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GEOLOGY AND FUEL RESOURCES OF THE SOUTHERN PART OF THE OKLAHOMA COAL FIELD

Part 2. THE LEHIGH DISTRICT
COAL, ATOKA, AND PITTSBURG COUNTIES

BY
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NOTE

The Geological Survey, in 1930, 1931, 1933, and 1934, conducted an investigation of the geology and coal resources of the portion of the southeastern Oklahoma coal field extending northeastward from Coalgate to McAlester and thence eastward through Wilburton and Howe to the Oklahoma-Arkansas State line. The geologists have prepared separate reports on the areas for which they were responsible. However, as these areas are adjacent and form a real unit both geographically and geologically, the four reports are issued as parts of a single bulletin covering this portion of the southeastern Oklahoma coal field. No edition of the consolidated volume will be published, but the four parts can be bound together if desired.

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GEOLOGY AND FUEL RESOURCES OF THE SOUTHERN PART OF THE OKLAHOMA COAL FIELD

PART 2. THE LEHIGH DISTRICT, COAL, ATOKA, AND PITTSBURG COUNTIES

By M. M. KNECHTEL

ABSTRACT

The rocks exposed in the Lehigh district, in the Arkansas-Oklahoma coal basin, aggregate at least 5,000 feet in thickness. All are of Pennsylvanian age, except scattered thin Pleistocene (?) and Recent deposits. Rocks of Pottsville age crop out extensively in the southwestern part of the district and include the Springer formation, Wapanucka limestone, and Atoka formation. The Pottsville rocks are overlain in the northeastern part by formations of Allegheny age, including the Hartshorne sandstone, McAlester shale, Savanna sandstone, Boggy shale, and Thurman sandstone. All the Pennsylvanian formations younger than the Wapanucka limestone are composed chiefly of shale containing rather widely spaced beds of sandstone that is generally fine grained in the western part of the area but contains varying quantities of chert pebbles in the eastern part. The pebbles were apparently derived from a land mass that lay to the east or southeast in late Pottsville and Allegheny time, and this land mass is believed to have been the source of much of the sediment that was deposited in this part of the coal basin in post-Pottsville Pennsylvanian time. Two wells within the area mapped have penetrated rocks of Mississippian, Devonian, Silurian, and Ordovician age. It is inferred from the records of these wells and from the geology of neighboring areas that the Arbuckle Mountain sequence of pre-Pennsylvanian rocks underlies the Pennsylvanian formations in all parts of the Lehigh district, though exposures of the dissimilar pre-Pennsylvanian rock sequence of the Ouachita Mountains occur in Black Knob Ridge of the Ouachita Mountains, a few miles to the east.

The Lehigh district lies in a belt of folded Paleozoic rocks extending from the Arbuckle Mountains northeastward adjacent to the northwestern frontal margin of the Ouachita Mountains. The structural axes within this belt trend northeastward, and the folding is therefore believed to be due to the same forces, directed northwestward, that caused extensive overthrusting in the Ouachita region in late Pennsylvanian time. The effects of forces acting from the direction of the Arbuckle Mountains, however, are apparent in the southwestern part of the district, where the oldest exposed rocks crop out, having been tilted northeastward in Pennsylvanian time.

Folds related to the northwestward thrusting are the Ashland, Savanna, and Coalgate anticlines. The origin of the Centrahoma dome is less clear. The structure of the Hunton anticline, which is faulted on both flanks, is similar in many respects to that of the other anticlines of the area, which are flat-topped and steep-sided. It may be essentially an anticline of their general type that has been more deeply eroded than the others.

An unconformity probably exists at the base of the Hartshorne sandstone, and one of less extent has been observed at the base of the Savanna sandstone. An unconformity within the Boggy shale has been reported immediately to the west but has not been recognized in the Lehigh district.

Two valuable coal beds, the Lower Hartshorne and Lehigh beds, occur in the Lehigh district in the Hartshorne sandstone and McAlester shale, respectively. Both beds have been mined, but the Lehigh bed has yielded much more coal than the Lower Hartshorne bed. These coal beds are separated by about 1,200 feet of beds and range in thickness from about 3 feet 4 inches to about 5 feet. The coal of the Lehigh bed is classified as high-volatile bituminous.

Wells have been drilled for oil and gas in several parts of the district, and gas has been struck, but not marketed, in the Ashland, Coalgate, and Centrahoma anticlines. Nearly all the wells penetrate only the Atoka and younger formations, reaching depths ranging from 1,300 to 3,380 feet. One dry hole on the Coalgate anticline, however, finished in the Atoka beds at a depth of 7,890 feet, and two dry holes in the western part of the district were completed in the Simpson formation (Ordovician) at depths of 5,146 and 7,126 feet. Most of the gas that has been found issues from the Hartshorne sandstone, but some was found in sandy layers in the McAlester shale and a little in the Savanna sandstone. No oil has been discovered to date, but the pre-Pennsylvanian rocks underlying the area have not been adequately tested by the drill.

INTRODUCTION

Location.—The area covered by this report (pl. 11, in pocket) comprises about 400 square miles in Atoka, Coal, and Pittsburg Counties, in southeastern Oklahoma. For convenience it is referred to as the Lehigh district, from the town of Lehigh, in the southern part of the district, which has a population of about 500. The largest town in the district is Coalgate, which has a population of about 2,000. The district was formerly a part of the Government reservation set aside for the Choctaw Nation, one of the Five Civilized Tribes, which in 1907 became part of the newly established State of Oklahoma. Interest in the geology of this part of Oklahoma has been stimulated by the discovery, in the summer of 1934, of the Fitts oil field, 12 miles west of the Lehigh district, and in 1935 of the Jesse oil field, about 6½ miles west of the district.

Routes of travel.—All parts of the Lehigh district are easily reached by automobile. State Highway 19 (U. S. Highway 75), which is paved, leads from Coalgate and Lehigh southeastward to Atoka and northwestward to a point 3½ miles northwest of Coalgate. At that point U. S. Highway 75 branches northward as a graveled road leading to Calvin and State Highway 19 continues northwestward to Ada. There are also good graveled roads from Coalgate and Lehigh westward to Wapanucka and northeastward to Kiowa. The villages and farming communities in the area are connected with these principal routes and with each other by numerous roads and trails. The Oklahoma City-Ada-Atoka Railway extends northwestward from Atoka through Coalgate to Ada, and the Chicago, Rock Island & Pacific Railway extends northeastward from Wapanucka through Coalgate to Hartshorne.

Industry.—The inhabitants of the district are mainly engaged in farming and in stock and poultry raising. Their chief crops are corn, oats, cotton, potatoes, and hay; cattle, hogs, horses, mules, and chickens are raised extensively. Coal mining was formerly a major industry and in 1913, the year of maximum output, 889,299 tons was produced. Drilling for oil has been carried on sporadically for many years, and mineral rights on much of the area have been leased. Leasing has been especially active since the recent discoveries of oil in areas immediately west of the district.

Land forms and drainage.—The Lehigh district lies in the Arkansas Valley section of the Ouachita physiographic province, adjacent to the northwest front of the Ouachita Mountains and northeast of the Arbuckle Mountains. The total relief of the Lehigh district is a little more than 350 feet. The highest point, as shown by 50-foot contours on the Atoka topographic map, is in the SE¼ sec. 19, T. 1 S., R. 10 E., where the highest contour is 900 feet above sea level; the lowest is on Muddy Boggy Creek near the northeast corner of sec. 4, T. 2 S., R. 11 E., where the altitude lies between 500 and 550 feet. Most of the district is hilly, owing to dissection of the surface by numerous watercourses. The two largest streams, Muddy Boggy and Clear Boggy Creeks, generally flow throughout the year, carrying little water during dry weather but frequently overflowing their banks after heavy rains. The smaller streams, tributary to these two principal watercourses, are dry except in wet weather.

The surface configuration of the Lehigh district is largely the result of the action of streams on rocks that differ greatly in their capacity for resistance to erosion. For that reason the topographic forms are intimately related in origin to the geologic structure and stratigraphy. The landscape in much of the district, consequently, is marked by numerous parallel ridges along the upturned, truncated edges of the hard sandstone, conglomerate, and limestone beds. The ridges are separated by relatively broad valleys that have been eroded in the intervening soft shales. Each ridge has been dissected in places by streams, and at many such places the ridge-forming rocks are concealed locally by alluvial deposits. As the ridges in general afford the best outcrops of rock to be found in the area, the ridge-forming sandstone beds, more than any other rocks, are utilized by the geologist as horizon markers in mapping the structure and rock strata. The ridges are in general coincident with the narrow belts of sandstone outcrops that are mapped on plate 11. Where the beds are steeply inclined the ridges are closely spaced, narrow, and more or less sharp-crested; where the rocks dip gently, the ridges are broader and more widely spaced. Over much of the northwestern part of the district the nearly horizontal sandstone beds form broad flat-topped hills, or mesas.

Vegetation.—The ridges and the higher areas in general support heavy growths of oak, hickory, elm, hackberry, persimmon, and sumac. The valley lands, though largely cleared for cultivation, include many areas covered with thickets of oak, wild plum, willow, and cottonwood. There are also areas of natural prairie, the most extensive of which is the broad shale area in which Coalgate and Cottonwood are situated.

Climate.—There is no meteorologic station within the Lehigh district, but climatic records are kept at McAlester, 15 miles northeast of the district; at Ada, 15 miles northwest; and at Durant, 25 miles south. Data on temperature and precipitation at those points are given in the following table:

Normal monthly and annual mean precipitation and temperature at McAlester, Ada, and Durant, Okla.

	Precipitation (inches)			Temperature (°F.)		
	McAlester	Ada	Durant	McAlester	Ada	Durant
January	2.19	2.66	2.22	40.6	39.8	41.1
February	2.12	1.52	2.08	44.6	44.2	45.2
March	3.15	2.59	2.90	54.0	53.0	54.7
April	4.61	4.23	3.63	62.1	61.2	62.7
May	6.14	5.61	5.35	69.4	68.5	70.8
June	4.47	4.41	3.75	78.2	76.3	78.7
July	3.23	2.32	3.39	83.3	82.3	82.0
August	3.56	3.36	3.14	82.2	81.9	82.7
September	3.40	3.41	2.89	76.0	74.9	76.5
October	3.02	3.82	4.32	63.3	64.3	64.5
November	2.72	2.32	2.42	53.0	52.3	53.7
December	2.61	2.12	2.64	42.6	42.3	43.4
Annual	42.70	37.89	39.73	64.2	63.4	66.5
Length of record (years)	38	28	33	32	28	33

Present investigation.—The greater part of the present investigation of the geology, coal resources, and oil and gas possibilities of the Lehigh district was carried on in the late summer and the autumn of 1934 with funds allotted to the United States Geological Survey by the Federal Emergency Administration of Public Works. Geologic field studies covering about 300 square miles were made at that time by the writer, assisted by C. B. Anderson, R. M. Hart, and W. Christian. In the course of an earlier investigation by the Geological Survey a tract of about 100 square miles in the northeastern part of the area to be described, adjacent to the McAlester district, had been mapped during parts of September and October 1931 by T. A. Hendricks, assisted by C. B. Read, R. M. Hart, and T. L. Metcalf. The locations of the coal beds, mines, and prospect pits in most of the area were mapped by T. A. Hendricks and C. B. Read in November and December 1933.

For the purpose of geologic mapping, stadia traverses carrying altitudes were run with plane table and alidade to all parts of the area. The accuracy of the traverses was frequently checked, as most of the roads have been laid out along the section and half-section lines that were surveyed by the United States Geological Survey in 1895–96. The iron-post benchmarks that were set at

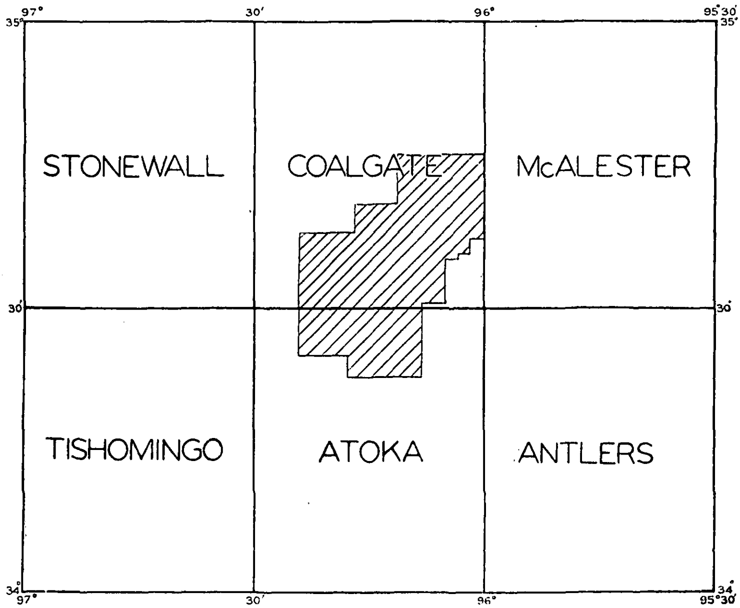

FIGURE 6.—Diagram showing relation of Lehigh district (shaded) to six 30-minute quadrangles in southern Oklahoma.

all township corners at that time remained intact in sufficient number in 1934 to provide good vertical control, though several of them have been uprooted in road-building operations.

Previous publications.—The first detailed geologic investigation of the Lehigh district was conducted by Taff,[1] who named and described the formations above the Atoka formation. Taff's report was accompanied by descriptions of collections of fossil plants from the area, by David White, and a chapter on the invertebrate fossils, by G. H. Girty. The most complete account of the geology, containing descriptions of the Atoka and older formations, as well as the younger formations, was given in later reports by Taff.[2] (See fig. 6.) A still later report by Taff[3] is accompanied by a map on

[1] Taff, J. A., Geology of the McAlester-Lehigh coal field, Indian Territory: U. S. Geol. Survey 19th Ann. Rept., pt. 3, pp. 429–593, 1899.

[2] Taff, J. A., U. S. Geol Survey Geol. Atlas, Coalgate folio (no. 74), 1901; Atoka folio (no. 79), 1902.

[3] Taff, J. A., Description of unleased segregated coal lands in the Lehigh-Ardmore districts, Choctaw and Chickasaw Nations, Indian Territory: 61st Cong., 2d sess., S. Doc. 390, pp. 329–359, pl. 10, 1910.

which are shown the locations of diamond-drill holes put down to determine the depths of the valuable coal beds at several points in the Lehigh district. Very little information on the geology of the Lehigh district has appeared in the geologic literature of Oklahoma since the results of Taff's work were issued, and the only new geologic maps of any part of the area that have since been published are a structure map of part of the Coalgate anticline that is included in a brief paper by Clawson,[4] and a preliminary edition of the geologic map giving the results of the present investigation,[5] which, with some later revision, is included in the present report as plate 11.

The west boundary of the Lehigh district lies 6 miles east of the Stonewall and Tishomingo quadrangles, the geology of which has been described by Morgan[6] and Taff,[7] respectively. The McAlester district, which has been described by Hendricks,[8] adjoins the Lehigh district on the northeast. A general account of the stratigraphy of the Arkansas-Oklahoma coal basin, in which the Lehigh district lies, is given in a paper by Hendricks, Dane, and Knechtel.[8a]

STRATIGRAPHY

Most of the information here presented on the geology of the Lehigh district has been gained from studies of the outcropping rocks and of the rocks penetrated by wells that have been drilled within the district. Some inferences, however, are of necessity drawn from the rocks of surrounding regions, and this is especially true of the rocks older than Pennsylvanian, for the reason that none of these crop out within the district, and because they had been reached by the drill in only two wells at the time of writing of the report.

EXPOSED ROCKS

CHARACTER

The rocks exposed in the Lehigh district are of sedimentary origin and aggregate at least 5,000 feet in thickness. (See columnar section, pl. 11.) All of them are Pennsylvanian (Pottsville and Allegheny) in age except the scattered Pleistocene (?) and Recent deposits.

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[4] Clawson, W. W., Jr., Oil and gas geology of Coal and Pittsburg Counties: Oklahoma Geol. Survey Bull. 40–JJ, pp. 14–15, 1928.

[5] Knechtel, M. M., Hendricks, T. A., Read, C. B., Anderson, C. B., Hart, R. M., Christian, W., and Metcalf, T. L., Geologic map of the Lehigh district, Coal, Atoka, and Pittsburg Counties, Okla. (preliminary ed.), U. S. Geol. Survey, 1934.

[6] Morgan, G. D., Geology of the Stonewall quadrangle, Okla.: Bur. Geology Bull. 2, pp. 63–70, 1924.

[7] Taff, J. A., U. S. Geol. Survey Geol. Atlas, Tishomingo folio (no. 98), 1903.

[8] Hendricks, T. A., Geology and fuel resources of the southern part of the Oklahoma coal field; Part 1, The McAlester district, Pittsburg, Atoka, and Latimer Counties: U. S. Geol. Survey Bull. 874–A (in press).

[8a] Hendricks, T. A., Dane, C. H., and Knechtel, M. M., Stratigraphy of Arkansas-Oklahoma coal basin: Am. Assoc. Petroleum Geologists Bull., vol. 20, no. 10, pp. 1342–1356, October 1936.

The rocks of Pottsville age include the Springer formation, Wapanucka limestone, and Atoka formation. These formations crop out in the Ouachita Mountains and underlie the rocks of Allegheny age in the Arkansas-Oklahoma coal basin, of which the Lehigh district is a part. The formations of Allegheny age are the Hartshorne sandstone, McAlester shale, Savanna sandstone, Boggy shale, and Thurman sandstone. These units form the most extensively exposed sequence of rocks in the coal basin.

In the formations exposed in the Lehigh district alternations of marine and continental deposits commonly occur, and many strata of continental origin merge laterally into marine strata. The formations younger than the Wapanucka limestone, which include nearly all the rocks exposed in the district, are made up predominantly of shale, in which relatively thin sandstone layers are intercalated, generally at widely spaced stratigraphic intervals. The Wapanucka limestone crops out prominently in the western part of T. 1 S., R. 9 E., but the known limestone beds elsewhere exposed in the district are confined to the Savanna sandstone and Boggy shale, are more or less impure, and are apparently merely locally developed phases of extensive sandstone beds. At any rate, they appear to grade laterally into sandstone within short distances along all their outcrops that were noted during the present investigation. Two valuable coal beds, one in the Hartshorne sandstone and the other in the McAlester shale, have been extensively mined in the vicinity of Coalgate and Lehigh. Two thin, valueless coal beds are also present in the McAlester shale.

In the Lehigh district all the Pennsylvanian rock formations younger than the Wapanucka limestone include sandstone beds that are conglomeratic in the eastern part of the district but contain little or no coarse material in the western part. The pebbles in the conglomerates are chiefly angular to subangular fragments of chert, the origin and significance of which are briefly discussed on pages 125–126.

Many minor unconformities occur locally in the Pennsylvanian rocks exposed in the Lehigh district, but the only unconformity that is suspected to extend over any great part of the area is that at the base of the Hartshorne sandstone. The upper boundary of that formation is marked by a coal zone, and the great variation in thickness of the formation from place to place may or may not be due to an unconformable relation with the underlying Atoka formation. Morgan[9] reports that the Hartshorne and McAlester formations overlap the Atoka, Wapanucka, and his so-called Caney (Springer) beds in the Stonewall quadrangle.

[9] Morgan, G. D., Geology of the Stonewall quadrangle, Okla.: Bur. Geology Bull. 2, pp. 63–70, 1924.

CARBONIFEROUS SYSTEM

PENNSYLVANIAN SERIES

FORMATIONS OF POTTSVILLE AGE

SPRINGER FORMATION

The oldest rocks that crop out in the Lehigh district, about 500 feet of poorly exposed strata underlying the Wapanucka limestone adjacent to the west line of T. 1 S., R. 9 E., are mainly dark shale and are assigned to the Springer formation.

The rocks that immediately underlie the Wapanucka limestone north of the Arbuckle Mountains were formerly classified as a portion of the Caney shale,[10] but in recent years rocks equivalent to the Springer formation (Pennsylvanian), which overlies the Caney shale (Mississippian) in the Ardmore Basin, have been recognized north of the Arbuckle Mountains[11] and in the Ti Valley-Choctaw belt in the Ouachita Mountains.[12] They have there been assigned to the Springer formation, the Caney shale being thus restricted to a shale unit of Mississippian age. The poorly exposed rocks below the Wapanucka limestone at the west side of the Lehigh district are therefore likewise assigned to the Springer in this report, though Taff mapped them as Caney shale. The base of the Springer formation was not recognized in mapping the outcrops in the western part of T. 1 S., R. 9 E. The Carter Oil Co.'s well at Centrahoma, in sec. 34, T. 2 N., R. 9 E. (see pp. 109–122), penetrated 910 feet of rocks, in large part if not entirely assignable to the Springer formation, overlying 210 feet of shales that were assigned to the restricted Caney shale (Mississippian). Probably the Springer formation makes up a large part of the section of 1,220 feet of rocks drilled between depths of 2,670 feet and 3,890 feet in the Amerada Petroleum Corporation's well in the SW¼NW¼SE¼ sec. 28, T. 1 S., R. 9 E., about 2 miles south of Olney. (See log, p. 122.) Taff[13] estimated the unrestricted Caney shale (including both the Mississippian unit and the Springer formation) to be 1,600 feet thick in the Atoka and Tishomingo quadrangles. Morgan,[14] however, states that the average thickness of the unrestricted Caney in the Stonewall quadrangle "is thought to be nearer 800 feet."

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[10] Taff, J. A., U. S. Geol. Survey Geol. Atlas, Atoka folio (no. 79), 1902.

[11] Harlton, B. H., Carboniferous stratigraphy of the Ouachitas, with special study of the Bendian: Am. Assoc. Petroleum Geologists Bull., vol. 18, no. 8, pp. 1020–1021, August 1934.

[12] Miser, H. D., Carboniferous rocks of the Ouachita Mountains: Am. Assoc. Petroleum Geologists Bull., vol. 18, no. 8, pp. 977–978, August 1934.

[13] Taff, J. A., U. S. Geol. Survey Geol. Atlas, Atoka folio (no. 79), p. 4, 1902; Tishomingo folio (no. 98), p. 5, 1903.

[14] Morgan, G. D., Geology of the Stonewall quadrangle, Okla.: Bur. of Geology Bull 2, p. 53, 1924.

WAPANUCKA LIMESTONE

The Wapanucka limestone crops out in the western part of T. 1 S., R. 9 E., as a prominent arcuate ridge, convex toward the east. The outcrop is cut off by the Clarita fault at the north end of the arc, near the west line of sec. 6, and by the Olney fault at the south end, in sec. 24, T. 1 S., R. 8 E. The ridge is largely covered by soil and vegetation and has a rather even top from end to end. As no stream has cut through it, no continuous exposure of more than a few feet of strata is offered. The exposures consist mainly of bluish-gray and yellowish-gray limestone, oolitic near the top and very fossiliferous in some of the beds near the base. Wallis,[15] who made a regional study of the Wapanucka limestone, gives the following section of the formation:

Section of Wapanucka limestone along line between secs. 7 and 8, T. 1 S., R. 9 E.

	Feet
Oolite	15
Blue fossiliferous limestone	100
Chert and brown sandstone	10
Total	125

The Carter Oil Co.'s well at Centrahoma, in sec. 34, T. 2 N., R. 9 E., penetrated at least 175 feet of Wapanucka limestone at 4,335 to 4,510 feet below the surface. (See log, p. 113.) The Amerada Petroleum Corporation's well in the SW¼NW¼SE¼ sec. 28, T. 1 S., R. 9 E., about 2 miles south of Olney, passed through 140 feet of beds classified as Wapanucka limestone in the log (p. 122).

Harlton,[16] on paleontologic grounds, classifies as "basal Wapanucka" the equivalent of the upper part of the Springer that occurs north of the Arbuckle Mountains. Harlton's "middle Wapanucka" is Taff's Wapanucka limestone as mapped in the Atoka folio, and Harlton's "upper Wapanucka" is the basal part of Taff's Atoka formation as mapped in the Atoka folio. R. C. Moore, as cited by Thompson,[17] states that "the lower part of the beds classed as Atoka in Coal County, Okla., are of Morrow age. The lithologic, faunal, and stratigraphic relationships of these beds indicate that they should be allied with the Wapanucka rather than Atoka deposits."

Notwithstanding the fact, however, that rocks above and below the limestone unit in T. 1 S., R. 9 E., are reported to be similar to it in faunal content, the name "Wapanucka" is retained in the present report for this limestone unit as it was mapped by Taff in the Atoka folio.

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[15] Wallis, B. F., Geology and economic value of the Wapanucka limestone of Oklahoma: Oklahoma Geol. Survey Bull. 23, p. 49, 1915.
[16] Harlton, B. H., op. cit., fig. 1, p. 1020.
[17] Thompson, M. L., Fusulinids from the lower Pennsylvanian Atoka and Boggy formations of Oklahoma: Jour. Paleontology, vol. 9, no. 4, p. 292, June 1935.

ATOKA FORMATION

The Atoka formation is composed chiefly of shale, in general poorly exposed, in which are intercalated at widely spaced intervals fairly well-exposed sandstone members that are conspicuous in the landscape because of their ridge-forming habit. The sandstones are fine-grained in the western part of the Lehigh district but contain chert pebbles in varying quantities in the eastern part. The outcropping edges of these sandstone layers are represented on plate 11.

The Atoka formation is extensively exposed in the southern part of the Lehigh district and undoubtedly occurs below the surface of the district everywhere north of its outcrop. It is exposed in a broad area on the north flank and the axial portion of the Hunton anticline and extends eastward along the margin of the district on the south side of the Lehigh syncline. Its base lies along the foot of the conspicuous ridge of Wapanucka limestone near the west line of the district. However, though the base of the Atoka formation and that of the overlying Hartshorne sandstone have been mapped in the Lehigh district, the full thickness of the Atoka formation there is not accurately known. The displacement of the Atoka beds on the Olney fault, in T. 1 S., R. 9 E., is unknown, and the Atoka may also be faulted in the neighborhood of Clear Boggy Creek in the north half of T. 1 S., R. 9 E. The Hartshorne sandstone, moreover, probably overlaps the upper Atoka beds in the Lehigh district, as it does in the Stonewall quadrangle, farther west, where Morgan[18] estimates that the exposed section of the Atoka is nowhere more than 800 feet thick. These circumstances defeat any attempt at accurate estimate of the total thickness of the Atoka formation in this area, though significant thicknesses may be determined from the map or are recorded in the logs of wells. In a dry hole that was begun in the McAlester shale in sec. 10, T. 1 N., R. 11 E., about 6,000 feet of Atoka rocks were penetrated in an unsuccessful attempt to reach the Wapanucka limestone. However, many geologists believe that this drilled thickness is not reliable as a basis for an estimate of the true stratigraphic thickness of the Atoka and are inclined to suspect the presence of some unknown structural condition, such as possible duplication of strata in the hole by faulting, as responsible for the apparently abnormally great thickness encountered in this well. The Amerada Petroleum Corporation's well in the SW¼ NW¼SE¼ sec. 28, T. 1 S., R. 9 E., which probably started considerably below the base of the Hartshorne, penetrated 2,480 feet of Atoka beds. Another drilled hole, which was begun in the NE¼ sec. 7, T. 2 S., R. 10 E., at a point 1,100 feet, by computation, below the

[18] Morgan, G. D., Geology of the Stonewall quadrangle, Okla.: Bur. Geology Bull. 2, pp. 63–64, 1924.

Atoka-Hartshorne contact, finished in the Atoka formation at a depth of 1,850 feet. The thickness of the Atoka is therefore probably at least 3,000 feet in that vicinity. The Carter Oil Co.'s well at Centrahoma, in sec. 34, T. 2 N., R. 9 E., showed 2,500 feet of the Atoka overlying the Wapanucka limestone. On the north side of the Hunton anticline, in the southwestern part of the Lehigh district, the thickness of Atoka rocks present in the area of poor exposures that lies between the outcrops of Wapanucka limestone and Hartshorne sandstone may be only 1,200 feet, or possibly even less.

David White, as cited by Miser,[19] states that "the Atoka formation, on the basis of plants obtained in the vicinity of Atoka, Okla., is upper Pottsville", and in a further statement by White [20] the Atoka is regarded as "for the most part at least, post-Morrow in age." As stated in the preceding section, however, some geologists and paleontologists consider that the basal Atoka beds exposed in the western part of the Lehigh district are of Morrow age.

FORMATIONS OF ALLEGHENY AGE

The Pennsylvanian rocks of the Lehigh district that are younger than the Atoka formation have been divided by Taff into five formations of rather uniform lithologic character, the section as a whole being largely composed of shale in which sandstone occurs at more or less widely spaced stratigraphic intervals, as shown on plate 11. These formations are differentiated mainly on the basis of the proportions of sandstone to shale in each. The Hartshorne sandstone, which is the oldest, is overlain by the McAlester shale, followed in turn by the Savanna sandstone, Boggy shale, and Thurman sandstone. All these units except the Thurman sandstone were traced from the McAlester district northward by Wilson,[21] who states that they thin in that direction and are represented in the lower part of the Cherokee shale of northeastern Oklahoma. White [22] and Read [23] report that the floras of the Hartshorne sandstone, McAlester shale, Savanna sandstone, and Boggy shale indicate that those formations are of basal Allegheny age.

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[19] Miser, H. D., Carboniferous rocks of Ouachita Mountains: Am. Assoc. Petroleum Geologists Bull., vol. 18, no. 8, p. 979, August 1934.

[20] White, David, Age of Jackfork and Stanley formations of Ouachita geosyncline, Arkansas and Oklahoma, as indicated by plants: Am. Assoc. Petroleum Geologists Bull., vol. 18, no. 8, p. 1016, August 1934.

[21] Wilson, C. W., Jr., Age and correlation of Pennsylvanian surface formations and of oil and gas sands of Muskogee County, Okla.: Am. Assoc. Petroleum Geologists Bull., vol. 19, no. 4, pp. 503–520, April 1935.

[22] White, David, U. S. Geol. Survey 19th Ann. Rept., pt. 3, pp. 457–534, pls. 67–68, 1899. Collier, A. J., White, David, and Girty, G. H., The Arkansas coal field: U. S. Geol. Survey Bull. 326, pp. 24–31, 1907.

[23] Hendricks, T. A., and Read, C. B., Correlations of Pennsylvanian strata in Arkansas and Oklahoma coal fields: Am. Assoc. Petroleum Geologists Bull., vol. 18, no. 8, pp. 1055–56, August 1934.

Like the sandstones in the Atoka formation, the sandstones of Allegheny age are generally fine-grained in the western part of the Lehigh district but in the eastern part contain varying quantities of chert pebbles that are locally so abundant as to form conglomerate. Much of the chert occurs as pebbles less than a quarter of an inch in diameter, but some an inch or more in diameter have been noted.

The Hartshorne sandstone forms the base of the coal-bearing portion of the Pennsylvanian rock sequence of the coal basin. The uppermost known coal occurs in the basal portion of the Boggy shale in the McAlester district, to the northeast, but in the Lehigh district no beds of coal are known to occur in rocks younger than the McAlester shale. The several coal beds are described elsewhere in this report.

HARTSHORNE SANDSTONE

The Hartshorne sandstone crops out in a narrow belt on the south side of the Lehigh syncline and extends northwestward from T. 2 S., R. 11 E., to T. 1 N., R. 9 E.; it presumably occurs below the surface in the areas north and northeast of its outcrop. The Hartshorne overlies the Atoka formation with an apparently irregular contact that may represent an erosional unconformity of sufficient magnitude to account for the extraordinary westward thinning of the exposed section of the Atoka which is apparent in the Lehigh district and which was explained by Morgan [24] as due to overlap of the Hartshorne on the lower part of the Atoka. Though the upper part of the Hartshorne carries much shale and an extensive coal bed about 25 feet below the top, signifying rather uniform conditions of deposition over a large area in late Hartshorne time, the thickness and lithologic character of the formation as a whole are extremely variable. The thickness ranges from less than 80 feet to about 500 feet. From sec. 33 to sec. 29, T. 1 S., R. 10 E., the thickness increases from about 80 feet to nearly 500 feet within a distance of 2 miles northwestward along the strike. Farther northwest it decreases rather irregularly, and in the extreme western part of the district the formation is probably less than 100 feet thick. Morgan [25] states that the Hartshorne is about 100 feet thick in the Stonewall quadrangle, and Hendricks [26] gives 168 to 300 feet as the thickness in the McAlester district. The variations in thickness of the Hartshorne are accompanied by variations in lithology, especially in the lower part of

[24] Morgan, G. D., Geology of the Stonewall quadrangle, Okla.: Bur. Geology Bull. 2, p. 64, 1924.

[25] Idem, p. 66.

[26] Hendricks, T. A., Geology and fuel resources of the southern part of the Oklahoma coal field; Part 1, The McAlester district, Pittsburg, Atoka, and Latimer Counties: U. S. Geol. Survey Bull. 874–A (in press).

the formation. Where the formation is thin it is made up largely of thin-bedded bluish-gray shale and fine-grained light-gray to yellow sandstone; the thickest sections are composed mainly of massive hard white to gray, somewhat coarse-grained sandstone. In the extreme southeastern part of the district and to a less degree in the western part the Hartshorne contains angular to subangular fragments of chert, some of which are a quarter of an inch and more in diameter.

Hendricks[27] has suggested that the variations in thickness and lithology of the Hartshorne may be due to submarine deposition of the coarser and thicker facies in channels extending seaward from the mouths of streams along a shore line that lay to the southeast in Hartshorne time, while the thinner and finer-grained facies were accumulating in the submarine interchannel areas.

A ridge supported by steeply inclined beds of sandstone containing angular fragments of chert lies immediately south of the fault near the south line of sec. 30, T. 1 N., R. 9 E. These beds are tentatively assigned to the Hartshorne because of their lithologic resemblance to the beds that crop out on the prominent ridge of Hartshorne sandstone about 3 miles to the southeast.

M'ALESTER SHALE

The McAlester shale overlies the Hartshorne sandstone conformably and crops out in three separate areas in the Lehigh district. The largest is an elongated area that may be divided into two structural segments. One of these segments extends 12 miles northeastward from the Phillips fault as a broad belt of rocks of the upper part of the formation extending through Coalgate and Cottonwood. The other segment, a broad belt of gently dipping rocks, including both the base and top of the formation and extending from the neighborhood of Phillips through Lehigh, turns northeastward in a broad curve in the northwestern part of T. 2 S., R. 11 E., and narrows greatly on the steeply upturned southeast limb of the Lehigh syncline north of Atoka. Outcrops of McAlester shale occur also in an area of about 3 square miles in the axial portion of the Ashland anticline in T. 3 N., Rs. 11 and 12 E., and in a small area southwest of Clear Boggy Creek, in the southwestern part of T. 1 N., R. 9 E. The McAlester shale probably occurs below the surface everywhere in the Lehigh district except in the extreme southern and southwestern parts, where older formations crop out.

[27] Hendricks, T. A., Geology and mineral resources of the western part of the Arkansas coal field: U. S. Geol. Survey Bull. 847–E (in press).

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A thickness of about 1,650 feet of McAlester shale is exposed in the central part of T. 1 S., R. 10 E., near the town of Lehigh. About 1,000 feet of McAlester beds crop out on the south limb of the Coalgate anticline in secs. 10 and 15, T. 1 N., R. 11 E., between the Savanna-McAlester contact and a well in which three coal beds were encountered at depths of 563, 680, and 725 feet. The coal at 725 feet is assumed to be the Lower Hartshorne coal; that at 680 feet, the Upper Hartshorne coal, which forms the base of the McAlester shale. The thickness of the McAlester in that vicinity is therefore probably somewhat less than 1,680 feet, the drilled thickness being greater than the true thickness, owing to dip. A similar measurement involving the outcropping Savanna-McAlester contact and a well drilled in the NE¼ sec. 19, T. 3 N., R. 12 E., indicates a thickness of about 1,150 feet of McAlester shale in that neighborhood. The Carter Oil Co.'s well in sec. 34, T. 2 N., R. 9 E., at Centrahoma, passed through 930 feet of rocks directly underlain by the Atoka formation, overlain by Savanna sandstone, and assigned by the company's geologists to the McAlester shale. It is understood, however, that the Hartshorne was either unrecognizable or absent in the cuttings but may be present in the coal-bearing basal 100 feet of the section designated McAlester in the well log (pp. 110–111). According to Morgan,[28] the McAlester shale is slightly more than 1,000 feet thick at the west line of the Coalgate quadrangle. A pronounced northwestward thinning of the formation in the Lehigh district is therefore indicated. Hendricks[29] states that the normal thickness of the McAlester shale in the McAlester district is 1,904 to 2,420 feet, but that on the Savanna anticline south of the town of Savanna the McAlester ranges from 1,500 to 2,800 feet in thickness at localities only 1 mile apart. These apparently abnormal thicknesses are explained by Hendricks as due to horizontal squeezing of the shale.

The McAlester shale of the Lehigh district is composed mainly of blue and black shale but includes four prominent and persistent ridge-forming sandstones, two additional sandstones in the extreme southeastern part of the district, one valuable coal bed, and two thin coal beds of no value. The coal beds are described elsewhere in this report. The sandstones are mostly buff and are fine-grained everywhere except in the extreme southeastern part of the district, where they contain much coarse debris, mainly of chert, the fragments of which are angular to subangular and measure in places half an inch or more in diameter.

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[28] Morgan, G. D., Geology of the Stonewall quadrangle, Okla.: Bur. Geology Bull. 2, p. 67, 1924.

[29] Hendricks, T. A., op. cit. (Bull. 874–A).

As indicated by rather abundant fossil remains of plants, invertebrates, and fish teeth, the McAlester shale of the Lehigh district includes both marine and continental members.

Difficulties are encountered in mapping the McAlester shale in the western part of the Lehigh district, owing to (1) the fault that extends southeastward through secs. 30 and 32, T. 1 N., R. 9 E., dropping the formations on its northeast side against older beds lying south of it, and (2) the broad belt of alluvium along Clear Boggy and Leader Creeks, under which a part of the succession is concealed.

An outcrop of the Hartshorne sandstone is represented on Taff's map of the Coalgate quadrangle[30] as extending from the NW¼ sec. 30, T. 1 N., R. 9 E., southeastward to the S½ sec. 33, where it is shown as cut off by a hypothetical northwestward-trending fault along Clear Boggy Creek that drops the beds on its northeast side. A different interpretation of the geology of this neighborhood has resulted from the discovery during the present investigation that the coal bed pitching northeastward in a small mine near the center of sec. 30, where Taff shows the Hartshorne sandstone, is in reality the Lehigh coal bed and not the Hartshorne coal bed, as he had evidently supposed. The present identification of the coal bed is based on the occurrence in the mine of a fossiliferous limy layer that characteristically forms part of the roof of the Lehigh bed. The rocks here mapped by Taff as the Hartshorne sandstone therefore belong in the upper part of the McAlester shale.

SAVANNA SANDSTONE

The Savanna sandstone in the Lehigh district is made up of several groups of sandstone and shale beds. The sandstones are more prominently exposed than the shales, though probably thinner in the aggregate. Locally the Savanna contains a few thin lenses of highly fossiliferous blue-gray marine limestone. Near the middle in the western part of the area there is a thin bed of calcareous sandstone that weathers dark brown and is locally supplanted by impure limestone containing abundant marine fossils. This bed was utilized as a valuable key in mapping the obscure relations along the Phillips fault in secs. 1, 2, and 3, T. 1 S., R. 9 E., as they are shown on plate 11. The proportion of sandstone to shale increases eastward within the district, as does also the grain size of the sandstones. Most of the beds in the southeastern part of the area contain abundant subangular fragments of chert and locally include some fragments that measure as much as a quarter of an inch in diameter; farther north and west the sandstones are mostly fine-grained,

[30] Taff, J. A., U. S. Geol. Survey Geol. Atlas, Coalgate folio (no. 74), 1901.

though some beds contain coarse cherty material in the belt of Savanna along the northwest flank of the Coalgate anticline.

Hendricks [31] states that the Savanna sandstone rests unconformably, but without marked angular discordance, on the McAlester shale in the McAlester district and describes an exposure in the Lehigh district, at the center of sec. 6, T. 1 N., R. 12 E., which exhibits an unconformable contact between Savanna and McAlester. Other than this no evidence of unconformity has been observed at this contact within the Lehigh district.

A belt of Savanna sandstone extends from the west boundary of the district southeastward for a few miles, then northeastward to the southern part of T. 2 N., R. 12 E., where it bends back around the northeastward-plunging nose of the Coalgate anticline south of Wardville, to follow a southwestward course to the vicinity of Coalgate, turning southeastward there and continuing for about 8 miles as a belt paralleling the course of Muddy Boggy Creek. A second belt of Savanna sandstone surrounds the area of McAlester shale on the Ashland anticline in T. 3 N., Rs. 11 and 12 E., and occupies the saddle between the Ashland and Savanna anticlines.

The Savanna sandstone beds of the Lehigh district contain fairly abundant fossil plants and marine invertebrates and therefore include both continental and marine deposits.

The Savanna sandstone, as mapped on plate 11, ranges in thickness from 1,400 to 1,600 feet at several localities on the outcrop, but no progressive regional change in thickness is revealed by the scattered rough measurements available. Like the rest of the coal-bearing Pennsylvanian formations of the Arkansas-Oklahoma coal basin, however, the Savanna probably thins gradually northwestward. Morgan [32] reports that the Savanna is 1,300 feet thick in the extreme southeastern part of the Stonewall quadrangle but thins westward toward the center of that quadrangle. Hendricks [33] states that the Savanna sandstone of the McAlester district normally ranges in thickness from 1,120 to 1,325 feet in measured sections but that abnormal thicknesses as great as 2,500 feet and as low as 500 feet occur locally. He explains these abnormal thicknesses as due to tectonic squeezing.

BOGGY SHALE

The Boggy shale, by far the most extensively exposed formation in the Lehigh district, crops out in a broad tract of land in the Lehigh syncline east of Muddy Boggy Creek, in Tps. 1 N. and 1 S., R. 11 E., and occupies almost all of the area northwest of a line

[31] Hendricks, T. A., op. cit. (Bull. 874–A).

[32] Morgan, G. D., Geology of the Stonewall quadrangle, Okla.: Bur. Geology Bull. 2, p. 74, 1924.

[33] Hendricks, T. A., op. cit. (Bull. 874–A).

through Coalgate, Cottonwood, and Wardville. It has been removed by erosion from a small area south of Ashland and from a broad area in the southern part of the district, in which Centrahoma, Cottonwood, Coalgate, Lehigh, and Olney are situated. It is concealed beneath the Thurman sandstone in a portion of the north half of T. 3 N., R. 11 E.

The Boggy shale consists largely of blue and gray shale but contains a number of widely spaced brown and gray irregular-bedded sandstones and locally a few thin lenses of highly fossiliferous blue-gray marine limestone. At many places the shale is mottled purple, red, and gray. Most of the Boggy sandstone beds exposed in the southeastern part of the district contain abundant chert pebbles.

The Boggy shale, as indicated by plant and invertebrate fossils, includes both marine and continental deposits. The top of the Boggy crops out in the Lehigh district only in the northern part of T. 3 N., R. 11 E., where estimates of the thickness exposed between the top and base, obtained from meager data, range from 1,250 to 1,500 feet. Morgan [34] states that the Boggy is about 1,500 feet thick on the east side of the Stonewall quadrangle. Hendricks [35] gives 2,850 feet as the thickness of the Boggy in the southeastern part of T. 4 N., R. 13 E., in the McAlester district.

Clawson [36] comments on the somewhat abrupt change in attitude on the flanks of the Coalgate anticline between gently dipping Boggy beds and the underlying steeply inclined Savanna beds and suggests that the less disturbed beds were deposited on an erosion plane that had been developed on intensely folded rocks. An unconformity exists near the base of the Boggy in the Stonewall quadrangle [37] and may extend eastward into the Lehigh district. Its continuation into this area has not been demonstrated, however, and the changes in dip referred to are represented by structure contours on plate 11 as if they were altogether the result of folding in post-Boggy time. In areas underlain by gently inclined strata of the Boggy shale the configuration of the datum horizon as interpreted on the map can therefore be valid only under the assumption that the unconformity near the base of the Boggy is absent in those areas.

THURMAN SANDSTONE

The Thurman sandstone crops out in the northern part of T. 3 N., R. 11 E., where it consists of brown sandstone, shale, and chert conglomerate. According to Taff [38] the proportion of shale in the

[34] Morgan, G. D., op. cit., p. 78.
[35] Hendricks, T. A., op. cit. (Bull. 874–A).
[36] Clawson, W. W., Jr., Oil and gas geology of Coal and Pittsburg Counties: Oklahoma Geol. Survey Bull. 40–JJ, pp. 14–15, 1928.
[37] Morgan, G. D., op. cit., pp. 77–80.
[38] Taff, J. A., U. S. Geol. Survey Geol. Atlas, Coalgate folio (no. 74), p. 4, 1901.

formation increases westward. Taff states that the Thurman sandstone is about 250 feet thick at the northeast corner of the Coalgate quadrangle but is only 80 feet thick in the western part of the quadrangle. The thickness of the Thurman in the Lehigh district is therefore probably intermediate between these extremes. Hendricks[39] estimates that the Thurman is about 200 feet thick in the McAlester district.

QUATERNARY (?) SYSTEM

GERTY SAND (PLEISTOCENE?)

In the northern part of T. 3 N., R. 11 E., and the northwestern part of T. 3 N., R. 12 E., deposits of fine sand and silt of Pleistocene (?) age rest unconformably on the Pennsylvanian rocks, forming benches above the present stream valleys. These deposits, known as the Gerty sand, are believed to be related to a former course of the Canadian River. Deposits of gravel that are possibly of the same age as the Gerty sand occur in three areas north of Clear Boggy Creek, near the west line of T. 1 N., R. 9 E.

QUATERNARY SYSTEM

RECENT ALLUVIUM

The beds of streams in all parts of the Lehigh district are underlain by deposits of Recent alluvium, mainly composed of silt and fine sand.

UNEXPOSED ROCKS

CAMBRIAN TO CARBONIFEROUS SYSTEMS

PRE-PENNSYLVANIAN ROCKS

Though no rocks older than the Springer formation (Pennsylvanian) are exposed in the Lehigh district, a well drilled to a depth of 7,126 feet at Centrahoma, in the northwestern part of the district, and another well 5,416 feet deep, 2 miles south of Olney, in the southwestern part, penetrate Ordovician, Silurian, Devonian, Mississippian, and Pennsylvanian rocks. The following sample log of the well at Centrahoma, prepared by D. L. Hyatt, is published through the courtesy of the Carter Oil Co. It is given in full because of the information it affords on the pre-Pennsylvanian rocks through which the well passes. The classification of the rocks into formations has been made by the present writer.

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39 Hendricks, T. A., op. cit. (Bull. 874–A).

Log of John Thompson No. 1 well, center of S½ sec. 34, T. 2 N., R. 9 E., at Centrahoma, Coal County, Okla.

[Owned by Carter Oil Co. Altitude above sea level at mouth of well, 699 feet. Samples from 250 to 7,126 feet examined by D. L. Hyatt. Drilling begun June 7, 1935; completed Feb. 2, 1936]

	Feet
Missing	0–250
Savanna sandstone:	
Sandstone, white, coarse, free	250–330
Sand, coarse; free	330–350
Shale, gray, some red; some sandstone, coarse and medium	350–370
Shale, green gray and red; sandstone, fine, cemented	370–390
Shale, green gray, some brown; some sandstone, fine and coarse	390–480
Shale, green gray, some brown; sandstone, fine, cemented, some micaceous	480–540
Shale, gray, some micaceous, fine, sandy; some sandstone, medium and coarse	540–560
Shale, gray, micaceous, sandy; some sandstone, fine and medium	560–600
Sand, fine to medium, cemented, some shaly	600–620
Shale, gray, dark gray, micaceous, sandy	620–640
Shale, gray and dark, micaceous, some sandy; some sandstone, fine, cemented, micaceous; a little conglomeratic sand	640–660
Shale, gray and dark, micaceous, some sandy; some sandstone, fine, cemented, micaceous; a little conglomeratic sand	660–680
Shale, gray, micaceous, sandy; some sandstone, gray, medium, cemented	680–700
Missing	700–712
Shale, dark gray, some green gray, some sandy; some sandstone, fine to medium	712–720
Shale, gray, green gray, some sandy; some brown shale; some sandstone, fine to medium	720–730
Shale, green gray, some sandy	730–740
Sandstone, white, fine to medium; trace of gas stain	740–760
Sand, fine to medium, some shaly; some conglomerate	760–770
Shale, blue gray, some green gray, trace of brown	770–780
Shale, blue gray, some sandy	780–790
Shale, dark gray, finely micaceous; trace of sand; some green-gray sandy shale	790–810
Sand, gray, medium, slightly calcareous; trace of mica; shaly	810–850
Shale, gray, sandy; some sandstone, gray, fine to medium	850–860
Shale, green gray	860–890
Shale, green gray, sandy to micaceous	890–900

Log of John Thompson No. 1 well, center of S½ sec. 34, T. 2 N., R. 9 E., at Centrahoma, Coal County, Okla.—Continued

	Feet
McAlester shale and Hartshorne sandstone:	
Shale, gray, micaceous, finely sandy; some green-gray shale	900–980
Shale, dark, finely micaceous	980–990
Shale, dark, micaceous; trace coal	990–1,000
Shale, dark, micaceous, some finely sandy; trace of lignite	1,000–1,040
Shale, dark, micaceous; trace of coal	1,040–1,050
Shale, dark, micaceous, some sandy; trace of calcitic shaly lime	1,050–1,070
Shale, gray to dark, micaceous, sandy	1,070–1,080
Sand, fine, micaceous, shaly; some micaceous shale	1,080–1,110
Sand, fine, some shaly	1,110–1,125
Sand, fine, micaceous, shaly; some dark micaceous shale	1,125–1,135
Shale, black, micaceous; trace of sand	1,135–1,150
Shale, black, micaceous, sandy; a little sandstone, medium calcareous, shaly	1,150–1,170
Shale, black, micaceous; trace of sand	1,170–1,210
Shale, dark, micaceous; a little sandstone, fine, micaceous, shaly	1,210–1,220
Shale, gray, micaceous, highly sandy; a little fine sand	1,220–1,240
Shale, gray to dark, micaceous, sandy	1,240–1,330
Shale, dark, micaceous, sandy; some sandstone, fine, micaceous, shaly	1,330–1,360
Shale, gray and dark; micaceous, sand	1,360–1,370
Shale, black, micaceous, some sandy	1,370–1,430
Shale, dark, micaceous, some green gray	1,430–1,450
Shale, dark, micaceous; trace of sand	1,450–1,510
Shale, black, micaceous, carbonaceous	1,510–1,520
Shale, gray to black, micaceous, finely sandy	1,520–1,540
Shale, gray, dark, micaceous; trace of fine sandstone	1,540–1,550
Shale, black, gray black, slightly gritty, some highly micaceous	1,550–1,600
Shale, gray black; trace of sandstone, fine and medium	1,600–1,610
Shale, gray to black; trace of sand	1,610–1,625
Sandstone, white, coarse, cherty, conglomeratic; show of gas; light oil stain	1,625–1,650
Core: 1,631–1,641 feet, 1 foot recovery; sand, coarse, cherty; show of gas; light oil stain; steel-line correction, 1,641 = 1,647 feet.	
Shale, gray black, black; trace of sand	1,650–1,730
Shale, gray black, micaceous, slightly sandy	1,730–1,740
Shale, gray black, slightly sandy, some micaceous; some sandstone, gray, fine, micaceous, shaly	1,740–1,750

Log of John Thompson No. 1 well, center of S½ sec. 34, T. 2 N., R. 9 E., at Centrahoma, Coal County, Okla.—Continued

	Feet
McAlester shale and Hartshone sandstone—Con.	
Sand, gray, fine to medium, some shaly; trace of lignite; trace of coal; some shale, black to gray, slightly micaceous	1, 750–1, 800
Shale, gray to black, micaceous, sandy; a little green-gray shale; some sandstone, fine to medium, micaceous	1, 800–1, 820
Shale, gray, micaceous, sandy; some black sand; gray shale; a little shaly sand	1, 820–1, 830
Atoka formation:	
Shale, dark gray, micaceous, some sandy; some black and gray shale	1, 830–1, 850
Shale, gray to black, slightly micaceous and sandy	1, 850–1, 900
Shale, black, sandy, slightly micaceous, carbonaceous	1, 900–1, 970
Shale, black, slightly micaceous, sandy, carbonaceous; some gray shale	1, 970–2, 020
Shale, greenish gray, sandy, micaceous; some black shale	2, 020–2, 070
Shale, black, some greenish gray, sandy, micaceous	2, 070–2, 110
Shale, green gray, very sandy; some black shale; a little sandstone, green gray, medium shaly	2, 110–2, 130
Shale, green gray, highly sandy; a little greenish-gray shaly sand	2, 130–2, 170
Shale, green gray, sandy, slightly micaceous; some black shale	2, 170–2, 260
Shale, black, some gray; black and gray, slightly sandy lime	2, 260–2, 510
Shale, gray, sandy, some black	2, 510–2, 530
Shale, black, some gray black, some sandy	2, 530–2, 630
Shale, black, some gray, sandy	2, 630–2, 660
Shale, black gray, slightly sandy and micaceous	2, 660–3, 220
Core: 3,111–3,114 feet, 4 inches recovery; sandstone, gray, coarse, quartzitic; shale streaks.	
Shale, gray black to black; traces of siderite	3, 220–3, 310
Shale, gray black, slightly sandy; traces of siderite	3, 310–3, 380
Sand, medium to coarse, calcareous	3, 380–3, 381
Core: 2 feet recovery, shale, black, dip 2°–3°	3, 381–3, 385
Shale, gray black to black, slightly sandy	3, 385–3, 450
Shale, black, some micaceous, trace of black, slickensided	3, 450–3, 510
Shale, black; trace of sand, coarse, calcareous	3, 510–3, 520
Shale, black, some sandy, white, coarse, calcareous	3, 520–3, 530
Shale, black, some micaceous; trace of sand; trace of black slickensided shale	3, 530–3, 570
Shale, black, carbonaceous; trace of slickensided	3, 570–3, 590
Shale, black, gray black; trace of sand; some black slickensided shale	3, 590–3, 640

Log of John Thompson No. 1 well, center of S½ sec. 34, T. 2 N., R. 9 E., at Centrahoma, Coal County, Okla.—Continued

Atoka formation—Continued.	Feet
Shale, gray black, slightly sandy; some black shale; trace of siderite	3, 640–3, 670
Shale, gray black to black, slightly sandy; trace of sandstone, medium, calcareous	3, 670–3, 690
Shale, black, gray black; trace of sand	3, 690–3, 710
Shale, black, gray black; trace of sand; trace of sandstone, fine, calcareous	3, 710–3, 735
Shale, black, gray black, slightly sandy; a little lime, brown, fine crystalline; a little calcareous sand	3, 735–3, 740
Core: 5 feet recovery; shale, black, with thin sand streaks; dip 3°	3, 740–3, 747
Shale, black, gray black, slightly sandy; trace of sandstone, fine, calcareous; traces of lime, brown, fine crystalline	3, 740–3, 790
Shale, black, gray black, slightly sandy	3, 790–3, 810
Shale, black, some gray, sandy; trace of sandstone, coarse, calcareous	3, 810–3, 820
Sand, coarse, quartzitic, calcareous, broken; trace of brown crystalline lime	3, 820–3, 835
Shale, dark gray to black, slightly sandy	3, 835–3, 850
Shale, black, some gray, slightly sandy; trace of calcareous sand; trace of siderite	3, 850–3, 890
Shale, gray, soft, some dark; trace of siderite	3, 890–4, 020
Shale, dark, some gray, slightly sandy; trace of siderite; trace of sandstone, medium calcareous, quartzitic	4, 020–4, 090
Shale, black, some dark gray; trace of siderite	4, 090–4, 110
Shale, dark; trace of siderite and quartzitic sand	4, 110–4, 120
Shale, dark, some gray, slightly sandy; trace of siderite	4, 120–4, 160
Shale, dark gray to black; trace of sand; a little lime, brown, crystalline, very sandy	4, 160–4, 180
Shale, dark gray to black, slightly sandy; trace of calcareous sand and brown crystalline sandy lime; trace of siderite	4, 180–4, 220
Shale, dark gray to black; trace of lime, brown, crystalline, sandy	4, 220–4, 240
Sand, white, coarse, quartzitic, calcareous, broken	4, 240–4, 250
Shale, dark gray to black; a little sandstone, medium to coarse, calcareous, quartzitic	4, 250–4, 260
Shale, dark gray to black; trace of lime, brown, crystalline, sandy, sideritic	4, 260–4, 280
Shale, dark gray to black; a little sandstone, medium, calcareous, sideritic	4, 280–4, 300
Sand, gray, medium to coarse, quartzitic, calcareous	4, 300–4, 301
Core: 6 inches recovery, black shale and siderite	4, 301–4, 306
Shale, gray to dark; trace of sandstone, medium calcareous	4, 306–4, 335

Log of John Thompson No. 1 well, center of S½ sec. 34, T. 2 N., R. 9 E., at Centrahoma, Coal County, Okla.—Continued

	Feet
Wapanucka limestone:	
Lime, brown, crystalline, sandy; trace of cherty and glauconitic conglomerate	4, 335–4, 340
Core: Full recovery; lime, brown, fine to medium, crystalline, some sandy; trace of chert and glauconite; show of gas; spotted, oil stained	4, 340–4, 341½
Core: No recovery	4, 342–4, 343
Lime, brown and gray, crystalline, slightly sandy, and conglomerate	4, 340–4, 347
Lime, brown, crystalline, slightly conglomeratic, fossiliferous, oolitic	4, 347–4, 351
Core: 3 feet recovery, lime, brown and gray, crystalline, fossiliferous, slightly conglomeratic, and glauconitic; trace of oolite	4, 351–4, 358
Lime, brown and gray, crystalline, fossiliferous, some oolitic	4, 351–4, 400
Lime, brown, crystalline, very oolitic; some oil stain	4, 400–4, 510
Springer formation:	
Shale, black, micaceous; some lime, brown, crystalline, oolitic	4, 510–4, 530
Shale, black, micaceous; trace of lime, brown, crystalline (drag?)	4, 530–4, 590
Shale, black; some lime, brown, crystalline	4, 590–4, 610
Shale, black, micaceous	4, 610–4, 620
Shale, black; some brown crystalline limestone	4, 620–4, 630
Shale, black, micaceous; some dark gray, soft	4, 630–4, 670
Shale, black, micaceous; trace of black slick shale; some gray, soft shale	4, 670–4, 715
Shale, black, micaceous; trace of gray, soft	4, 715–4, 730
Shale, black, micaceous; some gray, soft; trace of sand, glauconitic	4, 730–4, 755
Shale, gray, soft, and black, micaceous; trace of embedded sand and glauconite, traces of fossils	4, 755–4, 770
Shale, dark gray, soft, some black, micaceous	4, 770–4, 800
Shale, dark gray, some black, micaceous; some sand, gray, fine to medium, calcareous, glauconitic	4, 800–4, 805
Shale, dark gray to black, some sandy, glauconitic; trace of sand, gray, calcareous, glauconitic; trace of limestone, brown, crystalline, sandy, glauconitic	4, 805–4, 815
Core: 5 feet recovery; black shale; not able to determine dip	4, 815–4, 822
Shale, black, micaceous, some dark gray, soft, trace of sand, glauconitic; trace of black slick shale	4, 822–4, 860
Lime, blue, sandy, shaly, glauconitic; some shale, black	4, 860–4, 905

Log of John Thompson No. 1 well, center of S½ sec. 34, T. 2 N., R. 9 E., at Centrahoma, Coal County, Okla.—Continued

	Feet
Springer formation—Continued.	
Core: 4 feet recovery; lime, blue, blue gray, shaly, sandy, glauconitic; black glauconitic shale streaks; dips 7° to 15° (most of the dips are 13°)	4, 897–4, 902
Core: 7 feet recovery; sandstone, medium to coarse, calcareous, glauconitic, soft in lower part, with shale streaks; light show of gas; small show of oil; dip 13°; black lignitic shale streaks	4, 905–4, 913
Core: 5½ feet recovery; top 4 feet sand, gray, medium, calcareous, glauconitic, lignitic streaks; smell of oil; 1½-feet of shale, gray to black, sandy, glauconitic, dip 13° to 15°	4, 915–4, 922
Shale, black, micaceous; some sand, gray, medium, calcareous, glauconitic	4, 922–4, 935
At 4,930 feet ran sand tester with wall packer; no show, no shut-off.	
Core: 5½ feet recovery; sand, gray, medium, calcareous, glauconitic; black shale streaks, dip 14°; light oil stain, good odor; show of gas	4, 935–4, 944
Core: 2½ feet recovery; top 6 inches black shale, bottom 2 feet sandstone, gray, medium, glauconitic, calcareous, light stain, fair odor	4, 944–4, 952
Core: 8 feet recovery; top 4 inches sand, gray, medium, light stain, fair odor; bottom 7 feet 8 inches shale, black, sandy, glauconitic, with shells of gray medium sand	4, 952–4, 961
Core: 9 feet recovery; top 7 feet shale, black, sandy, glauconitic, dip 14°; bottom 2 feet sandstone, gray, medium, glauconitic, oil-stained, fair odor	4, 961–4, 975
Steel-line correction, 4,975=4,981 feet.	
Core: 6 feet recovery; sand, gray, coarse, shaly, glauconitic, slightly lignitic; light oil stain, show of gas; ran sand tester with cone packer at 4,981 feet; good shut-off, no show	4, 981–4, 992
Core: 7½ feet recovery; top 2½ feet shale, black, sandy, glauconitic; brown crystalline limestone breaks; bottom 5 feet sandstone gray, coarse, glauconitic, slightly marly; fair light oil stain, good odor; show of gas	4, 992–5, 001
Core: 6½ feet recovery; shale, dark, very sandy, glauconitic; some thin sand lenses; bottom 1 foot black shale	5, 001–5, 010
Core: 8 feet recovery; top 7½ feet sandstone, gray, coarse, shaly, glauconitic; light smell of oil; bottom 6 inches sandstone, gray, coarse; good stain and light odor	5, 010–5, 020
Shale, black, slightly sandy; some sandstone, medium shaly, glauconitic	5, 001–5, 020
Shale, black, sandy, glauconitic	5, 020–5, 140

Log of John Thompson No. 1 well, center of S½ sec. 34, T. 2 N., R. 9 E., at Centrahoma, Coal County, Okla.—Continued

	Feet
Springer formation—Continued.	
Shale, black, slightly sandy	5, 140–5, 280
Shale, black; trace of limestone, brown, black, dolomitic	5, 280–5, 290
Shale, black, trace of sand; traces of black dolomitic limestone, trace of siderite	5, 290–5, 425
Caney shale (top uncertainly placed):	
Shale, black, brown black; trace of siderite	5, 425–5, 480
Shale, black, some sandy, gritty, micaceous	5, 480–5, 495
Limestone, gray, gritty, micaceous	5, 495–5, 500
Shale, black; a little limestone, gray, gritty, micaceous	5, 500–5, 630
Shale, brown, dark brown, cherty; some glauconitic limestone	5, 630–5, 635
Woodford chert (?):	
Shale, dark brown and some black; trace of siderite	5, 635–5, 683
Core: 3 feet recovery; shale, brown, poorly developed spores; dip 15°	5, 683–5, 689
Shale, black, some brown; trace of siderite	5, 690–5, 735
Hunton limestone:	
Core: 1 foot recovery; shale, brown and black; poorly developed spores	5, 735–5, 739
Steel-line correction, 5,772=5,752 feet.	
Limestone, grayish white, coarse and fine crystalline	5, 735–5, 755
Core: 5 feet recovery; limestone, gray, coarse crystalline, some fine crystalline, highly fractured and veined; light show of gas; light smell of oil	5, 755–5, 765
Core: 3 feet recovery; limestone, blue gray, fine granular crystalline, some fracturing, dip not determined; show of gas; smell of oil, no staining (Haragan shale)	5, 765–5, 774
Limestone, gray, granular, crystalline	5, 774–5, 781
Core: 6½ feet recovery; limestone, blue, fine granular, crystalline, some fracturing	5, 781–5, 788
Limestone, gray, fine granular	5, 788–5, 855
Limestone, white and pink, coarse crystalline (Chimney Hill limestone)	5, 855–5, 858
Core: 3 feet recovery; top, limestone, white and pink, coarse crystalline; base, limestone, white, crystalline; trace of glauconite	5, 858–5, 869
Core: 1 foot recovery; limestone, gray, crystalline, cherty	5, 869–5, 871
Core: 1 foot recovery; limestone, gray, crystalline, cherty; trace of glauconite; spotty light oil stain	5, 871–5, 873

Log of John Thompson No. 1 well, center of S½ sec. 34, T. 2 N., R. 9 E., at Centrahoma, Coal County, Okla.—Continued

	Feet
Hunton limestone—Continued.	
Core: 8 feet recovery; top, 6 inches limestone, gray, crystalline, glauconitic, show of oil; middle, 5½ feet limestone, gray, crystalline, oolitic, dark oil stain along fractures, some joint planes; basal, 2 feet shale, green, green gray, dip 15° at contact	5, 873–5, 883
Sylvan shale:	
Core: Shale, green, green gray, dip 15° at contact	5, 881–5, 883
Shale, green gray	5, 883–5, 970
Viola limestone:	
Limestone, gray and pink mottled, coarse crystalline	5, 970–5, 985
Limestone, white, coarse crystalline, trace of dark burnt stain	5, 985–6, 030
Limestone, gray, coarse crystalline, some fine crystalline, slightly sandy; trace of dark stain; smell of gas in cuttings	6, 030–6, 046
Core: 4 feet recovery; lime, brown, medium and coarse crystalline, slightly sandy; some spotty dark oil stain, smell of oil, show of gas	6, 046–6, 056
Lime, brown and gray, crystalline, slightly sandy; trace of dark oil stain, smell of gas	6, 056–6, 063
Core: 2 feet recovery; lime, brown, fine crystalline, some coarse crystalline; trace of dark oil stain, smell of oil	6, 063–6, 073
Limestone, brown, fine and medium crystalline; trace of dark oil stain; trace of asphalt	6, 073–6, 075
Limestone, brown and gray, fine crystalline; trace of dark stain	6, 075–6, 090
Limestone, brown and gray, crystalline, cherty; trace of dark stain; smell of oil in wet cuttings	6, 090–6, 095
Limestone, brown and gray, crystalline; trace of dark stain	6, 095–6, 120
Limestone, gray, medium to coarse crystalline; a little black shale	6, 120–6, 125
Limestone, gray, medium and coarse crystalline; trace of dark asphaltic oil stain	6, 125–6, 130
Limestone, grayish white, coarse crystalline	6, 130–6, 140
Limestone, grayish white, coarse crystalline; small oil show	6, 140–6, 145
Limestone, brown, crystalline, slightly argillaceous and sandy, oil-stained; good odor	6, 145–6, 155
Core: 2½ feet recovery; top, limestone, brown, crystalline, coarse, soft, slightly argillaceous, sandy, oil-stained, good odor; base, limestone, brown, fine crystalline, oil-stained, fair odor	6, 150–6, 155
Core: 3 feet recovery; limestone, brown, fine crystalline, some medium crystalline; spotty brown oil stain; smell of oil; small show of gas, dip 30°	6, 155–6, 160

Log of John Thompson No. 1 well, center of S½ sec. 34, T. 2 N., R. 9 E., at Centrahoma, Coal County, Okla.—Continued

	Feet
Viola limestone—Continued.	
Limestone, brown and gray, fine crystalline, slightly sandy; some coarse crystalline; oil-stained; fair odor of oil	6, 160–6, 180
Limestone, brown and gray, crystalline, dolomitic; trace of asphalt; a little shale, black, calcareous	6, 180–6, 190
Limestone, brown, black-brown, medium, some fine to dense crystalline, dolomitic; trace of asphalt; some shale, black, calcareous; trace of chert	6, 190–6, 205
Limestone, brown, brown black, fine crystalline, dolomitic, some gray, coarse crystalline; trace of asphalt; some shale, black, calcareous	6, 205–6, 215
Limestone, black, finely crystalline, dolomitic; trace of asphalt; some shale, black, calcareous	6, 215–6, 220
Limestone, brown, dense	6, 220–6, 225
Simpson group (Bromide formation of Decker):	
Limestone, grayish white, dense; some brown, dense	6, 225–6, 230
Limestone, gray, medium to coarse crystalline; some gray and brown, dense; bailed down, had 125-feet 38° gravity oil in hole	6, 230–6, 235
Core: 1 foot recovery; limestone, gray, coarse crystalline; spotty stain; light show of gas, smell of oil	6, 235–6, 244
Limestone, gray and brown, coarse crystalline; trace of embedded rounded sand	6, 244–6, 250
Limestone, gray and brown, coarse crystalline; trace of embedded coarse sand; smell of oil in wet cuttings; trace of gray-white dense limestone	6, 250–6, 255
Limestone, gray, coarse crystalline; some embedded coarse sand	6, 255–6, 260
Limestone, gray, coarse crystalline; some dark brown, granular, dolomitic; trace of embedded sand	6, 260–6, 265
Limestone, gray, fine granular, dolomitic; some embedded sand; some brown and gray dense limestone	6, 265–6, 270
Limestone, brown and gray, crystalline; some embedded sand; some brown, dense	6, 270–6, 280
Dolomite, gray, fine granular; trace of sand; trace of brown dense limestone	6, 280–6, 290
Dolomite, gray, fine granular, slightly sandy; a little sandstone, coarse, calcareous	6, 290–6, 305
Limestone, brown and gray, fine granular, crystalline, dolomitic, sandy	6, 305–6, 310
Limestone, gray, green gray, crystalline, dolomitic	6, 310–6, 315

Log of John Thompson No. 1 well, center of S½ sec. 34, T. 2 N., R. 9 E., at Centrahoma, Coal County, Okla.—Continued

Simpson group (Bromide formation of Decker)—Con.	Feet
Limestone, gray, crystalline, sandy, slightly oolitic	6,315–6,320
Limestone, gray, crystalline, dolomitic, slightly sandy and shaly	6,325–6,335
Limestone, gray, crystalline, dolomitic, sandy	6,335–6,340
Limestone, gray, medium and coarse, crystalline, sandy	6,340–6,345
Limestone, gray, crystalline, slightly sandy and dolomitic; shale, dark green	6,345–6,350
Dolomite, gray, fine granular, crystalline; trace of sand; trace of green shale	6,350–6,355
Dolomite and dolomitic limestone, gray, granular, sandy	6,355–6,360
Limestone, brown, dense; some brown dolomite, gray, fine granular, slightly sandy	6,360–6,370
Dolomite, gray, fine granular, slightly sandy	6,370–6,375
Dolomite and dolomitic limestone, gray, slightly sandy; some limestone, brown, dense	6,375–6,390
Limestone, brown, dense	6,390–6,395
Dolomite, brown, some green, fine granular, crystalline; trace of green shale; trace of white sandy limestone	6,395–6,400
Limestone, brown, dense; some gray dolomitic; trace of sandstone, medium, calcareous	6,400–6,405
Limestone, brown, dense, trace of gray, dense	6,405–6,410
Dolomite, gray, fine granular; smell of oil; a little limestone, brown, dense	6,410–6,415
Dolomite, gray, fine granular; trace of brown dense lime	6,415–6,420
Dolomite, brown, fine granular; sand; slight stain and smell of oil	6,420–6,425
Limestone, gray, medium crystalline, sandy (5 percent of sand)	6,425–6,430
Limestone, gray, crystalline, sandy and shaly, dolomitic; trace of brown dense limestone	6,430–6,435
Limestone, gray, crystalline, sandy (10 percent sand); some brown dense limestone	6,435–6,440
Limestone, brown, dense; trace of gray, dense	6,440–6,460
Limestone, gray, dense; some dolomite, gray, fine granular, slightly sandy	6,460–6,465
Sandstone, coarse, dolomitic, tight; light oil stain; gasoline odor	6,465–6,467
Core: 4 feet recovery; sandstone, coarse, dolomitic; fair show of gas; light oil stain, smell of oil	6,467–6,471
Limestone, light brown, dense	6,471–6,474
Limestone, gray, crystalline, highly dolomitic and sandy; some brown dense limestone	6,474–6,480
Sandstone, coarse, calcareous; light oil stain, no odor	6,480–6,485

Log of John Thompson No. 1 well, center of S½ sec. 34, T. 2 N., R. 9 E., at Centrahoma, Coal County, Okla.—Continued

Simpson group (Bromide formation of Decker)—Con.	*Feet*
Limestone, brown, some gray, dense; dolomite, gray, fine granular	6, 485–6, 490
Dolomite, gray, fine granular	6, 490–6, 495
Dolomite, light gray, fine granular	6, 495–6, 500
Dolomite, light gray, granular, slightly sandy	6, 500–6, 505
Sandstone, coarse, calcareous, oil-stained, light odor	6, 505–6, 508
Steel-line correction, 6,508=6,526 feet.	
Core: 4 feet recovery; top, 2-foot dolomite, gray, fine granular, with sand streaks, spotty show of oil; 20-inch dolomite, gray, fine granular; bottom, 6-inch limestone, brown, dense, dip 20°	6, 526–6, 530
Dolomite, gray, fine granular, small show of oil; trace of sandstone, coarse, dolomitic, show of oil; small trace of green shale and dense limestone	6, 530–6, 543
Dolomite, green gray, some gray, granular, crystalline; trace of dolomitic sand; green shale and dense limestone	6, 543–6, 550
Dolomite, green gray, granular, slightly shaly; trace of sand; trace of green shale	6, 550–6, 570
Dolomite, green gray, shaly, slightly sandy; trace of dense limestone	6, 570–6, 585
Dolomite, green, shaly, slightly sandy; small show of oil; trace of dense limestone	6, 585–6, 590
Limestone, brown, dense; small show of oil along fractures and joint planes	6, 590–6, 605
Limestone, brown, bluish gray, dense	6, 605–6, 640
Limestone, gray, dense; some dolomite, gray, granular	6, 640–6, 645
Limestone, gray, dense; some white, dense	6, 645–6, 655
Sandstone, medium to coarse, highly calcareous; small show of oil	6, 655–6, 660
Sandstone, coarse, calcareous; light stain and light odor	6, 660–6, 665
Dolomite, green, granular, sandy	6, 665–6, 668
Limestone, white, dense; sandstone, coarse; light stain and odor	6, 668–6, 670
Limestone, gray and brown, dense; some sandstone; coarse dolomite; small show of oil	6, 670–6, 675
Dolomite, gray, granular, sandy; small show of oil	6, 675–6, 680
Sandstone, fine to medium; dolomite; some light stain	6, 680–6, 685
Sandstone, medium, dolomitic; light stain, slight odor	6, 685–6, 690
Sandstone, medium to coarse, dolomitic; oil-stained	6, 690–6, 699
Core: 5 feet recovery; sandstone, gray, coarse; light stain, light odor; estimated porosity 12–15 percent	6, 699–6, 705

Log of John Thompson No. 1 well, center of S½ sec. 34, T. 2 N., R. 9 E., at Centrahoma, Coal County, Okla.—Continued

	Feet
Simpson group (Bromide formation of Decker)—Con.	
Core: 5-feet recovery; sandstone, gray, medium to coarse, uniform; light stain and light odor; estimated porosity 10–12 percent	6, 705–6, 710
At 6,710 feet tested and had salt water.	
Sandstone, coarse, porous; light stain (poor sample)	6, 710–6, 725
Sandstone, medium to coarse; dark stain (sample in place?)	6, 725–6, 730
Sandstone, medium to coarse; light stain, some dark stain; light smell of oil	6, 730–6, 735
Tested at 6,731 feet and had 5,700 feet of salt water.	
Core: 1 foot recovery; dolomite, gray, granular, slightly sandy with green shale streaks; light stain and smell of oil	6, 735–6, 733
Sandstone, gray, medium, very dolomitic; light stain	6, 733–6, 737
Sandstone, medium, dolomitic; some limestone, gray, dense	6, 737–6, 750
Dolomite, gray, granular, sandy; some limestone, gray, dense	6, 750–6, 760
Dolomite, gray, green gray, granular, sandy	6, 760–6, 770
Dolomite, green, green gray, shaly	6, 770–6, 775
Dolomite, gray, sandy, slightly shaly; a little sandstone, medium, dolomitic; small show of oil	6, 775–6, 785
Sandstone, fine to medium, dolomitic; some sandy dolomite and green shale	6, 785–6, 790
Dolomite, green, shaly; a little dolomitic sand	6, 790–6, 795
Dolomite, green, shaly; some green shale	6, 795–6, 810
Sandstone, fine to medium, dolomitic; small show of oil	6, 810–6, 815
Dolomite, gray, granular sandy; small show of oil; some green shale	6, 815–6, 820
Sandstone, medium, dolomitic; small show of oil; some shale, dark green, slick	6, 820–6, 825
Sandstone, fine to medium, dolomitic; some sandy dolomite and green shale	6, 825–6, 830
Sandstone, gray, fine to medium, dolomitic; some green shale	6, 830–6, 835
Dolomite, gray, green gray, very sandy; some shale, green, calcareous	6, 835–6, 840
Dolomite, gray, granular, sandy; some limestone, brown, finely crystalline; some green shale	6, 840–6, 845
Limestone, brown, dense; dolomite, gray, green gray, sandy, slightly shaly	6, 845–6, 855
Dolomite, brown, granular, sandy; some limestone, brown, dense	6, 855–6, 860
Shale, green, calcareous; some sandstone, coarse, dolomitic	6, 860–6, 870

Log of John Thompson No. 1 well, center of S½ sec. 34, T. 2 N., R. 9 E., at Centrahoma, Coal County, Okla.—Continued

	Feet
Simpson group (Bromide formation of Decker)—Con.	
Shale, dark green, calcareous; some sandstone, coarse, dolomitic, tight, slightly conglomeratic	6, 870–6, 880
Sandstone, fine to medium and coarse, highly dolomitic; some sandy limestone and some green shale	6, 880–6, 885
Limestone, gray, crystalline, sandy, dolomitic; a little green shale	6, 885–6, 895
Limestone, gray, crystalline, sandy; some green shale; a little sandstone, coarse, dolomitic; small show of oil	6, 895–6, 900
Limestone, gray, crystalline, sandy, dolomitic, some green shale and tight dolomitic sand	6, 900–6, 920
Limestone, gray, crystalline, sandy, dolomitic; trace of dark-green shale and tight sand; show of oil	6, 920–6, 930
Sandstone, medium, dolomitic; light stain, smell of oil; a little sandy limestone and green shale	6, 930–6, 945
Limestone, gray, crystalline, sandy, shaly; some sandstone, medium, dolomitic; small show of oil	6, 945–6, 955
Sandstone, fine to medium, dolomitic, rather tightly cemented	6, 955–6, 965
Sandstone, medium and coarse, dolomitic, light stain; estimated porosity 10 percent	6, 965–6, 970
Sandstone, fine to medium, dolomitic, tight; small show of oil	6, 970–6, 975
Sandstone, medium and coarse, slightly dolomitic; estimated porosity 15 percent; residue stain	6, 975–6, 980
Sandstone, medium, calcareous, tight; small show of oil	6, 980–6, 990
Sandstone, medium, porous; some dead oil stain	6, 990–6, 995
Sandstone, medium, calcareous	6, 995–7, 005
Sandstone, medium and coarse, aggregated	7, 005–7, 015
Limestone, light gray, dense	7, 015–7, 030
Sandstone, medium, calcareous	7, 030–7, 035
Missing	7, 035–7, 040
Sandstone, medium, calcareous; trace of dark-green shale	7, 040–7, 045
Sandstone, medium, calcareous; a little gray dense limestone and dark-green shale	7, 045–7, 055
Sandstone, medium, porous; light stain of dead oil	7, 055–7, 060
Sandstone, medium, calcareous; estimated porosity 10 percent	7, 060–7, 070
Sandstone, medium, calcareous; a little fine granular dolomite	7, 070–7, 075
Sandstone, medium, calcareous; estimated porosity 10 percent	7, 075–7, 080

Log of John Thompson No. 1 well, center of S½ sec. 34, T. 2 N., R. 9 E., at Centrahoma, Coal County, Okla.—Continued

Simpson group (Bromide formation of Decker)—Con.	Feet
Limestone, gray, dense; some sandstone, medium dolomitic	7, 080–7, 085
Sandstone, medium, some dolomitic; some dense lime	7, 085–7, 090
Dolomite, white, fine crystalline; some sandstone, medium and coarse, dolomitic	7–090–7, 095
Sandstone, medium, slightly dolomitic; some white dolomite	7–095–7, 105
Sandstone, medium to coarse, slightly dolomitic	7, 105–7, 115
Sandstone, medium to coarse, calcareous	7, 115–7, 120
Sandstone, medium to coarse, calcareous; a little dolomite, green gray, crystalline, shaly; trace of green shale	7, 120–7, 126
Total depth, 7,126 feet; plugged back to 6,510 feet.	

Following is the log filed with the Oklahoma Corporation Commission on the well that was drilled south of Olney. The altitude above sea level at the mouth of the well is about 575 feet. From 50 to 2,530 feet in depth probably all the rocks passed through belong to the Atoka formation.

Log of Travelers Life Insurance Co. well no. 1, SW¼NW¼SE¼ sec. 28, T. 1 S., R. 9 E., Coal County, Okla.

[Owned by Amerada Petroleum Corporation. Drilling begun June 12, 1935; completed Aug. 14, 1935]

	Feet	
Surface clay	0–30	
Gravel	30–50	
Shale	50–110	
Gravel	110–160	
Shale	160–260	
Gravel-sand	260–290	
Broken sand and shale	290–515	
Sand, lime	515–630	
Sand	630–820	
Sand, shale	820–830	
Sand	830–945	
Shale	945–1, 200	
Shale and sand	1, 200–1, 415	
Shale	1, 415–1, 700	
Sandy shale	1, 700–1, 815	
Shale	1, 815–2, 050	
Shale, sand	2, 050–2, 105	
Shale	2, 105–2, 335	
Sand, hard	2, 335–2, 365	
Sand, shale	2, 365–2, 415	
Sand	2, 415–2, 440	
Sand, shale	2, 440–2, 515	
Shale	2, 515–2, 530	
Lime, Wapanucka	2, 530–2, 670	270 (2,530–2,800)
Broken lime and shale	2, 670–2, 718	
Lime	2, 718–2, 730	
Lime, shale, and sand	2, 730–2, 768	
Broken lime and shale	2, 768–2, 800	
Shale	2, 800–2, 838	
Sand, hard	2, 838–2, 878	
Broken lime and shale	2, 878–2, 900	
Caney	2, 900–3, 810	910
Mayes	3, 810–3, 890	80
Woodford	3, 890–4, 065	265
Hunton	4, 065–4, 320	255
Sylvan	4, 320–4, 467	147
Viola	4, 467–4, 770	303
Bromide	4, 770–4, 790	20
Asphalt	4, 790–4, 810	20
Bromide	4, 810–4, 825	15
Asphalt	4, 825–4, 885	60
Bromide	4, 885–5, 115	230
McLish	5, 115–5, 392	277
Burgen	5, 392–5, 416	24

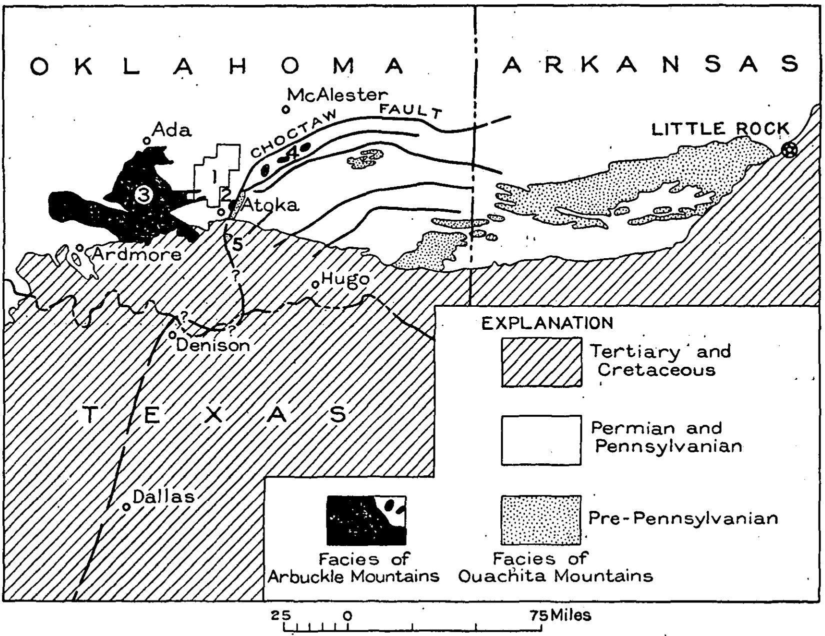

FIGURE 7.—Map showing areal distribution of rock exposures in portions of Oklahoma, Arkansas, and Texas, illustrating the probability that the Lehigh district is wholly underlain by pre-Pennsylvanian rocks of the sequence exposed in the Arbuckle Mountains and the Ti Valley-Choctaw belt. 1, Lehigh district. 2, Black Knob Ridge segment of Choctaw fault; Ordovician of Ouachita sequence on east side of fault is in juxtaposition with Mississippian and Pennsylvanian rocks of facies of Arbuckle Mountains on west side of fault. 3, Arbuckle Mountain region. 4, Small areas of Devonian and Mississippian rocks of facies of Arbuckle Mountains lying between Choctaw and Ti Valley faults. 5, Small exposure of Ordovician rocks of facies of Ouachita Mountains in Frounterhouse Creek.

The sequence (fig. 7) of the pre-Pennsylvanian sedimentary rocks exposed in Black Knob Ridge [39a] and eastward in the Ouachita Mountains differs from the sequence that represents the same portion of the Paleozoic era in the Arbuckle uplift. In the Ti Valley-Choctaw belt, described by Miser [40] as extending along the frontal margin of the Oklahoma salient of the Ouachita Mountains from Stringtown to the Arkansas boundary, the outcropping sequence from the Woodford chert (Devonian ?) to the Atoka formation (Pennsylvanian) is similar to the sequence of rocks of equivalent age in the Arbuckle uplift. A normal section of the Arbuckle sequence of rocks was encountered in the Hansen et al. well [41] in the SE¼NW¼ sec. 17, T. 4 S., R. 11 E., in the Gulf Coastal Plain about 13 miles south of Atoka. The Pennsylvanian Springer formation and the Mississip-

[39a] Hendricks, T. A., Knechtel, M. M., and Bridge, Josiah, Geology of Black Knob Ridge, Okla.: Am. Assoc. Petroleum Geologists Bull., vol. 21, no. 1, pp. 1–29, January 1937.

[40] Miser, H. D., Carboniferous rocks of Ouachita Mountains: Am. Assoc. Petroleum Geologists Bull., vol. 18, no. 8, pp. 973–979, August 1934.

[41] Miser, H. D., Pre-Cretaceous rocks found in wells in Gulf Coastal Plain south of Ouachita Mountains: Am. Assoc. Petroleum Geologists Bull., vol. 15, no. 7, pp. 804–808, July 1931.

pian Caney shale of the Arbuckle sequence crop out on the west side of the Choctaw fault south of Stringtown and are in faulted contact with shale of Ordovician age of the Ouachita sequence. The areal distribution of the formations, as thus outlined, considered together with the structural relations along the Ti Valley and Choctaw faults, indicates that the Ouachita and Arbuckle sequences of rocks were originally more or less distantly separated and were brought together by late Paleozoic thrusting from the southeast.

PENNSYLVANIAN ROCKS

The Springer formation (Pennsylvanian) and the Wapanucka limestone (Pennsylvanian), like the pre-Pennsylvanian formations of the facies of the Arbuckle Moutains, differ lithologically and faunally from the sequence of rocks (Stanley, Jackfork, Johns Valley) representing the same general geologic time interval in the area east of Black Knob Ridge. The Springer and Wapanucka have been observed in the Lehigh district only in the small area in which they crop out near the west line of T. 1 S., R. 9 E., and in the cuttings from the Centrahoma and Olney wells, as set forth in the logs given above. They are present in the Ti Valley-Choctaw belt, to the east, and in the Arbuckle uplift, to the west. It is therefore assumed that the Springer is present beneath the surface in all parts of the district in which Wapanucka and younger formations are mapped on plate 11. The Wapanucka limestone, however, may be absent in some places, as Miser and Hendricks[42] report that it is apparently absent in the section overlying the Springer in North Boggy Creek in sec. 29, T. 1 S., R. 12 E., about 4½ miles east of the Lehigh district.

It is almost certain that the Atoka formation, which is widely exposed both in the Ouachita Mountains and in the Arkansas-Oklahoma coal basin, occurs beneath all the areas in which younger rocks are mapped on plate 11. This view is supported by data from wells drilled in widely distributed localities within those areas. The Hartshorne and younger formations, outcrops of which are confined to the coal basin, are likewise believed to extend under all parts of the district from which they have not been removed by erosion.

ORIGIN OF THE PENNSYLVANIAN ROCKS

The southeastward coarsening and thickening of the sandstone beds of the Pennsylvanian formations of the Lehigh district indicate that most if not all of the sediments that compose those formations were transported from the southeast or south to the basin in which they were deposited. Most of the materials of the Atoka formation were furnished by the land area, Llanoria, that existed during most of the Paleozoic era in Louisiana and Texas and probably at times

[42] Hendricks, T. A., Knechtel, M. M., and Bridge, Josiah, op. cit., p. 14.

extended into southern Oklahoma and southern Arkansas.[43] Llanoria was probably also the source of some of the Hartshorne and younger sediments. The sediments, however, probably were derived in part from uplifted and exposed earlier Paleozoic sedimentary rocks of the facies of the Ouachita Mountains that had been deposited in the Llanoria geosyncline, which lay north of Llanoria. Part of the sediments may have been derived from rocks of the Arbuckle and adjoining areas.

Beginning with orogenic movements that occurred immediately prior to Atoka time and continuing through most of the period of downward warping in the Arkansas-Oklahoma coal basin, a land area lay southeast and south of the Lehigh district. During the deposition of a large part of the Atoka formation the northern boundary of the land lay far to the south, possibly in northern Texas, but by the end of Atoka time it may have shifted northward to a position in Oklahoma somewhere within the area occupied by the present Ouachita Mountains, there to remain during a large part of Allegheny time. Within the land area pre-Carboniferous sedimentary rocks of the Ouachita Mountains facies of sedimentation were extensively exposed, as indicated by cherty conglomerates in the Strawn group of Texas, the lower and middle units of which are believed by Moore[44] to be equivalent in age to the formations of the Arkansas-Oklahoma coal basin. Pebbles in the Brazos River and Turkey Creek sandstone members of the Strawn are regarded by Bay[45] as having been transported westward from formerly uplifted rocks of Ouachita facies now buried under deposits of the Coastal Plain south of the Oklahoma portion of the present Ouachita Mountains. Erosion of the rocks of this former vast land area probably produced most of the loose materials that were carried by streams and redeposited as sediments in the Arkansas-Oklahoma coal basin.

Atoka and younger sandstone beds that are conglomeratic in the southeastern part of the Lehigh district are described on preceding pages of this report. The rock fragments in the conglomeratic portions of these beds are composed predominantly of chert, which must have been transported in Pennsylvanian time from older formations exposed to the southeast. The Woodford chert (Devonian?) and Pine Top chert (Middle Devonian) of the Ti Valley-Choctaw sequence appear to be capable of yielding much cherty debris. The Arkansas novaculite (Devonian) of the Ouachita sequence, however,

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[43] Miser, H. D., Llanoria, the Paleozoic land area in Louisiana and eastern Texas: Am. Jour. Sci., 5th ser., vol. 2, pp. 61–89, August 1921.

[44] Moore, R. C., Late Paleozoic crustal movements of Europe and North America: Am. Assoc. Petroleum Geologists Bull., vol. 19, no. 9, p. 1265, September 1935.

[45] Bay, H. X., A study of certain Pennsylvanian conglomerates of Texas: Texas Univ. Bull. 3201, pp. 149–188, February 1933.

would have been a productive source, and the Bigfork chert (Ordovician) of the Ouachita sequence might have furnished some. The derived coarse cherty material in the conglomeratic layers in the coal-basin formations might be expected in either case to diminish northward, and this is what actually occurs, such material not being present in large amount in the part of the coal basin northeast of the neighborhood of Stringtown.

The Bigfork chert (Ordovician) and the Arkansas novaculite (Devonian) are well exposed in Black Knob Ridge, which might therefore seem to be the obvious source of the chert fragments. Most geologists, however, now believe that the rocks exposed in Black Knob Ridge were deposited as sediments many miles southeast of their present location and were brought here by overthrusting in late Pennsylvanian time. That the coarse cherty material in the rocks of the coal basin is abundant only in the part of the basin adjacent to the extensive novaculite and Bigfork chert exposures along Black Knob Ridge must therefore be regarded as fortuitous, because the ridge did not exist while the rocks of the coal basin were being deposited. At that time the coal basin probably extended eastward beyond the site of the present ridge.

Prior to Atoka time only a moderate thickness of Carboniferous rocks, all of them of the general facies of the early Carboniferous of the region surrounding the Arbuckle Mountains, had been deposited in the Lehigh district. On the other hand, strong downward warping movements farther southeast had permitted accumulation of the enormously thick clastic deposits of the Stanley and Jackfork formations, of Pennsylvanian age, which together are believed to be equivalent in age to the relatively thin Springer formation, part of which is exposed in the western part of the Lehigh district and in the Ti Valley-Choctaw belt. In early Atoka time these rapid sinking movements spread northward, and the Lehigh district, becoming involved in the general subsidence, received thousands of feet of clastic sediments of the Atoka, Hartshorne, McAlester, Savanna, Boggy, and Thurman formations.

STRUCTURE

General features.—The Pennsylvanian rocks that were deposited in the Lehigh district were later extensively folded and to a less degree faulted. Most of the district lies within a larger area of folded Pennsylvanian rocks of the Arkansas-Oklahoma coal basin adjacent to the arcuate frontal margin of the Ouachita Mountains. The larger area is referred to by some writers as the "open-fold zone." In the Lehigh and McAlester districts the open-fold zone trends northeastward. East of the McAlester district it trends eastward and extends into western Arkansas. According to Van der Gracht[46] it is present in north-central Texas under a cover of Cretaceous deposits of the Gulf Coastal Plain. In Oklahoma it ranges in width from about 10 to 35 miles. Northwest of the open-fold zone in the region north of the Lehigh district the middle and late Pennsylvanian rocks dip regionally northwestward at low angles.

The most characteristic structural features of the open-fold zone are broad flat synclines and relatively narrow anticlines. The axes of these folds are in general parallel to the frontal margin of the Ouachita Mountains, and their direction in the Lehigh district is therefore northeastward. The rock strata exposed on several anticlines of the open-fold zone, including three of those in the Lehigh district, dip gently outward on both sides of the axis, but half a mile or more from the axis they bend abruptly downward at steep angles on both sides of the anticline.

Hendricks[47] believes that structural thickening and thinning of the rocks, particularly the shales, occur in several closely folded anticlines in the McAlester district, but no evidence of this phenomenon seems to be present in the Lehigh district.

The structure of the open-fold zone is principally related to deformational movements, probably in Pennsylvanian time, involving horizontal compressive forces directed northwestward and accompanied by overthrusting in the Ouachita region. The structure of the southwestern part of the Lehigh district, however, appears to have been modified by uplift in Pennsylvanian time, which also affected the rocks of the Ardmore Basin and the Arbuckle Mountains.

For general discussions and bibliographies concerning the stratigraphy and structure of the Arbuckle and Ouachita Mountains, the reader is referred to papers by Miser,[48] Powers,[49] Van der Gracht,[50] Tomlinson,[51] and Dott.[52]

Several anticlines, synclines, and faults that have been recognized in the Lehigh district are described below.

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[46] Van der Gracht, W. A. J. M. van Waterschoot, Permo-Carboniferous orogeny in south-central United States: Am. Assoc. Petroleum Geologists Bull., vol. 15, no. 9, p. 1046, September 1931.

[47] Hendricks, T. A., op. cit. (Bull. 874–A).

[48] Miser, H. D., Carboniferous rocks of Ouachita Mountains: Am. Assoc. Petroleum Geologists Bull., vol. 18, no. 8, pp. 971–1009, August 1934.

[49] Powers, Sidney, Age of the folding of the Oklahoma mountains—the Ouachita, Arbuckle, and Wichita Mountains of Oklahoma and the Llano-Burnet and Marathon uplifts of Texas: Geol. Soc. America Bull., vol. 39, pp. 1039–1072, 1928.

[50] Van der Gracht, W. A. J. M. van Waterschoot, op. cit., pp. 991–1057.

[51] Tomlinson, C. W., Oil and gas geology of Carter County: Oklahoma Geol. Survey Bull. 40–Z, 1928.

[52] Dott, R. H., Overthrusting of Arbuckle Mountains, Oklahoma: Am. Assoc. Petroleum Geologists Bull., vol. 18, no. 5, pp. 567–602, May 1934.

Centrahoma dome.—The Centrahoma dome lies in the south half of T. 2 N., R. 9 E., where the rocks exposed at the surface dip outward in all directions from a point half a mile south of the town of Centrahoma. These rocks were formerly assigned by the writer and by Taff to the Boggy shale, but their lithology and the depth at which the Lehigh coal was encountered in wells drilled on the dome indicate that they belong to the Savanna sandstone. At most points the beds involved are inclined at angles of less than 10° from the horizontal, but at a few places they dip more steeply. Near the center of sec. 28, for example, a dip of 25° NW. was recorded, and in the SW¼ sec. 26 a sandstone bed dips 24° E. The outcrops of the beds involved in the folding appear to terminate at a line trending in a northeasterly direction along the east side of the dome. East of this line are extensive areas of nearly horizontal strata. A fault has been tentatively drawn along this line on the map (pl. 11), though the relations along it might perhaps be equally well explained by unconformity and westward overlap of the flat-lying beds on the tilted beds of the dome.

Of five wells drilled on the Centrahoma dome, one reached the Simpson group (Ordovician). Four finished in the Pennsylvanian, and two of these are gas wells. The gas has not been marketed. Further data on these wells are given on pages 142–143.

Ashland anticline.—The Ashland anticline enters the Lehigh district from the west, trends northeastward across T. 3 N., R. 11 E., and dies out in the east half of T. 3 N., R. 12 E. The highest point on the axis of the anticline, as exposed at the surface, lies within an area in which rocks belonging to the McAlester shale crop out near the line between Rs. 11 and 12 E. Beds of the overlying Savanna sandstone, which crop out in a surrounding belt, and of the succeeding Boggy shale, which closes around the southwest end but not the northeast end of the anticline, dip away in all directions with reference to this area at angles that vary from place to place. The steepest dips occur on the northwest side of the anticline in a narrow belt and are indicated on the accompanying map by close spacing of the structure contours. In this belt dips ranging from 15° to 90° have been recorded in the Savanna and basal Boggy beds. A zone of steeply dipping rocks involving beds at the same stratigraphic horizons occurs on the south side of the anticline along the south boundary of T. 3 N., R. 11 E. The strata exposed at all other points on the Ashland anticline are inclined at angles of less than 15° from the horizontal. The structural closure in the Ashland anticline is estimated at 1,000 feet. Gas has been encountered in Hartshorne and McAlester beds at depths ranging from 313 to 1,379 feet in several wells drilled within the area in which the McAlester shale comes to the surface. The gas has not been commercially developed.

Savanna anticline.—The Savanna anticline of the McAlester district extends westward about 1½ miles into the Lehigh district and dies out at a point in the southeastern part of T. 3 N., R. 12 E., south of the east end of the Ashland anticline.

Coalgate anticline.—The Coalgate anticline begins at the Phillips fault, near the north line of T. 1 S., R. 10 E. Its axis plunges northeastward from the fault to a point about half a mile north of the town of Coalgate, whence it rises as far as sec. 9, T. 1 N., R. 11 E. From that locality it plunges to a point in the McAlester district about 5 miles to the northeast, beyond which it rises eastward for about a mile and dies out against steeply inclined beds that dip northwestward near the Choctaw fault. An anticlinal axis that plunges northeastward in the region east of Olney, involving surface rocks of Atoka, Hartshorne, and McAlester age, may be a southwestward continuation of the axis of the Coalgate anticline beyond the Phillips fault.

The surface beds involved in the Coalgate anticline northeast of the Phillips fault are the McAlester shale, Savanna sandstone, and Boggy shale. As in the Ashland and Savanna anticlines, narrow belts of steeply inclined strata occur on both flanks of the Coalgate anticline. The belt on the northwest side is characterized by dips ranging from about 15° to 60°, that on the southeast by dips as high as 28°, and all other parts of the anticline by relatively low dips. Southwest of Coalgate the anticline is believed to close against the Phillips fault. The part lying northeast of Coalgate is a closed anticline similar to the Ashland anticline. The Indian Territory Illuminating Oil Co.'s dry hole drilled near the axis in the north half of T. 1 N., R. 11 E., was discontinued in the Atoka formation at a depth of 7,890 feet, and several more shallow wells have been drilled, one of which, a caved hole in the southwestern part of T. 1 N., R. 11 E., initially yielded 2,500,000 cubic feet of gas.

Hunton anticline.—The Hunton anticline, known to some Oklahoma geologists as the Clarita horst, extends southwestward from the Lehigh district to the Tishomingo quadrangle. It is bounded on the north by the Clarita fault and on the south by the Olney fault. Its axis plunges in a northeasterly direction, and dies out in the north half of T. 1 S., R. 9 E. Where it enters that township from the west it brings to the surface the Springer formation, the oldest formation exposed in the district, followed eastward by the Wapanucka limestone and the Atoka formation. Its relation to the structure of the rocks east of Clear Boggy Creek is obscure.

Wardville syncline.—The Wardville syncline occupies the area between the Ashland and Coalgate anticlines. Its axis extends from T. 2 N., R. 10 E., eastward and dies out near the northeast corner of T. 2 N., R. 12 E. The lowest point, structurally, lies along the axis in the central part of T. 2 N., R. 11 E., where the uppermost stratigraphic horizon exposed is about 2,000 feet above the base of the Boggy shale. In contrast with the flanking anticlines, which are relatively narrow and are bordered by zones of steeply inclined strata, the Wardville syncline is a broad, shallow, open fold, in which the rock strata at all exposures dip at low angles.

Lehigh syncline.—The Lehigh syncline lies south and east of the Coalgate anticline and is bounded on the east by the northeastward-trending belt of steeply inclined Pennsylvanian strata that lies adjacent to the Choctaw fault. The main axis of the syncline extends from a point near the southern boundary of Coal County northeastward into the McAlester district. From the main axis a minor synclinal axis branches northwestward and dies out near Coalgate. South of the Phillips fault, which cuts the Coalgate anticline near its south end, and around the southern and eastern margins of the syncline, the surface beds involved include all the formations from the Atoka formation to the Boggy shale.

Phillips fault.—A major fault terminates the Coalgate anticline near the north line of T. 1 S., R. 10 E., and dies out about a mile west of Phillips. Its throw, which is downward on the north side, increases gradually westward and may amount to several hundred feet near the east line of T. 1 S., R. 9 E. Near Phillips only McAlester beds are involved at the surface. Farther west Savanna sandstone north of the fault is dropped against McAlester shale on the south, and still farther west, in the neighborhood east of Clear Boggy Creek, against Hartshorne sandstone. The Phillips fault may continue westward across Clear Boggy Creek and is possibly the eastward continuation of the fault, involving at the surface McAlester shale and questionable Hartshorne sandstone, which enters the Lehigh district at the west line of sec. 30, T. 1 N., R. 9 E. Slickensided fragments of sandstone occur in the vicinity of the Phillips fault in the N½ sec. 4, T. 1 S., R. 10 E.

Olney and Clarita faults.—The Olney fault has its dropped side to the south, enters the Lehigh district in sec. 19, T. 1 S., R. 9 E., and extends along the southeast side of the Hunton anticline northeastward through Olney, east of which its course is hidden by the alluvial deposits along Clear Boggy Creek. The portion of the Olney fault lying within the Lehigh district involves only Atoka beds at the surface. The Clarita fault, named from the settlement of Clarita, in T. 1 S., R. 8 E., extends eastward into the Lehigh district on the north side of the Hunton anticline and possibly dies out at some point west of Clear Boggy Creek. Atoka beds are exposed on the downthrown north side of the portion of this fault that extends into the district, and Wapanucka limestone on the south side.

Minor faults.—Two normal faults occur in Hazelton No. 1 mine, in the NW¼ sec. 32, T. 1 N., R. 10 E. One of these cuts the Lehigh coal bed at a slope distance of about 2,000 feet from the mine opening. It dips about 45° NW. and drops the coal 10 feet on its northwest side. A small fault shown on plate 11 was encountered trending northwestward in the Keystone mine, in the SW¼ sec. 28, T. 1 N., R. 10 E., the coal being dropped 30 feet on the northwest side. The fault in the Keystone mine continues into Coalgate No. 5 mine, in the NE¼NE¼ sec. 22, T. 1 N., R. 10 E. It drops the Lehigh coal 32 feet on its northwest side at a slope distance of about 2,000 feet and dips about 65° NW. After driving westward 200 feet from the bottom of Coalgate No. 5 mine shaft, which is 600 feet deep, the miners raised to find the westward continuation of the Lehigh coal beyond a fault that trends northwestward, dropping the coal on its northeast side. The possibility is suggested that this fault, involving beds that are inclined northwestward, is a tear fault along which the rocks on the southwest side are displaced horizontally northwestward relative to those northeast of the fault.

Origin of the faults and folds.—Major elements of the open-fold zone in the Lehigh district that appear to have originated mainly under the influence of thrusting from the direction of the Ouachita Mountains are the Ashland and Coalgate anticlines, the broad, openly folded Wardville and Lehigh synclines, and possibly the Hunton anticline (called the "Clarita horst" by some oil geologists). The northeastward dip of the strata over most of T. 1 N., R. 9 E., and of most of the strata exposed southwest of the Lehigh syncline in the southern part of the Lehigh district may, however, have resulted from uplift in late Pennsylvanian time associated with faulting and folding in the Arbuckle Mountains and the Ardmore Basin. As a result of the northeastward tilting and later planation, the oldest rocks exposed in the Lehigh district crop out in the southwestern part. The Atoka formation is there extensively exposed, and the Wapanucka limestone and Springer formation appear at the surface of the Hunton anticline. Nevertheless, the northeasterly trend of the axis of the Hunton anticline indicates that its structure is primarily related to that of the open-fold zone. Taff's description of the structure of the Hunton anticline,[53] the greater part of which lies west of the Lehigh district, is as follows:

At the eastern end of the Arbuckle uplift one of the northern folds, called the Hunton anticline, enters the northwest corner of the Atoka quadrangle, pitching eastward at an angle of 10° The axial portion is broad and flat, while the sides are sharply flexed downward and even faulted. The displacement of the faulted strata on each side of the fold is several hundred feet.

[53] Taff, J. A., U. S. Geol. Survey Geol. Atlas, Atoka folio (no. 79), p. 7, 1902.

Toward the east these faults die out in the Carboniferous strata, but toward the west they increase and join a number of fractures of the same nature.

The Hunton anticline, therefore, may be essentially an anticline of the open-fold zone which, because of tilting of its axis, has become more deeply eroded than the Ashland and Coalgate anticlines northeast of it in the Lehigh district. Like the central portions of those anticlines, the central part of the Hunton anticline is a broad, low arch, and the faults on its flanks suggest analogy with the marginal belts of steep dip that characterize these two anticlines of the open-fold zone. No adequate evidence of the nature of the subsurface structure of the Lehigh district is at present available, however, and any interpretation of it must on that account be highly speculative.

Prior to middle Pottsville time sedimentary rocks, chiefly of marine origin and ranging in age from early Paleozoic to early Pennsylvanian, had accumulated over much of southern Oklahoma. Orogenic movements of varying intensity, which deformed the rocks in the Arbuckle and Ouachita regions at intervals from middle Pottsville time until the late Pennsylvanian, and possibly the Permian, are discussed by Miser,[54] Powers,[55] and others. The only rocks now exposed in the Lehigh district that had been formed when these movements began are the Wapanucka limestone and the Springer formation, which crop out in the Hunton anticline near the west line of T. 1 S., R. 9 E. Later orogenic movements occurred in the region during the deposition of the Atoka formation,[56] and overlap of younger formations on the Wapanucka limestone and the Caney shale [57] in the Stonewall quadrangle indicates deformation in Hartshorne, McAlester, and Savanna time.

Intense folding of the Pennsylvanian rocks of the Lehigh district occurred after the deposition of the rocks of the lower part of the Boggy shale, for these strata are steeply inclined on the flanks of the Ashland and Savanna anticlines and in the eastern part of the Lehigh syncline. It seems probable that these folds resulted from the same compressive forces, directed northwestward, that brought about most if not all of the Ouachita overthrusting. This conclusion is indicated by the general parallelism in the trend of the structural axes between the Ouachita Mountains on the one hand and the

[54] Miser, H. D., Carboniferous rocks of Ouachita Mountains: Am. Assoc. Petroleum Geologists Bull., vol. 18, no. 8, pp. 971–1009, August 1934.

[55] Powers, Sidney, Age of the folding of the Oklahoma mountains: Geol. Soc. America Bull., vol. 39, pp. 1039–1072, 1928.

[56] Miser, H. D., op. cit., p. 1008.

[57] Morgan, G. D., Geology of the Stonewall quadrangle, Okla.: Bur. Geology Bull. 2, p. 19, 1924.

Arkansas-Oklahoma coal basin on the other, as well as by the prevailing decrease in the intensity of deformation from the Ouachita Mountains northwestward across this portion of the coal basin. There is, however, much difference of opinion among authors regarding the date of the northwestward overthrusting. Hendricks[58] states that the Thurman sandstone is involved in related folding in the McAlester district, and Morgan[59] states that the Choctaw fault and many of the structural features of the Stonewall and Coalgate quadrangles resulted from movements that occurred in late Wewoka (middle Pennsylvanian) time. Clawson,[60] as stated elsewhere in this report (p. 107), believes in a great angular unconformity near the base of the Boggy shale and expresses the opinion that "the large, steeply folded structural features typical of the Coalgate-McAlester area and associated with the Ouachita overthrust were well developed by middle or late Boggy time, subsequent folding consisting more of a tilting and gentle warping, with compressive forces acting from the northeast and southwest, rather than from the direction of the Ouachita mass to the southeast." Melton,[61] however, prefers to explain the marked change in dip near the base of the Boggy shale on these folds as due to the cushioning effect of the thick Boggy shale, "dissipating some of the forces arising from the Ouachita compression, thus protecting some of the more rigid overlying formation from folding." Melton[62] concluded, chiefly on the basis of statistical studies of the orientation of joints in the rocks exposed northwest of the Ouachita Mountains at widely scattered points in eastern Oklahoma, that at least the "more intense phases" of the deformation are of post-early Permian age. Honess,[63] Powers,[64] and Miser,[65] however, are in agreement in the opinion that the deformation of the Ouachita Mountain region occurred mainly in Pennsylvanian time.

As already stated, the northeastward dip of most of the strata exposed in the southwestern part of the Lehigh district and the

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[58] Hendricks, T. A., op. cit. (Bull. 874–A).

[59] Morgan, G. D., op. cit., p. 19.

[60] Clawson, W. W., Jr., Oil and gas geology of Coal and Pittsburg Counties: Oklahoma Geol. Survey Bull. 40–JJ, pp. 14–15, 1928.

[61] Melton, F. A., Age of the Ouachita orogeny and its tectonic effects: Am. Assoc. Petroleum Geologists Bull., vol. 14, no. 1, pp. 64–65, January 1930.

[62] Idem, pp. 66–72.

[63] Honess, C. W., Geology of the southern Ouachita Mountains of Oklahoma: Oklahoma Geol. Survey Bull. 32, p. 259, 1923.

[64] Powers, Sidney, Age of the folding of the Oklahoma mountains: Geol. Soc. America Bull., vol. 39, no. 4, pp. 1031–1071, 1928.

[65] Miser, H. D., Carboniferous rocks of Ouachita Mountains: Am. Assoc. Petroleum Geologists Bull., vol. 18, no. 8, p. 1009, August 1934.

northeastward plunge of the axis of the Hunton anticline are possibly related to deformation in the Ardmore Basin and the Arbuckle Mountains that occurred, according to Tomlinson,[66] in late Pennsylvanian time (Deese of Goldston).

ECONOMIC GEOLOGY

COAL

OCCURRENCE

Two coal beds have been mined profitably in the Lehigh district. The lower of these beds, formerly designated the "Atoka coal", occurs in the Hartshorne sandstone about 45 feet below the base of the McAlester shale. It occupies nearly the stratigraphic position of the Lower Hartshorne coal bed of the McAlester district and is referred to as the Lower Hartshorne bed in this report. The Lower Hartshorne coal is reported to be about 4 feet thick at the Hickory Hill strippings, in T. 2 S., R. 10 E. A thin bed of coal of little or no value, known as the Upper Hartshorne bed, occurs at the base of the McAlester shale. The upper valuable bed, known as the Lehigh coal, is in the McAlester shale, 400 to 500 feet below the top of the formation, or about 1,200 feet above the Lower Hartshorne bed. It occurs at about the horizon of the McAlester coal bed of the McAlester district. An unnamed thin coal bed of no value occurs about 30 feet above the Lehigh coal bed. The thickness of the Lehigh bed ranges from about 3 feet 4 inches to about 5 feet and shows a general increase from southwest to northeast within the district. The following sections of the Lehigh bed, measured at widely separated localities, show the general character of the bed. The first section was measured by the writer; the others are taken from the work of Moose and Searle.[67]

Sections of Lehigh coal

J. L. Gaddo mine, NW¼NE¼ sec. 36, T. 1 S., R. 10 E., 3 miles south of Lehigh

[Measured Dec. 7, 1935, in room 50 feet northeast of shaft that is 45 feet deep]

	Ft.	*in.*
Hard gray shale containing marine shells; some sulphur	4	6+
Bone coal		2
Dark-gray shale (roof of coal)		2
Hard bright coal; a little pyrite	1	2
Soft dull coal		2½
Hard bright coal; a little pyrite	1	8½
Bone coal		4
Hard gray shale (floor)	1+	

[66] Tomlinson, C. W., The Pennsylvanian system in the Ardmore Basin: Oklahoma Geol. Survey Bull. 46, pp. 47–48, 1929.

[67] Moose, J. E., and Searle, V. C., A chemical study of Oklahoma coals: Oklahoma Geol. Survey Bull. 51, pp. 38–39, 1929.

Keystone No. 1 mine, SW¼SW¼ sec. 28, 3½ miles southwest of Coalgate

[Section A was cut from face of 8 west entry, 2,490 feet from mouth of slope; section B was cut from face of long wall off 3 west entry, 1,200 feet from mouth of slope. Sections measured Aug. 6, 1928]

	A	B
Roof, soapstone.	*Inches*	*Inches*
Coal	3½	1
Pyrites	½	⅛
Coal	6	1½
Pyrites	¼	----
Coal	7¾	13½
Pyrites	⅛	⅛
Coal	4	6
Streak.		
Coal	6½	7
Pyrites	⅛	¼
Coal	9	1
Floor, soft clay.		

M. K. & T. mine 21, SE¼NE¼ sec. 17, T. 1 N., R. 11 E., 3½ miles northeast of Coalgate

[Section A was cut from face of 5 west entry, 2,100 feet from mouth of slope; section B was cut from face of room 4 off 4 west entry, 2,050 feet from mouth of slope; section C was cut from face of room 56 off 1 east entry, 3,260 feet from mouth of slope]

	A	B	C
Roof, soft soapstone.	*Inches*	*Inches*	*Inches*
Coal	3	5½	4½
Mother of coal (mineral charcoal).			
Coal	4½	1½	1½
Pyrites	¼	¼	¼
Coal	2¾	2¼	13
Pyrites	----	----	¼
Coal	6	6¼	11
Pyrites.			
Coal	6½	9¼	7½
Pyrites.			
Coal	10½	6¾	14
Floor, soft clay.			

Neither the Lehigh bed nor the Hartshorne bed has been traced continuously between the Lehigh and McAlester districts, and correlation of these beds from one area to the other cannot be made with certainty.

A good general description of the outcrop of the Lehigh and Hartshorne coals, as related to the geologic structure of the Lehigh district is given in the following quotations from a report by Taff:[68]

The coal of the Lehigh district lies in a wide oval basin in the central and southern parts and in the sides of an upward or anticlinal fold in the northwest side. The downward fold is known as the Lehigh Basin [syncline] and is named for the mining town located on the west side. It is broad and deep in the central part opposite Lehigh and is much contracted in the northeast end. In

[68] Taff, J. A., Maps of segregated coal lands in the Lehigh-Ardmore district, Choctaw and Chickasaw Nations, Indian Territory: 61st Cong., 2d sess., S. Doc. 390, pp. 331–332, 1904.

the east side of this basin, extending across the eastern part of T. 1 S., R. 11 E., and the southeast part of T. 1 N., R. 12 E., the coal and associated rocks are so steeply folded and disturbed that the coal is considered to be of little value and has not been included in the segregated lands. In the south end and west side, however, the coal beds are well disposed structurally, and the coal outcrop can be easily traced and successfully mined. * * * From Coalgate northeastward the coal pitches downward at a low angle, to rise again to the surface near the eastern border of T. 1 N., R. 10 E. From the border of this township to the northeast corner of T. 1 N., R. 11 E., the coal crops in a long oval around the axial part of the upward fold. Farther toward the northeast the coal pitches in a low slope to the northeast. * * * From Coalgate southwestward the anticlinal fold becomes broad and low, the coal in the north side cropping in a southwesterly direction. In the other side it strikes south through Phillips and Lehigh.

Both the Lehigh and Atoka [Lower Hartshorne] coals crop out at the southern end and southwest side of the Atoka [Lehigh] Basin, but only the Lehigh comes to the surface in the Coalgate anticlinal fold. * * * In the south side of this upward fold the coal approaches the surface at angles varying from 10° to 20°, except very near the town of Coalgate, where it is somewhat lower. In the northwest side, however, the coal is steeply inclined and can be exploited most economically by slope mining.

Southwest of Coalgate the Lehigh coal bed is cut by the Phillips fault, which has brought it into contact with the older beds that crop out on the south side of the fault. The rocks against which it is thus faulted near the northwest corner of T. 1 S., R. 10 E., are in the lower part of the McAlester shale. Where the coal rises to the surface on the north side of a fault that may be the continuation of the Phillips fault, about 4 miles farther west, the rocks exposed on the south side of the fault belong to the Atoka formation. The Lehigh coal is recognized in a small mine in the N½ sec. 30, T. 1 N., R. 9 E., by the presence of a characteristic layer of fossiliferous limestone that also occurs immediately above that bed in the mines in the vicinity of Coalgate and Lehigh.

QUALITY

On the basis of its chemical composition, as shown in the following table of analyses by the United States Bureau of Mines,[69] the coal of the Lehigh (McAlester) bed of the Lehigh district is classified as a high-volatile bituminous coal. A few typical analyses of the bituminous coal of the McAlester bed of the McAlester district are included in the table for comparison, showing in general higher heating value, larger percentages of fixed carbon, and smaller percentages of moisture and ash than are present in the Lehigh coal. As no mines in the Lower Hartshorne bed were operating during the period of the present investigation, no fresh exposures of that bed were accessible for sampling, and no analyses of the Lower Hartshorne coal are available for the Lehigh district.

[69] Mostly quoted from U. S. Bur. Mines Tech. Paper 411, 1928.

Chemical analyses of mine samples of coal from the McAlester and Lehigh districts

Locality, bed, mine, etc.	Sample: Laboratory No.[1]	Sample: Kind[2]	Sample: Condition[3]	Proximate: Moisture	Proximate: Volatile matter	Proximate: Fixed carbon	Proximate: Ash	Ultimate: Sulphur	Ultimate: Hydrogen	Ultimate: Carbon	Ultimate: Nitrogen	Ultimate: Oxygen	Air-drying loss	Calorific value: Calories	Calorific value: B. t. u.	Softening temperature
M'ALESTER DISTRICT																
Dow; sec. 26, T. 5 N., R. 16 E.; Milby & Dow mine, McAlester bed (composite of samples A21280, A21281, and A21282).	A21283	B	1	2.9	36.5	55.7	4.9	0.6	5.4	77.7	1.8	9.6	0.9	7,661	13,790	
			2		37.6	57.4	5.0	.6	5.2	80.0	1.9	7.3		7,889	14,200	
			3		39.6	60.4		.6	5.5	84.2	2.0	7.7		8,306	14,950	
2 miles west of McAlester, No. 4 mine, McAlester bed (composite of samples A21128 and A21129).	A21130	B	1	3.0	36.6	55.0	5.4	.9	5.3	77.4	1.9	9.1	.9	7,639	13,750	
			2		37.8	56.7	5.5	.9	5.1	79.8	2.0	6.7		7,872	14,170	
			3		40.0	60.0		.9	5.4	84.5	2.1	7.1		8,339	15,010	
Pittsburg; McAlester-Edwards No. 1 and No. 2 mines, McAlester bed (composite of samples A21276 and A21277).	A21278	B	1	4.0	37.0	53.3	5.7	1.1	5.3	75.2	1.7	11.0	1.1	7,361	13,250	
			2		38.5	55.5	6.0	1.1	5.0	78.3	1.8	7.8		7,667	13,800	
			3		41.0	59.0		1.2	5.3	83.2	1.9	8.4		8,156	14,680	
LEHIGH DISTRICT																
Lehigh, ½ mile north of; No. 5 mine, Lehigh bed (face of 8 south entry, 5 slope).	1150	A	1	5.3	37.5	45.1	12.1	3.8					1.6			
Same (face of 3 north entry, south slope)	1151	A	1	6.5	39.0	45.2	9.3	3.7					1.9	6,578	11,840	
			2		41.7	48.3	10.0	3.9						7,039	12,670	
3,000 feet northeast of; Folsom Morris No. 5 mine, Lehigh bed (face of 1 south entry, 8½ slope, top entry).	30707	A	1	6.6	38.2	42.6	12.6	4.2					1.9	6,205	11,170	2,090
Same (face of 11 south entry, 5½ slope, bottom entry)	30708	A	1	7.0	38.3	42.3	12.4	3.7					2.1	6,228	11,210	1,950
Same (face of 4 south entry, 5½ slope, bottom entry)	30709	A	1	7.7	38.5	42.3	11.5	5.2					2.5	6,183	11,130	2,200
Same (face of 14 north entry, 5 slope, top entry)	30710	A	1	6.6	39.8	41.9	11.7	3.7					2.0	6,267	11,280	2,230
Same (face of 13 north entry, 5 slope, top entry)	30711	A	1	6.2	39.3	42.6	11.9	4.5					1.6	6,294	11,330	2,110
Same (composite of samples 30707 to 30711, inclusive)	30712	A	1	6.6	38.6	42.9	11.9	4.3	5.0	62.8	1.5	14.5	2.0	6,256	11,260	
			2		41.3	45.9	12.8	4.6	4.6	67.2	1.6	9.2		6,700	12,060	
			3		47.4	52.6		5.2	5.3	77.0	1.9	10.6		7,678	13,820	
1½ miles east of; Folsom Morris No. 8 mine, Lehigh bed (face of 6 south entry, main slope, bottom entry).	30713	A	1	6.3	38.3	43.1	12.3	4.3					1.7	6,289	11,320	1,970
Same (face of 6 south entry, plane entry, top entry)	30714	A	1	7.1	40.4	42.3	10.2	3.5					2.1	6,344	11,420	2,130
Same (face of 7 south entry, plane entry, top entry)	30715	A	1	7.1	39.7	42.4	10.8	3.7					2.3	6,316	11,370	2,210
Same (face of 5 north entry, main slope entry, bottom entry).	30716	A	1	6.1	40.3	42.6	13.0	4.8					1.9	6,239	11,230	2,220
Same (face of 6 north entry, plane entry, top entry)	30717	A	1	7.1	40.6	41.7	10.6	3.4					2.4	6,322	11,380	2,250
Same (composite of samples 30713 to 30717, inclusive	30718	A	1	6.9	39.4	42.2	11.5	3.9	5.0	63.2	1.5	14.9	2.1	6,300	11,340	
			2		42.3	45.4	12.3	4.2	4.5	67.8	1.6	9.6		6,767	12,180	
			3		48.2	51.8		4.8	5.1	77.3	1.8	11.0		7,717	13,890	
1½ miles southeast of; Lehigh No. 8 mine, Lehigh bed (face of 19 room, 3 north entry, 2,000 feet northwest of shaft).	10054	A	1	7.1	36.4	45.7	10.8	3.6	5.1	64.4	1.4	14.7	3.0	6,372	11,470	2,160
			2		39.2	49.1	11.7	3.9	4.7	69.3	1.6	8.8		6,855	12,340	
			3		44.4	55.6		4.4	5.3	78.4	1.8	10.1		7,761	13,970	

See footnotes at end of table

Chemical analyses of mine samples of coal from the McAlester and Lehigh districts—Continued

Locality, bed, mine, etc.	Sample: Laboratory No.[1]	Sample: Kind[2]	Sample: Condition[3]	Proximate: Moisture	Proximate: Volatile matter	Proximate: Fixed carbon	Proximate: Ash	Ultimate: Sulphur	Ultimate: Hydrogen	Ultimate: Carbon	Ultimate: Nitrogen	Ultimate: Oxygen	Air-drying loss	Calorific value: Calories	Calorific value: B. t. u.	Softening temperature[4]
LEHIGH DISTRICT—continued																
Lehigh, 3 miles southwest of; J. L. Gaddo mine, Lehigh bed (room 50 feet northeast of shaft, 45 feet below surface).	B-10021	B	1	9.0	37.3	39.7	14.0	4.6	5.2	59.3	1.2	15.7	5.7	5,989	10,780	2,210
			2		39.6	42.1	14.8	4.8	4.8	62.9	1.3	11.4		6,344	11,420	
			3		48.5	51.5		5.9	5.4	77.0	1.6	10.1		7,772	13,990	
Phillips, ½ mile east of; Folsom Morris No. 6 mine, Lehigh bed (face of 10 north entry, 6½ slope, top entry).	30719	A	1	6.1	40.0	45.1	8.8	3.3					2.2	6,656	11,980	2,220
Same (face of 10 north entry, main slope entry, bottom entry).	30720	A	1	5.8	40.1	45.7	8.4	3.8					1.9	6,706	12,070	2,240
Same (face of 11 south entry, main slope entry, top entry).	30721	A	1	5.6	39.9	45.4	9.1	3.4					1.4	6,667	12,000	2,170
Same (face of 10 south entry, 6½ slope, top entry)	30722	A	1	5.7	40.3	46.4	7.6	3.3					1.8	6,789	12,220	2,210
Same (face of 10 south entry, main slope entry, top entry).	30723	A	1	5.9	39.1	45.2	9.8	4.0					1.8	6,539	11,770	2,110
Same (composite of samples 30719 to 30723, inclusive	30724	A	1	5.9	39.5	45.8	8.8	3.6	5.1	67.0	1.6	13.9	1.8	6,678	12,020	
			2		42.0	48.6	9.4	3.8	4.7	71.2	1.7	9.2		7,100	12,780	
			3		46.3	53.7		4.2	5.2	78.6	1.9	10.1		7,834	14,100	
Coalgate, 4½ miles southwest of; Old Hazleton mine, Lehigh bed (face of 13 room, 3 west entry, slope distance 800 feet).	B-786	B	1	8.3	37.1	42.4	12.2	3.6	5.1	62.0	1.4	15.7	3.7	6,144	11,060	2,300
			2		40.5	46.2	13.3	3.9	4.6	67.6	1.5	9.1		6,700	12,060	
			3		46.7	53.3		4.5	5.3	78.0	1.8	10.4		7,728	13,910	
4 miles southwest of; Keystone mine, Lehigh bed (face of 1 east parting entry, 100 feet east of slope; slope distance 300 feet).	B-785	B	1	8.4	36.5	44.9	10.2	3.4	5.5	63.9	1.4	15.6	3.5	6,322	11,380	2,100
			2		39.8	49.1	11.1	3.8	5.0	69.8	1.5	8.8		6,906	12,430	
			3		44.8	55.2		4.2	5.6	78.5	1.7	10.0		7,767	13,980	
3½ miles northeast of; M. K. T. No. 21 mine, Lehigh bed (3 east entry, 3 panel slope, room 1 on east side, 60 feet from panel slope).	B-10266	B	1	7.2	34.8	52.0	6.0	.8					4.1	6,850	12,330	2,340
			2		36.3	54.3	6.2	.9						7,144	12,860	
			3		40.1	59.9		1.0						7,889	14,200	
Same (plane, 7 west entry, 2,700 feet west of main slope, room 1 on west side of plane, 225 feet from panel slope).	B-10267	B	1	6.0	36.7	50.6	6.7	1.8					3.6	6,928	12,470	2,290
			2		38.1	52.3	7.0	1.9						7,183	12,930	
			3		42.0	58.0		2.1						7,939	14,290	
Same (1 west parting, 50 feet west of main slope, 850 feet from mouth of main slope).	B-10268	B	1	6.7	37.0	48.6	7.7	3.0					4.0	6,761	12,170	2,280
			2		38.6	50.6	8.1	3.1						7,044	12,680	
			3		43.2	56.8		3.5						7,894	14,210	
Same (composite of samples B-10266 to B-10268, inclusive).	B-10269	B	1	6.7	36.2	50.2	6.9	1.9	5.4	69.5	1.6	14.7	3.9	6,850	12,330	
			2		37.7	52.2	7.2	2.0	5.2	72.4	1.7	11.5		7,128	12,830	
			3		42.0	58.0		2.2	5.4	80.5	1.9	10.0		7,928	14,270	

[1] Laboratory numbers with a prefix "W" represent samples analyzed in the Washington laboratory of the bureau; all others were analyzed at the Pittsburgh laboratory.
[2] A, mine sample collected by an engineer of the Bureau of Mines; B, mine sample collected by a geologist of the U. S. Geological Survey.
[3] 1, sample as received; 2, dried at 105° C.; 3, moisture and ash free.
[4] Figures in this column represent the temperature at which the cone of coal ash has fused to a spherical lump when heated in the furnace in a slightly reducing atmosphere.

MINING

Mining of coal has been carried on in the Lehigh district for more than 50 years. Most of the coal has been taken from the Lehigh coal bed, but some has been taken from the Lower Hartshorne bed, notably at the Hickory Hill strippings, in T. 2 S., R. 10 E. Formerly a large amount of the coal produced provided fuel for the locomotives of the Atchison, Topeka & Santa Fe and Missouri, Kansas & Texas Railroads. Some coal was shipped to distant markets, and some was consumed locally. The small present production is partly sold locally for domestic purposes, and many of the operating mines at present are "wagon mines" from which the consumers buy coal in small quantities to be hauled home in wagons or motor trucks. The coal is mined both by stripping along the outcrop and by the room and pillar method in underground operations. The extent of the workings up to 1934 is shown on plate 11, and further information on most of the mines is given in the following table:

Coal mines in the Lehigh district

[All on Lehigh bed except the last, which is on the Lower Hartshorne bed]

Location				Mine operator or name	No.	Kind	Approximate average thickness (height) of coal		Dip (pitch)	Remarks
Quarter	Sec	T.	R. E.				*Ft.*	*In.*	°	
SE¼SE¼	31	1 N.	10	Citron slope		Slope	3	8	10	Coal is faulted.
NW¼SW¼	32	1 N.	10	Hazelton	2	do	3	10	11	
SE¼NW¼	32	1 N.	10	do	1	do	3	10	11½	Coal faulted at 1,000 and 2,000 feet distance.
NW¼NE¼	32	1 N.	10	do	3	do	3	10	12	
SW¼SW¼	28	1 N.	10	Keystone	1	do	3	4	12	Coal faulted at 1,000 feet slope distance.
SE¼SW¼	28	1 N.	10	Taylor & Williamson.		do	3	10	12	
NE¼SW¼	28	1 N.	10	Cleland		do	3	10	12	
NW¼SE¼	28	1 N.	10	Bristow		do	4		12	
SE¼NE¼	28	1 N.	10	Coalgate Coal Co.	4	do	4		12½	
NW¼NW¼	27	1 N.	10	do	3	do	4		12½	
SW¼SE¼	22	1 N.	10	do	2	do	4		12½	
NE¼NE¼	22	1 N.	10	do	5	Shaft	4	6	13½	Fault 200 feet west of bottom of shaft.
NE¼NE¼	23	1 N.	10	do	1	Slope	4	6	-------	
SW¼NE¼	13	1 N.	10	M.-K.-T. R. R.	2	Shaft	4		20	
NE¼SW¼	13	1 N.	10	do	5	do	4		10	
SW¼SE¼	13	1 N.	10	do	10	do	4		6	
SW¼	18	1 N.	11	Sunshine		Slope	4		5	
NW¼SW¼	18	1 N.	11	Noel	1	do	3	6	6	
SW¼SE¼	18	1 N.	11	M.-K.-T. R. R.	9	Shaft	4		8	
SW¼SW¼	17	1 N.	11	do	17	do	5		14	
SE¼NE¼	17	1 N.	11	do	21	Slope	5		13½–16	
NE¼NE¼	16	1 N.	11	Trespass		do	4		-------	
NE¼SW¼	7	1 N.	11	M.-K.-T. R. R.	14	do	4	6	40–65	Slope distance 1,400 feet to bottom of mine. Pitch steepens gradually.
NE¼SE¼	26	1 N.	10	do	4	Shaft	4	6	14	Old no. 4.
NE¼NW¼	25	1 N.	10	do	12	do	4	6	14	New no. 12.
SW¼SW¼	25	1 N.	10	do	12	do	4	6	13	Do.
NW¼NE¼	35	1 N.	10	do	4	Slope	4	6	13	New no. 4.
SW¼NW¼	35	1 N.	10	Jones slope		do	5		12	
NE¼SW¼	35	1 N.	10	Folsom-Morris	7	Shaft	5		11	

Coal mines in the Lehigh district—Continued

Location				Mine operator or name	No.	Kind.	Approximate average thickness (height) of coal		Dip (pitch)	Remarks
Quarter	Sec.	T.	R. E.				*Ft.*	*in.*	°	
NE¼NW¼	2	1 S.	10	Davidson		Shaft	5		11	
SE¼NE¼	2	1 S.	10	Folsom-Morris	6	do	4	6	9	
NE¼NW¼	11	1 S.	10	Klondike	2	Slope	4	6	9	
NE¼SW¼	11	1 S.	10	E. & G		do	4	6	8	
NW¼NE¼	14	1 S.	10	Folsom-Morris	5	Shaft	4	6	8	
NE¼NE¼	23	1 S.	10	Shamrock		do	4	6	8	
SE¼SE¼	13	1 S.	10	Folsom-Morris	8	do	4	6	4	
SW¼SW¼	14	1 S.	10	do	4	do			6	New no. 4.
NE¼NW¼	36	1 S.	10	Pope		Slope	3	10	6	Small fault about 100 feet from mouth.
SE¼NE¼	36	1 S.	10	Midway	1	Shaft	4		6	Thickness includes shale parting, 4 to 6 inches thick, known as "middle band."
NE¼NE¼	36	1 S.	10	do	3	do	4		6	
NW¼NE¼	36	1 S.	10	J. L. Gaddo		do	3	1	6	Do.
NE¼NW¼	6	2 S.	11	A. & M	2	do	4		6	Do.
	3	2 S.	10	Hickory Hill		Stripping	4		5	

The total coal production of Coal County for each year from 1908 to 1935 is given in the following table, compiled from "Mineral Resources of the United States", published annually by the United States Geological Survey until 1925 and by the United States Bureau of Mines since. Nearly all of this coal was produced from the area shown on plate 11, though small quantities came from a few wagon mines in T. 1 N., R. 8 E., in western Coal County.

Coal produced in Coal County, Okla., 1908–35

	Tons		*Tons*		*Tons*
1908	576, 746	1918	542, 254	1928	131, 110
1909	658, 159	1919	427, 306	1929	134, 328
1910	498, 658	1920	461, 394	1930	96, 931
1911	778, 746	1921	187, 451	1931	53, 396
1912	816, 155	1922	79, 847	1932	42, 886
1913	889, 299	1923	33, 464	1933	46, 671
1914	676, 292	1924	29, 249	1934	42, 886
1915	556, 479	1925	52, 862	1935	38, 913
1916	524, 954	1926	83, 452		
1917	581, 770	1927	124, 015		

OIL POSSIBILITIES

Though several anticlines that have been described on preceding pages appear, on the basis of observations made at the surface, to favor the accumulation of oil, the imperfect state of our present knowledge regarding their subsurface character makes the choice of drilling sites difficult. The drilling for petroleum on these anticlines has not yielded commercial amounts of oil. Only a few showings of oil have been reported in the wells that have been drilled, and the information at hand that bears upon the problem of oil development indicates that oil in commercial amounts is not likely to be found in the Lehigh district in formations younger than the basal part of the Atoka formation. The pre-Atoka rocks of the Lehigh district, which are largely concealed beneath Atoka and younger Pennsylvanian rocks, have not, however, been adequately explored by the drill. The Wapanucka limestone and older formations have, so far as the writer is aware, been reached in only two wells in the area at the time of writing. Though both of these holes were dry, the log of one, the Amerada Petroleum Corporation's well in the SW¼NW¼SE¼ sec. 28, T. 1 S., R. 9 E., about 2 miles south of Olney (p. 122), shows a total of 80 feet of asphalt in the Bromide formation of Decker, in the Simpson group, and "shows" of oil and gas are reported at many horizons in the log of the Carter Oil Co.'s deep well in the NE¼NW¼ sec. 34, T. 2 N., R. 9 E., near Centrahoma (pp. 109–122). Moreover, the gas that has been found in the Centrahoma, Coalgate, and Ashland anticlines in Pennsylvanian rocks is probably derived from potential source beds of petroleum in the older formations. The possibility that oil may have accumulated at lower horizons at these and other apparently favorable localities in the Lehigh district will probably lead to further deep drilling in the area. The vertical section of 6,989 feet of Atoka beds passed through from a depth of 870 feet to the bottom of the Indian Territory Illuminating Oil Co.'s dry hole in the SE¼SW¼NW¼ sec. 10, T. 1 N., R. 11 E., near the axis of the Coalgate anticline, may be much greater than the normal thickness of the Atoka in that locality, owing to possible unknown structural conditions at depth. The base of the Atoka formation may be nearer the surface at other points on the Coalgate anticline.

Further data regarding most of the wells that have been drilled in the Lehigh district are contained in the following table:

Wells drilled for oil and gas in Lehigh district, Oklahoma

Company	Well no.	Farm	County	Approximate location: Quarter	Sec.	T.	R. E.	Date of completion	Total depth (feet)	Remarks [1]
Conewango Oil Co.	1	T. F. Danenhour	Atoka	NE¼NW¼NE¼	7	2 S.	10	Mar. 18, 1919	1,850	Dry.
Cripples Corporation	1	Butler-Wylie	do	SW¼NW¼NW¼	8	2 S.	11	Dec. 1, 1923	1,660	Dry; O. S. 800–807 feet, 836–842 feet; salt water 1,083–1,115 feet.
Amerada Petroleum Corporation.	1	Travelers Life Insurance Co.	Coal	SW¼NE¼	28	1 S.	9	Aug. 14, 1935	5,416	Dry. (See log, p. 122.)
G. F. Galbreath	1	Galbreath-Rummel	do	SW¼SW¼SE¼	24	1 N.	9	June 1, 1929	3,380	Dry; G. S. 620–632 feet; O. S. 2,460–2,470 feet.
Unknown			do	SE¼SW¼	10	1 N.	11		2,542	Gas; 2.5 Ml 1,202–1,229 feet; G. S. 2,493–2,542 feet. Caved well. Coalgate anticline.
Indian Territory Illuminating Oil Co.	1	Cook	do	SW¼SW¼NW¼	10	1 N.	11	July 14, 1928	1,980	Dry.
Do	1A	do	do	SE¼SW¼NW¼	10	1 N.	11	July 30, 1929	7,890	Dry; G. S. 2,621–2,625 feet, 2,750–2,752 feet, 2,759–2,760 feet, 3,219–3,226 feet, O. S. 2,750–2,752 feet, 2,759–2,760 feet.
Do	1	do	do	NW¼NW¼SW¼	10	1 N.	11	Jan. 12, 1928	1,350	Dry.
J. A. Bearman	1	Payne	do	NW¼NE¼	34	2 N.	9	July 14, 1923	2,670	Gas, 0.1 Ml 245 feet, 0.5 Ml 416 feet, 10 Ml 790 feet. Centrahoma dome.
Carter Oil Co.	1	John Thompson	do	NE¼NW¼	34	2 N.	9	Feb. 2, 1936	7,126	Dry. (See log, pp. 109–122.) Centrahoma dome.
J. W. Berryman and others.	1	Starr	do	NW¼NE¼	34	2 N.	9	Dec. 18, 1924	2,870	Gas, 5 Ml 780–820 feet, 3 Ml 1,655–1,679 feet. Centrahoma dome.
J. R. Kitchel	1	Oklahoma Portland Cement.	do	NW¼SW¼NE¼	34	2 N.	9	Jan. 25, 1927	2,130	Dry; G. S. 390–475 feet, 630–635 feet, 1,150–1,160 feet. Centrahoma dome.
Mike Huber & Co.	1	Downward	do	NW¼NW¼SW¼	16	2 N.	10	Feb. 1, 1924	3,225	Dry.
Homer Gas-Oil Co.	1	James Cunningham	do	SW¼SE¼SE¼	23	3 N.	11	Oct. 27, 1912	2,300	Dry; G. S. 500–503 feet. Ashland anticline.
Do	1	Walter Cunningham	do	SW¼NW¼SE¼	24	3 N.	11	July 4, 1912	1,675	Gas, 0.54 Ml 365–388 feet; O. S. 420–425 feet. Ashland anticline.
Do	2	John Cunningham	do	NE¼SW¼SW¼	17	3 N.	12	Feb. 12, 1914	2,505	Gas, 0.3 Ml 538–708 feet, 1,410–1,425 feet. Ashland anticline.
Do	1	Lulu Myrtle Casey	Pittsburg	SE¼SE¼SW¼	18	3 N.	12	Apr. 20, 1914	1,300	Dry. Ashland anticline.
Do	1	S. Battles	do	SW¼NW¼	19	3 N.	12	Dec. 14, 1912	1,285	Gas, 0.56 Ml 313–322 feet; G. S. 245–248 feet, 472 feet, 1,158 feet. Ashland anticline.

Do	2	do	do	SE¼SE¼NW¼	19	3 N.	12	Mar. 10, 1914	1, 216	Gas, 0.165 Ml 395–518 feet, 2.1 Ml 1,176–1,216 feet. Ashland anticline.
Do	1	John Cunningham	do	SE¼NE¼NE¼	19	3 N.	12	Nov. 5, 1913	1, 374	Gas, 0.395 Ml 482–503 feet, 1.5 Ml 562–604 feet; G. S. 446–456 feet. Ashland anticline.
Do	1	J. S. Moran	do	SW¼SE¼NE¼	19	3 N.	12	Sept. 30, 1913	1, 379	Gas, 0.4 Ml 484–632 feet; 1.57 Ml 1,340–1,379 feet. Ashland anticline.
Do	1	Irvin Featherston	do	NE¼NE¼SW¼	19	3 N.	12	Apr. 15. 1913	1, 903	Gas, 0.56 Ml 460–482 feet; 2.4 Ml 1,237–1,262 feet. Ashland anticline.
Do	1	W. H. Johnston	do	NW¼NW¼NW¼	30	3 N.	12	July 21, 1913	1, 447	Dry.

[1] G. S., show of gas; O. S., show of oil; Ml, million cubic feet.

Drillers' logs of these wells are obtainable at small cost from the Corporation Commission, Oklahoma City, Okla.

Some encouragement for further search for oil in this area may be derived from the proximity of producing fields and from the carbon ratios of the coal. Oil is produced from the rocks of the Simpson, Viola, and Hunton formations in the Fitts field, about 12 miles west of the Lehigh district, and also at Jesse, about 6½ miles west of the district; showings of oil in the Wapanucka limestone are reported in two wells in sec. 35, T. 1 N., R. 8 E., a little more than a mile west of the district. All these formations occur below the surface within the district. (See pp. 108–124).) East of the area, oil seeps[70] and deposits of grahamite[71] have been known for many years to occur within a belt 20 miles wide extending from the west end of the Ouachita Mountains eastward into Arkansas, and a few wells in that belt have yielded small amounts of oil.[72]

The percentage of fixed carbon in coal samples from the Lehigh district which have been analyzed by the United States Bureau of Mines ranges from 51.5 to 59.9 (ash-, moisture-, and sulphur-free basis). (See table, pp. 137–138.) The carbon ratios[73] are therefore well below the limit, approximately 62 percent, above which the indicated chances would be against the presence of commercial amounts of oil.

NATURAL GAS

As shown in the preceding table, eight wells on the Ashland anticline, two on the Centrahoma dome, and one on the Coalgate anticline have yielded gas in notable quantities, though none of it has been marketed. The gas occurs mainly in the Hartshorne sandstone, but sandy beds in the McAlester shale yield some gas and the Savanna sandstone yields a little.

The gas wells on the Ashland anticline all lie within a quarter of a mile of the anticlinal axis as drawn on plate 11 and extend for nearly 3 miles along that axis within the area of exposure of the McAlester shale. In these wells gas occurs in the Hartshorne sand-

[70] Miser, H. D., Relation of Ouachita belt of Paleozoic rocks to oil and gas fields of Mid-Continent region: Am. Assoc. Petroleum Geologists Bull., vol. 18, no. 8, p. 1065, 1934.

[71] Taff, J. A., Grahamite deposits of southeastern Oklahoma: U. S. Geol. Survey Bull. 380, pp. 386–397, 1909.

[72] Vanderpool, H. C., Oil southeast of the Choctaw fault: Oklahoma Acad. Sci. Proc., vol. 14, pp. 58–60, 1934.

[73] White, David, Some relations in origin between coal and petroleum: Washington Acad. Sci. Jour., vol. 5, no. 6, pp. 189–212, 1915; Metamorphism of organic sediments and derived oils; Am. Assoc. Petroleum Geologists Bull., vol. 19, no. 5, pp. 589–617, May 1935. Fuller, M. L., Carbon ratios in Carboniferous coals of Oklahoma: Econ. Geology, vol. 15, no. 3, pp. 225–235, April-May 1920. Hendricks, T. A., Carbon ratios in part of Arkansas-Oklahoma coal field: Am. Assoc. Petroleum Geologists Bull., vol. 19, no. 7, pp. 937–947, July 1935. Fisher, D. J., Carbon ratios north of the Ouachitas: Am. Assoc. Petroleum Geologists Bull., vol. 20, no. 1, pp. 102–105, January 1936.

stone at depths ranging from 1,176 to 1,410 feet, and in sandy beds in the McAlester shale at depths of 313 to 708 feet. According to available information the daily open-flow volumes of the wells at the time of completion ranged from 300,000 to 2,960,000 cubic feet. By far the greatest yield came from the Hartshorne sandstone. Though none of the gas in the Ashland anticline has been marketed, the present low rock pressure of the gas indicates that the supply has been depleted through leakage since the wells were drilled, in 1912, 1913, and 1914. Colton[74] reports that in 1932 the rock pressures in all the sands were subnormal, being 140 pounds to the square inch for shallow sands and 300 pounds for the Hartshorne sandstone. He states that "the reserve of the shallow and Hartshorne zones, calculated by the porosity method, is about 8 billion cubic feet."

Of the two wells that yielded gas on the Centrahoma dome, one, the J. W. Berryman well, obtained it from the Hartshorne sandstone at depths of 1,655 to 1,679 feet and from the McAlester shale or Savanna sandstone at 780 to 820 feet; the other obtained it mainly from a sandstone at a depth of 790 feet, either in or slightly above the McAlester shale, and small quantities from beds at 245 and 416 feet, which are probably in the Savanna sandstone. The total initial daily open-flow volume of gas from these two wells was reported to be 18,600,000 cubic feet. The flow of 2,500,000 cubic feet of gas at 1,202 to 1,229 feet, reported in the caved well in the SE¼SW¼ sec. 10, T. 1 N., R. 11 E., on the Coalgate anticline, probably issued from the Hartshorne sandstone.

If markets should ever become available for gas from the Lehigh district, the Centrahoma, Ashland, and Coalgate anticlines would offer the best opportunities for development of further supplies. Other than these, no structural features are believed to possess closure within the district, and it is therefore improbable that potential gas fields exist elsewhere in the area.

[74] Colton, E. G., Natural gas in Arkansas Basin of eastern Oklahoma, in Geology of natural gas, edited by Harry A. Ley, pp. 519–520. Am. Assoc. Petroleum Geologists, 1935.

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