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THE GEOLOGY OF THE HARTSHORNE COALS (DESMOINESIAN) IN PARTS OF THE HEAVENER 15' QUADRANGLE LE FLORE COUNTY, OKLAHOMA

A THESIS

APPROVED FOR THE SCHOOL OF GEOLOGY AND GEOPHYSICS

By

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THE UNIVERSITY OF OKLAHOMA

GRADUATE COLLEGE

THE GEOLOGY OF THE HARTSHORNE COALS (DESMOINESIAN) IN PARTS OF THE HEAVENER 15' QUADRANGLE LE FLORE COUNTY, OKLAHOMA

A THESIS

SUBMITTED TO THE GRADUATE FACULTY

in partial fulfillment of the requirements for the

degree of

MASTER OF SCIENCE

BY

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ABSTRACT

An 119-square-mile area within the Heavener 15' quadrangle, Le Flore County, in the eastern part of the Arkoma Basin, Oklahoma, was investigated to determine the geology of the coals in the Hartshorne Formation (Desmoinesian). The Lower Hartshorne coal lies about 60 feet above the base of the Hartshorne Formation, and is low- to medium-volatile bituminous in rank (70-84% fixed-carbon, mmf). It is low in sulfur (0.5-3.0%) and ash (8.6-14.2%), is 1.5 to 6 feet thick, and has a calorific value of about 14,000 Btu. A free-swelling index of 9 indicates that the coal makes a strong blast-furnace coke. Approximately 13,356,000 short tons of coal has been mined and lost-in-mining, leaving an estimated 313,478,000 tons in the remaining-resources category.

The northeastward increase in rank of the Lower Hartshorne coal was probably caused by a deep-seated heat source in eastern Arkansas. In the Arkoma Basin, folding induced by the Ouachita orogeny apparently did not affect the rank of the coal.

The Upper Hartshorne coal lies between 60 and 120

feet stratigraphically above the Lower Hartshorne coal. The coal is low- to medium-volatile bituminous in rank, is 1½ to 3 feet thick, contains 0.8-2.6% sulfur, and it contains 126,161,000 tons of coal in the remaining-resources category.

Hundreds of fossil tree trunks, stems, and leaves are evidence for deposition within a crevasse splay and overbank environment. A southwestward flowing distributary stream was active during the deposition of the upper Hartshorne Formation. The Upper Hartshorne coal is thin where it overlies a channel-fill sandstone in the distributary; the coal is thicker in areas adjacent to the channel because of greater subsidence. It is proposed that the sediments which formed the Hartshorne Formation were deposited within a prograding deltaic-plain environment.

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INTRODUCTION

Location and Description of Area

The study area encompasses 119 square miles and is located in eastern Oklahoma in central Le Flore County. This area is a portion of the northern one-half of the Heavener 15' topographic quadrangle map, and contains parts of Township 5 North, Ranges 24, 25, 26, and 27 East, and the southern one-half of Township 6 North, Ranges 24, 25, 26, and 27 East (figure 1).

The town of Heavener, from which the quadrangle was named, is located in the south-central part of the area and is accessible by U.S. Highway 59 and 270, which intersect at the north edge of the town. The Heavener area is served by the Kansas City Southern railroad and the Chicago, Rock Island and Pacific railroad. The historic Runestone State Park is located northeast of Heavener on Poteau Mountain. The Runestone is believed to have been left by Norsemen who were exploring North America in pre-Christopher Columbus days.

figure 1 - Index map of Oklahoma showing location of the Heavener area.

Lake Wister State Park is located at the western edge of the study area. The Wister dam was constructed in 1943 by the U.S. Army Corps of Engineers, creating Lake Wister reservoir. The state park serves as a recreation area.

Most of the study area is accessible by primary and secondary roads. Poteau Mountain is an exception, and is relatively inaccessible except along the southern edge, where a dirt road provides relatively easy passage. The remainder of Poteau Mountain may be traversed along trails and some primitive roads, which can be seen on the Heavener 15' quadrangle map, Plates 1-4 of this report, and on aerial photographs.

Topography and Drainage

The Heavener area is an area of reverse topography with anticlines forming valleys and synclines forming flat-topped mountains (Plate 1). Resistant sandstone units have formed ridges whose linear trends easily identify the geologic structure of the area. The slopes of the synclinal mountains and sandstone ridges are commonly very steep.

The area is drained northwestward by the Poteau River which joins the eastward flowing Arkansas River in northern Le Flore County. The course of the Poteau River is influenced by the numerous sandstone ridges in the area, creating a number of small-scale water gaps.

Poteau Mountain is the highest topographic feature in the study area, having a vertical relief of 1,300 feet and covering approximately 25 square miles. Poteau Mountain extends east of the study area into Arkansas and is a formidable topographic feature.

Purpose of Investigation

The objective of this thesis is to accurately map and interpret the geology of the Hartshorne coals, and estimate the coal resources. The Hartshorne coals occur stratigraphically within the Middle Pennsylvanian (Desmoinesian) Hartshorne Formation. The exact number of coals and stratigraphic position of each coal bed was determined and the character of the intervening strata was examined.

The series of ten maps and five cross-sections presented in this study serve to depict the geology of the Hartshorne coals in greater detail than previous studies have been able. It is the intent of the writer that this study will increase our knowledge of the geology of eastern Oklahoma and serve to stimulate the exploration and development of the coal resources in the Heavener area.

Data utilized in this study were derived from measured sections of surface exposures, records of 138 coal test boreholes and drillers' logs, oil and gas well data, aerial photographs, and previously published information. The drillers' logs used in this study were supplied by the

Oklahoma Geological Survey and private coal companies, and are tabulated in appendix I. The names of the contributing coal companies are strictly confidential. Chemical analyses (proximate) of coals sampled at the surface and in cores were used in constructing several of the maps presented. A table of proximate chemical analyses is presented in appendix II. Field examinations of outcrops and of active, idle, and abandoned coal mines were made.

An estimation of the original and remaining coal resources of the Heavener area was made using plotted mine maps, structure maps, isopach maps, and a planimeter.

The objective of this thesis is to accurately interpret the geology of the Hartshorne coals. This was accomplished by mapping the distribution, outcrop, structure, thickness, and stratigraphic positions of the coals. Structure and isopach mapping of the coals (Plates 1-4) was done on a scale of 1:24,000 (1 inch equals 0.379 miles), which is a larger scale than that used by previous workers. The larger scale is desirable in that the maps are more accurate and can be used in the exploration for coal and in planning for future mining development. The remainder of the maps are presented at a scale of 1:63,360 (1 inch equals 1 mile). Structure contours were drawn of the top of the Upper Hartshorne coal and of the Lower Hartshorne coal (Plates 1 and 2). The delineation of the outcrop was accomplished by the use of aerial photographs, underground and surface mine maps, and field investigations. Isopach maps of the Upper and Lower Hartshorne coals were prepared in an effort to determine depositional variations and coal resources (Plates 3 and 4). An isochore map of the stratigraphic interval between the coals was made to aid in the interpretation of the depositional environments of the coals and associated strata (Plate 5). The stratigraphic positions of the coals were determined by the correlation of a series of five stratigraphic cross sections. Lithofacies variations were examined in the field and in five cross sections in order to interpret the depositional environment of the coals (Plates 6-10). An isocarb map (fixed carbon percentage as determined in the proximate analysis) was produced to depict the variations in the rank of the Lower Hartshorne coal; the variations possibly being a function of the proximity to either the strongly deformed Oachita foldbelt or the Ozark Uplift (Plate 11).

A sulfur map (sulfur percentage as determined by chemical analysis) was made in an attempt to determine the depositional environment, and as an illustration of the sulfur concentration of the Lower Hartshorne coal for use in further development of the coal resources of the area (Plate 12). Depositional trends were also demonstrated in a map showing contours of equal ash percentage of the Lower Hartshorne coal (Plate 13). The coking quality of the Lower Hartshorne coal was depicted on a map showing the variations in the free-swelling index of the coal (Plate 14). The ash percentage and free-swelling index of each field sample and core sample were determined from the chemical analyses. Depositional trends within the study area are illustrated on a map showing the net sandstone thickness within the interval between the Upper Hartshorne coal and the Lower Hartshorne coal (Plate 15).

Previous Investigations

The first published work in the coal-bearing regions of eastern Oklahoma was authored by Chance in 1890. He described and measured the thickness and dips of the coal beds in eastern Oklahoma and presented chemical analyses of coal samples from adjacent areas. He named the stratigraphically lowest coal the Grady coal after the Grady Coal Basin. Chance's chief prospector, Mitchell, discovered and mapped a synclinal coal basin bearing the Grady coal and named it the Mitchell Basin. The Mitchell Basin was renamed the Pine Mountain syncline located in the thesis area. Chance mapped the outcrop of the Grady coal on a crude sketch map which is included in his report.

Hill (1891) made a reconnaissance of the western part of the Choctaw Coal Field. He observed the general structural trends and located on his reconnaissance maps the lowest productive coal (Grady) recognized by Chance(1890).

Stevenson (1895) also investigated the coalfield of the southern part of the Choctaw Nation. He correlated the work done by Chance (1890) and Hill (1891) with an unpublished section of rocks in Arkansas described by Winslow.

Drake (1897) made a general survey of nearly the entire coalfield of the Indian Territory. He mapped the limits of the coalfields of the Indian Territory and correlated them with those found in Kansas and Arkansas. Drake separated the coal-bearing strata into formations, showing the principal coal beds and the general stratigraphy and structure.

Taff and Adams (1900) did a regional geologic study of the eastern Choctaw Coal Field. They described the general topography of the area, made a generalized structure map which included the outcrop of the Lower Hartshorne coal, and desrcibed and mapped the major anticlines, synclines, and faults. They included a general description of the strata, identified major lithologic units, and described and named key formations. Taff and Adams renamed the Grady coal the Lower Hartshorne coal. Also included were descriptions and the distribution of the coal basins in which the major coal beds occur. Taff and Adams provided chemical analyses of some of the coal samples and included a section measured in the thesis area which showed two thin, noncommercial coal beds lying 90 and 130 feet stratigraphically below the Lower Hartshorne coal. They also discovered and named the Upper Hartshorne coal which lies fifty feet above the Lower Hartshorne coal.

Taff (1902, 1905, 1910) reported on the progress of his field work in eastern Oklahoma, including the further development of the stratigraphic column, a geologic map and several geologic cross sections. In Senate Document 390 (1910), Taff presented structure maps at a scale of 1" equals 1 mile by geographic districts, which included the Indian segregated coal land areas. He also estimated the extent and value of the coal reserves in eastern Oklahoma.

Snider (1914) did geologic work of a reconnaissance nature by mapping anticlines in search for natural gas. He confirmed, by field observations, the work of Taff by using Taff's structural maps and stratigraphic descriptions. He recognized and confirmed Taff's placement of the stratigraphic position of the Hartshorne coals.

Greater detail was achieved in the description of the structure and stratigraphy of Oklahoma coals by Cooper and Shannon in 1926. They included a geologic map (Plate XII, 1" equals 12½ miles) of eastern Oklahoma which included the Heavener area.

Moose and Searle (1929) sampled coal from all of the active coal mines in Oklahoma in 1928 and presented proximate analyses for each of the mines in an attempt to compare and contrast Oklahoma coals and determine variations within each coal bed. They presented a written description and a measured section of the coal in each mine that they sampled.

Stone and Cooper (1929) very briefly described anticlinal structures in Le Flore County, Oklahoma, in a regional oil and gas study.

Thom (1935) authored a preliminary map (scale: 1" equals 1 mile) of northern Le Flore County which showed the regional drainage, the outcrops of the Upper and Lower Hartshorne coals, structural trends and diagrammatic sketches of the underground coal mines. Thom's map also showed the federal segregated coal areas. The thesis area lies south of this study.

Hendricks (1939) mapped the Howe-Wilburton District of Le Flore and Latimer Counties at a scale of 1" equals 1 mile. His map follows the format of Thom's map (1935), showing the outcrop of the Lower Hartshorne coal and diagramatically depicting the underground mines in the Lower Hartshorne coal. Hendricks described the stratigraphy in greater detail than previous workers and recounted the major structural features described by Taff (1910). Measured sections of the coals, geologic cross sections and chemical analyses of coal samples were presented in this fairly comprehensive regional report.

Knechtel (1944) published a preliminary structural map (scale: 1" equals 1 mile) of northern Le Flore County which showed the outcrops of the coal beds, the locations of underground mines and of the major gas fields. The datum of the structure map (contour interval of 100 feet) was the top of the Hartshorne sandstone. The map included a table of measured sections of the coals. The southern boundary of Knechtel's map is five miles north of the thesis area.

Knechtel (1949) completed his work in northern Le Flore County in a comprehensive regional study which followed the format of a similar study done in the adjacent Haskell County by Oakes and Knechtel (1948). Knechtel expanded and improved the stratigraphic descriptions of Taff (1910) and Hendricks (1939). Knechtel recognized the Upper Hartshorne coal to be at the top of the Hartshorne sandstone and he placed it in the Hartshorne Formation. He included a geologic map and a refined version of his 1944 structural map. To date, this study stands as the most comprehensive geologic study of northern Le Flore County. The thesis area is south of Knechtel's map area.

Trumbull (1957) reviewed earlier estimates and did not accept them. He re-estimated the original and remaining coal resources in Oklahoma. His estimates were conservative and were based on surface observations and sparse drilling data. Trumbull predicted that estimates of the coal resources would probably be increased as additional mapping and exploratory work were done. He categorized the resources by coal bed, coal thickness, and depth and rank in each county. Trumbull's resource map showed general structural and thickness contours of the Lower Hartshorne coal in the thesis area. The contour interval of the structural map was 1,000 feet and the isopachous interval was six inches.

Friedman (1974) re-evaluated the Oklahoma coal resources in a report to the Ozarks Regional Commission. He determined by county the original, remaining, and net recoverable resources and reserves for each bed, following similar categories and parameters used by Trumbull (1957). Friedman's estimates of the original and remaining coal resources were double those of Trumbull (1957) because, as Trumbull had predicted, numerous additional borehole data were available to Friedman. Friedman discussed potential uses for the Oklahoma coals, restated the history of production as noted by Trumbull (1957), presented updated production tables through 1973, and described the current status of coal mining in Oklahoma. Also included in the report were data on mining costs and selling price of coal and information on sulfur content of coals.

STRATIGRAPHY

General Statement

The bedrock of the Heavener area is of Middle Pennsylvanian age (Hendricks, 1939). Hendricks tentatively classified some of the unconsolidated sediments as Quaternary (?) in age and illustrated their distribution on a geologic map. Recent alluvium has filled stream valleys and forms the floor of the flood plains of the Poteau River drainage system. The Pennsylvanian (Atokan and Desmoinesian) age rocks of the Heavener area correspond approximately in age to Upper Pottsville and Allegheny beds of the eastern United States (Trumbull, 1957). The Pennsylvanian rocks of the Heavener area are economically important in that they contain 8-12 coal beds, four of which are commercial in other parts of the Arkoma Basin. The Pennsylvanian rocks have been named in ascending order; the Atoka, Hartshorne, McAlester, Savanna, and Boggy Formations. All but the Atoka Formation are in the Krebs Group (Oakes, 1953). All of these formations consist of alternating beds of shale and sandstone deposited in a shallow-water environment. No limestone has been identified in the Hartshorne Formation, and Hendricks (1939) reported no carbonates in the Heavener area within any of these formations. All of these formations contain coal beds which range from less than one inch to six feet in thickness.

The section of Pennsylvanian rocks in the Heavener area was deposited under shallow-water conditions in a deeply subsiding basin named the Arkoma Basin. The Arkoma Basin of Oklahoma is continuous into Arkansas. The formations under investigation have been correlated with those in Arkansas (Hendricks and Parks, 1937, p. 274-275).

The general lithologic character, thickness, and age of the Pennsylvanian formations exposed in the Heavener area are illustrated on Plate 16.

Pennsylvanian System

Atoka Formation

The Atoka Formation was named and described by Taff and Adams in their report published in 1900. The type locality was not indicated, but most workers assumed that it is the town of Atoka, Atoka County, Oklahoma, about 90 miles southwest of Heavener (Oakes and Knechtel, 1948). The Atoka Formation is the oldest exposed formation and it crops out in the southwestern part of the area, covering approximately 30 square miles. The formation crops out on the Heavener anticline with an exposed thickness of 7,750 (Hendricks, 1939, Plate 27). Hendricks (p. 265) estimated that the entire Atoka Formation is greater than 9,000 feet thick in the Heavener area.

The formation consists mainly of gray-to-black sandy shale with thick sandstone units interbedded at widely-spaced intervals. The shale units are brown to black, micaceous, and contain lenses and nodules of siderite. The shale units in the Atoka Formation are more silty and less clayey than those of the younger, overlying Pennsylvanian formations (Knechtel, 1949). The Atoka sandstone units are mostly fine-grained and silty, forming topographic ridges at the surface.

Two thin coals, each 0.5 feet thick, occur 10 feet and 40 feet, respectively, below the top of the Atoka Formation. No other coals have been reported within the Atoka Formation. Trumbull (1957) and Knechtel (1949) tentatively included one or two thin, noncommercial coals at the top of the Atoka Formation in Le Flore County. Hendricks (1939) presented a stratigraphic section measured in the Petros railroad cut (sections 30 and 31, T.5 N., R.26 E., measured section 2, appendix 4) in which he placed the two thin coals mentioned above in the Hartshorne Formation rather than in the Atoka Formation.

The contact between the Atoka Formation and the overlying Hartshorne Formation is defined as being at the base of the Lower Hartshorne sandstone (Oakes and Knechtel, 1948, p.19). It seems apparent that Hendricks incorrectly placed the base of the Lower Harsthorne sandstone at the bottom of a 1½-foot-thick, laterally discontinuous, sandstone lens. This thin sandstone does not exist in the roadcut along U.S. Highway 59, one mile west of the section measured by Hendricks, nor does it occur in a drill hole 13 miles east of the railroad cut. The Atoka-Hartshorne contact correctly belongs at the base of the massive Lower Hartshorne sandstone, some 42 feet above the thin sandstone lens used by Hendricks. The two thin coals occur below the Lower Hartshorne sandstone and are therefore included in the Atoka Formation by the writer.

The boundary between the Hartshorne and Atoka Formations may occur in the shale beneath the Lower Hartshorne sandstone as determined paleontologically. Oakes (1977) placed the Atoka Formation in the Desmoinesian at the type locality in Atoka, Oklahoma, based on the abstract of an unpublished paper by Wilson (1976). The evidence for placing the Atoka Formation in the Desmoinesian has not been published in any recognized journal.

Hartshorne Formation

The Hartshorne Formation (pronounced Harts-horne) is commonly called the Hartshorne Sandstone in Oklahoma, and is the basal unit of the Des Moines series (Middle

Pennsylvanian) (Branson, 1954, p. 8). The formation is conformably underlain by the Atoka Formation and overlain conformably by the McAlester Formation, and is a clastic unit which contains no carbonate units.

H.M. Chance (1890) first described and mapped the "Tobucksy" sandstone in and to the west of the Heavener area. Taff (1899) renamed the unit the Hartshorne Sandstone. The type locality was assumed by later workers to be exposures near the town of Hartshorne, Oklahoma (Oakes and Knechtel, 1948, p. 22). Taff and Adams (1900) expanded the upper boundary of the formation to include the Lower Hartshorne coal and some overlying shale and sandstone. Oakes and Knechtel (1949) recognized a convergence of the Upper and Lower Hartshorne coals in northern Le Flore and eastern Haskell Counties. The Hartshorne coal (undivided to the north) splits along a northeast-southwest-trending line into the Upper and Lower Hartshorne coals to the south. Oakes and Knechtel (1948) redefined the upper Hartshorne Formation boundary in 1943-1944 to be at the top of the Upper Hartshorne coal in Haskell and Le Flore Counties. This placed the Upper Hartshorne coal in the Hartshorne Formation rather than in the overlying McAlester Formation. Trumbull (1957) maintained that this definition applies only for Haskell and Le Flore Counties and not for the remainder of the Arkoma Basin.

Branson (1956) followed the definition of Oakes and Knechtel for the boundaries of the Hartshorne Formation, but suggested resurrecting Chance's 1890 term "Tobucksy" for the lowest sandstone member. Mc Daniel (1961) also supported the Hartshorne Formation boundaries as defined by Oakes and Knechtel, but proposed that the formation be divided formally into an upper and lower member; the upper member consisting of the strata between the top of the Upper Hartshorne coal and the top of the Lower Hartshorne coal, and the lower member consisting of the strata between the top of the Lower Hartshorne coal and the base of the lowest sandstone. Mc Daniel named the sandstone in the upper member the Upper Hartshorne sandstone, and the sandstone in the lower member the Lower Hartshorne sandstone (figure 2).

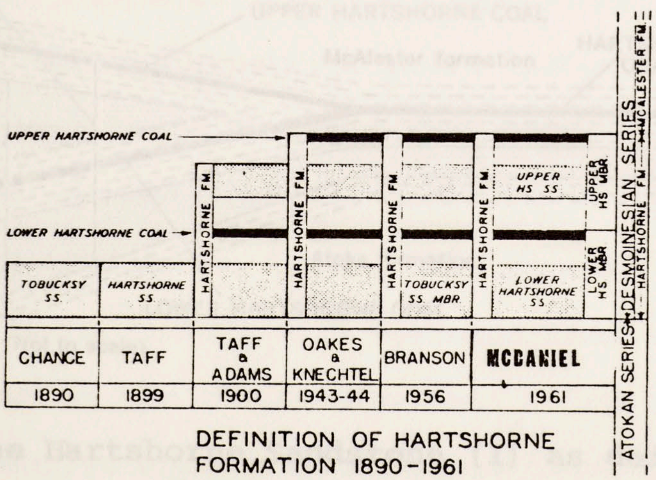

figure 2 - Definition of Hartshorne Formation 1890-1978 (modified from McDaniel, 1961).

This definition of the Hartshorne Formation has proven to be practical and is used in this report. Figure 3 is a diagram which shows the various definitions of the Hartshorne Sandstone in the Arkoma Basin of Oklahoma.

The Upper and Lower Hartshorne sandstones are highly variable in character and thickness both vertically and laterally. The Lower Hartshorne sandstone is about 50 feet thick in the southern part of the study area. Good exposures of the Lower Hartshorne Member can be seen in the roadcut along U.S. Highway 59, south of Heavener (sec. 36, T.5 N., R.25 E.), in the Petros railroad cut (sec. 31, T.5 N., R.26 E.), and in outcrop along the

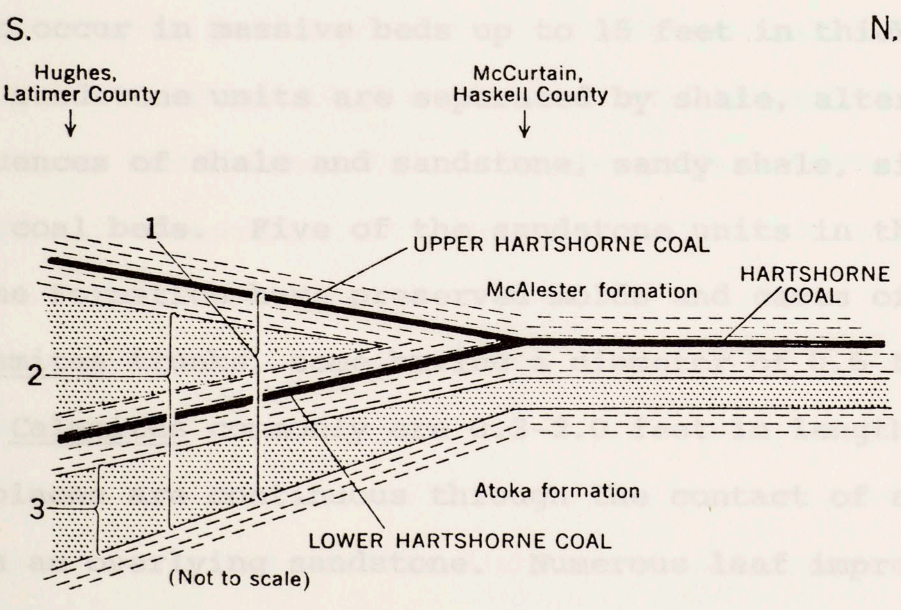

figure 3 - The Hartshorne Sandstone (1) as defined in Haskell County, Okla., (2) of general Oklahoma usage, and (3) of Arkansas usage (from Oakes and Knechtel, 1948, in Trumbull, 1957).

the unpaved steep road leading down the south slope of Pine Mountain (sec. 34, T.5 N., R.25 E.). The Upper Hartshorne sandstone ranges in thickness from about 30 feet to more than 100 feet. The entire section of the Upper Hartshorne Member is not well exposed at the surface, because the upper part of the section consists mainly of shale overlain at the top by the Upper Hartshorne coal. The lower part of the formation is well exposed in an abandoned strip mine on Pine Mountain (sec. 26, T.5 N., R.25 E.).

The sandstone units within the Hartshorne Formation are medium gray in fresh exposures which weather buff. They are mostly interbedded with gray shale, but also occur in massive beds up to 15 feet in thickness. The sandstone units are separated by shale, alternating sequences of shale and sandstone, sandy shale, siltstone, and coal beds. Five of the sandstone units in the Hartshorne Formation have preserved molds and casts of upright Calamites trunks, some having a diameter of 0.6 feet. The Calamites commonly are 0.3-2.0 feet in length, and in places are continuous through the contact of a shale with an overlying sandstone. Numerous leaf impressions were preserved in the shale above and below the Lower Hartshorne coal, commonly in siderite nodules. Good collecting sites for plant remains are in the abandoned strip pit on Pine Mountain (sec. 26, T.5 N., R.25 E.), in the U.S. Highway 59 roadcut south of Heavener (sec. 36, T.5 N., R.25 E.), and in the idle Paul Rees Coal Company Heavener surface mine (sec. 25, T.5 N., R.25 E.).

The Hartshorne Formation is a good surface marker because the resistant sandstone units form prominant ridges throughout most of the study area and the Arkoma Basin. The Hartshorne Formation was therefore used by early workers in correlating the Middle Pennsylvanian strata in the Arkoma Basin.

Three coal beds occur within the Hartshorne Formation. The Upper Hartshorne coal has already been mentioned (p. 17) as being the uppermost unit within the formation, and it ranges from one-half foot to 3 feet in thickness. It is low- to medium-volatile bituminous coal in rank which lies between 60 and 120 feet stratigraphically above the Lower Hartshorne coal. The Upper Hartshorne coal is potentially commercial, but has not been mined in the study area.

In the north-central part of the study area, an unnamed coal, ranging from less than one-half foot to 2 feet in thickness, was noticed by the writer. This coal is highly variable in thickness and is restricted to the north-central part of the study area, and cannot be correlated with the Upper or Lower Hartshorne coals (Plates 6-9). The unnamed coal, which the writer calls, for convenience, the Middle Hartshorne coal, lies about 55 feet stratigraphically above the Lower Hartshorne coal in the Upper Hartshorne

Member within a black shale unit.

The Lower Hartshorne coal is important economically in that it has as recently as 1976, been mined in the Heavener area and is presently being mined in many parts of the Arkoma Basin. The coal ranges from 1½ to 6 feet in thickness and is a low- to medium-volatile bituminous coking coal with a relatively low sulfur content (0.5-1.5%). The coal occurs within a shale unit which divides the Upper and Lower Hartshorne Members, about 60 to 70 feet stratigraphically above the Hartshorne-Atoka contact. The outcrop of the Lower Hartshorne coal is relatively easy to find due to the abandoned underground and surface mines that are present, and the coal's stratigraphic association with the overlying ridge-forming Upper Hartshorne sandstone.

McAlester Formation

The McAlester Formation was named and first described by Taff in 1899 from exposures around the town of McAlester, Pittsburg County, Oklahoma. The McAlester Formation conformably overlies the Hartshorne Formation, with the contact being at the top of the Upper Hartshorne coal (Plates 6-10). The formation is approximately 2,200 feet thick in the Heavener area, consisting mostly of gray shale and siltstone, with sandstone units interbedded at intervals of several hundred feet.

The McAlester Formation crops out in a broad band just north of the Hartshorne outcrop, forming a topographic valley interupted only by sandstone ridges. The formation consists mostly of shale, but about 8 recognizable sandstone units and two coal beds are interbedded with the shale.

The lowermost shale unit is approximately 700 feet thick in the study area and is known as the McCurtain Shale Member. The shale is dark gray, sandy, and contains numerous ironstone nodules and plant material. The lower boundary of the shale member is the top of the Upper Hartshorne coal, and the top boundary is the base of the Warner Sandstone Member. The McCurtain Shale Member contains a few thin sandstone units, including the McCurtain sandstone, which lies about 250 feet above the base of the formation. Above the Warner Sandstone Member is a stratigraphic sequence of shale interbedded by the Lequire and Cameron Sandstone Members. The shale above the Cameron Sandstone Member contains the economically important Lower McAlester and Stigler (?) coal beds, which are separated from each other by about 58 feet of gray and black shale (Hendricks, 1939). Hendricks suggested that the coal above the Lower McAlester coal may be correlative with the Stigler coal of northern Le Flore and Haskell Counties. The exact correlation of the Stigler coal with the McAlester coal of southern Le Flore and Latimer Counties has not yet been determined. The Stigler coal may correlate with the Lower McAlester coal, and the upper coal, named tentatively by Hendricks in 1939 as being the Stigler, may be more appropriately named the Stigler rider coal (Friedman, 1978, personal communication). Four thin coal beds (1 foot or less in thickness) are present at least locally between the Stigler (?, upper coal) and the top of the McAlester Shale (Hendricks, 1939).

The Tamaha and Keota Members occur above the coal zone, and are separated from the coal zone and each other by gray and black shale. The uppermost unit consists of gray shale, and the top of the McAlester Formation is at the base of the Savanna sandstone of the overlying Savanna Formation.

The McAlester Formation is highly variable in thickness within the Heavener area. The formation is about 1,240 feet thick on the south side of Poteau Mountain, and increases to a thickness of about 2,200 feet in the northwest corner of the Heavener area (Hendricks, 1939). Hendricks presented an isopach map of the McAlester Formation in his 1939 report which showed that the McAlester Formation is thickest along an east-west trend between McAlester, Oklahoma, and the northwest corner of the Heavener area. He postulated that the thickness variations within the McAlester Formation were due to the depositional conditions rather than subsequent erosion. Hendricks suggested, on his isopach map, that maximum subsidence during McAlester deposition occurred along this east-west trend.

Savanna Formation

The Savanna Formation was named and described by Taff in 1899 from exposures near the town of Savanna, Pittsburg County, Oklahoma. The Savanna Formation is commonly called the Savanna Sandstone because the formation consists of interbedded sandstone and shale; the sandstone units forming prominant ridges which distinguish the formation at the surface.

The lower boundary of the formation is at the base of the lowermost Savanna Sandstone. The Savanna Formation overlies the McAlester Formation with an irregular contact, although at some places the transition from one formation to another appears to be gradational (Hendricks, 1939). The lower sandstone unit of the Savanna Formation changes facies north of the Heavener area in northwestern Haskell County and Muskogee County, possibly into the Spaniard Limestone, which occupies the equivalent stratigraphic position (Knechtel, 1949). The lower boundary of the Savanna Formation has therefore been placed at the base of the Spaniard Limestone in the northeastern shelf area of Oklahoma (Knechtel, 1949). The upper boundary of the Savanna Formation is at the base of the Bluejacket Sandstone Member of the overlying Boggy Formation.

The shale units are mostly gray and sandy with interbedded black carbonaceous shale containing well-preserved plant fossils (Hendricks, 1939, p. 272). Some of the shale units are calcareous and locally contain marine invertebrates. The sandstone units are highly variable in character, varying from buff, fine-grained, silty, and thin-bedded to almost white, coarse-grained, well-sorted, and massive. The individual sandstone units range from about 10 to 180 feet in thickness.

Hendricks (1939) computed the thickness of the Savanna Formation in the Heavener area from plane-table traverses across the formation in T.6 N., R.25 E. to be about 1,750 feet. He presented an isopach map of the Savanna Formation in which he showed that the formation attains its greatest thickness in the the northwest part of the Heavener area, and thins to the north. On the Geologic Map of Oklahoma, Miser (1954) showed the upper boundary of the Savanna Formation to be at the base of the Bluejacket Sandstone of the overlying Boggy Formation, because the Bluejacket Sandstone was the longest continuous mappable boundary available. Taff's (1899) original formational contact was about 650 feet below the Bluejacket Sandstone. Miser's (1954) redefinition of the contact moved 650 feet of sandstone and shale from the Boggy Formation into the Savanna Formation. Hendrick's (1939) report predated the formational boundary change, making his thickness computation and isopach map show the Savanna Formation to be about 650 feet too thin for the present-day definition.

The economically important Lower Cavanal coal occurs in the upper-middle part of the Savanna Formation, is 1.2-2.2 feet thick, and has been mined in the northwest corner of the study area. The Lower Cavanal coal occurs within a zone of coal beds which may contain as many as four coal beds. A thinner unit, the Upper Cavanal coal lies 20 to 50 feet above the Lower Cavanal coal, and has not been mined in the Heavener area. The Rowe (Lower Witteville ?) coal occurs in a sandy gray shale unit within the 650-foot-stratigraphic interval, which was added to the uppermost part of the Savanna Formation by Miser in 1954.

Boggy Formation

The Boggy Formation was named and described by Taff in 1899 from exposures along the North Boggy Creek, Pittsburg and Atoka Counties, Oklahoma. The Boggy Formation is commonly called the Boggy Shale in Oklahoma and consists of alternating gray shale and sandstone.

The lower boundary of the formation was redefined by Miser (1954) to be at the base of the Bluejacket Sandstone. The Bluejacket Sandstone ranges from 10 to 65 feet in thickness and consists of alternating beds of gray shale and thick-bedded, medium-grained, well-sorted sandstone (Oakes, 1977, p. 30). The Bluejacket Sandstone crops out in the extreme northwest corner of the study area in sec. 14, T.6 N., R.24 E. The lower portion of the Bluejacket Sandstone is the only part of the Boggy Formation that is exposed in the study area.

Quaternary System

Recent Alluvium

The stream valleys in the Heavener area are filled with recent alluvium. At some places this material is an ashy-gray silt, and at others, particularly in the valley of the Poteau River, it is a very dark-gray, clayey silt (Hendricks, 1939). The alluvium covers a rather large area within the floodplain of the Poteau River, and somewhat smaller areas in the smaller stream valleys.

Stratigraphic Correlation Sections

Lithologic variations in the Hartshorne Formation are depicted on five stratigraphic cross sections (Plates 6-10). Plates 6-9 contain lithologic columnar sections showing the correlation of the Lower, Middle, and Upper Hartshorne coals at a horizontal scale of 1:12,000 (1 inch equals 0.189 mile), and a vertical scale of 1 inch equals 50 feet. The datum of the cross sections (Plates 6-10) is the top of the Lower Hartshorne coal. Plates 6-9 also contain structural cross sections which show the present structural configuration of the Lower, Middle, and Upper Hartshorne coals in relation to the land surface (datum is sea level). These structural cross sections are at a horizontal scale of 1:12,000 and at a vertical scale of 1 inch equals 1,000 feet.

Plate 10 is a lithofacies cross section which shows the stratigraphic relations of the coals and sandstones in the Hartshorne and Atoka Formations (at a horizontal scale of 1 inch equals 1 mile, and a vertical scale of 1 inch equals 50 feet). The datum is the Lower Hartshorne coal. The geometry of each lithologic unit is depicted, showing the inferred changes in lithofacies. This cross section shows the correlation of the upper Atoka, Hartshorne, and lower McAlester Formations from Oklahoma into Arkansas. The stratigraphic positions of the flora recognized in the study area (upright Calamites, Lepidodendron, and leaf impressions) are also depicted on this cross section.

STRUCTURE

Regional Structural Geology

The Heavener area lies in the southeast corner of the Oklahoma part of the Arkoma Basin. The Arkoma Basin is a relatively deep depositional basin which was formed by subsidence of Paleozoic sediments along down-to-the-south growth faults. The Arkoma Basin lies north of the Ouchita Mountain foldbelt in Oklahoma and Arkansas. Figure 4 is an index map of Oklahoma which shows the Heavener area and the relation of the Arkoma Basin to the other major tectonic provinces of Oklahoma. The Arkoma Basin tectonic province is separated from the Ouachita Mountain foldbelt by the Choctaw fault, which trends east-west and lies about 1½ miles south of the Heavener area. The Choctaw fault is the northernmost thrust fault in the Ouachita foldbelt, and may exist as a zone of thrust faults. The Arkoma Basin is bordered to the north by the Northern Shelf area and the Ozark dome.

The Arkoma Basin possibly was a southward-facing divergent continental shelf in the early Paleozoic (Briggs and Roeder, 1975). Sediments (Ouachita facies) in the Ouachita foldbelt were deposited on the continental slope and rise,

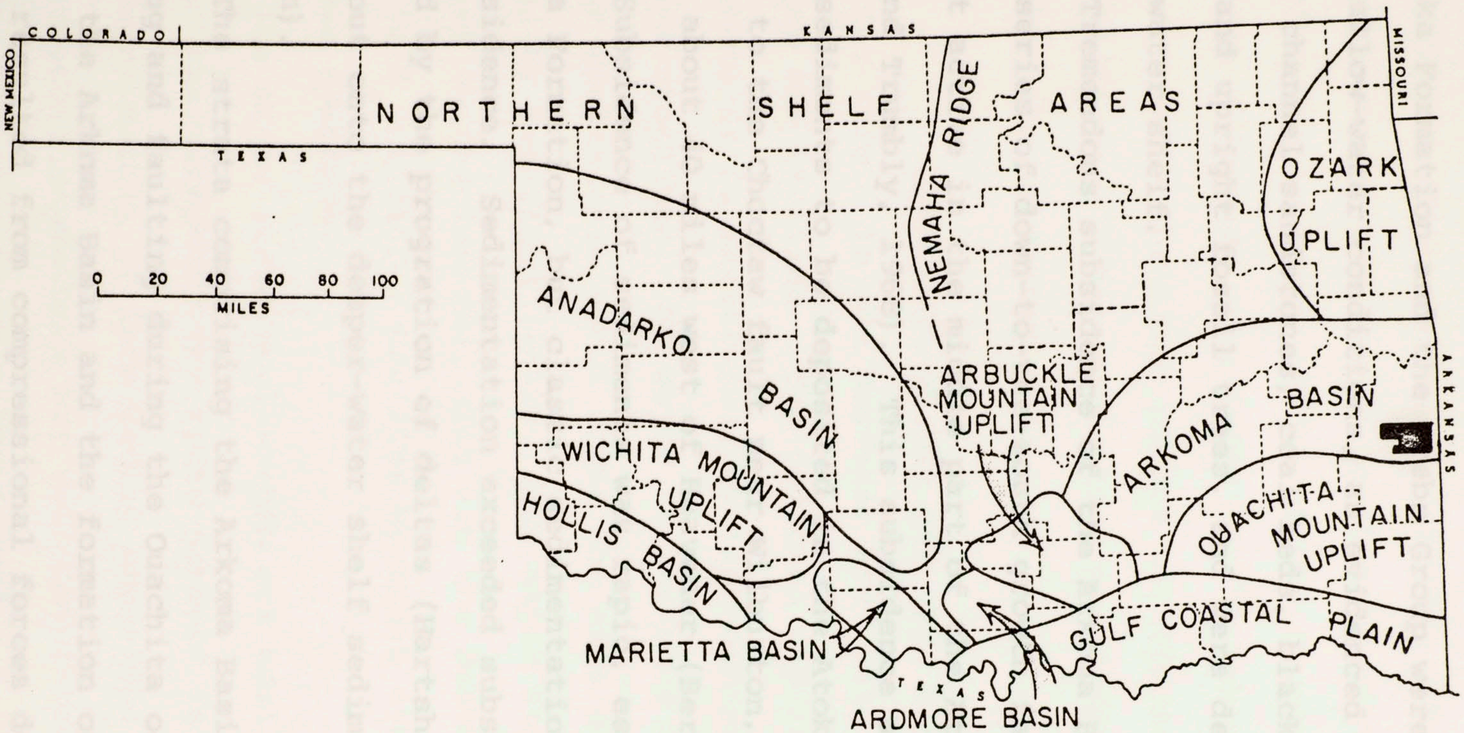

figure 4 - Map showing the study area and major tectonic provinces of Oklahoma (modified from Johnson and Denison, 1973).

and were later thrust northward over the subsiding Arkoma shelf to form the Ouachita Mountains (Briggs and Roeder, 1975). In the Arkoma Basin, the sediments in the uppermost Atoka Formation and the Krebs Group were deposited under shallow-water conditions, as evidenced by the occurrence of channel sandstones, coal beds, black carbonaceous shales, and upright fossil trees, and were deposited on a shallow-water shelf.

Tremendous subsidence of the Arkoma Basin occurred along a series of down-to-the-south growth faults, which were most active in the middle part of the Atoka Formation (Berry and Trumbly, 1968). This subsidence allowed 10,000 feet of sediments to be deposited in the Atoka Formation adjacent to the Choctaw fault near Wilburton, Oklahoma, which is about 40 miles west of Heavener (Berry and Trumbly, 1968). Subsidence of sediments was rapid, especially in the Atoka Formation, but clastic sedimentation kept pace with subsidence. Sedimentation exceeded subsidence, as evidenced by the progration of deltas (Hartshorne Formation) farther out onto the deeper-water shelf sediments (Atoka Formation).

The strata comprising the Arkoma Basin were deformed by folding and faulting during the Ouachita orogeny. Deformation of the Arkoma Basin and the formation of the Ouachita foldbelt resulted from compressional forces derived from the south, possibly associated with the collision of the North

American craton with a southern continent (South America ?) (Wickham and others, 1976). This continental collision began in early Pennsylvanian time and was over by early Permian time (Wickham and others, 1976). The Ouachita facies were strongly deformed southwards of the Choctaw fault. The Arkoma Basin (north of the Choctaw fault) was only mildly deformed. The folds in the Arkoma Basin are symmetrical, with the limbs of the structures having dips of 5 to 55 degrees. The anticlines are commonly more tightly folded than the synclines.

Structure of the Heavener Area

The strata in the Heavener are have been deformed by folding and faulting. The regional dip is northward, except where it is interrupted by eastward-plunging anticlines and synclines. No major faults have been recognized, but minor faults were noted along the axis of the Heavener anticline by Hendricks (1939). The major structural features recognized in the Heavener area are the Heavener anticline, the Hartford anticline, the Pine Mountain syncline, and the Poteau syncline.

The major structural trends are easily recognized on aerial photographs. The rocks exposed in the Heavener area consist mainly of interbedded sandstone and shale units. The interbedded sandstones are well-indurated and resistant to erosion, forming parallel topographic ridges. The size of each ridge is dependent upon the thickness of the sandstone; the thicker sandstone units forming higher topographic ridges. The interbedded shale is less resistant to erosion, and therefore it forms wide valleys between the sandstone ridges. The resultant topography is thus structurally controlled (Plate 1).

The anticlines are sharply folded in relation to the synclines in the Heavener area. This structural configuration is common throughout the Arkoma Basin. The synclines are broad, shallow folds, which plunge to the east. The limbs of the synclines have dips which are fairly shallow, ranging from 6 to 30 degrees. Conversely, the anticlines are narrow and sharply folded, with dips of greater than 45 degrees.

Two maps (Plates 1 and 2) are presented which show structure contours of the top of the Lower and Upper Hartshorne coals respectively. A detailed discussion of these maps is presented in the next chapter.

Most of the Heavener surface area is occupied by four large structural features. Descriptions of these features are given below.

Heavener anticline

The Heavener anticline occupies the central part of the Heavener area. It is an east-west trending anticline which plunges to the east. The anticline begins in sec. 10, T.5 N., R.26 E., and extends westward to sec. 11, T.5 N., R.24 E., where it passes beneath Lake Wister. Hendricks' report in 1939 predated the construction of the Lake Wister reservoir. He stated in his report that the anticline could not be recognized at the surface westward of sec. 11, T.5 N., R.24 E., because the anticline passed beneath the alluvium of the Poteau River, but that it probably continued beneath the alluvium for several miles.

The Heavener anticline is tightly folded and symmetrical, with dips of 40 to 65 degrees on both the north and south flanks (Hendricks, 1939). As mentioned above, many of the beds exposed near the crest of the fold are broken and slickensided, and it is probable that much minor faulting has occured near the axis and on the flanks of the fold (Hendricks, 1939). More than 7,000 feet of rocks of the Atoka Formation have been exposed in the central part of the anticline.

Differential erosion of the sandstone and shale units within the Atoka Formation has created a system of parallel sandstone ridges which easily distinguish the structure of the Heavener anticline. The Hartshorne Formtion crops out around the Heavener anticline, and the crop line can be seen on Plates 1 and 2. The anticline plunges to the east, and appears to die out in sec. 10, T.5 N., R.26 E., where it encounters the intersection of the Pine Mountain and Poteau syncline.

Hartford anticline

The Hartford anticline lies in the northeast corner of the Heavener area. It begins in Howe and extends eastward into Arkansas. It trends northeast-southwest and consists of two sections, divided by a structural saddle (Plates 1 and 2). The southwestern section plunges to the northeast towards the saddle, and the northeast section plunges to the southwest. The anticline is symmetrical and the beds are gently folded. Sandstone and shale units of the McAlester shale are exposed at the surface in the central part of the anticline. The configuration of the Hartford anticline is portrayed on the structural maps of the Upper and Lower Hartshorne coals (Plates 1 and 2).

Poteau syncline

The Poteau syncline lies in the eastern north-central part of the Heavener area, between the Hartford anticline and the Choctaw fault. It has an east-west trend which begins in sec. 31, T.6 N., R.26 E., and extends eastward into Arkansas. The Poteau syncline is notable in that the beds deformed into the syncline form Poteau Mountain which is one of the larger topographic features in the Arkoma Basin. The syncline is symmetrical with dips of 6 to 18 degrees on both the north and south limbs. The Bluejacket Sandstone (Boggy Formation) is the youngest rock exposed at the surface along the axis of the syncline on Poteau Mountain. The structure of the Poteau syncline is shown on the structure maps of the Upper and Lower Hartshorne coals (Plates 1 and 2).

Pine Mountain syncline

The Pine Mountain syncline lies in the southern part of the Heavener area between the Heavener anticline to the north, and the Choctaw fault to the south. The syncline has an east-west trend and plunges to the east. It begins in sec. 14, T.5 N., R.26 E., and extends westward out of the Heavener area to about sec. 13, T.5 N., R.23 E., for a distance of about 19 miles. The Pine Mountain syncline is symmetrically folded, with dips of 5 to 9 degrees on both the north and south limbs. The Hartshorne Formation is exposed at the surface of the nearly flat-topped Pine Mountain, which is capped by the Upper Hartshorne sandstone (secs. 25-28 and 33-36, T.5 N., R.25 E.). Rocks of the Atoka Formation are exposed along the syncline, west of Pine Mountain, and also on the north and south flanks.

Hendricks, in his 1939 report, included a map showing the surface geology of the Howe-Wilburton district which included the entire area covered by this report. The geologic structure of the area is easily recognized on his map because he distinguished and mapped the prominent sandstone units of the Atoka Formation. The structural trends around the Heavener anticline and the Pine Mountain syncline are most apparent, as portrayed by the sandstone outcrops in the Atoka Formation. The McAlester Formation is exposed east of Pine Mountain along the trend of the syncline, on the flanks of Poteau Mountain.

THE HARTSHORNE COALS

Distribution of Data

The data used in this study was derived mainly from drillers' logs of coal test boreholes, and from chemical analyses of coal cores taken from the borehole. Information was also gathered from maps of underground and surface mines, and from field examinations of outcrops.

Drillers's logs from 138 drill holes were made available to the writer by the Oklahoma Geological Survey and from private coal companies. Most of the logs were provided by private coal companies, and are strictly confidential and not available to the public. Of the 138 logs, 90 included a chemical analysis of the coal. Data pertaining to the Hartshorne coals are tabulated in appendixes 1 and 2. Each drill hole is numbered, and the location, surface elevation, chemical analysis, and altitudes, depths, and thicknesses of the Upper and Lower Hartshorne coals are included.

The drill holes are fairly well distributed throughout the area. There are two areas of high data density, one on Pine Mountain, and one in the center of the study area. There were 41 drillers' logs on Pine Mountain available to the writer, yielding excellent control in mapping. Another clump of data, consisting of logs from 11 drill holes, is in secs. 24 and 25, T.5 N., R.26 E. and sec. 19, T.5 N., R.27 E. A large data gap occurs beneath Poteau Mountain and along the south outcrop of the Hartshorne coals (secs. 26-28 and 32, T.5 N., R.26 E.). Another data gap occurs in the northwest corner of the area. A high density of data is located in the center of the area, east of Howe. There are 11 holes that are fairly well distributed to the north of the outcrop along the north flank of the Heavener anticline, and 6 holes which distinguish the northeast part of the Hartford anticline. The data is more densely distributed in areas where the Hartshorne coals are relatively near the surface. The interpretations presented in this study are more complex in areas of data control, and less complex where inferred, away from the control points. The interpretations of the geologic nature of the Hartshorne Formation are speculative in the areas where there are gaps in the data, but geologic inferrences made by the writer are fairly well-supported by information obtained from the 138 coal test boreholes surrounding the data gaps.

Lower Hartshorne Coal

The Lower Hartshorne coal is stratigraphically the lowest commercial coal bed in the Arkoma Basin. It occurs about 60 feet above the base of the Hartshorne Formation within a gray shale interval which separates the Upper and

Lower Hartshorne sandstone units. The coal is underlain by a thin (1 to 6 inches thick) rooted underclay. The Lower Hartshorne coal is laterally continuous throughout the Arkoma Basin, and is low- to medium-volatile bituminous in rank, low in sulfur and ash, and has a heating value of about 14,000 Btu. The coal ranges from 1.5 to 6 feet in thickness within the Heavener area. The sulfur percentage of the coal ranges from less than 0.5 to about 3.0 percent and averages about 1.0 percent.

The Lower Hartshorne coal crops out along an arcuate trend, and underlies most of the Heavener area, except in the southwest part of the area on the Heavener anticline, and along the southern margin, where it has been removed by erosion and older rocks of the Atoka Formation are exposed.

Discussion of the Structure Map of the Lower Hartshorne Coal

A map of the structure of the Lower Hartshorne coal is presented at a scale of 1:24,000 (1 inch equals 0.379 mile) on Plate 1. The datum of the map is the top of the Lower Hartshorne coal. The structure is drawn on an enlargement of the Heavener 15' topographic quadrangle base which was enlarged photographically to the 7.5' scale (1:24,000). The Heavener 15' quadrangle was published in 1959, and many new cultural features are not included on the base map. The writer has therefore included the new U.S. Highway 59 (obtained from aerial photographs), a major highway through the area. The Heavener 15' quadrangle is presently being subdivided into four 7.5' quadrangle maps by the U.S. Geological Survey, but these maps were not available at the time of this writing.

The outcrop of the Lower Hartshorne coal is depicted on the structure map, and is easily traced from the locations of numerous abandoned underground and surface mines. The abandoned underground mines are all drift mines, except for the Howe Coal Company, No. 1 mine (mine no. 18, Plate 1), which was a slope mine, and two abandoned shaft mines. Hendricks (1939, Plate 27) mapped the location of two abandoned shaft mines, both of which probably were additional entrances to drift mines. The underground mines shown on Plate 1 are plotted to scale from the mine maps submitted to the Chief Mine Inspector of Oklahoma.

The Lower Hartshorne coal was mined extensively underground along the outcrop on the north limb of the Heavener anticline, as can be seen by the number and extent of the underground mines (Plate 1).

The Lower Hartshorne coal crops out in sec. 19, T.5 N., R.27 E., at the eastern margin of the area. In this part of the area, the Upper Hartshorne Member of the Hartshorne Formation consists completely of shale; that is the Upper Hartshorne sandstone is absent and is believed to have not been deposited here. The Lower Hartshorne Member consists of sandy shale interbedded with sandstone. The prominent ridge commonly formed by the Hartshorne Sandstone is not present in secs. 24-27, T.5 N., R.26 E. The outcrop can still be traced in the area, where the ridge is missing, from the locations of the abandoned strip mines at Coaldale that had been dug in the Lower Hartshorne coal (secs. 24-26, T.5 N., R.26 E., and sec. 19, T.5 N., R.27 E.). The Coaldale mines have not been reclaimed, and spoil piles are present on both sides of the mines. The present outcrop of the coal is at the base of the highwall which was left by the mining operations, but it is beneath the water-line of the ponds formed in the mines. The lower part of the Upper Hartshorne Member of the Hartshorne Formation is exposed in the highwall of these strip pits, and consists mostly of gray and black shale. The original position of the outcrop of the coal was inferred by the writer where the coal has been mined.

The Upper Hartshorne sandstone ridge is noticeable in sec. 28, T.5 N., R.26 E., and is continuous throughout the rest of the Heavener area. The Upper Hartshorne sandstone is about 15 feet thick in sec. 31, T.5 N., R.26 E. (drill hole 130), and the Lower Hartshorne sandstone is about 28 feet thick in sec. 36, T.5 N., R.25 E. (measured section 1, appendix 4). The outcrop of the coal can be traced through two abandoned drift mines which were mapped in sec. 29 and 32, T.5 N., R.26 E. by Hendricks (1939,

Plate 27). The present writer has located the mine entries on Plate 1, but the extent of mining cannot be determined because no mine maps are available. The mines probably consist only of a main entry, with mining only on a small scale. The outcrop can be precisely located in the abandoned Petros surface mine of the Paul Rees Coal Company (sec. 31, T.5 N., R.26 E.). The Petros mine was the last mine in the Heavener area to be developed, and was partly reclaimed by August, 1977. An exposure of the Upper Hartshorne Member is present at the east end of the mine. The extent of mining was mapped (Plate 1) by the use of mine maps supplied by the mining engineer of the Petros mine.

The lower part of the Hartshorne Formation is exposed in a railroad cut in sec. 31, T.5 N., R.26 E. The Lower Hartshorne coal and two thin coals in the uppermost part of the Atoka Formation crop out and were measured by Hendricks (1939, measured section 2, appendix 4). The Lower Hartshorne coal also crops out on the west side of old U.S. Highway 59, about 100 feet west of the railroad cut. The same section that is exposed in the railroad cut is also exposed one mile west in a large roadcut along the new U.S. Highway 59 in sec. 36, T.5 N., R.25 E., about 1½ miles south of Heavener, Oklahoma. This roadcut provides the best accessible exposure of the Hartshorne Formation in the Heavener area. The lower two-thirds of the Hartshorne Formation and the uppermost part of the Atoka Formation are exposed, and a measured section is presented in appendix 4 (measured section 1). This roadcut is included on a lithofacies cross section, which shows the correlation of rock units in the Hartshorne and Atoka Formation of the study area with those in Arkansas (Plate 10). Numerous casts and molds of Calamites are preserved within the sandstone units at this site. Leaf impressions are preserved within the shales and are commonly found preserved in siderite nodules.

The Lower Hartshorne coal crops out along the south flank of Pine Mountain, although exposures are poor, and mostly covered by soil. The Hartshorne Formation and uppermost Atoka Formation are exposed on the north side of the dirt road leading down the south flank of Pine Mountain in sec. 34, T.5 N., R.25 E. This section of rocks is very similar to the section exposed in the new U.S. Highway 59 roadcut and the railroad cut. The outcrop of the Lower Hartshorne coal is continuous around the western tip and the northern flank of Pine Mountain. Exposures along the northern flank are poor to nonexisting.

Pine Mountain was formed by differential erosion along the Pine Mountain syncline. The Hartshorne Formation is exposed at the surface westward from secs. 25 and 36, T.5 N., R.25 E. Pine Mountain is capped by the Upper Hartshorne sandstone, which ranges in thickness from zero to 50 feet, depending upon the amount of erosion. The Lower Hartshorne coal was mined in the abandoned Pine Mountain strip

figure 5 - Calamites preserved in the gray shale that overlies the Lower Hartshorne coal in Pine Mountain strip pit (sec. 26, T.5 N., R.25 E.).

figure 6 - Unidentified fossil tree trunk preserved in the Upper Hartshorne sandstone in the Pine Mountain strip pit (sec. 26, T.5 N., R.25 E.).

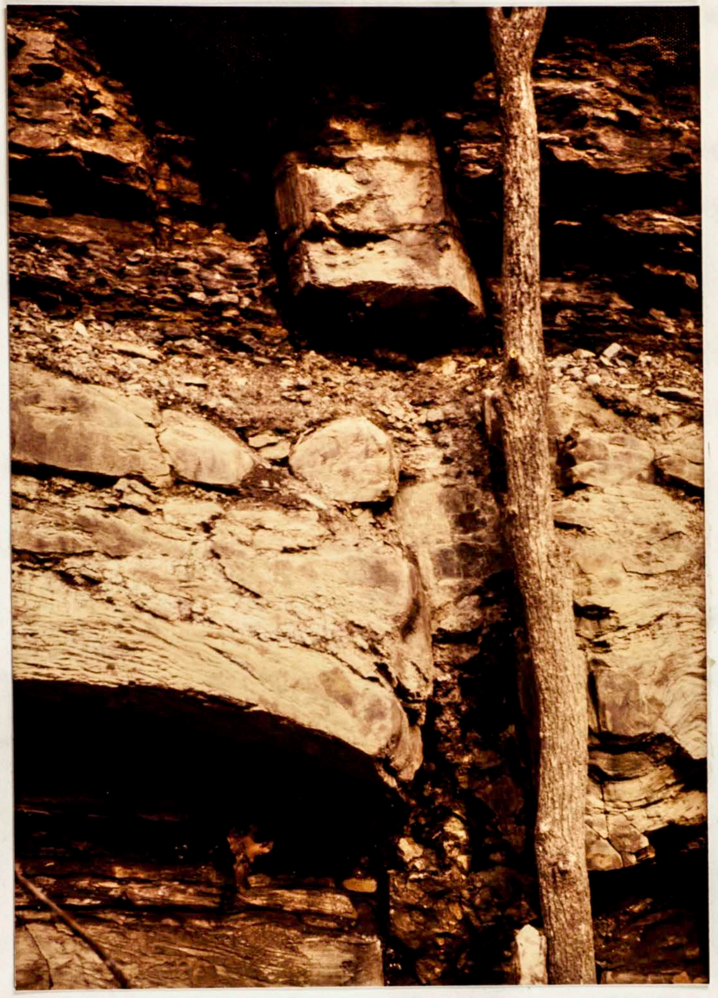

figure 7 - Unidentified fossil tree which is about 8 feet tall, preserved in the Upper Hartshorne Member, Pine Mountain strip pit (sec. 26, T.5 N., R.25 E.).

pit (secs. 26 and 35, T.5 N., R.25 E.). The Upper Hartshorne sandstone is well exposed in the highwall of the mine, containing numerous upright Calamites and fossil tree trunks (figures 5-7). Lepidodendron also have been preserved in the strip pit within the sandstone and shale overlying the Lower Hartshorne coal.

The Lower Hartshorne coal has been mined in the Paul Rees Coal Company Heavener surface mine in sec. 25, T.5 N., R.25 E. (Plate 1). The mine was active in 1976, but was idle at the time of this writing. The Heavener mine is about 1¼ miles northeast of the Pine Mountain strip pit, and contains the same flora. Numerous casts and molds of Calamites have been preserved in the Upper Hartshorne sandstone. An unidentified fossil tree stump (2½ feet in diameter) was discovered in a siderite zone within the gray shale which overlies the Lower Hartshorne coal. S.A. Friedman of the Oklahoma Geological Survey, in conjuction with Dr. Keever Greer of the University of Oklahoma Stovall Museum, recovered the fossil tree stump, and placed it on display at the museum.

The outcrop of the Lower Hartshorne coal passes beneath the town of Heavener north of the Paul Rees Coal Company Heavener mine. The outcrop is located precisely in sec. 18, T.5 N., R.25 E., at the location of the abandoned underground mine (mine no. 20, Plate 1) of the Heavener Smokeless Coal Company. The writer was fortunate in discovering a subcrop of the Lower Hartshorne coal in sec. 18, T.5 N., R.25 E. (figure 9). Figure 9 is a photograph of a rectangular excavation made for a stock pond during the summer of 1977, which exposed the contact of the subcrop of the Lower Hartshorne coal with the base of the surface soil zone. The outcrop is easily traced westward along the north flank of the Heavener anticline by the positions of the abandoned underground mines. Some of the main entries are open at the surface, but the mines are filled with water and probably are caved in. The outcrop extends westward to sec. 36, T.6 N., R.24 E., where it passes beneath Lake Wister. Quarry Island, in Lake Wister, is an emergent portion of the ridge formed by the Upper Hartshorne sandstone. The Lower Hartshorne coal should crop out at the base of the ridge on the south side of Quarry Island, but it was not exposed above the water line. The ridge of Hartshorne sandstone is continuous west of Lake Wister, and its westernmost location in the Heavener area is in sec. 35, T.6 N., R.24 E.

Thickness of the Lower Hartshorne Coal

An isopachous map of the Lower Hartshorne coal is presented on Plate 3. The map is at a scale of 1:24,000 (1 inch equals 0.379 mile). The contour interval is 0.5 feet. Underground and surface mines in the Lower Hartshorne coal are shown in detail on this map. Coal test drill hole data, underground mine maps, and surface measurements

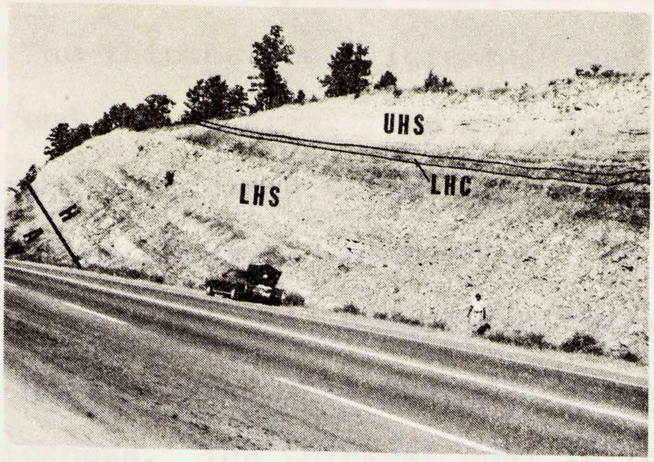

figure 8 - Photograph of the northwest side of the roadcut along U.S. Highway 59 showing Upper Hartshorne sandstone (UHS), Lower Hartshorne coal (LHC), Lower Hartshorne sandstone (LHS), and the contact between the Hartshorne (H) and Atoka (A) Formations.

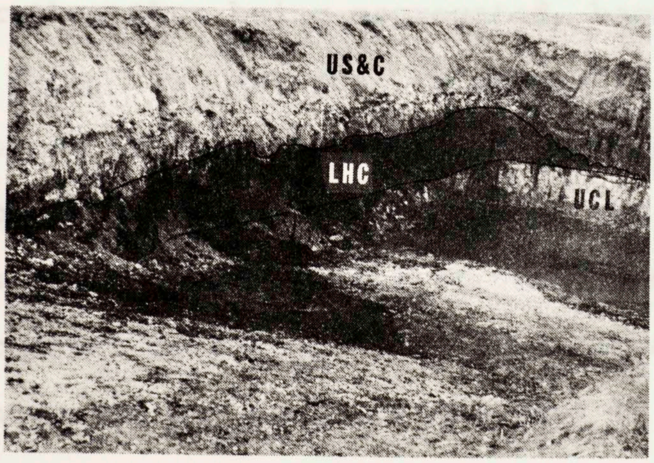

figure 9 - Subcrop of the Lower Hartshorne coal at the base of the weathered zone (sec. 18, T.5 N., R.25 E.).

were used in constructing this isopach map. The thickness of the Lower Hartshorne coal varies from 1.5 to 6 feet. The thickness of the coal exposed along the outcrop averages about 3 feet. The thickest coal (greater than 4 feet) occurs at the eastern end of the area. The coal in the northeast corner of the area averages 4.4 feet thick, and the southeast corner averages about 5.5 feet thick. No thickness data is available for the coal underlying Poteau Mountain, but the writer has inferred that the coal averages about 3.5 feet in thickness. The thickest coal is in the southeast corner of the area where the Lower Hartshorne coal is 6.7 feet (boreholes 120 and 134). The thickness of the coal reported in boreholes 120-124, and 134-138 is suspiciously thick, and probably includes one or more shale partings. An examination of the chemical analyses of the coal samples from these holes suggests that shale partings were included in the coal, rather than being segregated, because the ash is abnormally high. The net coal thickness in each of these holes is therefore probably a few inches thinner than reported.

The Lower Hartshorne coal contains one or more shale partings which probably persist throughout the area. The partings consist mainly of black carbonaceous shale. The ash percentage of the coal, as measured in the proximate analysis, increases markedly if partings are included within the coal. To increase the selling price, the partings are often removed from the coal by a water washing and screening process and other methods prior to shipment. The thicknesses used in making the isopachous map (Plate 3) are the net thicknesses of the coal, excluding most of the shale partings.

<u>History of Mining</u>

Coal has been mined in the Heavener area since before 1907, when Oklahoma became a state (Hendricks, 1939, p. 279). Coal was probably mined underground and produced commercially prior to 1900. A battery of 40 coke ovens at Howe manufactured coke from the Lower Hartshorne coal between 1900 and 1905 (Hendricks, 1939, p. 281). The remains of the Beehive coke ovens can still be seen south of the town. The coke was reported to have been of good quality, but the coking was abandoned due to the distance from a commercial market (Hendricks, 1939, p. 281).

All the mining in the Heavener area has been in the Lower Hartshorne coal. The coal is of coking quality in most of the area as indicated by the high free-swelling index (Plate 14). The coal has been mined primarily for steam and coking coal, although some has been sold for domestic use as a fuel for stoves and space heating. The coal was used extensively by the railroads to fire the boilers of steam locomotives. Much of the coal was used as steam coal to form electricity in the Lincoln Power Company generator whose ruins are still standing (sec. 31, T.6 N., R.25 E.).

Hendricks (1939, p. 281) reported that charcoal briquets were made from slack coal at the Lincoln Power Company No. 1 mine (mine no. 1, Plate 1), and sold commercially. All the coal mined within the past ten years (1966-1976) has been sold as coking coal, with much of it being sold to the steel industry to make coke for use in the blast furnace. Higher prices are received for coking coal than steam coal. Prices of coking coal are almost double that of steam coal, depending upon the type of contract made between the mining company and the buyer (S.A. Friedman, 1978, personal communication).

The Lower Hartshorne coal has been mined underground extensively along the north flank of the Heavener anticline (Plate 1). The underground and surface mines in the Lower Hartshorne coal are listed in table 1. The last underground mine to close was the Howe Coal Company No. 1 mine which began in 1967 and closed in 1973 (mine no. 18). Howe Coal Company experienced difficulty in the Howe No. 1 mine for various reasons, and was forced to close prematurely. The Lower Hartshorne coal has been mined recently by the Paul Rees Coal Company in its Heavener (mine no. 22) and Petros (mine no. 24) mines (Plate 1). The Heavener mine is idle at present. The highwall of the Heavener mine is between 35 and 40 feet high, and contains a portion of the Upper Hartshorne sandstone. The Heavener mine and the mining technique and reclamation were described in the Coal Mining and Processing Journal (1976), and a photograph of the mine was

Table 1 - Mines in the Lower Hartshorne Coal (Data from mine maps supplied by Chief Mine Inspector of Oklahoma).

Mine No.[1]	Mine Name	Location	Dates Mined[2]
Underground Mines			
1	Lincoln Power Co.[3] No. 1	sec.6, 5N-25E	4/29-4/1/30
2	Lincoln Power Co.[3] No. 2	sec.6, 5N-25E	4/29-4/1/30
3	Lincoln Power Co.[3] No. 3	sec.4, 5N-25E	4/29-4/1/30
4	Lincoln Power Co.[3] No. 4	sec.4, 5N-25E	4/29-4/1/30
5	Martin Coal and Coke Co. No. 7	sec.4, 5N-25E	11/21-1/12/31
6	Martin Coal and Coke Co. No. 8	sec.4, 5N-25E	11/21-1/12/31
7	Dawes Bros. Coal Co.[4] No. 8	sec.3, 5N-25E	11/21-1/12/31
8	Dawes Bros. Coal Co.[4] (unnamed slope)	sec.3, 5N-25E	? -7/1/70
9	Dawes Bros. Coal Co.[4] No. 1	sec.3, 5N-25E	? -7/1/70
10	Dawes Bros. Coal Co.[4] No. 2½	sec.2, 5N-25E	? -7/1/70
11	Dawes Bros. Coal Co.[4] No. 2	sec.2, 5N-25E	? -7/1/70
12	Kelly Mine	sec.11, 5N-25E	?
13	Dawes Bros. Coal Co.[5] No. 4	sec.11, 5N-25E	? -7/25/67
13b	Dawes Bros. Coal Co. (Hanraty slope)	sec.12, 5N-25E	?
14	Interstate Coal Co. No. 3	sec.12, 5N-25E	? -7/25/67
14b	Interstate Coal Co. (McGuire slope)	sec.12, 5N-25E	? -7/25/67
15	Dawes Bros. Coal Co.	sec.12, 5N-25E	? -7/25/67

Mine No.[1]	Mine Name	Location	Dates Mined[2]
16	Dawes Bros. Coal Co. (Elder Mine)	sec.7, 5N-26E	?
17	Standard Coal Co. No. 5	sec.7, 5N-26E	? -1/31
18	Howe Coal Co. Howe No. 1	sec.7, 5N-26E	? -10/1/71
19	Heavener Smokeless Coal Co. (Manway)	sec.18, 5N-26E	11/18/21-10/30
20	Heavener Smokeless Coal Co. (No. 6)	sec.18, 5N-26E	11/18/21-10/30
21	Choctaw Coal and Mining Co.	sec.25, 5N-26E	? -3/12/34
Surface Mines			
22	Paul Rees Coal Co. (Heavener mine)	sec.25, 5N-25E	?/75-present
23	Pine Mountain strip pit	secs.26 and 35, 5N-25E	prior to 1939
24	Paul Rees Coal Co. (Petros mine)	sec.31, 5N-26E	4/76-6/77
25	Coaldale strip pits	secs.24-26, 5N-26E and sec.19, 5N-27E	?

1 Mine numbers are the same as those on Plate 1.
2 As determined from mine map; date does not necessarily indicate term of activity.
3 Formerly Poteau Valley Coal Co..
4 Formerly McCurtain Coal and Coke Co.(9/23-1931), Degnan and McConnel Coal and Coke Co.(1931-?), Martin Coal and Coke Co., Mexican Gulf Coal and Transportation Co., and Potter Smokeless Coal Co..
5 Formerly Interstate Coal Co..

included on the front cover. The Petros mine was active during the summer of 1976. The 30-foot highwall consisted of shale and siltstone. The Petros mine was partly reclaimed in August of 1977, and is presently idle.

The development of mining is influenced by the availability of leases for the coal. The U.S. government owns the coal leases of large tracts of land in the Arkoma Basin (Bureau of Land Management, 1975, attachment 1). The federal coal lease boundaries are shown on Plates 1-4. The Bureau of Land Management (BLM) manages the coal leases, and evaluates formal bids offered by private operators for the leases. Leases in areas under federal coal lease are difficult to obtain, and therefore the federal coal lands have not been developed, except in some areas operating under existing leases. A private coal operator who is new to the area would therefore be somewhat restricted to the non-federal areas unless he made a deal with a company who presently holds a federal lease.

Fixed-Carbon Percentage of the Lower Hartshorne Coal

A map showing variations in the fixed-carbon percentage (shown by isocarb lines) of the Lower Hartshorne coal is presented at a scale of 1 inch equals 1 mile on Plate 11. The fixed-carbon percentage is determined on a dry, mineral-matter-free basis from the chemical (proximate) analysis. The proximate analysis normally includes the moisture, ash, fixed-carbon, and volatile matter percentages of the coal. The fixed-carbon percentage must be computed on a dry, mineral-matter-free (mmf) basis when one is constructing an isopach map, using the following equation (American Society for Testing and Materials, 1975, p. 215, D388).

fixed-carbon (mmf) = fixed-carbon% ÷ (100% - (ash% + moisture%))

The fixed-carbon percentage (mmf) is indicative of rank; with coal having a fixed-carbon percentage (mmf) of between 78 and 86 percent defined as low-volatile bituminous in rank, and coal having between 69 and 78 percent fixed-carbon (mmf) defined as medium-volatile bituminous in rank (American Society for Testing and Materials, 1975, p. 215, D388). The rank in coal is a metamorphic series, and was established by the American Society for Testing and Materials (ASTM) (American Society for Testing and Materials, 1975, p. 215, D388). The Lower Hartshorne coal in the Heavener area is low- and medium-volatile bituminous in rank. The boundary between the two ranks (78% isocarb) is accentuated on the isocarb map (Plate 11), and trends east-west through the area.

The fixed-carbon percentage (mmf) ranges from 70 to 84 percent in the Heavener area, and fairly constantly decreases from the northeast to the south. The percentage of fixed-carbon in coal is dependent upon the thermal history and the original depth of burial of the coal; the higher ranked coals having a history of exposure to higher temperatures (Stach, 1975, p. 41-47). The fixed-carbon percentage of the Lower Hartshorne coal increases to the northeast in the Heavener area, and was influenced by post-depositional thermal activity to the east, possibly from heating associated with rifting along the Mississippi Aulacogen. The rank of the Lower Hartshorne coal increases eastward in Arkansas (Damberger, 1974, p. 61). The ranks of the Pennsylvanian coals increase from low-volatile bituminous to anthracite in Arkansas (Trumbull, 1960). Increased lateral compression did not influence the percentage of fixed-carbon to the same degree. The rank does not increase with proximity to the Ouachita foldbelt to the south. Rather, the fixed-carbon percentage decreases toward the Ouachita foldbelt, indicating that increased pressure was not a controlling influence on the rank in the Heavener area. Wilson (1971) presented an isocarb map of the Desmoinesian (Pennsylvanian) coals in the Arkoma Basin. He showed the low-medium volatile bituminous boundary line (78%) to trend northeast-southwest through the Heavener area. Hendricks (1939, p. 296) presented an isocarb map of the Arkoma Basin that was very similar to that of Wilson (1971). The rank boundary lines drawn by Wilson (1971) and Hendricks (1939) were perpendicular to the rank boundary line of the Lower Hartshorne coal as presented in the present study. The boundary mapped in this report should be accepted due to greater amount of data (138 coal test boreholes) available to the writer, which was not available to Wilson and Hendricks.

Sulfur Percentage of the Lower Hartshorne Coal

A map showing the sulfur percentage of the Lower Hartshorne coal is presented on Plate 12 at a scale of 1 inch equals 1 mile. The contour interval is 0.5 percent. The sulfur percentage of the Lower Hartshorne coal ranges from 0.5 to 3.3 percent, and averages about 1.0 percent. The coal in the northern half of the area is relatively low in sulfur, averaging less than 1 percent. The greatest range in sulfur percentage (0.53 to 3.3 percent) occurs in the coal underlying Pine Mountain. No trends in the sulfur percentage have been recognized, and the major contribution of the map is as an aid in coal mining development. Most of the sulfur in the Lower Hartshorne coal occurs in the form of pyrite (Friedman, 1974, p. 23).

Ash Percentage of the Lower Hartshorne Coal

A map showing the percentage of ash in the Lower Hartshorne coal is presented on Plate 13 at a scale of 1 inch equals 1 mile. Ash in coal consists of any inorganic sediments incorporated within the coal. The majority of the ash in coal is concentrated in thin zones along the bedding planes. Ash is deposited in coal during sediment influx into the area during peat deposition. If inorganic sediments were or had been deposited above a peat layer, a shale parting would result. Conversely, rapid peat deposition, without inorganic sediment influx commonly results in a pure coal with a low ash percentage.

A linear trend in the ash percentage is mapped in the upper half of the area. The ash percentage contours form a west-to-northeast trend of relatively high ash percentage. The contour interval of the map is 1.0 percent. The ash percentage of the coal is greatest in three boreholes along the trend, in boreholes 7, 35, and 38. The coal in borehole 38 has the highest percentage of ash with 15.6 percent.

The ash varies from 6 percent to 15 percent and averages about 9 percent. The coal underlying Pine Mountain varies laterally in ash percentage from 8.6 to 14.2.

The data used in preparing the ash percentage map was derived from the proximate analysis of the net coal. The ash percentage of the coal is largely dependent upon the percentage of ash which occurs in partings, and the number of partings which were included within the coal in the proximate analysis. Partings greater than three-eigths of an inch thick should be excluded from the sample (Schopf, 1960, p. 51).

The ash percentages determined for samples derived from drill holes 120, 121, 124, 134, 135, and 138 are much higher than the average for the area. These samples probably included shale partings greater than three-eigths of an inch thick, rather than only the net coal. The ash percentages of the coal derived from these holes were therefore not used in making the map.

The Free-Swelling Index (FSI) of the Lower Hartshorne Coal

A map showing the free-swelling index of the Lower Hartshorne coal is presented on Plate 14 at a scale of 1 inch equals 1 mile. The free-swelling index is a relative measure of the free-swelling properties of a coal during heating. The free-swelling index is determined by heating a small sample of coal (1 gram) in a crucible of specified size (17 cm^3) to a specified temperature ($820^o \pm 5^o$ Celcius), for a specified time (2½ minutes) (American Society for Testing and Materials, 1975, p. 243, D720). Low- to medium-volatile coal tends to cake during this test, forming a button of coke in the crucible. The profile of the coke-button is visually compared with a chart of profiles, each having a corresponding free-swelling index number from 1 (no free-swelling) to 9 (maximum free-swelling). Coals with good coking qualities generally have a free-swelling index greater than 8. The American Society for Testing and Materials (ASTM) has set the standards for the type and size of equipment to be used, and the temperature and time of which the test is to be run (American Society for Testing and Materials, 1975, p. D720). These standards must be followed if the test is to have meaning.

The free-swelling index of the Lower Hartshorne coal in the Heavener area varies from 1½ to 9, averaging about

8. The coal mining industry was fortunate in that the free-swelling index of the Lower Hartshorne coal along the outcrop on the north flank of the Heavener anticline is 9. The free-swelling index is lower progressively northward to 6 away from that outcrop (secs. 21-35, T.6 N., R.25 E., Plate 14). The free-swelling index is the lowest (1½) in the northeast corner of the area in samples from drill holes 23 and 24. These low values were derived from coal samples from the drill holes in the north flank of the Hartford anticline, possibly making that area unattractive for underground mining in the near future. The free-swelling index is 9 near the coal outcrop around the Heavener anticline, except on Pine Mountain, where it varies from 5½ to 8½ (Plate 14).

The Lower Hartshorne coal is of coking quality in most of the Heavener area. This quality, associated with low sulfur and ash percentages and good thickness, should make it readily marketable.

Identified Resources of the Upper and Lower Hartshorne Coals

The Upper and Lower Hartshorne coals in the Heavener study area contain 439,639,000 short tons of bituminous coal in the remaining-resources category. Approximately 13,356,000 short tons of coal have been mined and lost-in-mining. Therefore, 452,995,000 short tons of coal were originally in-place, and fall in the original-resources category. The remaining coal resources are present beneath 46,242 acres of land in the Heavener area.

Identified Resources of the Lower Hartshorne Coal

The Lower Hartshorne coal in the Heavener area contains 313,478,000 short tons of bituminous coal in the remaining-resources category. No commercial mining has taken place in the Upper Hartshorne coal. Therefore remaining resources equal original resources in the Upper Hartshorne coal. All the coal in the mined and lost-in-mining category is the Lower Hartshorne coal. Approximately 13,356,000 short tons of Lower Hartshorne coal have been mined and lost-in-mining. The Lower Hartshorne coal, which was mined and lost-in-mining, involved 1,466 acres of land. The original resources of the Lower Hartshorne coal consisted of 326,834,000 short tons of coal. The remaining Lower Hartshorne coal resources are present beneath 46,242 acres of land in the Heavener area. These resource determinations were current as of March 1, 1978, and will need to be updated as more drilling and production information is made available.

A complete breakdown of the original, mined and lost, and remaining resources is tabulated in appendix 3. Additional coal-resources data and the details of the categories of data, such as the depth of the coal and the reliability of data (measured, indicated, and inferred) are also presented in appendix 3.

The strippable resources of the Lower Hartshorne coal include all remaining coal resources that have less than or equal to 150 feet of overburden. In the Heavener area, 17,544,000 short tons of the Lower Hartshorne coal are in the strippable remaining-resources category. This constitutes only 5.6 percent of the remaining coal resources in the area.

Coal in the mined and lost-in-mining category is coal which has been removed by underground or surface methods, coal left in place to support the overburden in underground mines (pillars), and the coal within a 300-foot-wide arbitrary barrier around the periphery of each underground mine. The periphery of each mine is arbitrarily extended 300 feet laterally and is considered to be lost in mining for these calculations, because of Federal and State safety requirements for future underground mining.

The methods used in determining the resources of the Upper and Lower Hartshorne coals were those prescribed by the U.S. Geological Survey (U.S.G.S.) (Averitt, 1967). The categories of resources, depths to the coals, and thicknesses of the coals were defined and standardized by the U.S.G.S., and have been applied to Oklahoma by Trumbull (1957), and with some modifications by Friedman (1974). These U.S.G.S. procedures are considered to be the standards for calculating coal resources, and should be followed if resource calculations from different regions are to have any meaning (appendix 3). Plate 17 is a map which shows the categories and methods used in calculating coal resources.

Upper Hartshorne Coal

The Upper Hartshorne coal lies between 60 and 120 feet stratigraphically above the Lower Hartshorne coal. The top of the Upper Hartshorne coal is the contact of the Hartshorne Formation with the overlying McAlester Formation (as described under stratigraphy in this report). The Upper Hartshorne coal is a low- to medium-volatile bituminous coal, which ranges from 1½ to 3 feet in thickness. The coal is of commercial quality and thickness, but has not been mined commercially in the Heavener area. It has been mined in other parts of northern Le Flore County, however. It contains 0.8-2.6 percent sulfur and averages 1.6 percent (Friedman, 1975).

The Upper Hartshorne coal crops out 400-500 feet north of the outcrop of the Lower Hartshorne coal, commonly near the base of the dip slope of the ridge formed by the Upper Hartshorne sandstone (Plate 2). Exposures of the Upper Hartshorne coal are rare, because the coal and associated shale weather easily. The outcrop is covered by soil and colluvium in most of the area. The coal is laterally continuous throughout the Arkoma Basin, and can be easily correlated between drill holes (Plates 6-10).

Structure Map of the Upper Hartshorne Coal

A map of the structure of the Upper Hartshorne coal is presented on Plate 2 at a scale of 1:24,000 (1 inch equals 0.379 mile). The datum of the map is the top of the Upper

Hartshorne coal, and the contour interval is 100 feet. The structure contours of the Upper Hartshorne coal are approximately parallel to the structure contours of the Lower Hartshorne coal (Plates 1 and 2). The structure contours of the two coals differ only in places where the interval between the coals shows sharp changes.

The outcrop of the Upper Hartshorne coal is approximately parallel to that of the Lower Hartshorne coal throughout most of the map area (Plates 1 and 2). The regional dip is northward, except on the south limbs of the Heavener and Hartford anticlines, and on the north limbs of the Poteau and Pine Mountain synclines, where the dip is southward. The Upper Hartshorne coal has been eroded from Pine Mountain, and it is not present in sec. 25, T.5 N., R.25 E. The coal is exposed in a ditch beside a dirt road in the northwest corner of sec. 12, T.5 N., R.25 E. (Plate 2).

The boundaries of the federal coal leases are shown on the structure map (Plate 2) and were obtained from the U.S. Bureau of Land Management (BLM) (1975, attachment 1). The importance of these boundaries to coal mining development was discussed on p. 57 of this report.

Thickness of the Upper Hartshorne Coal

An isopachous map of the Upper Hartshorne coal is shown on Plate 4, at a scale of 1:24,000. The contour interval is 0.5 feet. This map shows that the coal varies from

0.1 to 3.2 feet in thickness and averages about 1.5 feet. The coal is thickest (3.0 and 3.2) in coal test boreholes 16 and 18. Coal thicknesses are tabulated for each of the drill holes in appendix 1.

An east-west trending elongate zone of thin (0.3-1.5 feet) Upper Hartshorne coal is approximately parallel to an elongate zone of high ash content (8.98-15.6%) in the Lower Hartshorne coal in the northern part of the map area (Plates 2 and 13). The trend extends west-northeast from sec. 31, T.6 N., R.25 E., to the north of Howe, where it extends southwards into sec. 31, T.6 N., R.26 E., and thence trends to the northeast to the west of Monroe, at the northeastern margin of the map area. The linear trend consists of thin Upper Hartshorne coal with uniform thickening of the coal towards the periphery of the trend. The linear trend branches southwestward into another area of thin coal in secs. 5, 7, and 8, T.5 N., R.26 E. The coal also thickens in both directions away from the southwestward-trending branch. This bifurcating thin trend in the Upper Hartshorne coal is believed to have been due to the depositional conditions, and is discussed on p. 78.

No thickness data is available for the coal underlying Poteau Mountain. The coal possibly thins beneath Poteau Mountain to the southeast because the Upper Hartshorne coal is not recognized as a discrete coal bed in secs. 24 and 25, T.5 N., R.26 E., and sec. 19, T. N., R.27 E. In these sections, the

Upper Hartshorne coal is represented by a black carbonaceous shale zone containing several thin streaks of coal.

Resources of the Upper Hartshorne Coal

The Upper Hartshorne coal in the Heavener area contains 126,161,000 short tons of bituminous coal in the remaining-resources category. This coal has not been mined commercially; thus, the remaining coal resources equal the original coal resources. The original and remaining resources of this coal underlies 33,393 acres in the Heavener map area. In the area, 11,312,000 short tons of the Upper Hartshorne coal are considered strippable resources, underlying 2,431 acres of land. The strippable resources constitute 9 percent of the remaining coal resources of this coal. Strippable resources are defined as all coal overlain by no more than 150 feet of overburden.

The Stratigraphic Interval between the Upper and Lower Hartshorne Coals

A contour map showing the stratigraphic interval between the Upper and Lower Hartshorne coals (thickness of the Upper Hartshorne Member) is presented on Plate 5. The scale of the map is 1 inch equals 1 mile and the contour interval is 20 feet. The outcrop boundary of both the Upper and Lower Hartshorne coals is shown on the map. The bedrock forming the interval between the coals, and including the Upper Hartshorne coal, is the Upper Hartshorne Member (of McDaniel, 1961). Thickness data of the interval was derived mainly from drilling data and partly from interpretations made by the writer along the outcrops by using triangulation, the distance between the two outcrops, and dip measurements. A study of this interval has not been published.

The stratigraphic interval between the two coals varies from a minimum of 20 feet in sec. 24, T.5 N., R.26 E., to a maximum of 169 feet in coal test borehole 12 (sec. 34, T.6 N., R.25 E.). A linear trend exists on the interval map which approximately parallels the linear trend mapped on the isopach map of the Upper Hartshorne coal and the ash percentage map of the Lower Hartshorne coal. The geologic significance of these trends is discussed on p. 74-78. The stratigraphic interval contours (isochores) form a linear trend connecting areas of greatest thickness, extending eastward from sec. 31, T.6 N., R.25 E., past the north edge of Howe to sec. 32, T.6 N., R.26 E., where the trend bends to the northeast, and it passes out of the Heavener area in sec. 18, T.6 N., R.27 E. The stratigraphic interval between the two coals beneath Poteau Mountain is uncertain, but possibly it is between 40 and 60 feet. The thickness of the stratigraphic interval is highly variable in the central portion of the map area (49-169 feet) where there is a high density of data (65 points). The interval in one area is noticably thin; in sec. 1, T.5 N., R.25 E. (52 feet), and sec. 6, T.5 N., R.26 E. (49 feet).

DEPOSITIONAL ENVIRONMENT OF THE HARTSHORNE COALS AND ASSOCIATED STRATA

The sediments which formed the Hartshorne Formation were deposited within a prograding deltaic plain environment. The sandstone units in the Hartshorne Formation were probably deposited in distributary channels and as crevasse splay and overbank deposits. The peat which formed the coals in the Hartshorne and uppermost Atoka Formations accumulated in interdistributary marshes and swamps within the delta plain.

The uppermost Atoka Formation (top 100 feet) consists of gray shale containing siderite nodules, black carbonaceous shale containing coal streaks and numerous leaf and stem impressions, and two thin coals (measured section 1, appendix 4). These sediments were possibly deposited in an interdistributary bay. The bay became a site of indigenous plant growth and accumulation (several root-bearing coals are present) which was later inundated with increasing frequency by crevasse splay and overbank deposits (Briggs and others, 1975, p. 93). The overbank deposits consist of gray, fine-grained sandstone units within the Hartshorne Formation. The base of the lowermost overbank sandstone is the contact of the Hartshorne Formation with the underlying Atoka Formation (Plate 10).

The Lower Hartshorne Member (110-150 feet thick) consists of interbedded gray, fine-grained, cross-bedded sandstone units and gray, thinly-laminated shale units (measured section 1, appendix 4). The sandstone units commonly contain upright Calamites, some of which are 6 inches in diameter and 2 to 3 feet in length. Calamites are a form of scouring rush which probably grew under marsh conditions in interdistributary areas within the delta plain. The Calamites were preserved in an upright growing position because of rapid influx of sand and silt into the interdistributary areas during flooding conditions, forming overbank deposits. The gray shale units contain siderite nodules and plant remains. Leaf and stem impressions are commonly preserved in siderite nodules or zones of sideritic shale.

The shale units of the Lower Hartshorne Member were probably deposited under low-energy condition within marshy interdistributary areas in the delta plain. Plant growth was abundant, as evidenced by the preservation of numerous Calamites, and leaf and stem remains. Sediment influx (very fine-grained) into the marsh areas caused the deposition of shale units, contaminating any peat accumulation. Low-energy shale deposition in the interdistributary areas was interrupted occasionally by the influx of coarser-grained clastics during flooding conditions, forming overbank deposits (represented by sandstone units). No distributary-channel sandstone-fill units have been recognized by the writer in the Lower Hartshorne Member. McDaniel (1968) showed a southwestward-flowing distributary channel in the northern part of the map area on a schematic paleogeographic map of the Arkoma Basin, representing the early stage of lower Hartshorne deposition. The writer has no evidence of this distributary channel in that area in the Lower Hartshorne Member. A southwestward-flowing distributary did exist in the position of the channel recognized by McDaniel (1968) in the Upper Hartshorne Member (Plate 15).

Sediment influx into the interdistributary area (map area) was reduced drastically during deposition of the Lower Hartshorne coal. The top of the Lower Hartshorne coal is the contact of the Lower and Upper Hartshorne Members. During accumulation of the peat which formed the Lower Hartshorne coal, the interdistributary area was protected from clastic sedimentation. Deposition of fine-grained clastics would have contaminated the accumulating peat, forming black shale, rather than coal. Minor influx of clastics during peat accumulation resulted in shale partings within the Lower Hartshorne coal (Plate 10). The source of sediments (probably a distributary channel) was possibly diverted away from the map area during the deposition of the peat which formed the Lower Hartshorne coal. The Lower Hartshorne coal is laterally continuous in most places throughout the Arkoma Basin. A major distributary-channel shift must have occurred high up in the upper deltaic plain to divert sediments away from the western part of the Arkoma Basin during the deposition of the Lower Hartshorne coal. The major distributary possibly shifted back to its original course after deposition of the Lower Hartshorne coal, and coarser clastics were deposited, forming the Upper Hartshorne Member. The Lower Hartshorne coal is directly underlain by a rooted underclay (Plate 10). This indicates that the plant material which formed the peat accumulated in the same areas in which it grew (Stach, 1975, p. 19).

The Upper Hartshorne Member (60-160 feet thick) consists of interbedded fine-grained, cross-bedded gray sandstone units and thinly laminated gray shale units. The lithologies of the Upper and Lower Hartshorne Members are similar, resulting from similar changes in the deltaic plain environment within the map area during deposition (cyclic sedimentation). During deposition of the Upper Hartshorne Member, the map area was a part of the Hartshorne deltaic plain. Gray shale deposition occurred in interdistributary areas, interrupted occasionally by overbank deposits (represented by gray sandstone units). Overbank deposits have preserved hundreds of molds and casts of upright Calamites in the Upper Hartshorne Member. Coradites, Calamites, and Lepidodendron have been preserved in the gray shale and sandstone directly overlying the Lower Hartshorne coal in the abandoned Pine Mountain strip mine (secs. 26 and 35, T.5 N., R.25 E.).

Hendricks (1939, Plate 20a) recognized a channel sandstone in the Upper Hartshorne Member in this abandoned mine. The channel sandstone represents a distributary which carried sediments southward through the map area during the deposition of the Upper Hartshorne Member. Seven large, unidentified, upright tree trunks (the largest of which is 2½ feet in diameter) are preserved within 30 feet of each other in the Upper Hartshorne sandstone which forms the north highwall of the abandoned Pine Mountain strip mine. These trees possibly grew on the periphery of the distributary channel recognized by Hendricks (1939). A modern analog of this type of growth in the Mississippi delta is described by Fisk (1960). The fossil tree trunks mentioned above were preserved in an overbank deposit (lowermost sandstone unit in the Upper Hartshorne Member). Good collecting sites in this sandstone unit include the roadcut along U.S. Highway 59 (sec. 36, T.5 N., R.25 E.), the abandoned Pine Mountain strip mine (secs. 26 and 35, T.5 N., R.25 E.), and the Heavener pit of Paul Rees Coal Company (sec. 25, T.5 N., R.25 E.).

The net sandstone thickness of the Upper Hartshorne Member is shown on an isopach map at a scale of 1 inch equals 1 mile (Plate 15). A northeast-southwest trend of thick net sandstone is shown in the northern part of the map area (Plate 15). This thick sandstone trend probably represents the channel-fill of a southward-flowing distributary that was active during the deposition of the Upper Hartshorne

Member. This distributary probably bifurcated in secs. 28 and 29, T.6 N., R.26 E., into two southwestward-flowing branches of the distributary (Plate 15). This bifurcating distributary probably supplied sediments to the map area during the deposition of the Upper Hartshorne Member. Breaks in the levee (crevasses) of this distributary formed during flooding conditions, probably allowed for the deposition of the crevasse splay deposits in the Upper Hartshorne Member.

The net sandstone thickness of the Upper Hartshorne Member decreases towards the southeast corner of the map area, and there is no Upper Hartshorne sandstone in secs. 24-26, T.5 N., R.26 E., and sec. 19, T.5 N., R.27 E. (Plate 15). This area was probably an interdistributary marsh area, which received little coarse clastic input. This conclusion is further supported by the increased thickness (5-6.7 feet) of the Lower Hartshorne coal in that area (Plate 3).

The ash percentage of the Lower Hartshorne coal is higher (11-15 %) along a linear trend which approximately parallels the channel-sandstone (distributary) trend in the Upper Hartshorne Member (Plates 13 and 15). This trend in high ash percentage of the Lower Hartshorne coal possibly represents the earliest stages in the formation of the distributary channel which later developed during the deposition of the Upper Hartshorne Member.

The southwestward-flowing distributary which had been supplying sediments to the map area was later diverted away from the map area during the deposition of the uppermost part of the Upper Hartshorne Member. Low-energy interdistributary conditions then prevailed which allowed for the accumulation of peat, which formed the Upper Hartshorne coal.

The Upper Hartshorne coal is thin (0.5-1.0 feet) along a linear trend which approximately parallels the channel-sandstone (distributary) trend in the Upper Hartshorne Member (Plates 4 and 15). During deposition of the Upper Hartshorne coal, the interdistributary marsh area was probably slightly higher topographically (possibly 1-2 feet) over the position of the underlying channel-fill sandstone. Subsidence of the sediments adjacent to the channel-fill sandstone was probably greater than that of the sandstone, creating the topographically high area in the marsh. This differential subsidence probably allowed for a greater accumulation of peat in areas adjacent to the topographic high than on the high itself. The Upper Hartshorne coal is therefore thinner (0.5-1.0 feet) over the position of the channel-fill sandstone, and thickens in both directions away from the channel (Plates 4 and 15).

CONCLUSIONS

This study of part of the Heavener 15' quadrangle has resulted in the following conclusions:

1) Three coals occur within the Hartshorne Formation. The Lower Hartshorne coal lies about 60 feet stratigraphically above the contact of the Hartshorne Formation with the underlying Atoka Formation. The Middle Hartshorne coal is laterally discontinuous, and lies about 55 feet stratigraphically above the Lower Hartshorne coal. The Middle Hartshorne coal is variable in thickness (½-2 feet) and is restricted to the north-central part of the study area. The Upper Hartshorne coal occurs between 60 and 120 feet stratigraphically above the Lower Hartshorne coal.

2) The Upper and Lower Hartshorne coals are fairly continuous through the Heavener map area, and have been correlated between coal test boreholes in Plates 6-10. The Middle Hartshorne coal is a discrete coal bed, and is not correlated as a split of either the Upper or Lower Hartshorne coal (Plates 6-9).

3) The Lower Hartshorne coal is important economically, and has been mined and produced commercially in the

Heavener area since before 1900. The coal is low- to medium-volatile bituminous in rank (70-84% fixed-carbon, mmf), is low in sulfur (0.5-3.0%, averages 1%) and ash (8.6-14.2%, averages 9%), is 1.5 to 6.0 feet thick, and has a calorific value of about 14,000 Btu.

4) The top of the Upper Hartshorne coal is the contact of the Hartshorne Formation with the overlying McAlester Formation. The coal is low- to medium volatile bituminous in rank and is 1½ to 3 feet thick. It contains 0.8-2.6 percent sulfur and averages 1.6 percent (Friedman, 1975).

5) The Upper and Lower Hartshorne coals in the Heavener map area collectively contain 439,639,000 short tons of coal in the remaining-resources category. The Lower Hartshorne coal contains 313,478,000 short tons of bituminous coal in the remaining-resources category. Approximately 13, 356,000 short tons of Lower Hartshorne coal have been mined and lost-in-mining, therefore, the original resources of the Lower Hartshorne coal consisted of 326,834,000 short tons of coal. The Upper Hartshorne coal contains 126,161,000 short tons of bituminous coal in the remaining-resources category. The original coal resources of the coal equal the remaining resources because the Upper Hartshorne coal has not been mined commercially.

6) The fixed-carbon percentage (mmf) of the Lower Hartshorne coal increases (70-84%) from the southwest to the northeast in the map area. This increase in fixed-

carbon percentage (mmf) was probably caused by post-depositional thermal activity to the east, possibly from heating associated with rifting along the Mississippi Aulacogen.

7) Two thin coals (each 0.5 foot thick) occur 10 feet and 40 feet, respectively, below the top of the Atoka Formation. The Atoka coals are exposed in the roadcut along U.S. Highway 59, south of Heavener (measured section 1, appendix 4).

8) The sediments which formed the Hartshorne Formation were deposited within a prograding deltaic plain environment. A southwestward-flowing distributary carried sediments through the north-central part of the map area during the deposition of the Upper Hartshorne Member (Plate 15). Gray shale was deposited in interdistributary marsh areas. The interdistributary areas were the site of lush plant growth, as evidenced by the occurrence of coals bearing rooted underclays, and the preservation of <u>Calamites</u>, <u>Cordaites</u>, <u>Lepidodendron</u>, and leaf and stem remains. The interdistributary areas were frequently inundated by crevasse splay and overbank deposits. A major distributary channel shift must have occurred higher in the deltaic plain to divert clastic sediments away from the map area (interdistributary area) during the deposition of the peat which formed the Lower, Middle, and Upper Hartshorne coals. The Upper Hartshorne coal thins (0.5-1.0 feet) over the position of the underlying channel-sandstone (distributary) because of greater

subsidence of the sediments deposited adjacent to the channel-sandstone than of the sediments deposited over the channel-sandstone.

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APPENDIX I

COAL TEST BOREHOLE DATA AND DRILLERS' LOGS

COAL TEST BOREHOLE DATA

Hole No.	Location Sec-T(N)-R(E)	Surface Elevation (feet)	Altitude of U.H. Coal (feet)	Depth to U.H. Coal (feet)	Thickness of U.H. Coal (feet)	Altitude of L.H. Coal (feet)	Depth to L.H. Coal (feet)	Thickness of L.H. Coal (feet)
1	25-6-25	478	-351	829	1.5	-445	923	3.5
2	25-6-25	512	-255	767	3.0	-348	860	3.8
3	31-6-25	465	+426	39	1.2	*	*	*
4	31-6-25	463	+ 62	401	1.0	+ 2	463	4.1
5	32-6-25	500	-360	859	0.5	-416	916	3.6
6	32-6-25	493	+ 48	444	1.2	- 6	499	3.6
7	33-6-25	512	-273	850	0.3	-381	893	2.0
8	33-6-25	490	-624	1170	2.2	-678	1223	4.2
9	33-6-25	537	-332	870	0.1	-427	965	3.7
10	33-6-25	489	+103	386	0.2	+ 49	440	3.5
11	34-6-25	514	?	?	?	-201	715	4.5
12	34-6-25	565	-267	832	0.3	-436	956	4.3
13	34-6-25	494	+146	347	0.4	+ 16	478	2.8
14	35-6-25	473	-111	584	1.8	-234	704	3.0
15	35-6-25	491	+ 45	446	1.8	- 77	568	6.2
16	35-6-25	552	+170	382	3.0	+ 65	487	2.3
17	36-6-25	481	-126	607	1.5	-232	713	3.0
18	36-6-25	496	- 34	530	3.2	-135	631	2.7
19	36-6-25	496	-155	650	1.5	-250	748	4.2
20	36-6-25	495	+ 46	449	2.5	- 15	510	?

Hole No.	Location Sec-T(N)-R(E)	Surface Elevation (feet)	Altitude of U.H. Coal (feet)	Depth to U.H. Coal (feet)	Thickness of U.H. Coal (feet)	Altitude of L.H. Coal (feet)	Depth to L.H. Coal (feet)	Thickness of L.H. Coal (feet)
21	36-6-25	495	- 44	539	2.2	*	*	*
22	13-6-26	552	-139	266	1.5	-206	759	4.4
23	14-6-26	600	-289	889	1.0	-345	945	4.0
24	16-6-26	467	-709	1176	1.1	-762	1229	3.8
25	20-6-26	504	-487	991	3.0	*	*	*
26	28-6-26	555	-343	899	2.5	-431	987	4.3
27	30-6-26	575	-375	950	2.0	-386	1006	4.2
28	31-6-26	521	-270	790	1.5	-392	912	3.0
29	31-6-26	490	-200	690	1.0	-322	812	2.6
30	31-6-26	528	-272	792	2.0	-362	881	4.1
31	31-6-26	489	-192	681	1.1	-301	790	3.6
32	31-6-26	495	-231	726	?	-299	794	2.9
33	31-6-26	515	-376	891	?	-439	954	3.8
34	32-6-26	581	-561	1142	2.2	-604	1245	3.6
35	32-6-26	577	-423	1000	2.0	-531	1108	3.8
36	19-6-27	570	+205	365	3.0	*	*	*
37	1-5-25	493	- 53	546	1.5	-111	604	2.4
38	1-5-25	495	- 43	540	2.2	-106	602	2.8
39	1-5-25	497	+ 1	496	2.2	-104	601	3.4
40	1-5-25	490	+ 41	449	2.4	- 19	509	3.4
41	1-5-25	582	+113	449	?	+ 62	520	3.4
42	1-5-25	512	- 85	597	3.0	-140	651	3.1
43	1-5-25	518	- 75	592	2.5	-133	651	2.1

Hole No.	Location Sec-T(N)-R(E)	Surface Elevation (feet)	Altitude of U.H. Coal (feet)	Depth to U.H. Coal (feet)	Thickness of U.H. Coal (feet)	Altitude of L.H. Coal (feet)	Depth to L.H. Coal (feet)	Thickness of L.H. Coal (feet)
44	1-5-25	546	+278	268	1.5	+180	366	3.1
45	1-5-25	555	+223	332	2.6	+144	411	2.8
46	12-5-25	528	+340	188	1.2	+255	273	3.7
47	12-5-25	538	+350	188	1.5	+270	268	3.0
48	12-5-25	550	+250	300	1.7	+162	388	2.2
49	12-5-25	530	+195	335	1.7	+121	409	2.7
50	12-5-25	553	+354	199	1.6	+284	269	3.5
51	12-5-25	563	+378	185	1.5	+299	264	3.2
52	12-5-25	562	+351	211	1.2	-331	893	3.6
53	12-5-25	560	+431	129	1.5	+339	221	3.1
54	12-5-25	550	**	**	**	+431	119	3.7
55	12-5-25	543	+474	69	1.4	+379	164	2.3
56	12-5-25	560	**	**	**	+491	69	3.5
57	25-5-25	597	**	**	**	+551	46	2.9
58	25-5-25	595	**	**	**	+558	37	3.4
59	25-5-25	670	**	**	**	+631	39	2.5
60	25-5-25	610	**	**	**	+538	72	3.6
61	25-5-25	598	**	**	**	+507	91	2.5
62	25-5-25	556	+540	16	1.5	+443	113	2.5
63	26-5-25	772	**	**	**	+720	52	0.8
64	26-5-25	752	**	**	**	+709	42	2.5
65	26-5-25	?	**	**	**	?	17	2.3
66	26-5-25	666	**	**	**	+606	59	2.2

Hole No.	Location Sec-T(N)-R(E)	Surface Elevation (feet)	Altitude of U.H. Coal (feet)	Depth to U.H. Coal (feet)	Thickness of U.H. Coal (feet)	Altitude of L.H. Coal (feet)	Depth to L.H. Coal (feet)	Thickness of L.H. Coal (feet)
67	26-5-25	633	**	**	**	+584	49	1.9
68	27-5-25	756	**	**	**	+722	28	2.2
69	27-5-25	710	**	**	**	+691	19	2.7
70	27-5-25	775	**	**	**	+745	30	2.0
71	27-5-25	739	**	**	**	+704	46	3.2
72	28-5-25	823	**	**	**	+777	46	2.5
73	28-5-25	774	**	**	**	+730	44	2.9
74	28-5-25	753	**	**	**	+712	41	2.8
75	33-5-25	743	**	**	**	+699	44	1.4
76	34-5-25	751	**	**	**	+697	54	2.0
77	34-5-25	740	**	**	**	+692	48	2.0
78	34-5-25	716	**	**	**	+674	42	1.8
79	34-5-25	703	**	**	**	+674	29	1.7
80	35-5-25	709	**	**	**	+657	52	2.4
81	35-5-25	661	**	**	**	+613	48	1.3
82	36-5-25	635	**	**	**	+548	87	2.5
83	36-5-25	608	**	**	**	+511	97	1.9
84	36-5-25	588	**	**	**	+492	96	2.9
85	36-5-25	690	**	**	**	+660	30	2.9
86	36-5-25	685	**	**	**	+629	56	3.1
87	36-5-25	694	**	**	**	+680	14	?
88	36-5-25	660	**	**	**	+603	57	2.3
89	36-5-25	620	**	**	**	+588	32	2.2

Hole No.	Location Sec-T(N)-R(E)	Surface Elevation (feet)	Altitude of U.H. Coal (feet)	Depth to U.H. Coal (feet)	Thickness of U.H. Coal (feet)	Altitude of L.H. Coal (feet)	Depth to L.H. Coal (feet)	Thickness of L.H. Coal (feet)
90	5-5-26	533	-438	971	?	-510	1043	3.6
91	5-5-26	599	-615	1213	1.5	-681	1280	1.6
92	5-5-26	563	-312	875	1.0	-417	979	1.8
93	5-5-26	563	-211	774	1.4	-309	871	1.9
94	5-5-26	578	-279	855	0.8	-375	953	3.0
95	6-5-26	505	-151	656	1.0	-201	706	3.0
96	6-5-26	518	- 67	585	?	-155	673	3.4
97	6-5-26	525	-162	687	1.5	-263	761	3.0
98	6-5-26	528	-265	793	1.4	-367	895	3.1
99	6-5-26	532	- 48	581	?	-157	690	3.0
100	6-5-26	551	+ 51	500	2.0	- 38	589	4.1
101	6-5-26	547	+ 24	523	2.0	- 69	616	3.7
102	6-5-26	540	- 54	594	2.0	-141	682	5.3
103	6-5-26	547	-50	597	2.0	-140	686	3.3
104	6-5-26	543	-207	751	1.5	-313	856	3.0
105	6-5-26	550	- 52	602	1.5	-139	689	4.2
106	7-5-26	580	+191	399	1.4	+ 90	490	3.5
107	7-5-26	577	+158	419	1.0	+ 73	504	3.5
108	7-5-26	555	- 75	629	2.7	-172	727	3.0
109	7-5-26	559	- 42	601	1.5	-155	709	4.2
110	7-5-26	567	+280	287	1.0	+194	373	3.1
111	7-5-26	559	+205	354	1.0	+115	444	3.3
112	7-5-26	561	+340	221	1.5	+247	314	4.4

Hole No.	Location Sec-T(N)-R(E)	Surface Elevation (feet)	Altitude of U.H. Coal (feet)	Depth to U.H. Coal (feet)	Thickness of U.H. Coal (feet)	Altitude of L.H. Coal (feet)	Depth to L.H. Coal (feet)	Thickness of L.H. Coal (feet)
113	7-5-26	550	+251	299	1.5	+160	389	3.5
114	7-5-26	556	+412	144	1.4	+299	257	4.2
115	7-5-26	579	+282	300	2.0	+182	398	3.1
116	7-5-26	583	+265	317	0.5	+176	407	4.1
117	7-5-26	619	+152	467	1.5	+ 59	559	4.0
118	7-5-26	573	+406	167	1.5	+302	270	3.3
119	8-5-26	570	- 10	581	1.5	-104	674	2.8
120	24-5-26	677	+272	405	0.1	+232	445	6.7
121	24-5-26	658	+261	397	0.1	+231	427	6.0
122	24-5-26	663	+358	305	0.1	+319	344	3.0
123	25-5-26	717	**	**	**	+532	185	6.0
124	25-5-26	619	**	**	**	+519	100	6.5
125	25-5-26	616	**	**	**	+579	37	3.0
126	30-5-26	552	+532	20	2.3	+446	106	2.9
127	31-5-26	548	**	**	**	+460	88	3.1
128	31-5-26	544	**	**	**	+454	89	2.7
129	31-5-26	542	**	**	**	+453	88	2.4
130	31-5-26	523	+455	68	3.0	+398	125	4.0
131	31-5-26	557	**	**	**	+537	20	2.3
132	31-5-26	549	**	**	**	+538	11	3.0
133	31-5-26	562	**	**	**	+548	13	3.0
134	19-5-27	706	+339	367	?	+301	405	6.7
135	19-5-27	666	+436	230	?	+395	271	5.7

Hole No.	Location Sec-T(N)-R(E)	Surface Elevation (feet)	Altitude of U.H. Coal (feet)	Depth to U.H. Coal (feet)	Thickness of U.H. Coal (feet)	Altitude of L.H. Coal (feet)	Depth to L.H. Coal (feet)	Thickness of L.H. Coal (feet)
136	19-5-27	634	**	**	**	+471	163	5.0
137	19-5-27	623	**	**	**	+569	54	4.5
138	19-5-27	623	**	**	**	+571	52	5.5
Coal test boreholes not in thesis area which were used in Plate 10								
139	20-5-27	691	+456	235	?	+403	288	5.3
140	16-5-27	715	+330	385	3.0	+296	419	7.2
141	24-3-33	703	+432	271	5.0	+314	389	7.9
142	19-3-32	700	-	-	-	-	-	-
143	19-3-32	748	+407	341	5.0	+303	445	6.7

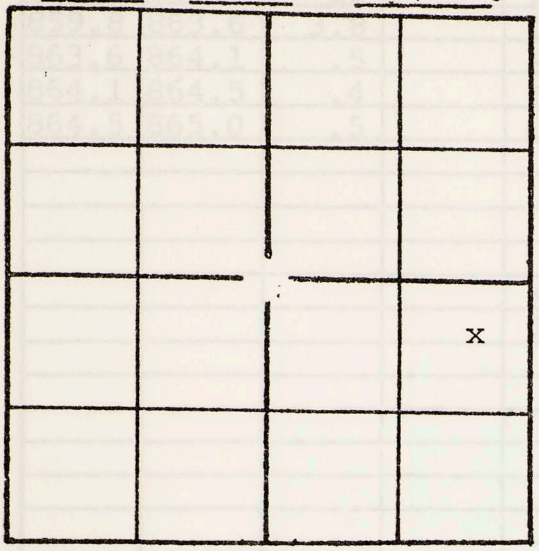
* coal test borehole not drilled deep enough to encounter Lower Hartshorne coal.

? data unknown.

** Upper Hartshorne coal absent.

- encountered Atoka Formation coals at 84 (0.2 feet thick) and 115 (2.6 feet thick) feet deep.

T 5 N . R 25 E. SEC 1 .



OKLAHOMA GEOLOGICAL SURVEY
NORMAN, OKLAHOMA 73069

ANALYSIS	
MOIST 0.4	VM 15.76
FC 75.56	ASH 7.65
ULTIMATE	
C	H
O	N
SULFUR 0.63	organic
pyritic	SO_4
Btu	FSI 5

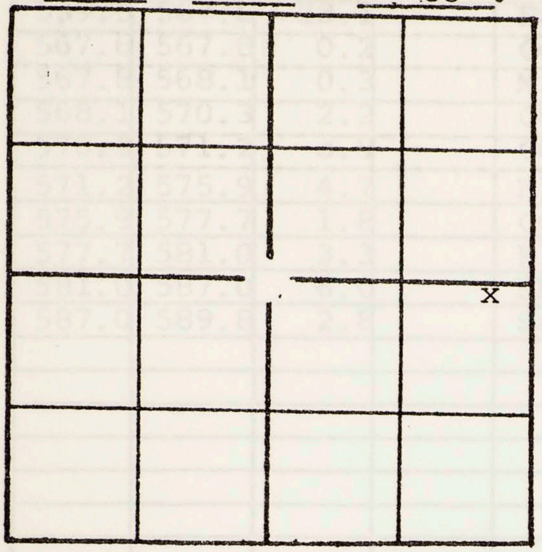
STATE Oklahoma
COUNTY LeFlore

LOCATION 200'W & 1985'N of SE COR
SURFACE ELEVATION 511.7 HOLE NO. 2
LESSEE/PERMITTEE
LEASE/PERMIT DRILLER
COMMENCED Feb. 23, 1965 FINISHED March 2, 1965
REMARKS

DEPTH FROM	IN FEET TO	THICK-NESS	FEET CORED	DESCRIPTION
0.0	5.0	5.0		Clay
5.0	11.0	6.0		Weathered Shale
11.0	30.0	19.0		Hard Shale with Sandstone Bands
30.0	180.0	150.0		Black Shale
180.0	212.2	32.2		Black Sandy Shale
212.2	267.0	54.8		Hard Sandy Shale with Thin Sandstone Bands
267.0	403.2	136.2		Hard Sandy Shale
403.2	416.0	12.8		Hard Sandstone
416.0	440.0	24.0		Hard Sandy Shale with Thin Sandstone Bands
440.0	657.2	217.2		Hard Sandy Shale
657.2	767.2	110.0		Hard Sandy Shale & Niggerheads
767.2	772.2	5.0		Coal and Bone
772.2	776.0	3.8		Hard Sandy Shale & Sandstone Bands
776.0	780.3	4.3		Sandstone with Thin Sandstone Bands
780.3	781.4	1.1		Sandstone
781.4	786.4	5.0		Hard Shale with Sandstone Bands
786.4	789.7	3.3		Hard Shale with Thin Brown Bands
789.7	790.6	.9		Hard Black Shale with Very Thin Coal Seams
790.6	790.9	.3		Bone and Coal
790.9	793.1	2.2		Hard Shale
793.1	847.6	54.5		Hard Sandy Shale with Sandstone Bands

DEPTH IN FEET FROM	TO	THICK-NESS	FEET CORED	DESCRIPTION
847.6	859.6	12.0		Hard Sandy Shale with Niggerheads
859.6	859.8	.2		Boney Shale with Thin Coal Seams
859.8	863.6	3.8		COAL
863.6	864.1	.5		Shale
864.1	864.5	.4		COAL
864.5	865.0	.5		Hard Shale with Thin Coal Seams
				Cemented Hole 5 Sacks
				Left 21.0' 4" Pile in Hole

T 6N . R 25E . SEC 35 .



OKLAHOMA GEOLOGICAL SURVEY
NORMAN, OKLAHOMA 73069

ANALYSIS	
MOIST	VM
FC	ASH
ULTIMATE	
C	H
O	N
SULFUR	organic
pyritic	SO_4
Btu	FSI

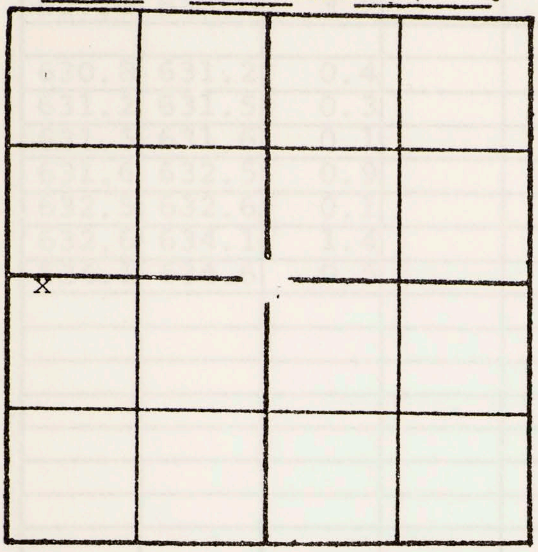
STATE Oklahoma
COUNTY LeFlore

LOCATION 1166' NE 110' W of SE COR
SURFACE ELEVATION 491.0 HOLE NO. 15
LESSEE/PERMITTEE
LEASE/PERMIT DRILLER
COMMENCED Jan. 2, 1965 FINISHED Jan. 8, 1965
REMARKS

DEPTH FROM	IN FEET TO	THICK-NESS	FEET CORED	DESCRIPTION
0.0	1.0	1.0		Top Soil and Gravel
1.0	8.0	7.0		Clay
8.0	11.0	3.0		Weathered Shale
11.0	30.0	19.0		Hard Gray Shale
30.0	38.5	8.5		Hard Sandy Shale with Sandstone Bands
38.5	38.9	.4		COAL
38.9	52.5	13.6		Hard Sandy Shale with Sandstone Bands
52.5	61.0	8.5		Hard Gray Sandstone
61.0	89.5	28.5		Hard Sandy Shale with Sandstone Bands (Cored 54.5-65.8)
89.5	330.0	240.5		Hard Sandy Shale
330.0	350.0	20.0		Hard Sandy Shale with Sandstone Bands
350.0	380.0	30.0		Sandy Shale
380.0	446.3	66.3		Sandy Shale and Niggerheads
446.3	448.1	1.8		Bone and Coal
448.1	453.0	4.9		Black Shale
453.0	473.0	20.0		Hard Sandy Shale with Sandstone Bands
473.0	475.8	2.8		Sandstone with Shale Bands
475.8	491.1	15.3		Sandstone and Shale (Cored 475.8-491.1)
491.1	495.8	4.7		Black Shale with Sandstone Bands
495.8	501.5	5.7		Black Shale with Coal Seams (Cored)
501.5	503.8	2.3		Hard Sandy Shale and Sandstone (Cored)
503.8	528.8	25.0		Sandstone, Medium Hard (Cored)

DEPTH FROM	IN FEET TO	THICK-NESS	FEET CORED	DESCRIPTION
528.8	539.5	10.7		Hard Sandy Shale with Sandstone Bands (Cored)
539.5	567.6	28.1		Hard Sandy Shale & Niggerheads
567.6	567.8	0.2		Coal
567.8	568.1	0.3		Middle Band
568.1	570.3	2.2		COAL
570.3	571.2	o.9		Coal & Bone
571.2	575.9	4.7		Black Shale with Coal seams
575.9	577.7	1.8		COAL
577.7	581.0	3.3		Black Shale with Coal Seams
581.0	587.0	6.0		Shale with Sandstone Bands
587.0	589.8	2.8		Sandstone

T 6N . R 25E . SEC 36 .



OKLAHOMA GEOLOGICAL SURVEY
NORMAN, OKLAHOMA 73069

ANALYSIS

MOIST		VM	14.71
FC	75.96	ASH	9.33

ULTIMATE

C		H	
O		N	
SULFUR	0.88	organic	
pyritic		SO_4	
Btu		FSI	9

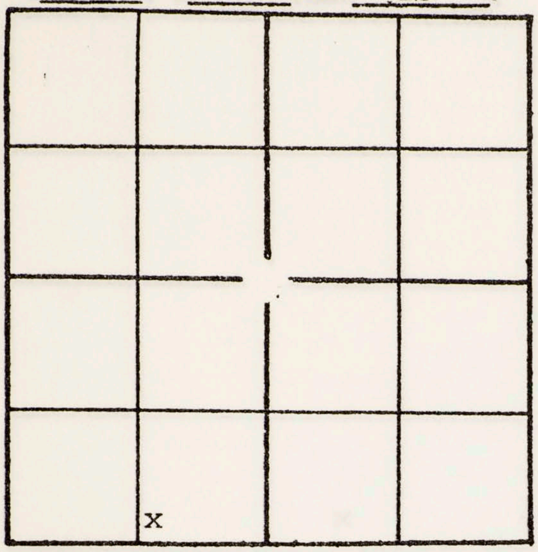
STATE Oklahoma
COUNTY LeFlore

LOCATION 487' E & 2528' N of SW corner
SURFACE ELEVATION 496.3 HOLE NO. 18
LESSEE/PERMITTEE
LEASE/PERMIT DRILLER
COMMENCED Feb. 17, 1965 FINISHED Feb. 22, 1965
REMARKS

DEPTH FROM	IN FEET TO	THICK-NESS	FEET CORED	DESCRIPTION
0.0	4.0	4.0		Clay
4.0	7.0	3.0		Gravel and Clay
7.0	12.0	5.0		Weathered Shale
12.0	85.0	73.0		Black Sandy Shale
85.0	123.0	38.0		Black Sandy Shale & Niggerheads
123.0	124.0	1.0		Boney Coal
124.0	130.0	6.0		Black Shale
130.0	136.0	6.0		Hard Sandy Shale with Sandstone
				Bands
136.0	142.0	6.0		Sandstone with Shale Bands
142.0	152.9	10.9		Shale with Sandstone Bands
152.9	155.0	2.1		Sandstone, Hard
155.0	160.0	5.0		Gray Shale
160.0	170.0	10.0		Hard Shale with Sandstone
				Bands
170.0	415.0	245.0		Hard Sandy Shale
415.0	530.2	115.2		Hard Sandy Shale with
				Niggerheads
530.2	533.4	3.2		Boney Coal
533.4	540.0	6.6		Hard Sandy Shale
540.0	568.2	28.2		Hard Sandy Shale with
				Sandstone Bands
568.2	569.2	1.0		Boney Coal
569.2	574.5	5.3		Black Shale with Coal Seams
574.5	579.0	4.5		Sandstone with thin Shale
				Seams
579.0	605.2	26.2		Sandstone

DEPTH FROM	IN FEET TO	THICK-NESS	FEET CORED	DESCRIPTION
605.2	627.6	22.4		Hard Sandy Shale with thin Brown Bands
627.6	630.8	3.2		Hard Broken Shale with Small Niggerheads
630.8	631.2	0.4		Boney Coal with thin Coal
631.2	631.5	0.3		COAL
631.5	631.6	0.1		Shale
631.6	632.5	0.9		COAL
632.5	632.6	0.1		Middle Band
632.6	634.1	1.4		COAL
634.1	634.6	0.5		Shale with thin Coal Seams

T 6N . R 26E .SEC 13 .



OKLAHOMA GEOLOGICAL SURVEY
NORMAN, OKLAHOMA 73069

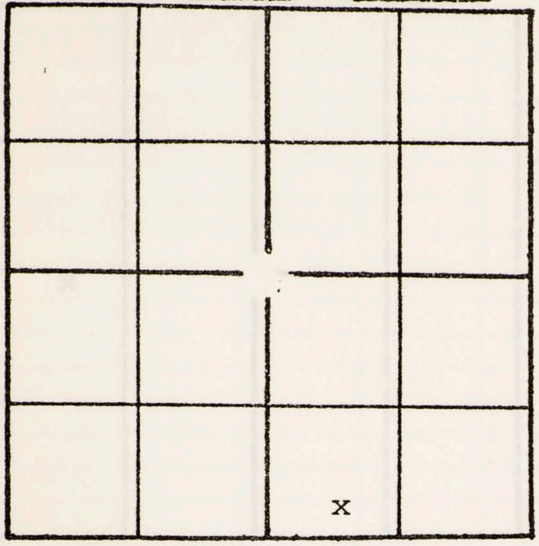
ANALYSIS	
MOIST	VM
FC	ASH
ULTIMATE	
C	H
O	N
SULFUR	organic
pyritic	SO_4
Btu	FSI

STATE Oklahoma
COUNTY LeFlore

LOCATION 100' N & 1315' E of SW corner
SURFACE ELEVATION 552.5 HOLE NO. 22
LESSEE/PERMITTEE
LEASE/PERMIT DRILLER
COMMENCED FINISHED June 20, 1966
REMARKS

DEPTH IN FEET FROM	TO	THICKNESS	FEET CORED	DESCRIPTION
0.0	8.0	8.0		Soil and Boulders
8.0	15.3	7.3		Yellow Clay
15.3	59.0	43.7		Soft blue Shale
59.0	85.5	26.5		Blue Shale and Sandstone Bands
85.5	188.0	102.5		Soft blue Shale
188.0	229.0	41.0		Soft blue Shale
229.0	266.5	37.5		Shale and Niggerheads
266.5	268.0	1.5		COAL
268.0	269.5	1.5		Sandstone with Shale Bands
269.5	296.0	26.5		Sandstone
296.0	317.0	21.0		Sandstone with Shale Bands
317.0	540.0	223.0		Hard Sandy blue Shale
540.0	568.0	28.0		Soft blue Shale
568.0	692.0	124.0		Sandy blue Shale and Niggerheads
692.0	693.5	1.5		COAL
693.5	694.5	1.0		Hard Black Shale
694.5	703.0	8.5		Rashy Black Shale
703.0	751.0	48.0		Sandstone and Shale Seams
751.0	759.4	8.4		Black Sandy Shale
759.4	763.8	4.4		COAL
763.8	767.3	3.5		Medium-hard Black Shale with Coal Seams

T 6N . R 26E .SEC 31 .



OKLAHOMA GEOLOGICAL SURVEY
NORMAN, OKLAHOMA 73069

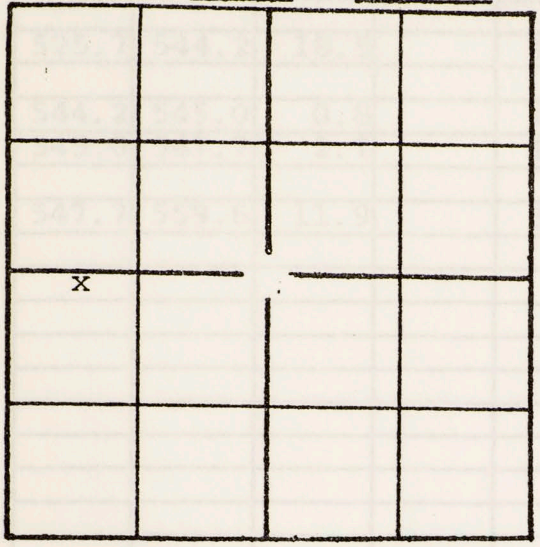
ANALYSIS	
MOIST	VM
FC	ASH
ULTIMATE	
C	H
O	N
SULFUR	organic
pyritic	SO_4
Btu	FSI

STATE Oklahoma
COUNTY LeFlore

LOCATION 2028' W & 380' N of SE corner
SURFACE ELEVATION 514.6 HOLE NO. 33
LESSEE/PERMITTEE
LEASE/PERMIT DRILLER
COMMENCED FINISHED July 19,1968
REMARKS

DEPTH FROM	IN FEET TO	THICK-NESS	FEET CORED	DESCRIPTION
0.0	6.0	6.0		Clay and Gravel
6.0	87.0	81.0		Gray Sandy Shale
87.0	295.0	208.0		Hard Sandy Shale
295.0	300.0	5.0		Medium gray Sandstone
300.0	413.0	113.0		Sandy Shale
413.0	475.0	62.0		Shale and Sandstone Bands
475.0	478.0	3.0		Hard gray Sandstone
478.0	491.0	13.0		Hard gray Sandstone
491.0	613.0	122.0		Hard Sandy Shale
613.0	761.0	148.0		Hard Sandy Shale
761.0	793.0	32.0		Shale and Sandstone Bands
793.0	878.4	85.4		Shale and Sandstone Bands
878.4	891.1	12.7		Hard gray Sandstone
891.1	897.1	6.0		Coal and Boney Shale
897.1	907.0	9.9		Gray Shale
907.0	937.0	20.0		Hard Gray Shale
937.0	953.6	16.6		Hard gray Sandstone
953.6	957.4	3.8		Coal
957.4	958.4	1.0		Boney Shale
958.4	959.4	1.0		Boney Coal
959.4	962.2	2.8		Boney Shale with Coal Streaks

T 5N . R 25E . SEC 1 .



OKLAHOMA GEOLOGICAL SURVEY
NORMAN, OKLAHOMA 73069

ANALYSIS	
MOIST	VM 17.81
FC 72.15	ASH 10.04
ULTIMATE	
C	H
O	N
SULFUR 0.45	organic
pyritic	SO_4
Btu	FSI 8½

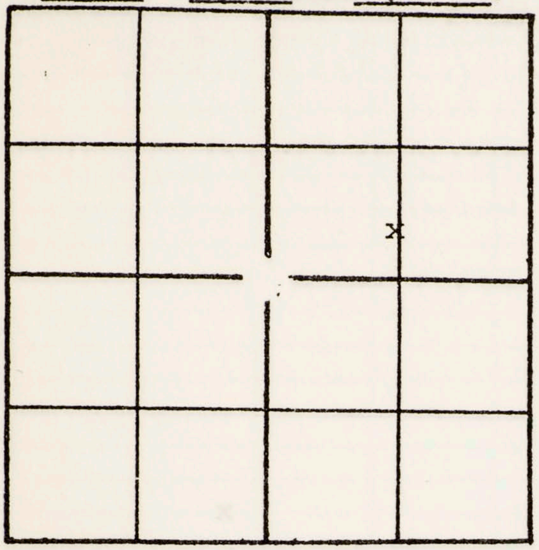
STATE Oklahoma
COUNTY LeFlore

LOCATION 2692' S & 800' E of NW corner
SURFACE ELEVATION 581.8 HOLE NO. 41
LESSEE/PERMITTEE
LEASE/PERMIT DRILLER
COMMENCED Feb. 11, 1965 FINISHED Feb. 16, 1965
REMARKS

DEPTH FROM	IN FEET TO	THICK-NESS	FEET CORED	DESCRIPTION
0.0	5.0	5.0		Clay
5.0	11.0	6.0		Weathered Shale
11.0	25.0	14.0		Hard Brown Sandstone
25.0	40.0	15.0		Hard Sandy Shale with Sand-stone Bands
40.0	295.0	255.0		Black Shale
295.0	320.0	25.0		Hard Sandy Shale with Sand-stone Bands
320.0	350.0	30.0		Hard Sandy Shale
350.0	390.7	40.7		Black Shale with Niggerheads
390.7	449.2	58.5		Hard Sandy Shale with Niggerheads
449.2	455.7	6.5		Coal & Boney with Shale streaks
455.7	458.0	2.3		Shale
458.0	471.0	13.0		Hard Sandy Shale with Sandstone Bands
471.0	498.2	27.2		Sandstone
498.2	503.6	5.4		Hard Sandy Shale with Sand-stone Bands
503.6	519.2	15.6		Hard Black Shale with thin Brown Bands
519.2	519.6	0.4		Boney Shale with Coal Seams
519.6	519.8	0.2		COAL
519.8	520.0	0.2		Middle Band
520.0	522.1	2.1		COAL
522.1	524.1	2.0		Black Shale with thin Coal Seams

DEPTH FROM	IN FEET TO	THICK-NESS	FEET CORED	DESCRIPTION
524.1	524.4	0.3		COAL
524.4	525.7	1.3		Black Shale with thin Coal Seams
525.7	544.2	18.5		Hard Black Shale with thin Coal Seams
544.2	545.0	0.8		COAL
545.0	547.7	2.7		Hard black Shale with Coal Seams
547.7	559.6	11.9		Sandstone with Shale Bands

T 5N . R 25E . SEC 27 .



OKLAHOMA GEOLOGICAL SURVEY
NORMAN, OKLAHOMA 73069

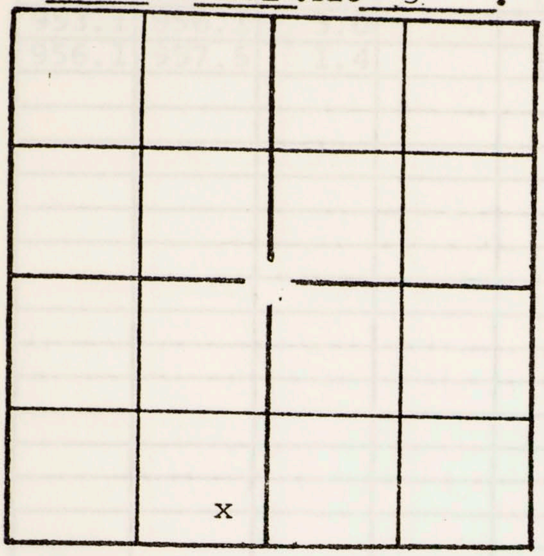
ANALYSIS			
MOIST	4.95	VM	23.26
FC	68.91	ASH	7.83
ULTIMATE			
C		H	
O		N	
SULFUR	0.61	organic	
pyritic		SO_4	
Btu	13189	FSI	

STATE Oklahoma
COUNTY LeFlore

LOCATION 1300' W and 1630' N of SE corner
SURFACE ELEVATION 775' HOLE NO. 70
LESSEE/PERMITTEE
LEASE/PERMIT DRILLER
COMMENCED FINISHED 1954
REMARKS Pine Mountain

DEPTH FROM	IN FEET TO	THICK-NESS	FEET CORED	DESCRIPTION
0	5.0	5.0		clay and boulders
5.0	16.2	11.2		hard sandstone
16.2	20.4	4.2		soft sandstone
20.4	22.0	1.6		brown sandstone
22.0	24.5	2.5		blue shale
24.5	25.0	0.5		yellow shale
25.0	27.4	2.4		blue shale
27.4	29.6	2.2		blue shale
29.6	30.2	0.6		black shale
30.7	32.2	2.0		coal (Lower Hartshorne)
32.2	33.2	1.0		fireclay

T 5N . R 26E . SEC 5 .



OKLAHOMA GEOLOGICAL SURVEY
NORMAN, OKLAHOMA 73069

ANALYSIS	
MOIST	VM
FC	ASH
ULTIMATE	
C	H
O	N
SULFUR	organic
pyritic	SO_4
Btu	FSI

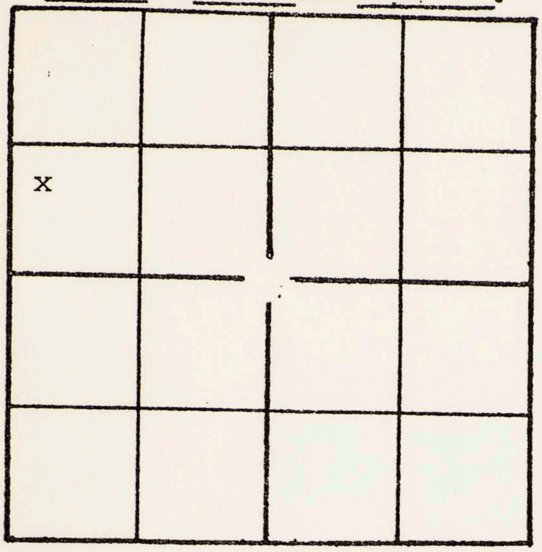
STATE Oklahoma
COUNTY LeFlore

LOCATION 2500' E & 200' N of SW corner
SURFACE ELEVATION 578.0 HOLE NO. 94
LESSEE/PERMITTEE
LEASE/PERMIT DRILLER
COMMENCED March 3, 1965 FINISHED March 10, 1965
REMARKS

DEPTH FROM	IN FEET TO	THICK-NESS	FEET CORED	DESCRIPTION
0.0	10.0	10.0		Clay
10.0	23.0	13.0		Clay and Gravel
23.0	83.2	60.2		Sandy Shale
83.2	195.0	111.8		Hard Sandy Shale
195.0	215.0	20.0		Hard Sandy Shale & Sandstone
215.0	290.0	75.0		Hard Sandy Shale with Sand-
				stone Seams
290.0	370.0	80.0		Hard Sandy Shale
370.0	398.0	28.0		Hard Sandy Shale & Niggerheads
398.0	398.5	0.5		Boney Coal
398.5	429.0	30.5		Hard Sandy Shale with Sand-
				stone Bands
429.0	434.0	5.0		Hard Sandstone
434.0	444.2	10.2		Hard Sandy Shale with Sand-
				stone Bands
444.2	452.0	7.8		Sandstone with Shale Bands
452.0	460.0	8.0		Hard Sandy Shale with Sand-
				stone Bands
460.0	725.5	265.5		Hard Sandy Shale
725.5	754.0	28.5		Hard Sandy Shale with Sand-
				stone Bands
754.0	830.0	76.0		Hard Sandy Shale with
				Niggerheads
830.0	855.2	25.2		Hard Shale with Niggerheads
855.2	856.0	0.8		COAL
856.0	872.0	16.0		Hard Shale
872.0	884.9	12.9		Hard Sandy Shale & Sandstone

DEPTH FROM	IN FEET TO	THICK-NESS	FEET CORED	DESCRIPTION
884.9	894.4	9.5		Sandstone with Shale Bands
894.4	953.1	58.7		Sandstone
953.1	956.1	3.0		COAL
956.1	957.5	1.4		Hard Shale

T 5N . R 26E .SEC 8 .



OKLAHOMA GEOLOGICAL SURVEY
NORMAN, OKLAHOMA 73069

ANALYSIS	
MOIST	VM
FC	ASH
ULTIMATE	
C	H
O	N
SULFUR	organic
pyritic	SO_4
Btu	FSI

STATE Oklahoma
COUNTY LeFlore

LOCATION 1550' S & 250' E of NW corner
SURFACE ELEVATION 570.0 HOLE NO. 119
LESSEE/PERMITTEE
LEASE/PERMIT DRILLER
COMMENCED Dec. 9, 1964 FINISHED Dec. 19, 1964
REMARKS

DEPTH FROM	IN FEET TO	THICK-NESS	FEET CORED	DESCRIPTION
0.0	13.0	13.0		Clay & Boulders
13.0	17.0	4.0		Weathered Shale
17.0	18.5	1.5		Soft Black Shale
18.5	104.0	85.5		Soft Black Shale
104.0	116.3	12.3		Black Shale & Niggerheads
116.3	116.8	0.5		COAL
116.8	124.3	7.5		Black Sandy Shale
124.3	130.4	6.1		Hard Sandy Shale with Sand-
				stone Bands
130.4	133.5	3.1		Hard Sandstone
133.5	171.0	37.5		Sandstone & Hard Sandy Shale
171.0	190.0	19.0		Hard Sandy Shale with Sand-
				stone Bands
190.0	220.0	30.0		Medium Hard Sandy Shale
220.0	460.0	240.0		Hard Sandy Shale
460.0	472.0	12.0		Hard Sandy Shale & Niggerheads
472.0	565.4	93.8		Black Sandy Shale & Niggerheads
565.4	580.8	15.0		Sandy Shale with Heavy Sand-
				stone Bands
580.8	582.3	1.5		Bone & Coal
582.3	587.0	4.7		Black Shale
587.0	600.0	13.0		Hard Sandy Shale
600.0	605.9	5.9		Hard Sandy Shale with Sand-
				stone bands
605.9	622.2	16.3		Sandstone with Shale Seams
622.2	674.2	52.0		Gray Sandstone
674.2	677.0	2.8		COAL
677.0	677.9	0.9		Black Shale

APPENDIX 2

CHEMICAL ANALYSES

CHEMICAL ANALYSES

Hole No.	Location Sec-T(N)-R(E)	Proximate Analysis (%) Moisture	Volatile Matter	Fixed Carbon	Ash	Sulfur (%)	FSI	Btu
1	25-6-25	*	*	*	*	*	*	*
2	25-6-25	*	15.76	75.56	7.68	0.63	5	*
3	31-6-25	*	*	*	*	*	*	*
4	31-6-25	*	*	*	*	*	*	*
5	32-6-25	*	16.88	70.95	10.51	1.66	9	*
6	32-6-25	*	18.60	68.80	10.94	1.66	9	*
7	33-6-25	*	16.50	71.82	11.68	1.20	7	*
8	33-6-25	*	17.32	73.86	8.82	1.51	*	*
9	33-6-25	*	16.73	76.94	6.33	0.57	6	*
10	33-6-25	*	20.97	72.86	6.17	0.77	9	*
11	34-6-25	*	*	*	*	*	*	*
12	34-6-25	*	16.47	71.88	11.64	1.24	5½	*
13	34-6-25	*	17.68	73.35	8.97	1.23	7½	*
14	35-6-25	*	17.85	75.83	6.32	*	*	*
15	35-6-25	*	*	*	*	*	*	*
16	35-6-25	*	18.69	67.95	13.36	0.52	8	*
17	36-6-25	*	*	*	*	*	*	*
18	36-6-25	*	14.71	75.96	9.33	0.88	9	*
19	36-6-25	*	16.32	76.53	7.15	0.86	7	*
20	36-6-25	*	*	*	*	*	*	*

enter all locations that have Volatile matter, Fixed carbon, Ash, at least

Hole No.	Location Sec-T(N)-R(E)	Moisture	Proximate Analyses (%) Volatile Matter	Fixed Carbon	Ash	Sulfur (%)	FSI	Btu
21	36-6-25	*	*	*	*	*	*	*
22	13-6-26	*	*	*	*	*	*	*
23	14-6-26	*	14.94	77.73	7.33	0.55	1½	*
24	16-6-26	*	15.10	75.92	8.98	0.77	1½	*
25	20-6-26	*	*	*	*	*	*	*
26	28-6-26	0.8	15.60	74.60	8.40	0.6	4	*
27	30-6-26	2.1	16.81	72.04	9.05	0.62	3½	*
28	31-6-26	*	15.75	74.37	9.88	0.93	4½	*
29	31-6-26	*	*	*	*	*	*	*
30	31-6-26	*	*	*	*	*	*	*
31	31-6-26	*	16.11	76.27	7.62	0.93	3½	*
32	31-6-26	*	16.52	74.49	8.99	0.60	5½	*
33	31-6-26	*	*	*	*	*	*	*
34	32-6-26	*	16.80	73.20	10.00	0.7	5	*
35	32-6-26	*	14.78	72.10	13.12	1.02	5½	*
36	19-6-27	*	*	*	*	*	*	*
37	1-5-25	*	*	*	*	*	*	*
38	1-5-25	*	15.88	68.44	15.58	0.32	5½	*
39	1-5-25	*	*	*	*	*	*	*
40	1-5-25	*	*	*	*	*	*	*
41	1-5-25	*	17.81	72.15	10.04	0.45	8½	*
42	1-5-25	*	*	*	*	*	*	*
43	1-5-25	*	18.66	74.14	7.20	0.53	9	*
44	1-5-25	*	17.70	72.14	9.16	0.52	9	*

Proximate Analyses (%)

Hole No.	Location Sec-T(N)-R(E)	Moisture	Volatile Matter	Fixed Carbon	Ash	Sulfur(%)	FSI	Btu
45	1-5-25	*	19.43	73.34	7.23	0.88	9	*
46	12-5-25	*	19.04	72.34	8.62	0.74	9	*
47	12-5-25	*	18.91	74.57	6.52	0.73	9	*
48	12-5-25	*	19.19	72.38	8.43	0.65	9	*
49	12-5-25	*	19.06	74.39	6.55	0.99	9	*
50	12-5-25	*	19.59	70.80	9.61	0.77	9	*
51	12-5-25	*	19.17	69.16	11.67	2.09	9	*
52	12-5-25	*	18.98	73.25	7.77	1.29	9	*
53	12-5-25	*	19.49	73.33	7.18	0.92	9	*
54	12-5-25	*	20.11	72.23	7.66	0.59	9	*
55	12-5-25	*	19.42	66.78	13.80	1.54	9	*
56	12-5-25	*	20.65	73.82	5.55	0.80	9	*
57	25-5-25	*	*	*	*	*	*	*
58	25-5-25	*	*	*	*	*	*	*
59	25-5-25	*	*	*	*	*	*	*
60	25-5-25	*	*	*	*	*	*	*
61	25-5-25	*	*	*	*	*	*	*
62	25-5-25	*	*	*	*	*	*	*
63	26-5-25	*	*	*	*	*	*	*
64	26-5-25	1.52	23.64	65.16	9.68	1.28	7½	13936
65	26-5-25	3.85	24.79	58.71	12.65	1.36	7½	12970
66	26-5-25	*	*	*	*	*	*	*
67	26-5-25	0.75	22.60	67.88	9.52	1.53	est. 6	14069
68	27-5-25	1.23	25.66	62.86	11.48	1.95	est. 5½	13703

Hole No.	Location Sec-T(N)-R(E)	Proximate Analyses (%) Moisture	Volatile Matter	Fixed Carbon	Ash	Sulfur (%)	FSI	Btu
69	27-5-25	2.82	23.87	58.92	14.39	0.87	*	12094
70	27-5-25	4.95	23.26	68.91	7.83	0.61	*	13189
71	27-5-25	*	*	*	9.05	1.26	*	14301
72	28-5-25	1.49	25.30	64.75	8.46	0.84	7½	14212
73	28-5-25	1.10	28.47	62.00	9.52	1.08	est. 5½	14029
74	28-5-25	1.01	23.11	66.55	10.34	1.71	est. 6	13915
75	33-5-25	*	*	*	9.21	1.37	*	*
76	34-5-25	1.57	23.45	63.47	11.51	1.96	8½	13719
77	34-5-25	0.80	22.01	64.81	13.18	3.00	est. 6	13338
78	34-5-25	0.90	22.09	63.76	14.15	2.38	est. 6	13466
79	34-5-25	0.65	23.12	67.03	9.85	1.12	est. 6	14168
80	35-5-25	*	*	*	10.07	2.74	*	14072
81	35-5-25	*	*	*	*	*	*	*
82	36-5-25	*	*	*	*	*	*	*
83	36-5-25	*	*	*	*	*	*	*
84	36-5-25	*	*	*	*	*	*	*
85	36-5-25	*	*	*	*	*	*	*
86	36-5-25	*	*	*	*	*	*	*
87	36-5-25	*	*	*	*	*	*	*
88	36-5-25	*	*	*	*	*	*	*
89	36-5-25	*	*	*	*	*	*	*
90	5-5-25	*	15.8	73.50	10.70	1.30	4	*
91	5-5-25	*	*	*	*	*	*	*
92	5-5-26	*	*	*	*	*	*	*

Hole No.	Location Sec-T(N)-R(E)	Proximate Analyses (%) Moisture	Volatile Matter	Fixed Carbon	Ash	Sulfur (%)	FSI	Btu
93	5-5-26	*	*	*	*	*	*	*
94	5-5-26	*	*	*	*	*	*	*
95	6-5-26	*	18.36	74.80	6.84	0.63	8½	*
96	6-5-26	*	18.73	70.52	10.75	0.54	5	*
97	6-5-26	*	16.67	74.50	8.15	0.60	9	*
98	6-5-26	*	16.81	72.04	11.15	0.58	9	*
99	6-5-26	*	20.77	60.89	18.34	1.40	5	*
100	6-5-26	*	17.88	73.00	9.12	0.69	9	*
101	6-5-26	*	19.51	70.10	10.39	1.04	9	*
102	6-5-26	*	15.60	75.33	9.07	1.48	9	*
103	6-5-26	*	19.67	72.96	7.37	0.73	9	*
104	6-5-26	*	*	*	*	*	*	*
105	6-5-26	*	17.82	73.40	8.78	1.24	9	*
106	7-5-26	*	18.61	74.10	7.29	0.82	9	*
107	7-5-26	*	19.16	72.31	8.53	0.93	9	*
108	7-5-26	*	*	*	*	*	*	*
109	7-5-26	*	17.41	75.68	6.91	0.76	9	*
110	7-5-26	*	18.61	71.55	9.84	0.76	9	*
111	7-5-26	*	17.51	77.11	5.38	0.68	9	*
112	7-5-26	*	18.87	73.50	7.73	1.11	9	*
113	7-5-26	*	19.08	72.84	8.08	1.23	9	*
114	7-5-26	*	18.66	68.77	11.57	1.76	9	*
115	7-5-26	*	18.67	74.96	6.37	1.19	9	*
116	7-5-26	*	18.86	72.89	8.25	0.69	9	*

Hole No.	Location Sec-T(N)-R(E)	Moisture	Proximate Analyses (%) Volatile Matter	Fixed Carbon	Ash	Sulfur(%)	FSI	Btu
117	7-5-26	*	18.73	74.31	6.78	0.64	9	*
118	7-5-26	*	18.69	74.69	6.62	0.73	9	*
119	8-5-26	*	*	*	*	*	*	*
120	24-5-26	*	*	*	23.18	1.25	8	*
121	24-5-26	*	20.40	62.77	16.83	0.88	8+	*
122	24-5-26	*	*	*	*	*	*	*
123	24-5-26	*	21.60	69.07	9.33	0.66	7½	*
124	25-5-26	*	20.97	63.21	15.82	1.45	8½	*
125	25-5-26	*	16.51	41.31	42.18	1.43	6	*
126	30-5-26	*	*	*	*	*	*	*
127	31-5-26	*	21.10	69.00	9.9	1.02	9+	*
128	31-5-26	*	21.16	64.43	14.41	1.65	9	*
129	31-5-26	*	22.29	68.75	8.96	1.02	9+	14332
130	31-5-26	*	*	*	*	*	*	*
131	31-5-26	*	20.66	73.27	6.07	1.24	9	14836
132	31-5-26	*	19.92	69.34	10.74	1.70	8+	14092
133	31-5-26	*	*	*	*	*	*	*
134	19-5-27	*	22.37	58.16	19.47	1.13	9	*
135	19-5-27	*	21.12	65.49	13.39	0.68	9	*
136	19-5-27	*	20.24	62.05	17.71	1.00	8	*
137	19-5-27	*	21.45	62.71	15.84	1.60	9	*
138	19-5-27	*	21.31	62.89	15.80	1.54	9	*

* Data not available.

APPENDIX 3

COAL RESOURCES

UNIVERSITY OF OKLAHOMA
LIBRARY

ORIGINAL RESOURCES

(in thousands of short tons)

Coal	Coal Depth	12-14 inches acres	12-14 inches tons	15-28 inches acres	15-28 inches tons	29-42 inches acres	29-42 inches tons	42+ inches acres	42+ inches tons	Total acres	Total tons
Lower	0-150	0	0	0	0	2,783	13,039	1,701	15,260	4,484	28,298
Hartshorne	151-1,000	0	0	376	1,421	7,124	46,356	8,202	56,993	15,702	104,770
	1,001-2,000	0	0	251	790	8,010	45,208	15,242	116,991	23,503	162,989
	2,001-3,000	0	0	304	821	1,344	8,467	2,371	21,489	4,019	30,777
	total									47,708	326,834
Upper	0-150	38	82	1,481	6,339	912	4,891	0	0	2,431	11,312
Hartshorne	151-1,000	171	316	9,978	33,274	2,995	14,977	0	0	13,144	48,567
	1,001-2,000	1,207	2,330	9,213	30,308	6,014	28,763	0	0	16,434	61,401
	2,001-3,000	0	0	1,089	3,554	295	1,327	0	0	1,384	4,881
	total									33,393	126,161

MINED + LOST IN MINING
(in thousands of short tons)

Coal	Coal Depth	Surface acres	Surface tons	Underground acres	Underground tons	Total acres	Total tons
Lower	0-150	151	3,706	894	7,048	1,045	10,754
Hartshorne	151-1,000	0	0	421	2,602	421	2,602
	1,001-2,000	0	0	0	0	0	0
	2,001-3,000	0	0	0	0	0	0
	total	151	3,706	1,315	9,650	1,466	13,356
Upper	0-150	0	0	0	0	0	0
Hartshorne	151-1,000	0	0	0	0	0	0
	1,001-2,000	0	0	0	0	0	0
	2,001-3,000	0	0	0	0	0	0
	total					0	0

MEASURED REMAINING RESOURCES
(in thousands of short tons)

Coal	Coal Depth	12-14 inches acres	12-14 inches tons	15-28 inches acres	15-28 inches tons	29-42 inches acres	29-42 inches tons	42+ inches acres	42+ inches tons	Total acres	Total tons
Lower Hartshorne	0-150	0	0	0	0	1,960	9,041	347	2,597	2,307	11,638
	151-1,000	0	0	252	975	2,891	17,068	2,447	14,711	5,590	32,754
	1,001-2,000	0	0	126	340	209	1,151	869	6,477	1,204	7,968
	2,001-3,000	0	0	0	0	0	0	0	0	0	0
	total									9,101	52,360
Upper Hartshorne	0-150	0	0	492	1,611	61	329	0	0	553	1,940
	151-1,000	126	227	2,740	7,889	958	4,708	0	0	3,824	12,824
	1,001-2,000	126	249	438	1,457	220	1,103	0	0	784	2,809
	2,001-3,000	0	0	0	0	0	0	0	0	0	0
	total									5,161	17,573

INDICATED REMAINING RESOURCES

(in thousands of short tons)

Coal	Coal Depth	12-14 inches acres	12-14 inches tons	15-28 inches acres	15-28 inches tons	29-42 inches acres	29-42 inches tons	42+ inches acres	42+ inches tons	Total acres	Total tons
Lower	0-150	0	0	0	0	481	2,302	317	1,346	798	3,648
Hartshorne	151-1,000	0	0	124	446	3,088	17,695	3,131	24,052	6,343	42,193
	1,001-2,000	0	0	125	450	2,551	13,928	4,251	33,710	6,927	48,088
	2,001-3,000	0	0	0	0	0	0	0	0	0	0
	total									14,068	93,929
Upper	0-150	38	82	575	2,115	645	3,483	0	0	1,258	5,680
Hartshorne	151-1,000	45	89	4,811	17,144	1,186	5,714	0	0	6,042	22,947
	1,001-2,000	1,071	2,063	2,362	8,056	2,048	9,216	0	0	5,481	19,335
	2,001-3,000	0	0	0	0	0	0	0	0	0	0
	total									12,781	47,962

INFERRED REMAINING RESOURCES
(in thousands of short tons)

Coal	Coal Depth	12-14 inches acres	12-14 inches tons	15-28 inches acres	15-28 inches tons	29-42 inches acres	29-42 inches tons	42+ inches acres	42+ inches tons	Total acres	Total tons
Lower	0-150	0	0	0	0	130	655	204	1,603	334	2,258
Hartshorne	151-1,000	0	0	0	0	748	9,216	2,600	18,005	3,348	27,221
	1,001-2,000	0	0	0	0	5,250	30,129	10,122	76,804	15,372	106,933
	2,001-3,000	0	0	304	821	1,344	8,467	2,371	21,489	4,019	30,777
	total									23,073	167,189
Upper	0-150	0	0	414	2,613	206	1,079	0	0	620	3,692
Hartshorne	151-1,000	0	0	2,427	8,241	851	4,555	0	0	3,278	12,796
	1,001-2,000	10	18	6,413	20,795	3,746	18,444	0	0	10,169	39,257
	2,001-3,000	0	0	1,089	3,554	295	1,327	0	0	1,384	4,881
	total									14,651	60,626

GRAND TOTAL - REMAINING RESOURCES
(in thousands of short tons)

Coal	Coal Depth	Total acres	Total tons
Lower Hartshorne	0-150	3,439	17,544
	151-1,000	15,281	102,168
	1,001-2,000	23,503	162,989
	2,001-3,000	4,019	30,777
	total	46,242	313,478
Upper Hartshorne	0-150	2,431	11,312
	151-1,000	13,144	48,567
	1,001-2,000	16,434	61,401
	2,001-3,000	1,384	4,881
	total	33,393	126,161
	Grand Total	79,635	439,639

APPENDIX 4

MEASURED SECTIONS

MEASURED SECTION NO. 1

Measured Stratigraphic Section of the west side of the roadcut along U.S. Highway 59, approximately 1½ miles south of Heavener, OK (uppermost 20 feet not included).

measured from	in feet to	thickness	description
Hartshorne Formation:			
175.5	177.5	2.0	Sandstone, gray, weathers buff (top of section).
161.5	175.5	14.0	Shale, interlaminated gray and brown, containing siderite nodules and upright <u>Calamites</u>
152.5	161.5	9.0	Sandstone, gray, fine-grained, containing upright <u>Calamites</u>
145.7	152.5	6.8	Shale, gray, interbedded with cross-bedded sandstone
138.9	145.7	6.8	Shale, gray, thinly laminated, containing siderite nodules
137.7	138.9	1.2	Shale, black, carbonaceous
135.8	137.7	1.9	Coal (Lower Hartshorne)
135.3	135.8	0.5	Underclay, rooted
125.9	135.3	9.4	Shale, gray, fissile, containing siderite nodules and streaks of coal
113.1	125.9	12.8	Sandstone, gray, cross-bedded containing upright <u>Calamites</u>, interbedded with gray shale containing siderite nodules
107.3	113.1	5.8	Shale, gray, containing siderite nodules
105.6	107.3	1.7	Sandstone, gray, fine-grained, containing upright <u>Calamites</u> one of which is 1.8 feet tall. The sandstone is variable in thickness.

101.4	105.6	4.2	Shale, gray, finely laminated with siderite nodules with which contain plant impressions
99.5	101.4	1.9	Sandstone, gray, finely-grained, cross-bedded
97.9	99.5	1.6	Shale, gray, thinly laminated, containing siderite nodules
97.4	97.9	0.5	Sandstone, gray, very fine-grained, cross-bedded
94.9	97.4	2.5	Shale, gray, thinly laminated, containing siderite nodules
89.7	94.9	5.2	Sandstone, gray, very fine-grained, containing upright _Calamites_
84.0	89.7	5.7	Shale, gray finely laminated, with siderite nodules which contain _Calamites_ and numerous leaf impressions
76.5	84.0	7.5	Sandstone, gray, fine-grained containing _Calamites_
Atoka Formation:			
70.8	76.5	5.7	Shale, gray, thinly laminated, containing siderite nodules
67.1	70.8	3.7	Shale, carbonaceous, containing thin coal streaks and siderite nodules
66.6	67.1	0.5	Coal
55.3	66.6	11.3	Shale, black, carbonaceous, with numerous coal streaks
48.8	55.3	6.5	Shale, gray, containing siderite nodules
37.3	48.8	11.5	Shale, gray
37.2	37.3	0.1	Shale, sideritic
36.1	37.2	1.1	Shale, black, carbonaceous, containing thin coal streaks and numerous plant impressions
35.6	36.1	0.5	Coal
34.7	35.6	0.9	Shale, black with coal streaks
33.8	34.7	0.9	Shale, black, containing siderite nodules
31.8	33.8	2.0	Shale, gray, containing siderite nodules
0	31.8	31.8	Shale, gray, thinly laminated, with interbedded sideritic shale (base of section)

MEASURED SECTION NO. 2

Measured Stratigraphic Section in the Petros railroad cut, in the NW¼ sec.31, T.5 N., R.26 E. (from Hendricks, 1939, p. 267).

measured from	in feet to	thickness	description
Hartshorne Formation:			
323.1	327.1	4.0	Sandstone, buff and platy, with shale partings (top of Hartshorne sandstone)
238.1	323.1	85.0	Shale, chocolate-colored and clayey at base, grading upward to buff and white, sandy, and limonitic
232.6	238.1	5.5	Sandstone, thin-bedded, with shale partings
231.0	232.6	1.6	Shale, buff and sandy
230.8	231.0	0.2	Sandstone, massive, coarse-grained, ashy white
146.8	230.8	84.0	Shale, fissile, black carbonaceous, with sandy streaks
142.7	146.8	4.1	Coal (Lower Hartshorne)
139.7	142.7	3.0	Shale, clayey and ferruginous
130.2	139.7	9.5	Shale, carbonaceous, with coaly streaks
128.9	130.2	1.3	Underclay, sandy, mixed with carbonaceous and ferruginous shale
124.9	128.9	4.0	Sandstone, buff and massive
62.4	124.9	62.5	Shale, sandy and buff
40.4	62.4	22.0	Sandstone, white; weathers buff; thin-bedded in upper part and and irregularly bedded in lower part
(Atoka Formation:)[1]			
35.2	40.4	5.2	Shale, thinly laminated, sandy, dark; weathers into concentric spheroids 2 to 5 inches thick; contains plant stems
29.2	35.2	6.0	Shale, chocolate brown; weathers lighter-colored; numerous clay ironstone partings
28.3	29.2	0.9	Shale, black and fissile

[1] Formational contact designated by present writer.

28.0	28.3	0.3	Coal
17.0	28.0	11.0	Shale, dark and carbonaceous, with some sandy shaly coal
2.5	17.0	14.5	Shale, clayey, brownish; contains numerous concretions and partings of clay ironstone
2.0	2.5	0.5	Coal
1.5	2.0	0.5	Underclay
0	1.5	1.5	Sandstone, shaly, grading downward into shale