was determined separately.
North Augusta field		50.22	21.32		0.31	28.15	Higher hydrocarbons, ...		853			
South Augusta field	Representative analyses	63.32	13.45	0.32	0.12	22.63	Higher hydrocarbons, 0.13	0.43	844	H. C. Allen	U. S. Geol. Survey Prof. Paper 121	Depth, 1,200 to 1,500 feet. Principal gas supply of the Augusta field. The helium is included in the residue and was determined separately.
South Augusta field		76.48	12 60	0.21		10.26	Higher hydrocarbons, 0.44		961			
South Augusta field	Moyle well No. 7							2.13		H. C. Allen	U. S. Geol. Survey Prof. Paper 121	Depth about 550 feet. No commercial production.
Montgomery county:												
Caney	Well east of Caney; Caney Gas & Mining Co.,	92.40		0.81	0.15	6.46	C_2H_2 0.10	0.08		H. P. Cady and D. F. McFarland	Am. Chem. Soc. Jour., vol. 29, p. 1530	Depth, 1,550 feet.
Oklahoma:												
Glenpool	Gas from oil wells	49.1	44.1	6.1			N 0.70		1,271	G. A. Burrell	Bur. Mines Bull. 42, 1913	———
Pearson	Gas at 900 feet	51.91	1.12		0.21	46.86		0.23 to 0.71	520		U. S. Geol. Sur. Prof. Paper 121	The helium is included in the residue and was determined separately. The percentage given represents the range in twelve analyses.
Texas:												
Petrolia	Beatty well No. 1	52.7	9.3	0.2			N 37.8	0.93	734	G. A. Burrell	U. S. Geol. Survey Bull. 629, p. 41	Analysis furnished by Lone Star Gas Co.
Petrolia											U. S. Geol. Survey Prof. Paper 121	General average for field.
Mexia-Groesbeck	Mexia Oil & Gas Co., Adamson well	98.4		0.6			N 1.0		1,047	G. A. Burrell	U. S. Geol. Survey Bull. 629, p. 102	———

(*c*) The percentage of helium in a natural gas seems to depend on the percentage of nitrogen in a gas, though there is no direct proportion between the two, the ratio varying greatly in different gases.

(*d*) Gases rich in helium do not occur at depths greater than about 1,600 feet.

(*e*) In fields of two or more gas sands, the shallowest is in most localities the richest.

The Eldorado field was found to contain the richest helium-bearing gas being produced on a commercial scale, but other considerations decided against the placing here of the first government helium-extracting plant.

The helium content of Eldorado gas was found in 33 samples to range from 0.48 to 1.70 per cent, with a general average of 1.12. The helium content of the 900-foot-sand gas averages 1.20 per cent (19 samples), and of the 1,125-foot, 1,200-foot and 1,275-foot groups of sands, 1.01 per cent (13 samples). No samples of the 1,475-foot sand were examined for helium.

Rogers has assumed the average helium content of the Eldorado gas to be 1.12 per cent, but this probably did not include the production from the 1,475-foot sand, of which no analyses were made. It, therefore, seems to the writer that 1.12 is too high as an average for all the gas produced; 1.0 per cent probably is more nearly correct. Assuming 1.0 per cent as the average, and assuming also that the total production of the field is one-third more than that indicated in figure 8, the total amount of helium that could have been obtained in the Eldorado field during the early months of 1918 was about 96,875 cubic feet daily.

In comparison with the near-by Augusta field, the Eldorado gas in general carries a much higher percentage of helium, even though one very shallow and unproductive sand of the Augusta field contains a gas with a helium content ranging as high as 2.13 per cent. The gas from the other producing sands has a helium content ranging from 0.16 to 1.14. The bulk of the production during 1918, which came from the south Augusta field, had an average helium content of only 0.43 per cent.

The Petrolia field, in Clay county, Texas, is the only other large gas field which is known to contain large quantities of helium. Rogers gives 0.93 per cent as the general average helium content for the field. The Petrolia gas was the source of the helium which was being produced for balloon warfare at the time the World War hostilities ceased.

WATER PROBLEM.

GENERAL CONSIDERATIONS.

Salt water is almost invariably present in oil and gas fields, and where it occurs in large quantities it is a very serious menace to their successful operation and one of the worst enemies of oil and gas operators. Salt water has caused not only the abandonment of single wells and individual leases, but probably also of entire fields long before the normal quantity of oil and gas present had been extracted. Its destructive action is brought about by encroaching on the oil and gas in the pay sands and entering the wells along with the oil, thereby decreasing the flow of the oil, and entailing increased expense not only for raising it to the surface but also for later separating it from the oil. In some instances it completely "drowns" the oil in otherwise good producing wells. In entering the well in company with the oil it often produces an emulsion of oil and water which is practically worthless until the two are separated by special processes, such as are described on pages 183-185, which further increase the cost of production. Salt water from a water sand may invade another sand which is oil-bearing, through failure to mud, plug or properly case off the sand from which it comes, or through improperly set casing. In places, too, it corrodes the casing, causing leaks. Some of these water troubles are due to negligence of drillers and operators, and for these the remedy is easily determined; but even where not due to negligence, most of the water troubles can be diagnosed and can be remedied by the application of progressive engineering methods. It must not be presumed that the water menace can be eliminated, but it can be expected that methods will be devised for successfully and economically combating the harm produced by salt water. The abilities of engineers, physicists and geologists are directed to increasing the oil extraction, both rate and total quantity, and the lowering of the cost of oil production. Notable contributions to the solution and the remedy of the water problem from a scientific point of view have been made by numerous writers.[6] At

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6. Chemical relations of the oil-field waters in San Joachim valley, California; by G. S. Rogers: U. S. Geol. Survey Bull. 653; 1917.

Petroleum hydrology applied to Midcontinent field; by Roy C. Neal: Am. Inst. Min. Engrs. Bull. 145, pp. 1-8; January, 1919.

Investigations concerning oil-water emulsion; by A. W. McCoy, H. R. Shidel, and E. A. Trager: Am. Inst. Min. & Met. Engrs., Bull. 152, pp. 1513-1537; August, 1919.

the time when the field work for this report was in progress the water menace in the Eldorado field was not of paramount interest, but since then it has become increasingly important. The information here presented does not include remedies for the problem, but brings attention to helpful means for determining the location of water trouble, which in the Eldorado field is confined mainly to the Stapleton zone.

In any specific water problem the first steps is to locate the trouble, which invariably resolves itself into determining the source of the water. Does it come from rocks below the oil pay, from within the oil sand, or from sands above the oil-bearing zone, or is it a combination of water from two or more of these sources? Physical means may at times locate the source of the water, as by the use of plugs, drilling tools, colored dyes, etc.; but when these fail, resort may be had to chemical analyses. Rogers was probably the first to publish on the subject of oil-field waters.[7] His results referred to the California fields, in which he showed that the waters from the various sands possessed individual chemical properties, and that from the analysis of a water it was possible to determine rather closely the sand from which it came. This is of great practical use, as in knowing the source of the water it can generally be determined whether faulty casing, unplugged sands, or too deep drilling, etc., is the cause of the water trouble. When the cause of the trouble is ascertained it usually is an easy matter for the engineer and operator to devise methods for its remedy.

ELDORADO WATERS.

Neal[8] pointed out that in the Eldorado field a very marked difference existed between the water in the Stapleton zone and that from above. This is clearly brought out in the analyses in the accompanying table (table D), which were very generously supplied by the Empire Gas and Fuel Company. For convenience of discussion, those waters occurring in the Stapleton zone are termed "bottom waters" and those in the higher sands "top waters." Nos. 1 to 4 in table D are bottom waters; 5, 6, 7 and 8 are top waters; and in No. 9 a contaminated water is given as an example of multiple water trouble.

The properties as given in the table accord with the termin-

7. Op. cit.
8. Op. cit.

ology introduced by Palmer,[9] and are determined by translating the physical weights of the constituents into their relative chemical reactive values on a percentage basis, and then by balancing the alkalies with the strong acids to form primary salinity, following which the remainder of the strong acids are balanced with the alkaline earths to form secondary salinity, and finally the remainder of the alkaline earths are balanced with the weak acids to form secondary alkalinity. The differences between the top and bottom waters are to be noted. The chloride salinity of the top waters is very close to 100 per cent, whereas in the bottom waters it averages about 93 per cent; in the top waters there is practically no sulphate salinity, whereas in the bottom waters it averages about 5 per cent. Probably the greatest difference between the top and bottom waters, and a difference which presumably is most readily determined, is the concentration of the dissolved salts. In the bottom waters this concentration, expressed in parts per million, ranges between 20,000 and 30,000, whereas in the top waters it is 6 to 8 times greater, ranging between 165,000 to 195,000.

These differences for the waters of the Augusta field, which are closely similar to those at Eldorado, are summarized by Neal, who states:

"The chief distinction between the top and bottom waters is the percentage of total solids. The content of solids in the top waters averages four or five times as great as that of the bottom waters. The difference in the chloride salinity between top and bottom waters is a reliable index to use in differentiating the various waters. The distinctive character of the waters as regards sulphate content can be used in classifying top and bottom waters."

Although chemical analyses are of great assistance in locating water troubles, their full value cannot be derived until interpreted by one who understands both the geology and chemistry of the specific problem. In this connection, the accuracy, trustworthiness and detail of a drilling log is of inestimable value. The abandonment of wells may often depend on the presence of even a thin shale or limestone break in the sand, which may determine whether or not the water can be effectively cemented or plugged off. The knowledge of such details will often also indicate, prior to testing, the proper length of the plug which should be inserted. This all points to the need of collecting and preserving samples of the drill cuttings every few feet while drilling into the pay sand, and of making accurate steel-line measurements thereto.

9. Palmer, Chase: The geochemical interpretation of water analyses; U. S. Geol. Survey, Bull. 479; 1911.

TABLE D.—ANALYSES SHOWING PROPERTIES AND COMPOSITION OF WATER IN ELDORADO FIELD.

	Bottom waters.				Average of bottom waters.	Top waters.				Average of top waters.	Contaminated waters.
Name of well	Stapleton No. 1.	Stokes No. 7.	Shriver No. 3.	Kirkpatrick No. 39.		Batman No. 10.	Batman No. 10.	Cardey No. 3.	Hegberg No. 5.		Cardey No. 5.
Sec., twp., and range	29-25-5	28-25-5	14-26-4	32-25-5	....	8-26-5	8-26-5	11-26-4	28-25-5	....	11-26-4
Depth of sand in feet	2,465-2,500	2,463-2,469	2,333	2,465-2,477	....	1,700	2,000	2,000	1,696	....	....
Properties:	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
Primary salinity	82.85	84.10	80.13	79.04	81.53	90.70	95.52	80.84	80.48	86.89	78.51
Secondary salinity	14.85	13.62	17.20	20.05	16.43	9.17	4.42	19.09	19.48	13.04	20.97
Secondary alkalinity	2.30	2.28	2.68	.90	2.04	.10	.06	.07	.04	.07	.52
Chloride salinity	94.42	94.30	91.00	92.35	93.02	99.92	99.85	99.93	99.96	99.91	99.22
Sulphate salinity	3.28	3.43	6.30	6.75	5.19	....	.09	None.	None.	.09	.26
Composition:	*Parts per million.*	*Parts per million.*	*Parts per million.*	*Parts per million.*	*Parts per million.*	*Parts per million.*	*Parts per million.*	*Parts per million.*	*Parts per million.*	*Parts per million.*	*Parts per million.*
Sodium and potassium	7,216	7,590	9,318	8,160	8,071	61,560	63,033	60,994	60,786	61,593	33,252
Iron	....	34	42	Trace.	38	45	170	13	18	61	116
Calcium	820	825	1,350	1,320	1,079	2,090	1,552	8,574	8,890	5,277	2,802
Magnesium	315	257	377	374	331	2,560	647	3,284	3,200	2,423	3,798
Sulphate	508	556	1,310	1,260	908	....	101	....	....	101	198
Chloride	12,896	13,312	16,640	14,976	14,456	106,080	101,920	118,560	118,560	111,280	66,960
Bicarbonate	382	388	587	177	383	83	68	88	63	75	392
Total solids	22,137	22,962	29,624	26,267	25,266	172,418	167,491	191,502	191,517	180,810	107,518

TECHNOLOGICAL FEATURES.

OUTLINING OF DESIRABLE ACREAGES.

Inasmuch as technological features are very subordinate to the main purpose of this report, they will receive but very brief treatment. The acreage which a modern and fully equipped company desires to lease is determined through the services of geologists who outline those areas which are geologically favorable to the accumulation of oil, where this can be done through field studies. In some localities field studies are impossible, but nevertheless here also the geologist, through his knowledge of developed fields in similar regions, is of great assistance in outlining the probable favorable acreage.

Where field studies are undertaken, the principal object is usually the making of a geologic structure map, which is generally based either on dip observations or on determined elevations of the outcropping key rocks. The structure map should show the location and extent of the anticlines, domes, synclines, and undeformed areas. From these advance investigations the structurally more favorable acreage is outlined as the more desirable. As described on page 10, the Empire Gas and Fuel Company by this method located 34 square miles of territory as the most promising for the development of oil in the Eldorado field (not including the Wilson and Robinson domes). Of these 34 square miles but 7 have since been proven barren of oil, and but 3½ square miles outside of the 34 have been found to contain oil.

LEASING.

After the desirable acreage is outlined, agents who specialize in land work obtain leases on the tracts by purchase, either from the fee landowners or from agents who have previously obtained leases. A typical lease form in use in the Kansas oil and gas fields is as follows:[1]

THIS INDENTURE, Made and entered into the........day of............A. D. 19...., by and between............of............, state of............, hereinafter called the lessor (whether one or more), of the one part, and............of............, hereinafter called the lessee (whether one or more), of the other part.

WITNESSETH, That the lessor, for and in consideration of the sum of ....dollars, cash in hand, paid by the lessee, the receipt of which is hereby acknowledged, and of the covenants and agreements hereinafter contained, on the part of the lessee to be paid, kept and performed, has

1. Oil and gas resources of Kansas; by R. C. Moore and W. P. Haynes: Geol. Survey of Kan., Bull. 3, pp. 358, 359; 1917.

granted, demised, leased and let, and by these presents does grant, demise, lease and let unto the lessee, his heirs, executors, administrators, successors or assigns, for the sole and only purpose of mining and operating for oil and gas, and of laying pipe lines and building tanks, power stations and structures thereon to produce and take care of said products, all that certain tract of land situate in the county of............, state of Kansas, of section...., township...., range...., and containing........acres, more or less.

It is agreed that this lease shall remain in force for a term of........ years from this date, and as long thereafter as oil or gas or either of them is produced from said land by the lessee, his heirs, administrators, executors, successors or assigns.

In consideration of the premises the lessee covenants and agrees:

First: To pay to the lessor, as royalty, the equal one-eighth part of the proceeds of all oil produced, saved and sold from the leased premises.

Second: To pay the lessor at the rate of .... dollars each year, in advance, for the gas from each well, where gas only is found, while the same is being used off the premises, and the lessor to have gas free of cost from any such well for all stoves and all inside lights in the principal dwelling house on said land during the same time, by making his own connections with the well.

Third: To pay the lessor for any gas produced from any oil well and used off the premises, at the rate of........dollars per year for the time during which such gas is being used, said payments to be made each three months in advance.

The lessee agrees to complete a well on said leased premises within ....from the date hereof, or pay the rate of........dollars in advance for each additional............such completion is delayed from the time above mentioned for the full completion of such well until a well is completed; and it is agreed that the completion of such well shall be and operate as a full liquidation of all rent under this provision during the remainder of the term of this lease.

The lessee shall have the right to use, free of cost, gas, oil and water produced on said land for his operations thereon, except water from wells of the lessor.

When requested by the lessor, the lessee shall bury his pipe lines below plow depth.

No well shall be drilled nearer than 200 feet to the dwelling house or barn on said premises.

The lessee shall pay for damages, caused by drilling, to growing crops on said land.

The lessee shall have the right at any time to remove all machinery and fixtures placed on said premises, including the right to draw and remove casing.

The lessee shall not be bound by any change in the ownership of said land until duly notified of any such change, either by notice in writing duly signed by the parties to the instrument of conveyance, or by receipt of the original instrument of conveyance or a duly certified copy thereof.

If the lessor owns a less interest than the entire and undivided fee simple estate in said land, then the royalties and rentals herein provided shall be paid to the lessor only in the proportion which his interest bears to the entire and undivided fee.

All payments which may fall due under this lease may be made directly to............or deposited by the lessee to his credit in............

The lessee, his heirs, executors, administrators, successors or assigns, shall have the right, at any time, on the payment of one dollar to the lessor, his heirs or assigns, to surrender this lease for cancellation, after which all payments and liabilities thereafter to accrue under and by virtue of its terms shall cease and determine.

All covenants and agreements herein set forth between the parties hereto shall extend to their respective successors, heirs, executors, administrators and lawful assigns.

IN WITNESS WHEREOF, The said parties have hereunto set their hands the day and year first above written.

Witnesses:

....	....
....	....
....	....

NOTE.—The signature by mark of a lessor who cannot write his name must be witnessed by two witnesses, one of whom must write lessor's name near such mark.

ACKNOWLEDGMENT.

STATE OF KANSAS, COUNTY OF............, SS.

BE IT REMEMBERED, That on this........day of............, A. D. 192...., before me, a notary public in and for said county and state, came............and ...., who........personally known to me to be the same person who executed the within and foregoing instrument, and as such person duly acknowledged the execution of the same.

IN WITNESS WHEREOF, I have hereunto set my hand and affixed my notarial seal, the day and year last above written.

.........................., *Notary Public.*

My commission expires.............

The purchase price of a lease in Kansas generally has a dual consideration—a bonus, or cost for the execution or transfer of the lease; and a yearly rental to the landowner, which applies either until the termination of the lease or until oil or gas are obtained in commercial quantities. When oil or gas is obtained the yearly rental is supplanted by a royalty, or a percentage of the oil and gas marketed. In the case of oil the usual royalty is one-eighth of the oil, and in the case of gas may either be a definite proportion of the marketed production or a definite yearly money rental for each gas well.

The bonus or cost of executing a lease varies greatly, depending in general upon the distance from oil and gas developments. It is the result of a bargain between the landowner and the lessee. For wildcat acreage at a distance from oil and gas fields, the bonus may be as low as $1 per acre, while near a productive well or field it may be several thousand dollars an acre.

The yearly rental which is paid to the fee landowner ranges generally from 50 cents to $1 per acre. Where rapid development is desired by the landowner, a larger rental is frequently obtained as a stimulus to early drilling, but this is offset by a correspondingly lower bonus.

It may not be out of keeping at this place to point out the conditions on which royalties are based. They depend in large measure on the principle that the landowner has an inherent right to a proportion of the profits derived from the output of his property, so that in case his property contains large quantities of valuable minerals his remuneration will be large; and if his property contains but a small mineral value his income will be proportionately small. This indicates that the theoretical basis for royalties is profits, not output; or, in other words, it is on the income in excess of expenses and a normal payment for the involved risks, and not upon the commodities produced which yield no profit to the producer. Although profits form the theoretical basis of royalties, this basis has not been found feasible or practicable in the oil industry in the United States. Several reasons lie back of this condition, the first of which probably is the fact that the property owner and the oil producer are not partners. The one is the owner of small quantities of raw, unmined material; the other is the miner and marketer of small holdings bought from many individuals. Another reason, which applies to conditions in the United States, is that the landowner is usually a farmer, a man who for our present purpose may be said to be familiar only with "small business," whereas the producer is a "big business" man. From the nature of existing conditions, the bookkeeping of an oil and gas enterprise lies in the hands of the producer; and as the intricate bookkeeping is usually beyond the understanding of the landowner, he requires a method of accounting which is not only simple, but which will also not permit the producer to manipulate his accounts to the disadvantage of the landowner. Further, the profits of an oil and gas enterprise can often not be ascertained for months and sometimes years after the oil has been brought to the surface of the ground, and for this delay the landowner does not usually consider himself responsible, nor is he willing to endure the delay.

These and many other considerations existing in the early history of the oil and gas industry brought about a simple division of the oil produced, with the further condition that in case the owner did not care to handle his own portion of the oil thus divided, the operator would buy his portion at the prevailing market price, thus relieving the landowner of all expense and trouble in transporting, storing, and the ultimate marketing of the oil produced.

Undoubtedly, in the early history of the oil-field developments the proportion of the oil which was credited to the property owner varied considerably, but the resultant widespread and almost axiomatic proportion of 12½ per cent (one-eighth) came to be the happy medium for conditions as they exist in this country. This 12½ per cent royalty is so universal in the United States that it is practically a tradition, and departures are exceptional. From a conservational standpoint, low royalties are advantageous to the public, since wells are pumped longer and the extraction is correspondingly more complete where the small royalty makes possible the longer pumping at a profit.

As has been said, the theoretical basis for a royalty of any kind is to be found in the extraordinary profits which in general have prevailed in oil-development enterprises. If profits form the theoretical basis, then it can readily be seen that where profits are small, especially in the developing of unexplored regions far removed from markets and where the cost of development and the hazards of failure are very great, the payment of any royalty whatever, even as low as 1 per cent, may determine the failure of an enterprise. Undoubtedly there are many undeveloped localities in which oil could be exploited to the advantage of the communities immediately interested, by supplying profitable work to the inhabitants, if it were not for the payment of the royalties, which eliminate the profits of the producer. In other words, royalties may prevent the establishment of industries which should by right be fostered. The fostering of an industry may go one step further, as in places where the benefits to be derived by the community are greater than the probable deficits which the operator may entail, under which circumstances an enterprise may require a subsidy of some kind, as preferential tariffs or active financial assistance—a not unlikely possibility for the United States government in the near future in foreign oil enterprises, if the government is at all concerned in the development of its foreign trade in competition with that of other countries. The time may also come when the country's need for oil will be so acute that the government to find new oil territory may be required to finance prospecting before private enterprise will assume the hazards of oil-field development.

In the opposite trend of possibilities, oil and gas properties may be so situated in exceedingly rich and proven districts that the risks involved in a development enterprise are entirely eliminated and the profits are certain to be excessively great. Under such conditions it can readily be seen that royalties in excess of 12½ per cent should be obtained. Although extremes of this type may exist, they are pointed out to indicate that exceptions to the traditional 12½ per cent royalty are possible, and that these exceptions may be in the direction of no royalty at all, and may even go to the extent of necessary subsidizing, or they may be in the direction of high royalties where exceedingly high profits are secured.

SPACING AND DRILLING OF WELLS.

After obtaining a lease, the next procedure is the drilling of test wells. Unless prevented by contract or other reasons, the initial well is located on the most favorable spot as determined by geologists. In Kansas there are no laws governing the location of wells with respect to land lines, but common sense and recognized practice usually limit the locations to certain arbitrary distances. In the Eldorado field it is the common practice to drill 9 wells to the Stapleton oil zone in each 40-acre tract; that is, at the rate of 1 well to 4 4/9 acres. These are spaced in regular checkerboard fashion, with the outside wells located 200 feet from the land lines. In this fashion 12 boundary-line wells are spaced within the distance of a mile. By mutual agreement between owners of adjacent leases, or where a single owner owns several adjacent leases, the wells may be more widely spaced and be located at greater distances from the boundary lines because of the ultimate greater economy of oil production by this method. In some parts of the Eldorado field where this condition exists the practice is to drill but 4 wells to each 40-acre tract, or at the rate of 1 well to each 10 acres, and to space them 660 feet apart and 330 feet from the land lines. This permits 8 boundary-line wells to the mile.

The 660-foot-sand wells are more closely spaced, but here too the practice varies, depending in general on the extent of the acreage held by a single company. Where adjacent acreage is held by competing companies, 16 wells to a 40-acre tract, or 1 well to 2½ acres, is the general practice, while where one company holds adjacent leases it is the more common practice to space 25 wells to each quarter section, or 1 well for each 6⅖ acres.

Gas wells are even more widely spaced, but since the reservoirs of gas are more or less local, the location of gas wells is dependent upon the presence of gas rather than upon land lines. Where the gas is more or less evenly distributed, 1 well to 40 acres is generally the practice.

It is the practice in the Eldorado field that wells on adjacent leases are directly opposite each other and at the same distance from the dividing line. It is the practice, also, that when a producing well is completed on a lease an offset well on the adjacent lease is started as soon as practicable. This procedure applies in general only to the border-line wells, but may also apply to the inside drilling locations. Boundary-line wells are almost invariably the first ones drilled, and in places the inside locations are left undrilled. By thus leaving the inside locations undrilled a larger drainage area is given to the boundary-line wells of a property.

Drilling in the Eldorado field is done by the churn method, the Stapleton oil-zone wells being drilled with a standard rig, including calf wheel, while the 660-foot sand and gas wells are generally drilled with portable rigs. It is the general practice to let the drilling of the wells be done by contract at a stipulated price per foot, with fuel, water, casing and rig furnished.

Several companies let the drilling of their wells to contractors to a depth which is considered near to the top of the Stapleton pay, and from there on have special company drillers hired on a time basis to drill into the oil pay. By this procedure the company obtains greater uniformity in the finishing of their wells and greater accuracy and uniformity in the recording of sand data. This probably applies only to the Stapleton oil-zone wells.

OIL PRODUCING.

When a flowing well is obtained in the Eldorado field every effort is made to let it produce to its full capacity, provided the output can be cared for. A lack of adequate tankage to hold the production may be sufficient reason to close in a well, but such a procedure is very hazardous and may be disastrous, as was the case when the Empire Gas and Fuel Company's Shriver farm well No. 3, previously cited (northeast corner location, NW¼, sec. 14, T. 26 S., R. 4 E.), was brought in with a flow of oil which amounted to 144 barrels in 9 minutes, or at the rate of about 23,000 barrels per day. No adequate tankage was immediately available, and instead of permitting the oil to escape down the valley, thereby endangering numerous other wells, the management closed in the well for a few days until this prodigious production could be handled. When reopened, the well, instead of producing oil, flowed salt water. A small production of oil was later obtained. In the flowing Stapleton oil-zone wells the oil is generally permitted to flow directly into a small open tank of 150 or 250 barrels capacity, from which it is pumped into storage reservoirs.

The flush production of the flowing wells is generally short lived, the time being measured generally in weeks rather than in months.[2] When their production has reached a low ebb, or when their initial production is low, most flowing wells are

2. Shumway well No. 5, cited on pages 22 and 23, is the most notable exception to this rule.

stimulated by swabbing.[3] When swabbing is no longer a sufficient stimulus, the well is tubed and rigged for pumping. Those wells whose initial capacity is low are rigged for pumping immediately after being completed. For a short time after being put to pumping, the drilling equipment of steam boiler, engine and walking beam are used for pumping, which as soon as feasible is replaced by a gas engine and pumping jacks. To permit cleaning of the well, the derrick is not removed.

In 1918 electric power began to supplant the gas engines for pumping wells, the innovation being instigated by the rapidly decreasing supply of gas. The success attendant on electrical pumping has resulted in adapting electric power to drilling, where it has proven to be much more economical than steam power.[4]

The 660-foot-sand wells, with possibly the exception of the first few that flowed when drilled in, are rigged for pumping immediately upon completion. As a general rule they are equipped with pumping jacks operated through shackle lines from centrally located power plants, with a dozen or more wells operated by a single unit. Portable outfits are used for cleaning the wells.

EMULSION TREATMENT.

Much of the oil obtained by pumping is accompanied by salt water in smaller or larger quantities. This water is present not only as an inert substance, in part readily separable through gravitative action, but very often is combined with the oil in an emulsion, generally spoken of as B.S, which must be broken down and the water eliminated before the oil can be refined. An emulsion is referred to as temporary emulsion when it will separate into comparatively free oil and water by settling under ordinary temperatures, but when the settling out is negligible, even after a long period of time, it is termed permanent emulsion. A large part of the permanent emulsion can be separated by various physical means into comparatively free petroleum and water, but a small portion, usually less than one per cent, very often is so emulsified that below distillation temperatures it remains in combination.

3. A swab is a pumping mechanism attached to the drilling stem which uses the casing as a working barrel. It is raised and lowered in the oil column by the walking beam and in this way assists the flow of oil.

4. Sevenson, S. B.; Oil and Gas News, vol. 6, No. 13, pp. 25-26; November 13, 1919.

Emulsion, or B S, as defined by McCoy and Trager,[5] is composed of a physical mixture of water, oil and air, with some included inert matter, either organic or inorganic. These are present as minute globules of water surrounded by films of oil, globules of air surrounded by films of water and oil, and globules of oil. The water in emulsion composes about two-thirds of the mixture. Such a mixture causes a marked increase in the viscosity and specific gravity of petroleum, and it is this thick and more or less gummy material which is the baneful emulsion, or B S, of the oil industry.

According to McCoy and Trager, the mere presence of globules of water and air in petroleum does not cause emulsification, at least not until these globules are packed rather closely together. In heavy oils the globules may be separated by distances several times their diameter, and cause emulsion; but in lighter oils the spacing must be more crowded. The spacing of the globules in the Augusta oil used by McCoy and Trager, which is but slightly different from the Eldorado oil, must be about equal to their diameters before the oil may be said to be emulsified. When the globules are generally less than 0.5 mm. in diameter, the emulsion is of the permanent type. The presence of foreign matter increases the permanency of the emulsion.

Pipe-line companies will not accept crude oil which contains more than a very small percentage of B S, generally about one per cent. This forces the operating companies to separate their oil and B S, and to break up as far as possible the B S into oil and water. In order to keep the production from each lease distinct, so that the correct royalty may be computed, a dehydrating plant is located on each lease.

The oil, B S and water will separate by being allowed to settle in settling tanks, in which the good oil will rise to the top, the water will go to the bottom, and the B S, which has a density between that of oil and water, will take an intermediate position.

The most generally used method for separating the oil and water in emulsion is through the agency of heat, which breaks down the surface tension of the water globules, permitting them to coalesce and form increasingly larger ones, which

5. Investigation concerning oil-water emulsion: Amer. Inst. Mining Engs., Bull. 152, pp. 1513-1537; August, 1919. The present discussion is principally a summary of this article.

reach a size that will settle to the bottom of the separating tank and permit the free oil to rise to the top, from which it is drawn off.

The practice generally followed in the Eldorado field is first to pump all the fluid obtained from the wells into a settling tank, from which the separated emulsion is drawn and turned into the bottom of a tank filled with water heated by live steam to a temperature of about 120° to 130° F., through which it rises in small particles after being distributed widely over the base of the tanks by means of radiating lead pipes. In ascending through the heated water the drops and particles of the emulsion are rapidly heated and the oil and water separate more or less. A single treatment of this kind is not sufficient to break up all the temporary B S, hence the oil and B S mixture collecting at the top of the tank is led off to the bottom of a second steaming tank, where the process is repeated in water which is heated 20° to 40° F. higher than that of the first tank. From the second tank the oil and B S mixture is led to a settling tank, where the freed oil, the more permanent B S and the liberated water are permitted to separate. From the settling tanks the good oil is pumped into the field storage, and the more permanent B S, together with a small amount of oil which cannot be well separated from it, is drawn off into earthen sumps, where it is periodically burned. The amount of oil and B S thus burned represents a wastage of about 1 per cent. While this percentage is low, yet it is very considerable when applied to the entire pumped production of the field. The above outlined simple treatment of emulsion is considerably modified in practice. Where the quantity of oil emulsion to be treated is large, specially designed concrete dehydrators are built in which the same steaming principle can be applied more efficiently and economically.

McCoy and Trager have demonstrated [6] that, although emulsion is essentially a mixture of water and oil, the presence of air or gas is essential to its formation. From field observations they have concluded that when air or gas enter the working barrel of a pumping well, the amount of B S produced is greatly increased; and hence, in pumping a well the fluid level in the well should at no time be permitted to fall below the level of the perforated tubing. The proper rate at which a well should be pumped to produce the least amount of B S is

6. Op. cit.

an individual problem for each well and can be determined only by testing. The demonstration that considerable control can be exercised over the amount of B S formed in a pumping well should be welcomed by all operators and should receive the serious attention of conservation commissions.

In this connection attention should also be directed to the progress made in eliminating the entrance of water into the wells. Although the methods employed are extremely technical, their descriptions are pertinent to the subject of water, and are therefore discussed under that subject on pages 172-175.

The oil obtained from any one lease is first placed into measuring tanks whose size conforms to the quantity of oil produced by that property. When the oil in these tanks is to be turned over to a pipe-line company, a gauger measures the oil in the tank or tanks, after which it is turned into the pipe line. Where not sold to a pipe-line company, the oil is loaded by pumping into tank cars for rail shipment.

The pipe-line companies transport the oil either to their affiliated refineries or else place it in storage on their tank farms, from which it can be drawn as needed.

REFINERIES AND PIPE LINES.

In the immediate vicinity of the Eldorado field are located five or six refineries, which were built primarily to handle Eldorado oil. They are of the skimming-plant type which produce gasoline, kerosene, gas and fuel oil, and distillates. The gas and fuel oil and distillates are sold to large refineries for further separation into lubricating oils, waxes, etc., or else are sold for fuel-oil purposes. The names and locations of these refineries, together with their capacities and locations in the field, are as follows:

Refineries in Eldorado field.[7]

Name and location.	Capacity in barrels, crude oil.
Eldorado Refining Company (SE¼ SE¼, sec. 27, T. 25 S., R. 5 E.)	1,500
Midland Refining Company (E½ SW¼, sec. 10, T. 26 S., R. 5 E.)	3,500
Fidelity Refining Company (Sec. 11, T. 26 S., R. 5 E.)	2,500
St. Louis Oil & Refining Company	1,500
Tri-State Oil & Refining Corporation (SW¼ SW¼, sec. 14, T. 25 S., R. 5 E.)	1,500
Reliance Refining Company	Building.

7. Data furnished by the Bureau of Mines.

Obviously these refineries can handle but a small part of the Eldorado production. The remainder is sold either to small near-by refineries, most of which receive their crude-oil shipments by tank cars, or to the large pipe-line companies for distribution to their associated refineries. Five or more of these small refineries are located at Wichita, a city of ——— population located twenty-five miles west of Eldorado. Among the large pipe-line companies which take oil from the Eldorado field are the following:

The Prairie Pipe Line Company.
The Sinclair Pipe Line Company.
The Gulf Pipe Line Company.
The Empire Pipe Line Company.
The Oklahoma Pipe Line Company.

The small refineries built in the neighborhood of an oil field during its development are generally of the skimming type, in contrast to the complete refinery; that is, they distill off only the higher fractions of the crude oil, gasoline and kerosene,[8] and sell and ship by tank cars the remainder, very often to complete refineries equipped for making lubricating oils and waxes. The liquid products of refining are generally shipped to distributing stations by tank cars, and for this purpose large fleets of tank cars are operated by the larger refining interests.

8. The percentages of the products obtained by the skimming plants under current practice have been given on page 168.

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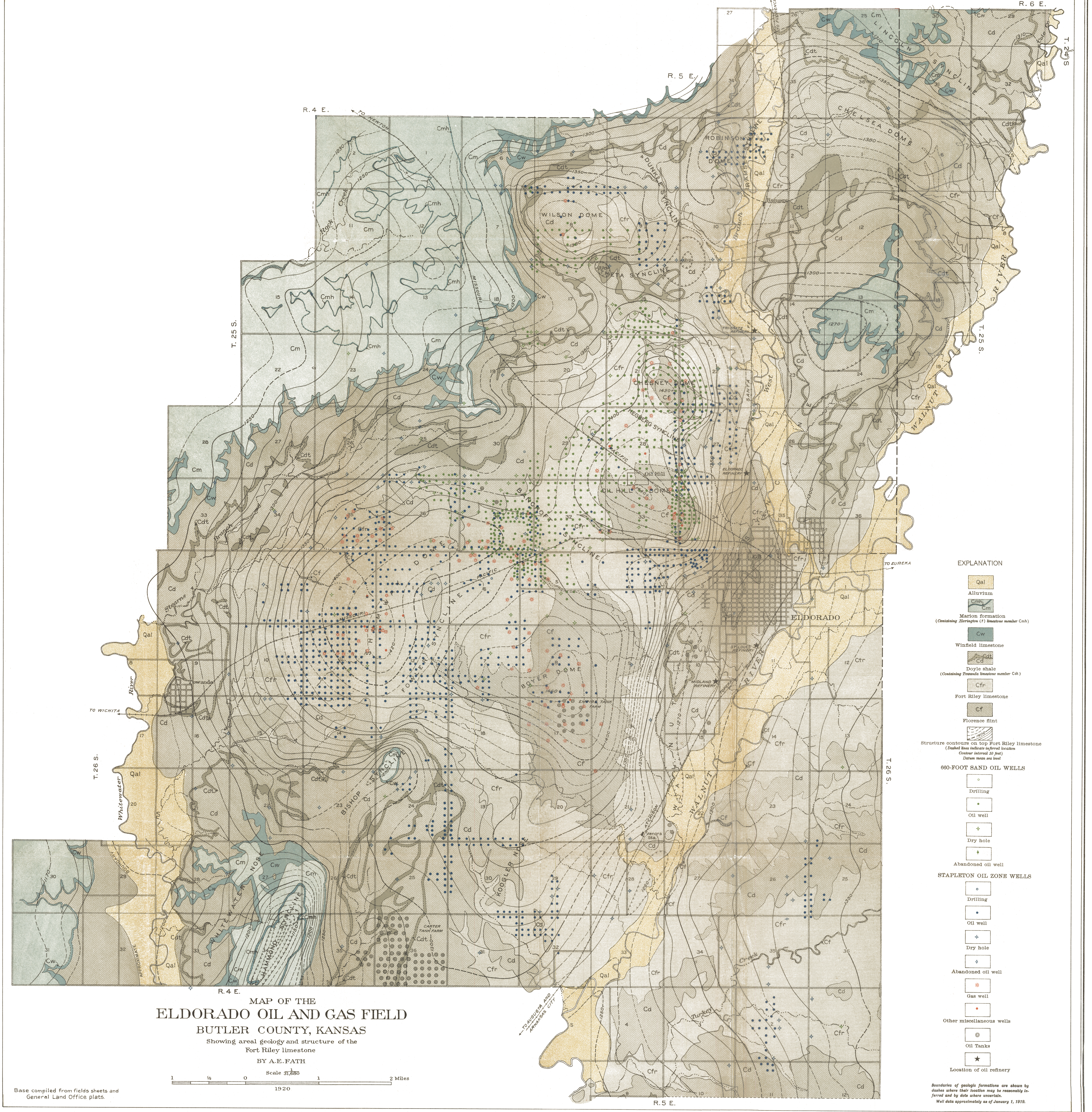


MAP OF THE ELDORADO OIL AND GAS FIELD

BUTLER COUNTY, KANSAS

Showing areal geology and structure of the Fort Riley limestone

BY A.E. FATH

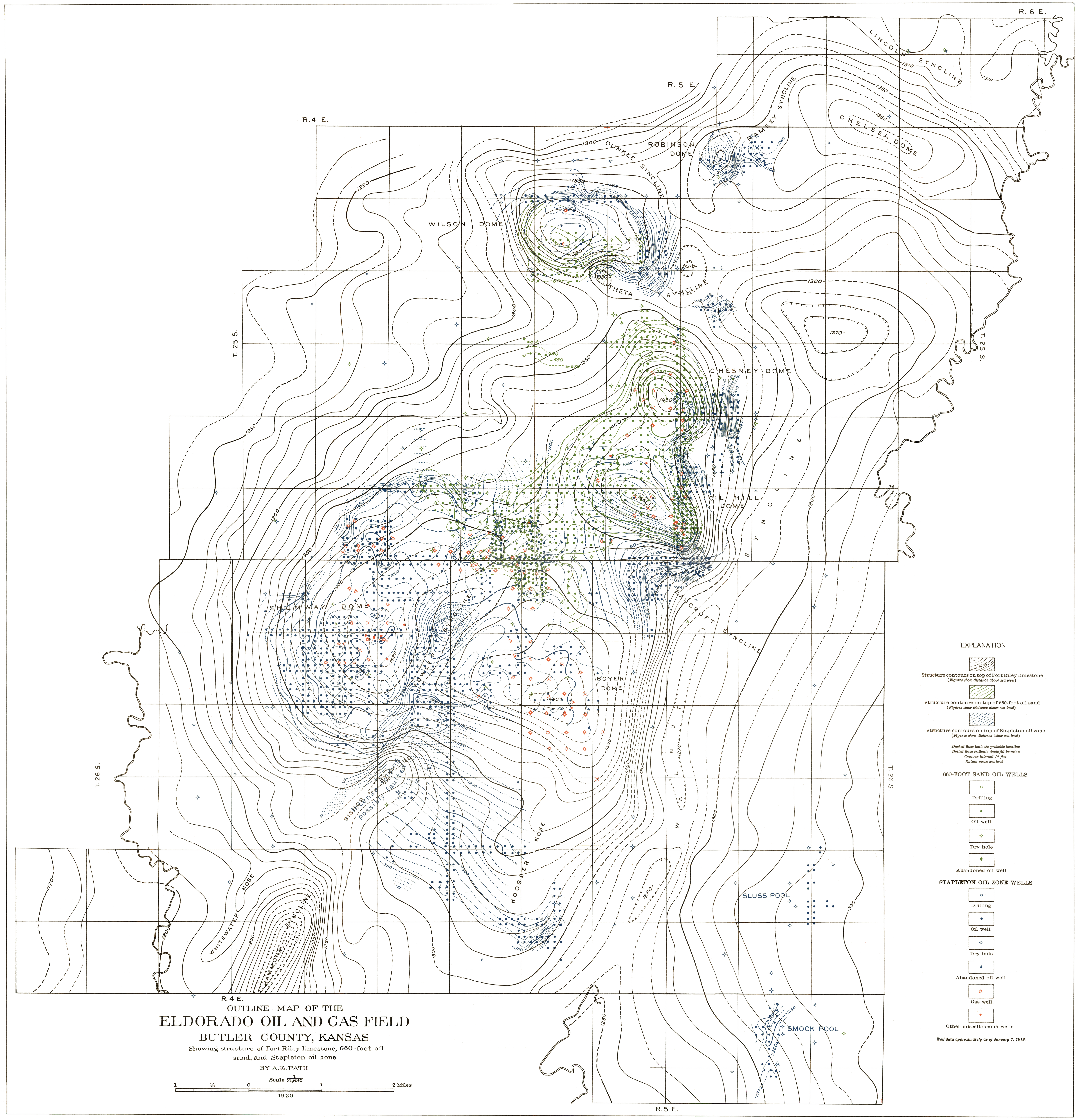
Scale $\frac{1}{31,680}$

1 ½ 0 1 2 Miles

1920

Base compiled from fields sheets and General Land Office plats.

A. Hoen & Co. Lith. Baltimore, Md.



OUTLINE MAP OF THE
ELDORADO OIL AND GAS FIELD
BUTLER COUNTY, KANSAS
Showing structure of Fort Riley limestone, 660-foot oil sand, and Stapleton oil zone.

BY A.E. FATH

1920