GEOLOGY OF THE HARTSHORNE COAL, McCURTAIN AND LAFAYETTE QUADRANGLES, HASKELL AND LEFLORE COUNTIES, OKLAHOMA

By

LEE EDWARD CATALANO

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Thesis Approved:

Cary T. Stewart
Thesis Adviser

Samuel A. Friedman

Douglas C. Kent

Norman N. Durham
Dean of the Graduate College

PREFACE

This thesis is a study of the geology of the Hartshorne coal of the McCurtain and Lafayette Quadrangles, Haskell and LeFlore Counties, Oklahoma. Structural-contour, coal-thickness, coal-quality and overburden maps were prepared to aid in the description of the geology of the coal and in estimation of coal resources.

I would like to thank Drs. John Trammell and Gary Stewart for suggesting the problem. Special thanks are extended to Dr. Gary Stewart, thesis adviser, for his enthusiastic support, in addition to assistance in field work and manuscript editing. Appreciation is expressed to Prof. Samuel A. Friedman, Oklahoma Geological Survey, for his helpful suggestions, comments and criticisms of this study. I also thank the Oklahoma Geological Survey for partial funding of the field work and for much data. Thanks are also extended to Mr. Jim Beam, mine operator, and Mr. Ken Nix, supervisor, Great National Corporation, McCurtain strip-mine, for helpful coal-test data and other information. I am also grateful to my fellow graduate students for their help and support, especially Charles E. Williams.

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ABSTRACT

The Desmoinesian Krebs Group contains the oldest commercially productive coal measures in Oklahoma. The Krebs consists mostly of silty to sandy shale that includes minor but geologically important strata of sandstone. Limestone beds are conspicuously absent for the most part. The Hartshorne Formation, which contains the Hartshorne coal beds, is the basal unit of the Krebs Group. The overlying McAlester Formation crops out throughout most of the study area.

An extensive, basin-wide progradation is recorded by the Tobucksy Sandstone Member, the basal unit of the Hartshorne Formation. The ensuing development of swamps and marshes upon the deltaic plain is represented by the Lower and Upper Hartshorne coal beds. A thin shale bed separates the coals throughout most of the study area. The thinness of this parting, relative to other portions of the Arkoma Basin where the split thickness reaches 180 ft., may indicate a more stable portion of the former peat swamp.

Rocks within the study interval have undergone moderate folding and show evidence of normal and reverse faulting. The Hartshorne coal is present throughout the area of study, except where eroded from the crests of anticlines or upthrown fault-blocks. Thickness of overburden is primarily a function of structural geology.

On the average, the medium-volatile bituminous Hartshorne coal contains between 1 and 3 percent sulfur, and therefore is best suited

for use in manufacture of coke. Remaining coal resources are 354,000,000 short tons with 6,700,000 short tons being in the strippable recoverable-reserves category (0-150 ft. of overburden); 172,800,000 short tons are classed as nonstrippable recoverable-reserves (151-1000 ft. of overburden).

INTRODUCTION

Location and General Stratigraphy of the Study Area

The area of study covers approximately 120 sq. mi. in east-central Oklahoma, primarily within T. 8 N. and T. 9 N., R. 21 E., R. 22 E. and part of R. 23 E., eastern Haskell County, and T. 8 N., R. 23 E., in the northwestern part of LeFlore County (Fig. 1).

Rock units cropping out in the study area are included within the Krebs Group, Desmoinesian Series, Pennsylvanian System (Fig. 2). Atokan rock is exposed as a small inlier in the southeastern part of the study area. In descending order, rock units are (1) the Savanna Formation; (2) the McAlester Formation, including the Keota Sandstone Member, the Tamaha Sandstone Member, the Cameron Sandstone Member, the Lequire Sandstone Member, the Warner Sandstone Member and the McCurtain Shale Member (unnamed shale members are between sandstone units); (3) the Hartshorne Formation, containing the Hartshorne coal beds and the Tobucksy Sandstone Member; and (4) the Atoka Formation. Figure 2 illustrates the stratigraphic position of these formations within the Arkoma Basin.

Statement of the Problem

The objective of this study is to determine the structural geology of the Hartshorne coal, its distribution, depth, thickness,

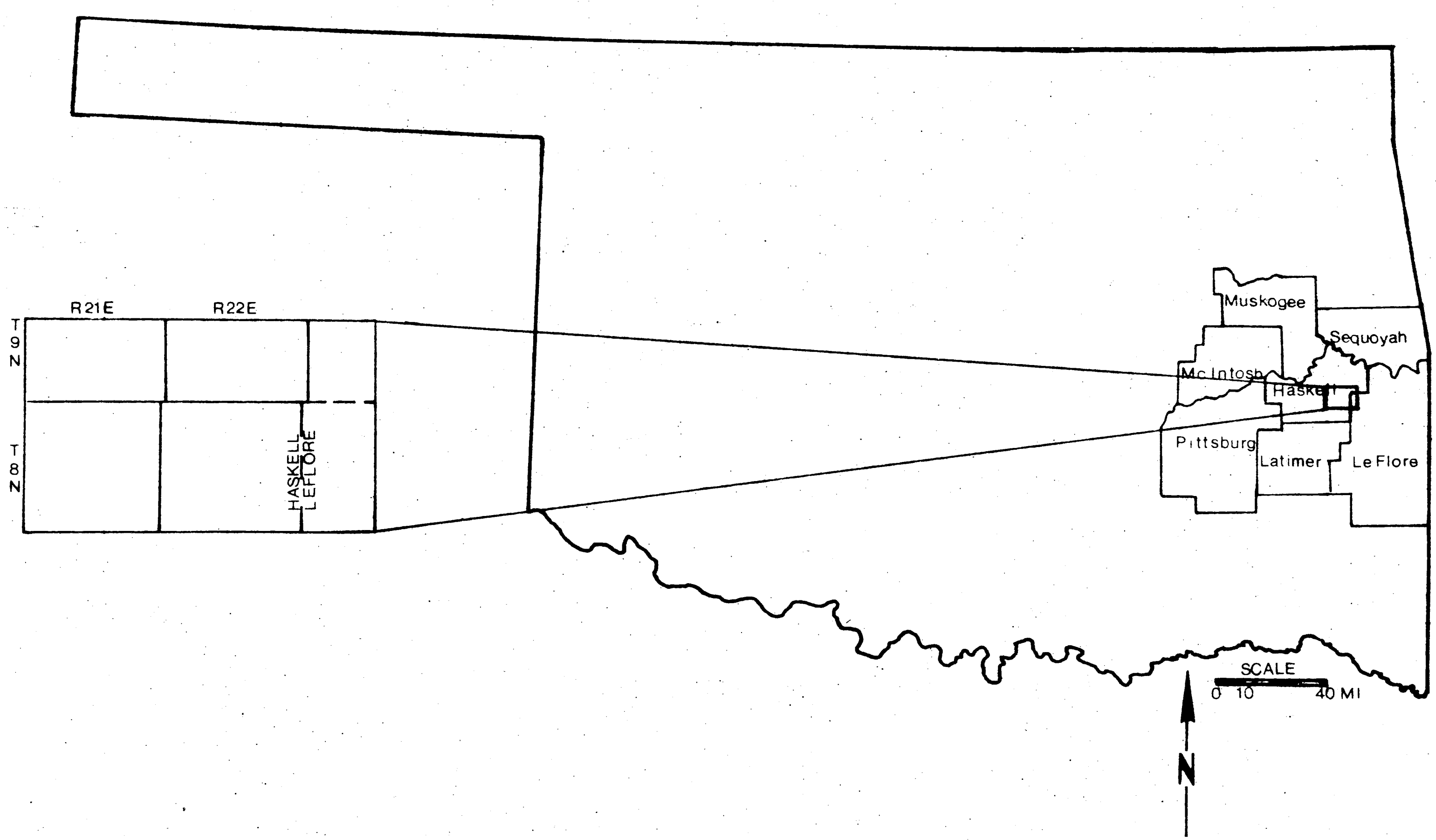


Fig. 1.--Location map of study area.

SYSTEM	SERIES	GROUP	FORMATION	MEMBER	BED
PENNSYLVANIAN	DESMOINESIAN	CABANISS	SENORA		
			STUART		
			THURMAN		
		KREBS	BOGGY	BLUEJACKET SS.	
			SAVANNA		
			McALESTER	WARNER SS.	STIGLER coal
			HARTSHORNE	TOBUCKSY SS.	UPPER HS. coal LOWER HS. coal
	ATOKAN		ATOKA		

Fig. 2.--Generalized columnar section, Arkoma Basin, Oklahoma.

quality, resources, and reserves in the Lafayette and McCurtain quadrangles, Haskell and LeFlore Counties, Oklahoma.

Methods and Procedures

A 7.5-minute geologic map (Pl. 1) of Lafayette and McCurtain quadrangles was made chiefly by enlarging previously published maps of Haskell and LeFlore Counties (Oakes and Knechtel, 1948; Knechtel, 1949). A geologic cross-section, with drillhole and coal-test control data, was constructed from this map. A structural contour map, a net-coal thickness map, an overburden map, and a coal-parting thickness map (Pls. 3, 4, 5, and 6, respectively) were based on data from coal-test borings, drillhole logs and completion tickets. Coal analyses provided by the Oklahoma Geological Survey were the basis for coal-quality maps (Pls. 7, 8, 9). Measured, indicated, and inferred coal reserves were estimated from data shown in Plates 4 and 5. Field work supplemented and confirmed structural and stratigraphic interpretations.

Previous Investigations

Early investigations of coal resources in the Oklahoma-Arkansas coal basin were by Chance (1890), Drake (1897), and Taff and Adams (1900). Mineral resources and geology of Haskell County were reported by Oakes and Knechtel (1948). The geology, coal and natural resources of northern LeFlore County were described by Knechtel (1949). Data on coal resources of Oklahoma was summarized by Trumbull (1957) and Friedman (1974). Palynology of the Hartshorne coal was described by Wilson (1970). An account of the Stigler coal and associated strata of Haskell and LeFlore Counties was given by Karvelot (1972).

The earliest stratigraphic study of the Oklahoma-Arkansas coal basin was made by Hendricks, Dane and Knechtel (1936). Thickening of the Krebs and Cabaniss Groups from the Northeast Oklahoma Platform into the Arkoma Basin was illustrated by Oakes (1953). The Hartshorne Formation in Oklahoma was redefined by Branson (1956). Stratigraphy of the Hartshorne at the surface was described by McDaniel (1961), who also studied directional sedimentary structures in sandstone in the lower part of the Hartshorne (McDaniel, 1968).

Several papers and reports have been written about history and structure of the Arkoma Basin, including Branson (1961, 1962), Diggs (1961), the Arkoma Basin Study Group (1961), Goldstein and Hendricks (1962), Yeakel (1973), and Frezon and Dixon (1975).

STRATIGRAPHY

Pennsylvanian System

Pennsylvanian rock units of the Arkoma Basin make up a thick sequence of shale and siltstone with small amounts of sandstone, which occurs either as persistent complexes or as lenses. Limestones are conspicuously absent or minor in amount. Units within the study area are included within the Atokan and Desmoinesian Series of Lower and Middle Pennsylvanian age (Fig. 2). Coal beds are numerous in rocks of the Desmoinesian Series, and, of course, they record the existence of widespread peat-forming environments. Most rocks cropping out at the surface in the study area are of the Krebs Group.

In the thesis area, silty shale and sandstone of the Upper Atoka Formation of the Atokan Series are exposed only on the Milton Anticline, primarily in secs. 16, 17, T. 8 N., R. 23 E. (Pl. 1).

The Krebs is the lowest group of the Desmoinesian Series in the Arkoma Basin. It lies conformably upon the Atoka Formation and is overlain unconformably by the Cabaniss Group (Oakes, 1953, p. 1524). In ascending order, formations included in the Krebs are the Hartshorne, McAlester, Savanna and Boggy. The Boggy is not exposed in the study area, and the Savanna is present only in the southeastern part (Pl. 1).

Hartshorne Formation

The Hartshorne Formation conformably overlies the Atoka Formation

(Oakes and Knechtel, 1948, p. 25) and underlies the McAlester Formation. The Upper and Lower Hartshorne coal beds, which merge within the study area, are contained in the Hartshorne Formation.

Boundaries of the Hartshorne have been interpreted in several fashions in the last 90 years (Fig. 3). Taff (1899, p. 436) defined the Hartshorne Formation from sandstone exposures near the town of Hartshorne, in Pittsburg County (Fig. 1). The Lower Hartshorne coal bed lies above this 200-ft.-thick sandstone, separated from it by a thin shale.

Taff and Adams (1900, p. 274), working in the eastern part of the basin, placed the upper boundary of the Hartshorne at the top of a persistent sandstone bed between the Lower Hartshorne coal and the Upper Hartshorne coal. They defined the Upper Hartshorne coal as being within the overlying McAlester Formation. The base of a thin shale unit underlying the Upper Hartshorne coal marked the boundary between the McAlester and the Hartshorne Formation.

Oakes and Knechtel (1948, p. 24), working in Haskell and northern LeFlore Counties (Fig. 1), where the upper and lower coals converge, redefined the upper boundary of the Hartshorne Formation, placing it at the top of the Upper Hartshorne coal bed.

Branson (1956, p. 96) defined the Hartshorne Formation to extend from the base of the sandstone unit overlying the Atoka Formation, to the top of the Upper Hartshorne coal bed. The lowermost sandstone, which according to Branson (1956, p. 96) can be traced throughout the basin, marks the base of the Desmoinesian Series; it was designated the Tobucksy Sandstone Member, a term first used by Chance (1890, p. 658).

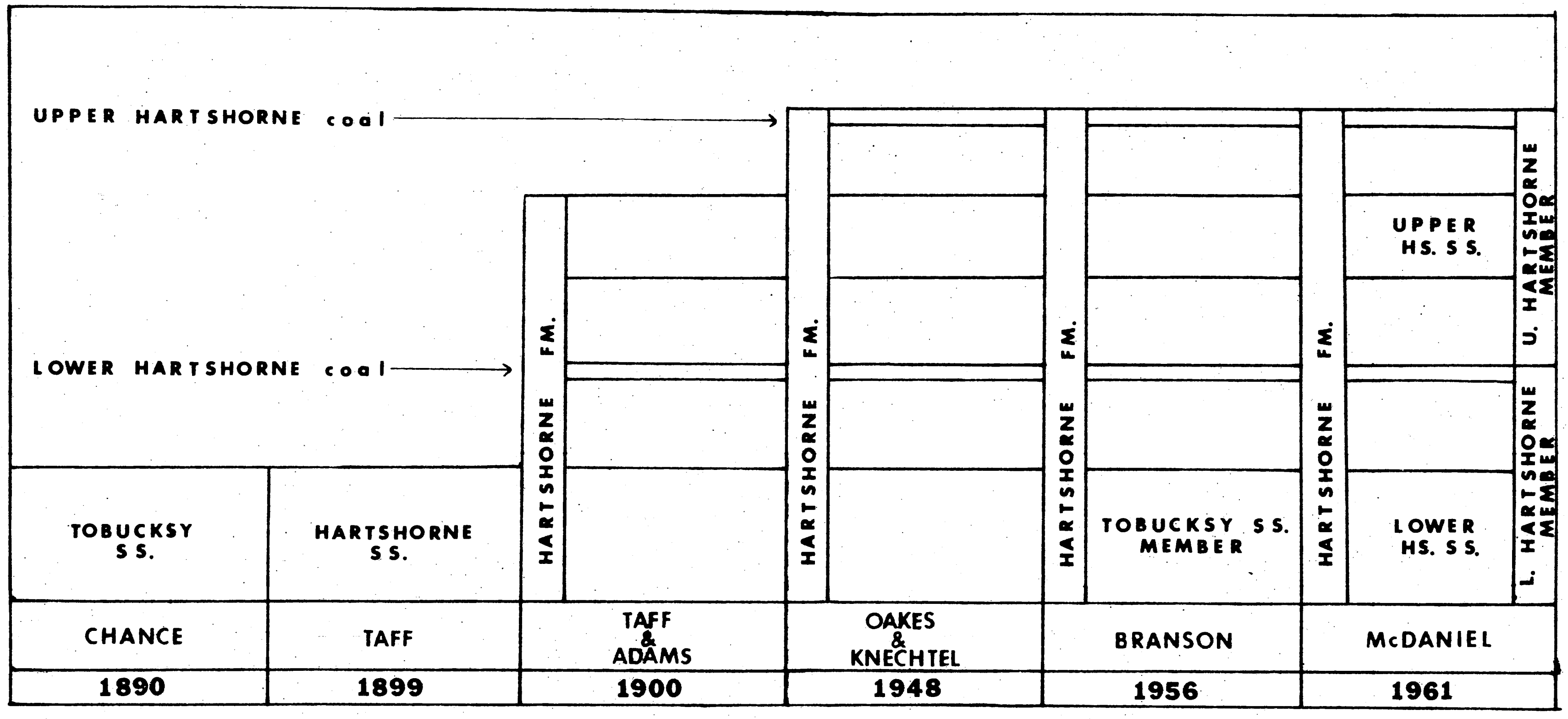


Fig. 3.--Usage of term "Hartshorne," 1890-1961 (from McDaniel, 1961, p. 68).

McDaniel (1961, p. 68; Fig. 3, this report), in trying to simplify terms as much as possible, divided the Hartshorne Formation into the Lower Hartshorne Member and Upper Hartshorne Member. The top of the Lower Hartshorne coal marked the boundary between the two members. The top of the upper coal defined the base of the McAlester Formation.

In the study area, the Hartshorne Formation (Fig. 4) includes only one member, the Tobucksy Sandstone Member at the base; it also includes an unnamed silty shale unit, and the upper and lower coal beds.

Oakes and Knechtel (1948, p. 25) estimated maximal thickness of the Hartshorne Formation to be 100 ft., in Haskell County. There the Tobucksy Member is a ripple-bedded sanstone and siltstone sequence, forming a prominent ridge on the flanks of the Milton Anticline. The Tobucksy is overlain by silty shale.

Total thickness of the combined Lower and Upper coal beds in the McCurtain strip mine (NE ¼, sec. 22, T. 8 N., R. 22 E.) is approximately 7 ft. with about 0.1 ft. of middleband (shale parting). This coal split increases to as much as 180 ft. of sandstone and shale in other parts of the Arkoma Basin (Trumbull, 1957, p. 345). The only outcrops of the Hartshorne Formation within the study area, other than in the mine, are on the upthrown sides of faults cutting the Pruitt Valley and the Milton Anticlines (Pl. 1).

The Upper Hartshorne coal has been correlated with the Riverton coal of the Northeast Oklahoma Platform, and of Kansas and Missouri (Branson, 1961, p. 457).

McAlester Formation

The McAlester Formation overlies the Hartshorne Formation and

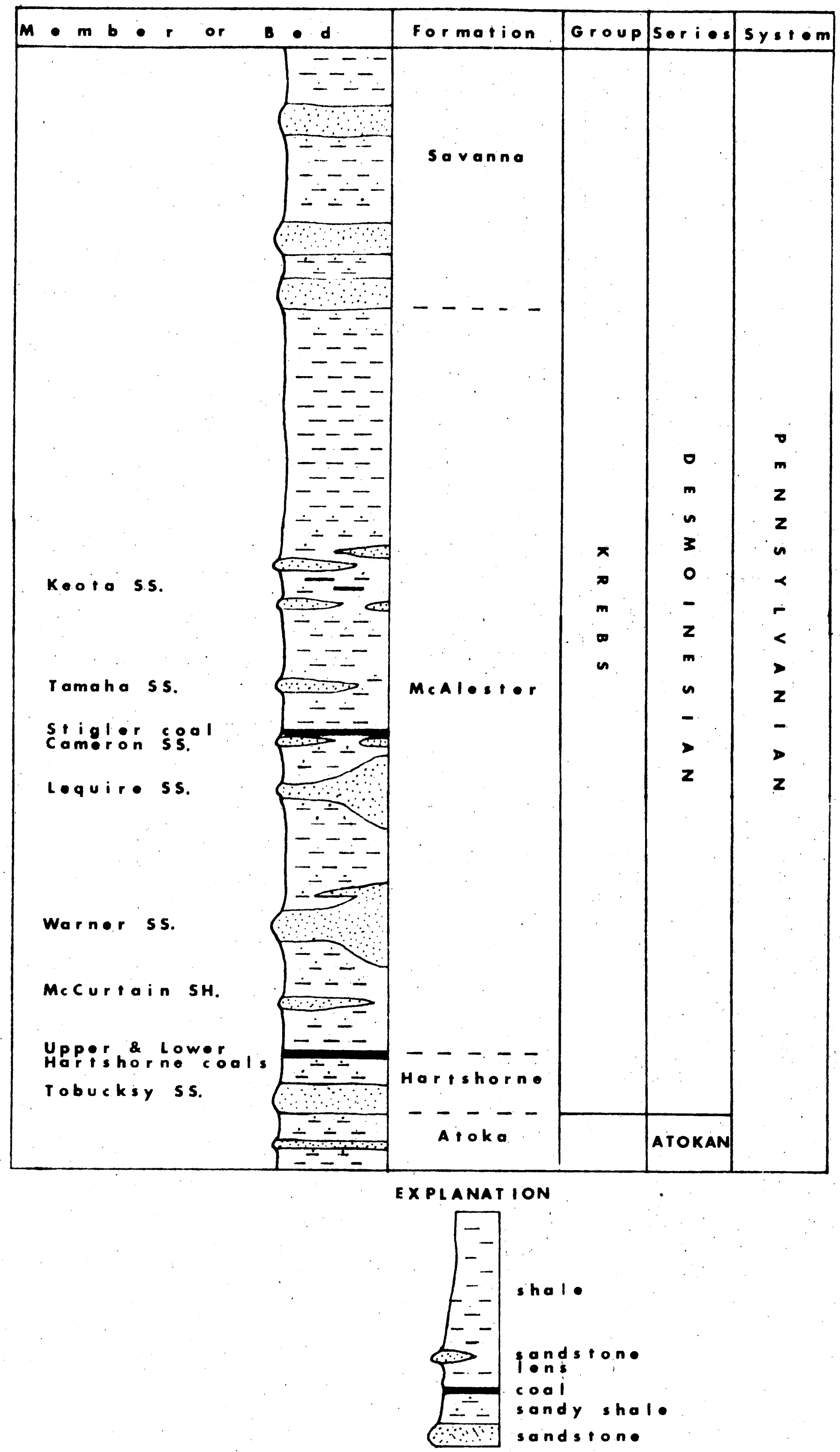


Fig. 4.--Generalized stratigraphic section within the study area.

underlies the Savanna Formation (Fig. 4), with both contacts being conformable within the study area (Oakes and Knechtel, 1948, p. 30). The contact between the McAlester and the overlying Savanna is placed at the top of the shale unit overlying the Keota Sandstone Member (Fig. 4). The McAlester is characterized by silty shale interbedded with sandstone. Several coal beds are within this formation (Pl. 2), including the Stigler coal, which is economically important at some localities. In ascending order, members of the McAlester are the McCurtain Shale Member, the Warner Sandstone Member, the Lequire Sandstone Member, the Cameron Sandstone Member, the Tamaha Sandstone Member and the Keota Sandstone Member (Fig. 4).

McCurtain Shale Member. A major outcrop of the McCurtain Shale Member is in a large arcuate belt on the flanks of the Milton Anticline across the southern portion of the study area (Pl. 1). Two other moderately large outcrops are inliers within the Pruitt Valley and Shropshire Valley Anticlines in the northwestern part of the area (Pl. 1). A coal-test boring drilled in sec. 36, T. 8 N., R. 21 E., showed more than 700 ft. of McCurtain shale. The McCurtain thins northward to about 400 ft. in sec. 30, T. 9 N., R. 22 E.

A sandstone bed within the McCurtain Shale Member as thick as 20 ft. is present in parts of the study area. Borehole records show this unit to be soft, gray to brown sandstone. A coal ranging from 0.2 to 1 ft. thick, is recorded next above this sandstone bed throughout the central portion of the study area. This is probably the sandstone within the McCurtain that was mapped by Oakes and Knechtel (1948) and Knechtel (1949); it crops out on the flanks of the Milton, the Pruitt Valley and the Shropshire Valley Anticlines (Pl. 1).

Another coal bed, approximately 50 ft. below the base of the overlying Warner Sandstone Member, is logged in several borings.

Warner Sandstone Member. The Warner Member crops out on the noses and flanks of the Milton, Pruitt Valley and Shropshire Valley Anticlines (Pl. 1), where it forms prominent ridges. Thickness of the Warner varies from 22 ft. in sec. 28, T. 8 N., R. 21 E., to 220 ft., as determined from the log of the Pan American Petroleum Corporation White No. C-1 Unit in the NW ¼, sec. 34, T. 8 N., R. 22 E.

Oakes and Knechtel (1948) described the Warner as an irregularly bedded sequence of slabby sandstone, siltstone and shale. Drillers' descriptions vary from medium to very hard, gray to brown to black sandstone.

A thin coal is near the top of the Warner in several of the exploratory boreholes logged; probably it is the coal mentioned by Oakes and Knechtel (1948, p. 34).

Unnamed Shale Member. The unnamed shale member between the Warner and the Lequire Sandstone Members is present throughout most of the area; however, east of Stigler (Pl. 1), the Warner and the Lequire merge (Oakes and Knechtel, 1948, p. 36). The log of the Pan American C-1 White, sec. 34, T. 8 N., R. 22 E., shows approximately 75 ft. of shale between the Warner and the Lequire. This shale generally is described by drillers as being black and sandy.

Lequire Sandstone Member. The Lequire Sandstone Member is the next highest unit of the McAlester Formation (Fig. 4). It forms prominent escarpments in the study area, where it crops out on the north and south flanks of the Milton Anticline and the south flank of the Shropshire Valley Anticline (Pl. 1). As is true of most sandstones of the McAlester, the Lequire is an interbedded sequence of thin-bedded, fine-grained sandstone and silty shale. Thicknesses determined from coal test-boring logs show a range of 20 to 95 ft.

The Lequire Member and the Warner Sandstone Member are represented by one sandstone unit in secs. 13 and 24, T. 9 N., R. 21 E. Whether this unit is the Warner, the Lequire or the two in contact is not known; Oakes and Knechtel (1948, Pl. 1) mapped it as the Warner-Lequire Sandstone Member.

The log of a coal-test boring in sec. 10, T. 8 N., R. 21 E. shows that the Stigler coal lies upon the Lequire Member; however, another test-boring in sec. 28, T. 8 N., R. 21 E., shows 60 ft. of black sandy shale separating the Lequire and the Stigler coal.

Units Between the Lequire and Keota Sandstone Members. Units between the Lequire and Keota Sandstone Members are highly variable in thickness as well as lateral extent. The Stigler coal is the only unit traceable throughout the study area, and it varies from 0.3 to 2.0 ft. thick. Strata above the Lequire (Fig. 4) are an unnamed shale member, the Cameron Sandstone Member, the Stigler coal, an unnamed shale member, the Tamaha Sandstone Member and an unnamed shale member.

Where the Stigler coal overlies the Lequire Member, the unnamed shale and the Cameron are not present, of course. Elsewhere, the Cameron is soft, silty sandstone or hard, sandy shale that contains lenses of sandstone as thick as 50 ft.

An unnamed shale member, varying from about 50 to about 200 ft. thick, overlies the Stigler coal (Fig. 4). A thin coal, called the "rider vein" by local miners (Oakes and Knechtel, 1948, p. 41), is approximately 30 to 50 ft. above the Stigler coal bed.

At some places, the Tamaha Sandstone Member lies between the Stigler coal and the Keota Sandstone Member (Fig. 4) and overlies an unnamed shale. Apparently the Tamaha is not a single bed, but is a complex of sandstone lenses (Oakes and Knechtel, 1948, p. 43). It crops out as a cuesta around the Cowlington Syncline (Pl. 1). A maximal thickness of 30 ft. is shown by a test-boring log in sec. 22, T. 8 N., R. 21 E. The Tamaha does not crop out in the southern portion of the study area. Gas-well logs of the Pan American Petroleum Corporation No. C-1 White Unit and Williams No. 1 Unit in secs. 34 and 36, T. 8 N., R. 22 E., show sandstone in the stratigraphic position of the Tamaha. Therefore, I conclude that this probably is the Tamaha, and that it pinches out in the shallow subsurface (see geologic cross-section, Pl. 1).

An unnamed shale member above the Tamaha Sandstone Member is believed to be overlain conformably by the Keota Sandstone Member (Oakes and Knechtel, 1948, p. 42). A thin coal locally is within this interval.

Keota Sandstone and Unnamed Shale Members. The Keota Sandstone Member crops out within the Cowlington Syncline (Pl. 1) as a series of small resistant knobs and ridges. This member is a persistent complex of sandstone lenses interbedded with sandy shale and includes one or more laterally discontinuous coals (Oakes and Knechtel, 1948, p. 43). The Keota is overlain by an unnamed shale. Lack of log data limits discussion on thickness and extent of this shale.

Savanna Formation

The contact between the unnamed shale above the Keota and the overlying Savanna Formation apparently is conformable within the study area (Oakes and Knechtel, 1948, p. 44). The Savanna is a thick section of shale and siltstone with several beds of sandstone. The sandstones are expressed as ridges in the southeasternmost portion of the study area (Pl. 1).

Quaternary System

Quaternary terrace deposits of alluvial sand, silt and clay were mapped by Oakes and Knechtel (1948, Pl. 1) in an area east and southwest of Stigler, in the northwestern part of the present study area. Another terrace deposit was mapped in sec. 32, T. 8 N., R. 21 E.

Stream valleys in all parts of the study area contain Recent silty and sandy alluvium, nowhere more than 100 ft. thick (Oakes and Knechtel, 1948, p. 63).

Depositional Environments

Rocks cropping out within the study area primarily are of shallow-water marine facies (Oakes and Knechtel, 1948, p. 14). They consist of shale, mostly silty or sandy, with a small but conspicuous amount of sandstone. Numerous coal beds within the section mark episodes of emergence, during which peat swamps formed. Deltaic systems were recognized within the Hartshorne and the McAlester Formations (McDaniel, 1968; Yeakel, 1973; Busch, 1953).

Atoka Formation

According to Blythe (1959, p. 25), the Atoka Formation on the north side of the Arkoma Basin was deposited in very shallow marine waters, probably shallower than water that covered the shelf area to the north. In the portion of the Arkoma Basin in Arkansas, the upper part of the Atoka Formation consists of alternating marine shales, channel-fill sandstones and thin, lenticular coal beds (Merewether, 1961, p. 85). Merewether (1961, p. 87) suggested an oscillating, near-shore to shoreline environment of deposition for the Atoka Formation in this area. Thin coals are also known in the upper part of the Atoka Formation in eastern Oklahoma (Friedman, 1978, p. 52). Briggs and Roeder (1975, p. 93) suggested a lower-deltaic-plain environment for these coals.

Branson (1961, p. 77) considered eroded Morrowan rocks of the Ouachita Uplift to be the primary source of Atokan sediments. However, results of a paleocurrent study conducted by Briggs and Cline (1967, p. 998) showed a southward transport direction of material in the Atoka Formation, and that the Ozark Uplift supplied some of the clastics.

Hartshorne Formation

Between the primarily marine Atoka Formation, and the Hartshorne coal lies the Tobucksy Sandstone Member and an unnamed shale, which were deposited during transition from marine to subaerial environments within the Arkoma Basin.

Yeakel (1973) divided the Tobucksy Member into four genetic types within the Arkoma Basin: (1) "low-energy" deltaic marine fringe, (2) "high-energy" deltaic marine fringe, (3) distributary channel sandstone and (4) fluvial-deltaic channel sandstone. Within the study area the Tobucksy Member is a section of ripple-bedded sandstone beds with interbedded silty shales. Ripple marks observed are linguoid and asymmetrical types. Rounded pebbles of red shale commonly are near bases of ripple-bedded, laterally continuous sandstone beds. Yeakel (1973, p. 15) considered the Tobucksy Member, within the thesis area, to have been deposited in a "low-energy" delta-fringe environment, and he proposed an eastern source of the sands.

McDaniel (1968, p. 1697) hypothesized that the Hartshorne Formation represented a westward-advancing deltaic system, aligned roughly northeastward between the Ozark and Ouachita Uplifts.

According to Yeakel (1973, p. 20), with progradation westward a deltaic plain was created, upon which widespread swamps and marshes formed. The Lower Hartshorne coal bed records this period of swamp development. Regional stability could not be maintained upon the deltaic plain everywhere within the basin, and submergence lead to burial by clastic sediments (Yeakel, 1973, p. 20). The Upper Hartshorne Sandstone Member (not present in the study area) and associated shales are evidence of this clastic deposition. A return to emergent conditions lead to another period of accumulation of peat, as shown by the Upper Hartshorne coal bed (Yeakel, 1973, p. 21).

Thinness of the shale parting between the Upper and Lower Hartshorne coals in the study area seems to indicate an area of relative stability within the peat swamp, in contrast to other parts of the Arkoma Basin, where the split is as thick as 180 ft. (Trumbull, 1957, p. 345).

An exposure in the McCurtain strip-mine, Karsh pit (NE ¼, sec. 22, T. 8 N., R. 22 E.; Pl. 1) allowed observation of the underclay of the Hartshorne coal. Flaser-bedded siltstone is overlain by laminated silty shale that contains abundant clay ironstones and rootlet impressions, many of which are near vertical (Fig. 5). Evidence of rootlets that extended into the underlying silty shales strongly indicates an autocthonous origin of the coal. The abundant silt in the rocks immediately underlying the coal may indicate that fluvial water was an important contributor to development and maintenance of the peat swamps (Friedman, personal communication, 1978).

McAlester Formation

Deposition of mud, represented by the gray to black shale of the McAlester Formation, records an end to deltaic sedimentation and a return to totally marine conditions within the Arkoma Basin (Yeakel, 1973, p. 21). Karvelot (1972, p. 32) identified several marine organisms in shales of the McAlester Formation within the study area. Yeakel (1973, p. 21) further suggested that the regional transgression was eustatic.

Busch (1953, p. 74), on the basis of distribution and geometry of the Warner Sandstone Member, the Booch sand of the subsurface (Jordan, 1957, p. 21), recognized the "Booch" deltaic distributary system on the north side of the Arkoma Basin. In the study area, the Warner Member is basinward from where Busch (1953) studied it; it almost certainly is the more distal portion of the "Booch Delta," perhaps what Yeakel (1973, p. 21) refers to as the marine fringe of the delta.

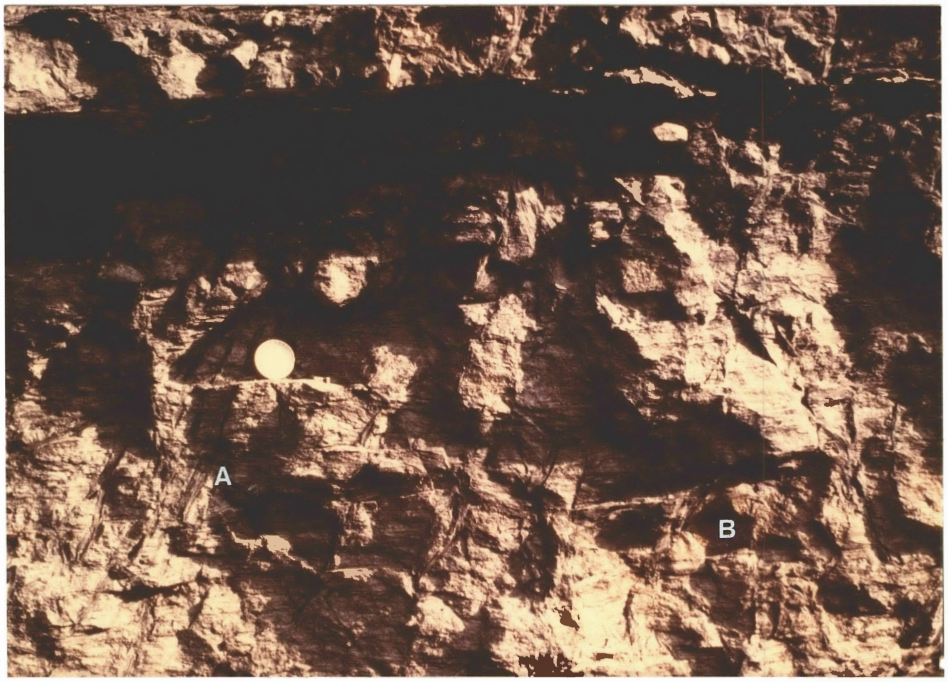


Fig. 5.--Underclay of the Hartshorne coal, containing nearly vertical rootlet impressions (A) and ironstone concretions (B), within a laminated silty shale in Karsh pit, NE ¼, sec. 22, T. 8 N., R. 22 E.

The source of the McAlester Formation, including the Warner Sandstone Member, was to the northeast (Busch, 1953, p. 74), probably within the Ozark Uplift or beyond.

At least four correlative coal beds within the McAlester Formation (see correlation cross-section, Pl. 2) provide evidence of periodic generation of swampy conditions. Of these coals, the Stigler is the most widespread.

Additional evidence supporting periodic subaerial environments during deposition of the McAlester Formation was observed at an outcrop of the Keota Sandstone Member in sec. 23, T. 9 N., R. 22 E. (Pl. 1). Laterally discontinuous sandstone beds at this exposure show evidence of channeling, medium-scale cross-bedding and slight fining upwards. Fragments of fossil wood and rounded clay galls, are both contained near bases of sandstone beds. These rocks probably were deposited in a distributary channel.

STRUCTURAL FRAMEWORK

Regional Structural Geology

The study area is centrally located within the Arkoma Basin, which extends from north-central Arkansas to western Coal County in south-eastern Oklahoma (Branson, 1962). The Arkoma Basin is bounded on the north by the Ozark Uplift and the Northeast Oklahoma Platform, on the south by the Ouachita Mountains, and on the southwest by the Arbuckle Mountains. According to Diggs (1961), the central part of the Arkoma Basin lies within two superimposed tectonic zones. The first zone is a region of normal faults with displacements of 300 to 2500 ft., and of moderate compressional folding, with dips ranging from 3 to 25 degrees. The second zone consists of moderate compressional folds, but there is no evidence of normal faulting. The area dealt with in this report borders a third tectonic zone that is composed of tightly folded, elongated compressional folds that show evidence of reverse faulting. The normal faults can be explained as a product of extensional strain due to relative upward movement of the Ozark Uplift and subsidence of the Arkoma Basin (Diggs, 1961). Northerly stress associated with the Ouachita orogeny produced compressional folding (Goldstein and Hendricks, 1962).

The Arkoma Basin was an actively subsiding foreland basin during Atokan and Desmoinesian time (Branson, 1962). Rock units thicken from the northern shelf area into the basin, where Desmoinesian rocks are as much as ten times as thick as equivalent strata on the shelf (Branson, 1962). The lower Desmoinesian Krebs Group, in which the Hartshorne Formation is included (Fig. 2), thickens from about 1500 ft. on the platform to about 5000 ft. in the basin (Yeakel, 1973) (Fig. 6). Maximal thickness of strata in the Arkoma Basin is more than 20,000 ft., in central Arkansas (Branson, 1961). The primary source of the sediment was deformed strata within the older and uplifted Ouachita geosyncline (Goldstein and Hendricks, 1962).

Local Structural Geology

Local structural configuration is shown by a structural contour map (Pl. 3) constructed on top of the Hartshorne coal; data for the map comprise drillhole logs, completion tickets and coal test-borings. This information is integrated with maps of structural geology of Haskell and northern LeFlore Counties, by Oakes and Knechtel (1948) and Knechtel (1949).

In order from southeast to northwest, major folds in the study area are the Milton Anticline, Cowlington Syncline, Shropshire Valley Anticline and the Pruitt Valley Anticline (Pl. 3). Associated with the anticlines are several large reverse and normal faults which strike subparallel to axes of the folds. Areal geology of the Cowlington Syncline shows no evidence of faulting.

Milton Anticline

The southwesterly plunging Milton Anticline is highly faulted and asymmetrical; the southern limb is the steeper (Pl. 3). In the study area, the axis extends from the southeastern quarter, sec. 9, T. 8 N.,

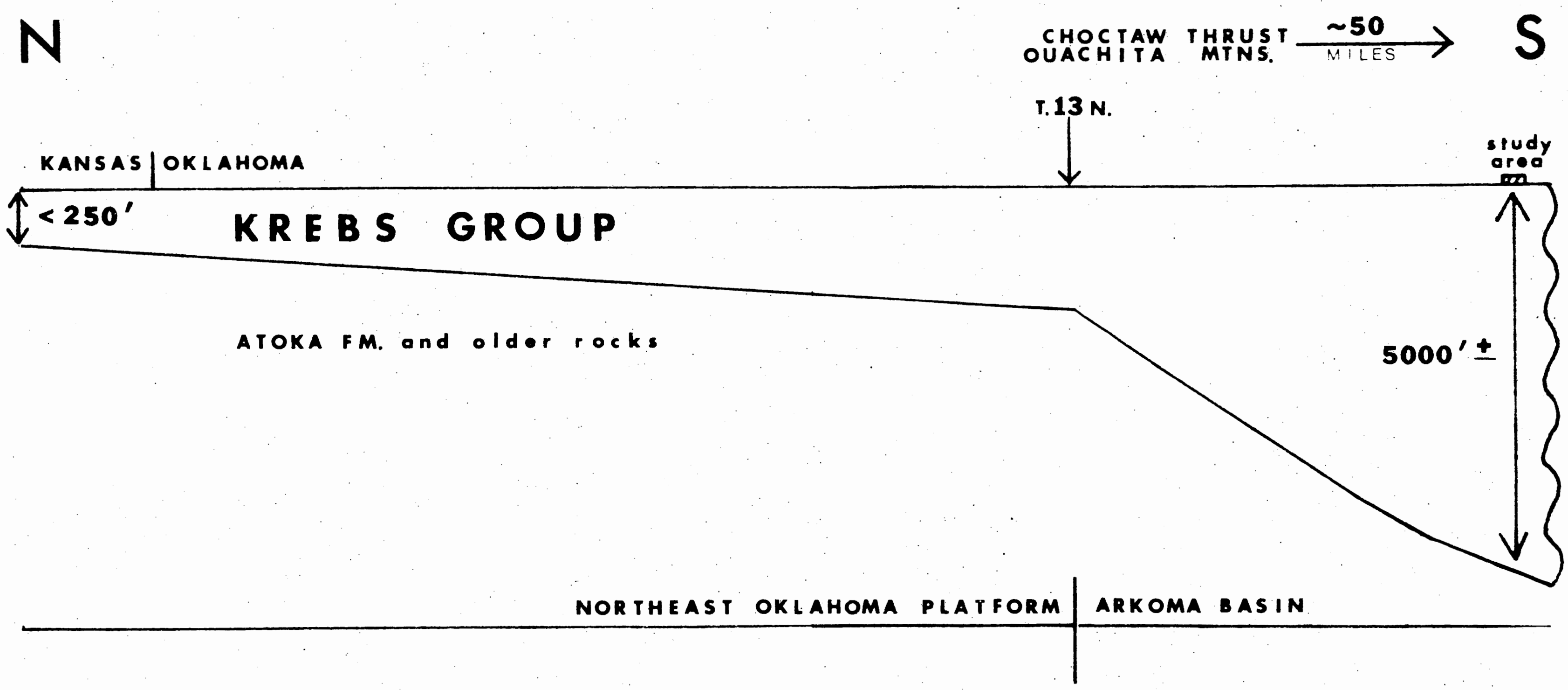


Fig. 6.--Generalized regional cross-section showing thickening of the Krebs Group in the Arkoma Basin (from Yeakel, 1973, p. 8).

R. 23 E., southwesterly (Pl. 3) through a saddle in sec. 29, T. 8 N., R. 22 E. Southward, the axis trends from the study area in sec. 31, T. 8 N., R. 22 E. (Pl. 3).

The Milton Anticline is complicated somewhat by faulting, especially north of McCurtain (Pl. 3). Data from coal-tests and drillhole logs, not available to Oakes and Knechtel (1948) and Knechtel (1949), seem to confirm most of their interpretations.

A normal fault, downthrown to the south (Oakes and Knechtel, 1948, p. 66), is mapped from sec. 32, T. 8 N., R. 21 E., along the northern flank of the anticline; it terminates in the northeastern corner, sec. 25, T. 8 N., R. 21 E. (Pl. 3). Throw is about 300 ft., as estimated from the structural contour map (Pl. 3).

A second large fault, also downthrown to the south, extends along the northern flank of the Milton Anticline, from sec. 35, T. 8 N., R. 21 E., northeastward to the southeastern corner, sec. 14, T. 8 N., R. 22 E., beyond which locality it is not mappable (Pl. 3). Oakes and Knechtel (1948, p. 66) believed this to be a normal fault. Observations of the fault zone in the McCurtain strip-mine, Karsh pit (NE ¼, sec. 22, T. 8 N., R. 22 E.), suggest an alternate hypothesis, namely that a reverse fault is present. Geology of the Karsh pit is complicated by many small faults that are associated with the above-mentioned large fault (Fig. 7). Among these is a small reverse fault on which approximately 20 ft. of throw was recorded in the pit (Fig. 7; see also Fig. 8). Fig. 9 shows the same fault, in an exposure farther to the west within the pit. I consider this explanation to be highly probable: stresses that caused the small fault also produced the large fault; therefore, if the small fault is a reverse fault, so should be the

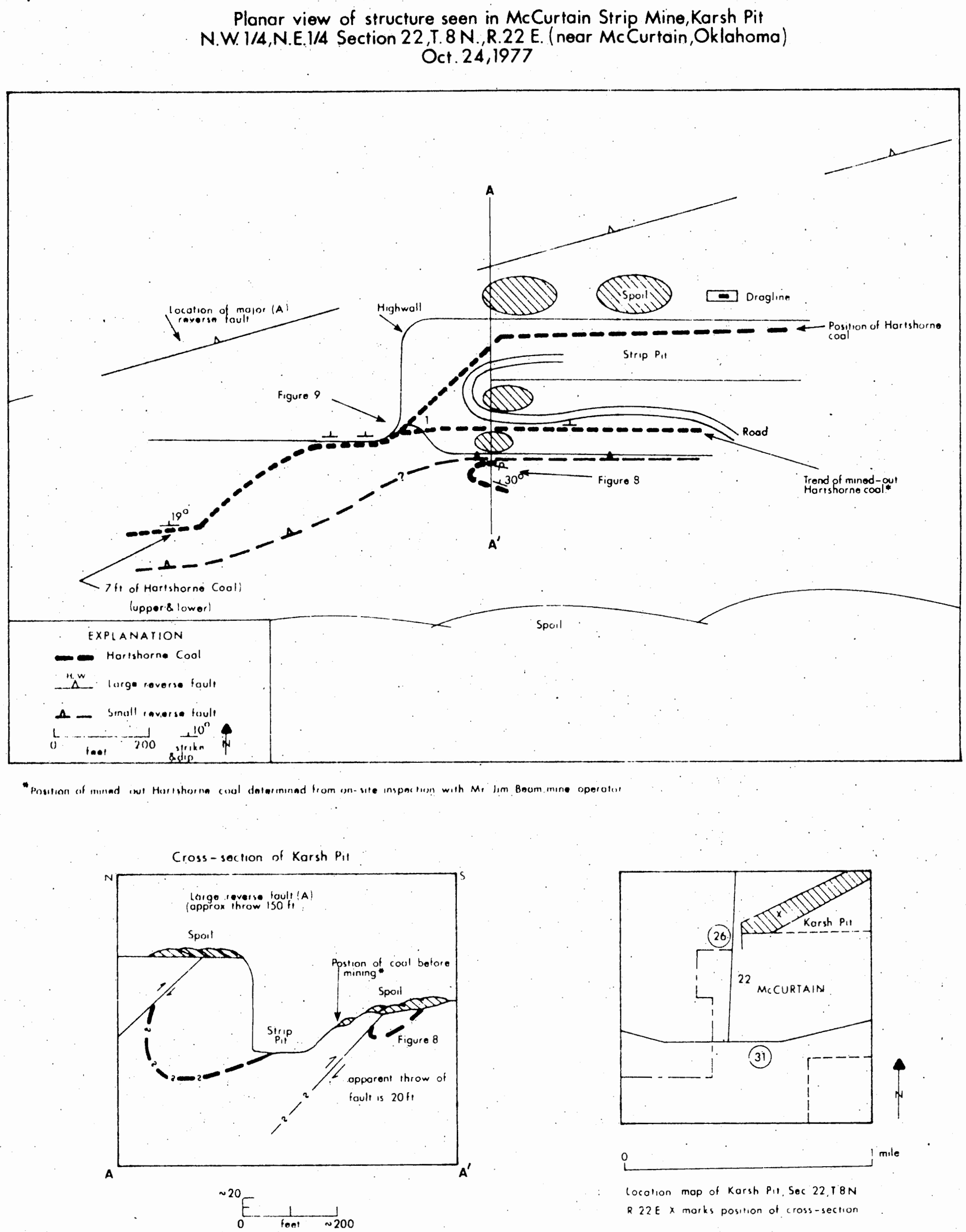


Fig. 7.--Structural interpretation of geology observed in Karsh pit, NE ¼, sec. 22, T. 8 N., R. 22 E. The apparent splitting of the Hartshorne coal at (1), is an illusion due to the method of mining. A large fault (A), believed to be normal by Oakes and Knechtel (1948, p. 66), is interpreted by me to be a reverse fault (see text).

Fig. 8.--Small reverse fault in Karsh pit (NE ¼, sec. 22, T. 8 N., R. 22 E.; north is to the left).

Fig. 9.--Small reverse fault located in Karsh pit (NE ¼, sec. 22, T. 8 N., R. 22 E.). North is to the right.

large fault. The use of information and of dips projected from exposures at the surface (see Pl. 1; geologic cross-section) seem to support this hypothesis. Estimated maximal throw is about 200 ft.

Another normal fault (Oakes and Knechtel, 1948, p. 66; Knechtel, 1949, p. 40), downthrown to the south, and having about 500 ft. of maximal displacement, strikes southwestward from sec. 9, T. 8 N., R. 23 E., to sec. 20, T. 8 N., R. 22 E., beyond where it is not mappable (Pl. 3). A small branch fault, also downthrown to the south, is present in sec. 13, T. 8 N., R. 22 E. Oakes and Knechtel (1948, p. 66) mapped it also as a normal fault.

A fault mapped from the southwestern corner, sec. 13, T. 8 N., R. 22 E., striking eastward and northeastward and extending beyond the study area to the northeastern corner, sec. 16, T. 8 N., R. 23 E. (Pl. 3), was interpreted as a reverse fault by Knechtel (1949, p. 40). This fault is upthrown to the south, with maximal displacement of approximately 150 ft. (Knechtel, 1949, p. 40).

In secs. 28 and 29, T. 8 N., R. 22 E., two faults were interpreted as reverse faults by Oakes and Knechtel (1948, p. 66; see also Pl. 3), both upthrown to the south. If this is true, the resultant structure is a small graben centered in the southern part of sec. 21, the northern one-third of sec. 28 and the northeastern quarter of sec. 29, T. 8 N., R. 22 E. (Pl. 3 and geologic cross-section).

Cowlington Syncline

The nearly symmetrical Cowlington Syncline, with gently dipping limbs, is the largest structure within the study area. The structural axis trends from sec. 14, T. 9 N., R. 22 E., and rises slightly at the southeastern corner, sec. 22, T. 9 N., R. 22 E. (Pl. 3). The thickest stratigraphic record within the syncline is in the northwestern quarter of sec. 12, T. 8 N., R. 21 E. (Pl. 3). Dip on the limbs steepens in T. 9 N., R. 22 E. (Pl. 3).

Shropshire Valley Anticline

The axis of the doubly-plunging Shropshire Valley Anticline strikes from sec. 5, T. 8 N., R. 21 E., northeastward and eastward ending in a dome located in sec. 25, T. 9 N., R. 21 E. (Pl. 3). A fault mapped by Oakes and Knechtel (1948) cuts the anticline from the northeastern quarter of sec. 32, T. 9 N., R. 21 E., following the northwestern limb, to sec. 24, T. 9 N., R. 21 E.; at this locality, a secondary fault branches off (Pl. 3). The branch fault is downthrown to the north, whereas the main fault is downthrown to the south, with maximal throw of approximately 100 ft. Whether these faults are normal or reverse is not determined.

Pruitt Valley Anticline

The axis of the Pruitt Valley Anticline can be mapped from sec. 24, T. 9 N., R. 21 E., westerly and southwesterly through sec. 31, T. 9 N., R. 21 E. (Pl. 3). Two faults that trend along the anticlinal axis converge in the southwestern corner, sec. 22, T. 9 N., R. 21 E. (Pl. 3) (Oakes and Knechtel, 1948). These faults are downthrown to the south and cut off the southern limb of the anticline.

Time of Deformation

Folds and faults in the thesis area trend generally northeastward.

Diggs (1961, p. 62) proposed tensional stress, caused by arching of the Ozark Dome, as a mechanism for normal faulting within the Arkoma Basin, until the time of deposition of the Desmoinesian Boggy Formation. Rocks younger than the Boggy Formation show no evidence of normal faulting that should be attributed to later periods of uplift of the Ozark region (Diggs, 1961). Compression from the Ouchita system, to the south, after deposition of the Krebs Group, probably caused the moderately intense folding and reverse faulting (Frezon and Dixon, 1975, p. 189). Rocks of the Krebs Group show this kind of deformation, while the overlying Cabaniss Group does not (Frezon and Dixon, 1975).

GEOLOGY OF THE HARTSHORNE COAL

Distribution

The Hartshorne coal is present throughout the area of study except where it was eroded from the crest of the Milton Anticline and from the upthrown sides of faults cutting the Pruitt Valley and the Milton Anticlines (Pl. 3). These are the only natural outcrops in the area and are where early mining was concentrated.

Thickness

Where a middle shale bed is present, the Hartshorne coal is composed of two units, called the Upper and Lower Hartshorne coals. The lower unit generally is the thicker (see Appendix B). A map of apparent net coal thickness (total thickness of upper and lower coals) is shown by Pl. 4.

The coal thins northwestward within the study area (Pl. 4). This trend seems to coincide roughly with the absence of a shale parting in the northwest. Minimal net thickness recorded in a coal-test boring is 1.8 ft., located in the southwestern quarter of sec. 32, T. 9 N., R. 21 E. (Pl. 4). Maximal net thickness of 8.3 ft. was recorded in a coal-test boring in the southeastern quarter of sec. 23, T. 8 N., R. 22 E., within a trend of thickening along the south flank of the Milton Anticline (Pl. 4), in the vicinity of McCurtain. Thicknesses of more than 6 ft. are common within this trend. In the McCurtain strip-mine, coal in the Karsh pit (northeastern quarter of sec. 22, T. 8 N., R. 22 E.) also showed net thicknesses exceeding 6 ft., with a maximal thickness of 8 ft. Thickness of coal along the northern flank of the Milton Anticline generally varies between 3.5 and 4.5 ft. Apparent net coal thickness increases to an average of 4.5 ft. within the Cowlington Syncline (Pl. 4).

Depth

Depth to coal is an important factor in determining the strippable reserves of the Hartshorne coal in the study area. Pl. 5 is an overburden map, with depths-to-coal-boundaries of 0, 150 and 1000 ft. In this report, 150 ft. of overburden is assumed to be the maximum for strippable coal resources. This limit is appropriate because the Hartshorne coal is more than 3 ft. thick in most areas and is of good quality (see Friedman, 1974, p. 15). Furthermore, in the McCurtain No. 2 mine, the maximal thickness of overburden was 107 ft. where the coal was approximately 6 ft. thick, and mining was profitable.

In the thesis area, overburden primarily is a function of the structural geology. The greatest depth to the Hartshorne coal in the Cowlington Syncline is where a coal-test boring penetrated 1409 ft. of overburden (SE ¼, sec. 11, T. 8 N., R. 21 E.) (Pl. 5). The minimal depth to the coal along the axis of the syncline is 948 ft., as determined by a coal-test boring in the NW ¼, SW ¼, sec. 29, T. 8 N., R. 21 E. (Pl. 5). Overburden decreases northwestward and southeastward upward along limbs of the syncline.

The Hartshorne coal rises to within the 150-ft. overburden limit on the Milton, Shropshire Valley and Pruitt Valley anticlines (Pl. 5).

Comparison of the overburden map (Pl. 5) and the structural contour map (Pl. 3), shows that the overburden-boundaries trend according to the structural pattern.

Parting Between Upper and Lower Hartshorne Coals

As mentioned previously, a thin shale (middleband) separates the Upper Hartshorne coal from the Lower Hartshorne coal within most of the study area. Pl. 6, a parting thickness map, is based on confidential data from coal-test borings.

In general, the shale parting thickens southeastward. The extreme northern and western portions of the study area show no evidence of the parting (Pl. 6). This suggests a locally stable area of continuous peat accumulation, with no significant influx of clastic sediment.

In a large area that is roughly coincident with the Cowlington Syncline, and that also includes part of the Milton Anticline (secs. 21 and 22, T. 8 N., R. 22 E.), the coal contains a shale parting ranging in thickness from 0.1 to 0.25 ft. (Pl. 6). On the northern limb of the Milton Anticline, north of McCurtain, thickness of the shale parting is between 0.25 and 0.5 ft. (Pl. 6). In general, within the part of the northern limb that is south and east of McCurtain, the shale parting is thicker than 0.5 ft. In contrast to the northern limb, within secs. 21, 22, 23, 28, T. 8 N., R. 22 E., on the southern limb of the Milton Anticline, coal-test borings record shale parting thicknesses of greater than 1 ft. (Pl. 6). The maximal thickness of 6.7 ft. is recorded in a boring located in sec. 23.

Another small area where the shale parting is thicker than 1 ft. is in the McCurtain strip-mine, East pit, north of McCurtain (secs. 13

and 14, T. 8 N., R. 22 E.; Pl. 6). According to the mine operator, a parting varied from about 2 ft. thick in the eastern part of the pit to 6 ft. in the western part.

Multiple shale partings within the Hartshorne coal were observed in several test-borings (Pl. 6). Altogether, they are quite thin.

Classification (Rank)

Rank of coal within the study area generally increases west to east from high-volatile A bituminous coal to medium-volatile bituminous coal, based on standards of the American Society for Testing and Materials (ASTM) (Averitt, 1974, p. 20). Most coal within the thesis area is medium-volatile bituminous. Largest fixed-carbon values recorded were from the Milton Anticline. Fixed carbon of the Hartshorne coal within the study area is shown by Pl. 7. Appendix A includes analyses of selected samples of Hartshorne coal.

Sulfur Content

Sulfur probably is the most important minor constituent contained in coal, because it reduces the quality of coke for metallurgical purposes as well as contributing to air pollution. Distribution of sulfur in the Hartshorne coal is shown by Pl. 8. Sulfur values in the study area all contained less than 4.7 percent sulfur. Values of more than 3 percent are concentrated in the Shropshire Valley area, the western one-half of the southwestern quarter of the study area, the SW ¼, sec. 20, T. 8 N., R. 23 E., and the SE ¼, sec. 29, T. 9 N., R. 23 E. (Pl. 8). Most of the Hartshorne coal in the study area contains less than 3 percent sulfur and is thus classified as intermediate

(1-3 percent) and low-sulfur (1 percent) coal (Friedman, personal communication, 1978).

Ash Content

Excess ash content in a coal will reduce the expansion process during coking, and thus is important in selecting a coking coal. A good coking coal should have less than 9 percent ash, according to ASTM specifications (Wilson and Welles, 1950, p. 95). Percentages of ash are shown by Pl. 9.

Values of ash in the Hartshorne coal smaller than 9 percent are in secs. 13, 14, 22, 23 and 24, T. 8 N., R. 22 E. (Pl. 9). Coal with ash that exceeds the 9-percent limit is concentrated in secs. 32 and 33, T. 9 N., R. 21 E., secs. 8 and 9, T. 8 N., R. 21 E., secs. 1, 11 and 12, T. 8 N., R. 21 E., secs. 6 and 7, T. 8 N., R. 22 E., and secs. 26 and 27, T. 9 N., R. 22 E. (Pl. 9). However, most of the Hartshorne coal contains less than 9 percent ash.

Resources

Estimates of resources of Hartshorne coal in the study area are shown by Table 1. Resources were calculated from data obtained from coal-test borings, completion tickets and other drillholes. Reliability of estimates, thicknesses of beds, and thicknesses of overburden following Averitt (1975, p. 38-39) were the basic data used to classify reserves. An average weight for bituminous coal of 1800 short tons per acre-ft. was assumed (Friedman, 1974, p. 17).

Coal-thickness limits of 14 to 28 in., 29 to 42 in., and more than 42 in. were used (see Averitt, 1974, p. 39). The majority of estimated

TABLE I

MEASURED, INDICATED AND INFERRED RESOURCES OF HARTSHORNE COAL, ORDERED BY THICKNESS OF COAL AND THICKNESS OF OVERBURDEN (IN THOUSANDS OF SHORT TONS)

Measured	Thickness (in.)					
	14-28		29-42		Over 42	
	acres	tons	acres	tons	acres	tons
T8N,R21E						
depth (ft.)						
0-150	60	200				
151-1000			1,151	6,300	762	6,100
over 1000			1,123	6,700	1,993	14,800
T8N,R22E	-	-	-	-	-	-
depth (ft.)						
0-150			79	500	73	700
151-1000			1,122	6,300	2,440	19,400
over 1000			257	1,400	1,337	10,200
T8N,R23E	-	-	-	-	-	-
depth (ft.)						
0-150					41	300
151-1000			46	200	23	200
over 1000					25	200
T9N,R21E	-	-	-	-	-	-
depth (ft.)						
0-150	151	500	344	1,700		
151-1000	222	800	707	3,600		
over 1000			52	300		
T9N,R22E	-	-	-	-	-	-
depth (ft.)						
0-150						
151-1000	377	1,500	972	4,900		
over 1000	112	500	724	3,500		
T9N,R22E	-	-	-	-	-	-
depth (ft.)						
0-150						
151-1000	520	2,100	204	1,000		
over 1000						

TABLE I (Continued)

Indicated

	Thickness (in.)					
	15-28		29-42		Over 42	
	acres	tons	acres	tons	acres	tons
T8N,R21E						
depth (ft.)						
0-150	294	1,000				
151-1000			3,058	16,800	2,784	22,800
over 1000					5,742	43,400
T8N,R22E	-	-	-	-	-	-
depth (ft.)						
0-150					21	200
151-1000			3,332	18,000	1,849	13,900
over 1000			1,690	9,100	2,892	22,200
T8N,R23E	-	-	-	-	-	-
depth (ft.)						
0-150					17	100
151-1000			184	1,000	71	500
over 1000					110	800
T9N,R21E	-	-	-	-	-	-
depth (ft.)						
0-150			205	800		
151-1000	1,206	4,300	2,022	10,200		
over 1000			105	600		
T9N,R22E	-	-	-	-	-	-
depth (ft.)						
0-150						
151-1000	2,493	10,000	2,232	11,300		
over 1000			1,680	7,600		
T9N,R23E	-	-	-	-	-	-
depth (ft.)						
0-150						
151-1000	106	400	2,402	10,800		
over 1000						

TABLE I (Continued)

Inferred

	Thickness (in.)					
	15-28		29-42		Over 42	
	acres	tons	acres	tons	acres	tons
T8N,R21E						
depth (ft.)						
0-150						
151-1000	1,179	5,400				
over 1000						
T8N,R22E	-	-	-	-	-	-
depth (ft.)						
0-150						
151-1000			149	100	160	1,700
over 1000					352	2,900
T8N,R23E	-	-	-	-	-	-
depth (ft.)						
0-150						
151-1000						
over 1000					79	600
T9N,R21E	-	-	-	-	-	-
depth (ft.)						
0-150	528	2,000	76	400		
151-1000	4,891	17,600	369	1,700		
over 1000						
T9N,R22E	-	-	-	-	-	-
depth (ft.)						
0-150						
151-1000	3,107	11,400	352	1,900		
over 1000			197	900		
T9N,R23E	-	-	-	-	-	-
depth (ft.)						
0-150						
151-1000	2,141	7,700				
over 1000						

resources are within the category of 29 to 42 in. Overburden categories of 0 to 150 ft. (economically strippable), 151 to 1000 ft., and more than 1000 ft. were defined. The last two categories are important, due to a continued interest in underground coal mining, namely, the Choctaw Mine, sec. 1, T. 8 N., R. 21 E., (Pl. 5). In the extreme southeastern part of the study area, overburden is thicker than 2000 ft. Because of the small size of this locality, the addition of a new category of overburden did not seem necessary. Of course, this area was included in the category of more than 1000 ft.

Remaining and recoverable resources are shown in Table 2. The "remaining" category includes all identified coal resources present in beds at the time of this report. Recoverable reserves consist of two groups: (1) recoverable by strip-mining (to the 150-ft.-overburden limit); (2) nonstrippable recoverable reserves (more than 150 ft. of overburden) (Friedman, 1974, p. 14). Estimated recovery factors of 80 percent for strippable reserves and 50 percent for nonstrippable reserves (Averitt, 1974, p. 30-31) were applied to arrive at the values of recoverable reserves.

Total estimated remaining reserves of Hartshorne coal are 354,000,000 short tons of which 172,800,000 tons are nonstrippable but recoverable; 6,700,000 short tons are strippable recoverable reserves. The most attractive area for strip-mining probably is in the Shropshire Valley (secs. 32 and 33, T. 9 N., R. 21 E.; see Pl. 5), where coal averaging 2.5 ft. thick is overlain by 150 ft. or less of overburden; however, higher sulfur content at this locality (Pl. 8) may prohibit its use as a coking coal.

TABLE II

REMAINING AND RECOVERABLE HARTSHORNE COAL RESOURCES (IN THOUSANDS OF SHORT TONS)

T8N, R21E	
Remaining resources	123,600
Non-strippable recoverable reserves	61,200
Strippable recoverable reserves	900
T8N, R22E	
Remaining resources	106,600
Non-strippable recoverable reserves	52,600
Strippable recoverable reserves	1,100
T8N, R23E	
Remaining resources	3,900
Non-strippable recoverable reserves	1,700
Strippable recoverable reserves	400
T9N, R21E	
Remaining resources	44,400
Non-strippable recoverable reserves	19,500
Strippable recoverable reserves	4,300
T9N, R22E	
Remaining resources	53,500
Non-strippable recoverable reserves	26,700
Strippable recoverable reserves	0
T9N, R23E	
Remaining resources	22,000
Non-strippable recoverable reserves	11,000
Strippable recoverable reserves	0

Suitabilities

The Hartshorne is a good coking coal, for the most part, with a high free-swelling index (Friedman, 1974, p. 28-29). In years past, medium-volatile to low-volatile Hartshorne coal was blended with higher-volatile coal, from areas farther west in the Arkoma Basin, to yield satisfactory blast-furnace and metallurgical coke (Oakes and Knechtel, 1948, p. 79). Presently, this coal is shipped crushed "mine-run" from the McCurtain strip-mine, Karsh pit, for manufacture of coke (Friedman, 1974, p. 29). However, sulfur content is greater at some other places in the study area (see Pl. 8), and cleaning of the coal may be necessary before use in manufacturing of coke.

CONCLUSIONS

The principal conclusions of this thesis are as follows.

1) Most rocks cropping out within the study area are part of the Krebs Group, Desmoinesian Series, Pennsylvanian System. Older Atokan rock is present as an inlier on the Milton Anticline. The Hartshorne Formation, which includes the Tobucksy Sandstone Member and the Hartshorne coal, is the basal unit of the Krebs Group.

2) Environments of deposition of the Krebs Group alternated generally between shallow-marine and subaerial conditions. Coal swamps formed as culminations of several deltas that prograded into this part of the Arkoma Basin. Peat was preserved because the delta was not eroded by strong waves or currents.

3) The study area lies in a zone of moderately intense compressional folding with attendant normal and reverse faulting. Upward movement of the Ozark Uplift, subsidence of the Arkoma Basin, and northerly stress associated with the Ouachita orogeny all influenced present-day structure.

4) The Hartshorne coal is composed of two beds, the Upper and Lower coals. Throughout most of the area these coals are separated by a shale that is maximally 7 ft. thick; in some other portions of the Arkoma Basin the split is as thick as 180 ft. Thinness of the shale in the study area is considered to be evidence of a comparatively stable portion of the peat swamp.

5) Thickness of the Hartshorne coal ranges from 1.8 to 8.3 ft. Most of the coal is deeper than the 150-ft. limit of economically strippable overburden.

6) Mostly, the rank of Hartshorne coal is medium-volatile bituminous, with a high free-swelling index. Sulfur content is less than 3 percent, on the average. Ash content generally is less than 9 percent.

7) Resources of Hartshorne coal within the study area are 354,000,000 short tons. Of this amount, 6,700,000 tons are classified as strippable recoverable reserves.

8) Hartshorne coal is best suited for use in making blast-furnace and metallurgical coke; however, coal from some localities where sulfur is relatively abundant must be cleaned before it can be used in coke manufacture.

SELECTED BIBLIOGRAPHY

Arkoma Basin Study Group, 1961, Stratigraphy of the Arkoma Basin, in Part II, Symposium on the Arkoma Basin: Tulsa Geol. Soc. Digest, v. 29, p. 54-88.

Averitt, Paul, 1974, Coal resources of the United States: United States Geol. Survey Bull. 1412, 131 p.

Blythe, J. G., 1959, Atoka Formation on the north side of the McAlester Basin: Okla. Geol. Survey Circular 47, 74 p.

Branson, C. C., 1956, Hartshorne Formation, early Desmoinesian, Oklahoma: Okla. Geol. Survey Geology Notes, v. 16, p. 93-99.

__________ 1961, Arkoma Basin, a Middle Pennsylvanian geosyncline, in Arkoma Basin and north-central Ouachita Mountains of Oklahoma, Tulsa-Ft. Smith Geol. Socs. Field Conference, 1961, Guidebook: Tulsa Geol. Soc., p. 76-78.

__________ 1962, Pennsylvanian System of the Mid-Continent, in C. C. Branson (Ed.), Pennsylvanian System in the United States: Am. Assoc. Petroleum Geologists, Symposium, p. 431-460.

Briggs, Garrett, and Cline, L. M., 1967, Paleocurrents of source areas of Late Paleozoic sediments of the Ouachita Mountains, southeastern Oklahoma: Jour. Sed. Petrology, v. 37, p. 985-1000.

__________ and Roeder, D., 1975, Sedimentology of Paleozoic flysch and associated deposits, Ouachita Mountains-Arkoma Basin, Oklahoma, in A guidebook to the sedimentology of Paleozoic flysch and associated deposits, Ouachita-Arkoma Basin, Oklahoma: Dallas Geol. Soc. Guidebook for the Am. Assoc. Petroleum Geologists national annual meeting, Dallas, 1975, 128 p.

Busch, D. A., 1953, The significance of deltas in subsurface exploration: Tulsa Geol. Soc. Digest, v. 21, p. 71-80.

Chance, H. M., 1890, Geology of the Choctaw coal fields: Trans. Amer. Inst. Mining Engineers, v. 18, p. 653-661.

Diggs, W. E., 1961, Structural framework of the Arkoma Basin, in Arkoma Basin and north-central Ouachita Mountains of Oklahoma, Tulsa-Ft. Smith Geol. Socs. Field Conference, 1961, Guidebook: Tulsa Geol. Soc., p. 62-65.

Drake, N. F., 1897, A geological reconnaissance of the coal fields of the Indian Territory: Am. Philos. Soc. Proc., v. 36, p. 326-419.

Frezon, S. E. and Dixon, G. R., 1975, Texas Panhandle and Oklahoma, in Paleotectonic investigations of the Pennsylvanian System in the United States: United States Geol. Survey Prof. Paper 853, p. 177-195.

Friedman, S. A., 1974, Investigation of the coal reserves in the Ozarks section of Oklahoma and their potential uses: Final report to the Ozark Regional Commission, 117 p.

__________ 1978, Desmoinesian coal deposits in part of the Arkoma Basin, eastern Oklahoma: Oklahoma City Geol. Soc. Guidebook for the Am. Assoc. Petroleum Geologists National Annual Meeting, Oklahoma City, 62 p.

Goldstein, A., and Hendricks, T. A., 1962, Late Mississippian and Pennsylvanian sediments of Ouachita facies, Oklahoma, Texas and Arkansas, in C. C. Branson (Ed.), Pennsylvanian System in the United States: Am. Assoc. Petroleum Geologists, Symposium, p. 385-430.

Hendricks, T. A., Dane, C. H., and Knechtel, M. M., 1936, Stratigraphy of Arkansas-Oklahoma coal basin: Am. Assoc. Petroleum Geologists Bull., v. 20, p. 1342-1356.

Jordan, Louise, 1957, Subsurface stratigraphic names of Oklahoma: Okla. Geol. Survey Guidebook VI, 220 p.

Karvelot, M. D., 1972, The Stigler coal and collateral strata in parts of Haskell, LeFlore, McIntosh, and Muskogee Counties, Oklahoma: Unpub. M. S. thesis, Oklahoma State Univ., 93 p.

Knechtel, M. M., 1949, Geology and coal and natural gas resources of northern LeFlore County, Oklahoma: Okla. Geol. Survey Bull. 68, 76 p.

McDaniel, Gary, 1961, Surface stratigraphy of the Hartshorne Formation, LeFlore, Latimer and Pittsburg Counties, Oklahoma, in Arkoma Basin and north-central Ouachita Mountains of Oklahoma, Tulsa-Ft. Smith Geol. Socs. Field Conference, 1961, Guidebook: Tulsa Geol. Soc., p. 66-71.

__________ 1968, Application of sedimentary directional features and scalar properties to hydrocarbon exploration: Am. Assoc. Petroleum Geologists Bull., v. 52, p. 1689-1699.

Merewether, E. A., 1961, Thickening of the Atoka Formation in the central part of the Arkansas Valley: United States Geol. Survey Prof. Paper 424-C, p. 85-87.

Oakes, Malcolm, and Knechtel, M. M., 1948, Geology and mineral resources of Haskell County, Oklahoma: Okla. Geol. Survey Bull. 67, 134 p.

__________ 1953, Krebs and Cabaniss Groups, of Pennsylvanian age in Oklahoma: Am. Assoc. Petroleum Geologists Bull., v. 37, p. 1523-1526.

Taff, J. A., 1899, Geology of McAlester-Lehigh coal field, Indian Territory: United States Geol. Survey 19th Annual Report, pt. 3, p. 423-456.

__________ and Adams, G. I., 1900, Geology of the eastern Choctaw coal field, Indian Territory: United States Geol. Survey 21st Annual Report, pt. 2, p. 257-311.

Trumbull, J. V. A., 1957, Coal resources of Oklahoma: United States Geol. Survey Bull. 1042-J, p. 307-382.

Wilson, L. R., 1970, Palynology of Oklahoma's ten foot coal seam: Okla. Geology Notes, v. 30, p. 62-63.

Wilson, P. J., and Wells, J. H., 1950, Coal, coke and coal chemicals: New York, McGraw-Hill, 509 p.

Yeakel, L. S., 1973, Field trip Guidebook - Depositional features in Late Paleozoic sandstone in eastern Oklahoma and western Arkansas: EPR Special Report 24 (Revised), Shell Exploration and Production Research, Houston.

APPENDIX A

SELECTED ANALYSES OF COAL

Locality	Sec.	Ident. No.	Proximate[1]			Ultimate Sulfur	Caloric Value Btu	Ref.[2]
			V	FC	A			
T9N, R21E								
SW,SW,NW	33	201/C	23.4	65.9	10.7	4.61		c
NW,NW,SW	33	200/C	24.5	65.6	9.9	3.37		c
T9N, R22E								
NE,NW,NE	23	M-6	19.4	74.9	5.6	0.68	14,673	c
C,NW	27	M-2			12.0	0.92		c
NW,NE,NW	30	17	23.4	69.3	7.4	1.48	14,573	c
C,SE	31	D-26	21.0	73.5	5.5	0.69	14,750	c
T9N, R23E								
SE,SW,SE	29	M-3	18.5	68.6	12.9	3.67	13,388	c
C,NW	31	M-5	20.0	72.3	7.7	1.50	14,361	c
T8N, R21E								
NE,SW,SW	1	D-21	21.3	71.0	7.7	1.34	14,422	c
NW,NE,NW	3	15	22.9	70.8	6.4	1.49	14.720	c
SE,SE,SE	9	13	21.5	71.4	7.1	2.82	14,607	c
SE,SE,SW	12	D-53	20.3	71.5	8.2	1.27		c
SW,NE,NE	15	D-6			5.5	1.31		c
NE,NE,NE	18	11	23.6	70.1	6.3	2.82	14,634	c
SE,SE,SW	22	D-5			7.1	3.03		c
SW,NW,SW	29	D-7	24.6	67.3	8.0	3.51		c
C,NE	34	SS-3	21.5	72.6	5.9	0.85		c
SE,NW,NE	36	SS-6	22.2	68.3	9.5	0.63		c
T8N, R22E								
SE,NE,SE	6	D-15	21.0	75.8	3.1	0.87	15,040	c
NE,NW,SW	7	D-48	20.1	75.2	4.7	0.58	14,242	c

Locality	Sec.	Ident. No.	Proximate[1] V	FC	A	Ultimate Sulfur	Caloric Value Btu	Ref.[2]
T8N, R22E (Continued)								
NW,NW,SW	13	74x10-12	20.4	73.3	2.9	0.60	14,762	o
SW,NE,NE	22	75x66	21.2	75.6	2.1	0.70	15,300	o
SW,SW,NW	24	Mc-3	21.1	74.8	4.3	0.91	15,162	c
T8N, R23E								
NE,SW,SW	20	Mc-1	19.7	72.0	8.0	4.31	14,348	c

[1] Headings under proximate analysis are: (V) Volatile matter; (FC) Fixed carbon; (A) Ash. Numbers show percentages.

[2] References: (c) indicates confidential company data; (o) analyzed by the Oklahoma Geological Survey.

APPENDIX B

THICKNESSES OF COAL

	Sec.	Bh. No.	Thickness (Ft.) U. coal	L. coal	Net	Source
T9N,R23E	29	2	1.8	0.5	2.3	Coal-test boring
	31	4			2.9	"
T9N,R22E	23	8	1.9	0.4	2.3	"
	26	10	2.0	0.9	2.9	"
	27	11	1.8	0.6	2.4	"
	29	14			2.1	"
		16	1.5	0.7	2.2	"
	30	17			2.5	"
	31	19	2.0	0.7	2.7	"
T9N,R21E	28	29	1.5	1.2	2.7	"
	30	30	1.8	0.4	2.0	OGS Bull. 67
		31			2.2	"
	32	32	1.1	0.8	1.9	Coal-test boring
	33	34			2.9	"
		35	1.8	1.1	2.9	"
		36	1.3	1.1	2.4	"
	34	38	1.7	1.8	3.5	"
	36	39			2.7	"
T8N,R23E	4	42			3.7	OGS Bull. 68
	7	46			3.3	"
		47			3.3	"
		48			3.5	"
		49			3.9	"
		50			4.9	"
	8	51			3.5	"
		52			4.7	"
		53			4.0	"
		54			4.8	"
		55			3.7	"
	9	56			3.8	"
		57			4.0	"
		58			3.0	"
		59			3.3	"
	19	60	2.0	2.0	4.0	Coal-test boring
	20	61			5.5	OGS Bull. 68
		67			6.7	"
	21	64			5.0	"
T8N,R22E	6	74	2.2	1.8	4.0	Coal-test boring
		76	2.2	1.7	3.9	"
		77			3.9	"
	7	78	1.9	2.0	3.9	"
		79	2.6	1.9	4.5	"
		81	2.1	2.0	4.1	"
		82	2.0	2.0	4.0	"
	11	88	1.9	1.8	3.7	"
	12	90	2.0	1.3	3.3	"
	13	91			3.4	"
		92			4.0	"
		93	1.9	1.9	3.8	"

	Sec.	Bh. No.	Thickness (Ft.) U. coal	L. coal	Net	Source
T8N,R22E	14	99			4.1	Coal-test boring
		100			3.7	"
		101	1.9	1.7	3.6	"
		102	2.1	1.3	3.4	"
		103			3.6	"
		104	2.1	2.9	5.0	"
		105	2.0	1.6	3.6	"
		106	2.1	2.9	5.0	"
		107	2.1	1.9	4.0	"
	15	119			3.8	"
		120	2.1	1.8	3.9	"
		121	2.1	1.6	3.7	"
		122	2.0	1.5	3.5	"
		123			3.8	"
		124			4.0	"
		125			3.7	"
		126			3.6	"
		127			3.7	"
		128	2.0	2.0	4.0	"
	16	130	2.0	1.5	3.5	"
		131	1.3	1.5	2.8	"
		132	1.3	2.2	3.5	"
		134	1.8	1.9	3.7	"
	18	136			4.3	"
	19	138			4.7	"
	20	139	2.1	1.9	4.0	"
		140	3.6	0.8	4.4	"
		141	2.1	3.4	5.5	"
		142	1.9	2.9	4.8	"
		143	1.8	2.1	3.9	"
		144	2.0	2.2	4.2	"
		145	1.8	2.5	4.3	"
		146	1.5	4.0	5.5	"
	21	147	1.3	2.6	3.9	"
		148	2.0	2.2	4.2	"
		150	2.2	3.8	6.0	"
		151	1.9	3.8	5.7	"
		152			4.3	"
		153	1.9	2.2	4.1	"
		155			4.9	"
		156	2.0	3.8	5.8	"
		157	1.3	4.5	5.8	"
		158	1.8	4.1	5.9	"
		160	2.7	3.5	6.2	"
		161			6.5	"
		162	1.6	5.3	6.9	"
		163			6.5	"
		164	2.4	4.2	6.6	"

	Sec.	Bh. No.	Thickness (Ft.) U. coal	L. coal	Net	Source
T8N,R22E	22	165			4.5	Coal-test boring
		166			5.1	"
		167			8.0	"
		168			4.5	"
		169			5.8	"
		170			6.6	"
		172			6.0	"
		174			7.0	"
		175			4.0	"
		176			4.0	"
		178			6.4	"
		179			4.3	"
		180			5.8	"
		181			6.8	"
		182			5.2	"
		183			8.3	"
	23	184			8.2	"
		185	2.6	3.3	5.9	"
		186			5.0	"
		188			6.5	"
		190			7.4	"
		191	2.7	3.3	6.0	"
	28	195	2.4	3.6	6.0	"
	30	198			3.5	"
T8N,R21E	1	204	1.7	1.3	3.0	"
		205			3.0	"
		206	1.8	2.0	3.8	"
		207	1.7	1.9	3.8	"
		208	2.0	2.0	4.0	"
	2	209			3.6	"
		211	1.8	2.1	3.9	"
	3	212	1.8	2.4	4.2	"
		213			2.9	"
	8	216	2.0	1.6	3.6	"
	9	217			2.7	"
		219			3.5	"
	10	220	1.8	2.4	4.2	"
	11	222	1.7	2.3	4.0	"
		223			4.3	"
	12	225			4.0	"
		227			3.8	"
	13	228	2.0	1.8	3.8	"
		229	1.8	1.6	3.4	"
	14	230	1.7	2.2	3.9	"
	15	232	1.0	3.4	4.4	"
	17	234	2.0	1.4	3.4	"
	18	235			3.2	"
	22	239	1.6	1.4	3.0	"

	Sec.	Bh. No.	Thickness (ft.) U. coal	L. coal	Net	Source
T8N,R21E	23	240	2.0	1.8	3.8	Coal-test boring
	24	243	2.5	1.8	4.3	"
	28	247	2.1	1.8	3.9	"
		249	1.5	2.1	3.6	"
	29	250			5.0	"
		251			4.0	"
	34	252	2.4	3.3	5.7	"
	36	253	2.3	4.1	6.4	"

APPENDIX C

MEASURED SECTIONS

1. McCurtain Strip Mine, Karsh Pit, NW ¼, NE ¼, sec. 22, T8N, R22E

Description of Unit	Thickness in Ft.
Hartshorne Formation (Rocks below Hartshorne coal)	
Shale, gray, clayey; contains abundant clay ironstone concretions and rootlets.	1.2
Silty shale, flaser-bedded, laminated in upper part; contains abundant pyrite-coated ironstones with coalified rootlets.	1.6
Siltstone, dark gray, flaser bedded; contains scattered rootlets.	0.7
Siltstone, dark gray; flaser bedded in lower half; contains rootlets in upper half.	1.2
Siltstone, dark gray; contains nearly vertical burrows.	1.5
Siltstone, dark gray; flaser-bedded.	12.0

2. Roadcut, Highway 82, SE ¼, SE ¼, SE ¼, sec. 17, T8N, R21E

Description of Unit	Thickness in Ft.
Tamaha Sandstone Member, McAlester Formation	
Sandstone, brown where fresh or weathered; hard, thin-bedded; composed of med. grnd. quartz grains with minor amounts of mica; beds vary from 1-5 in.; forms cuesta.	9.5
Shale, light gray, covered.	5.0
Sandstone, light brown to gray-green where fresh, tan where weathered; thin-bedded; contains thin interbeds of siltstone between sandstone beds; composed of fn. grnd. quartz grains, abundant mica and carbonaceous streaks.	2.5
Sandstone, olive-green where fresh, tan where weathered; thin (½cm) siltstone interbeds; composed of fn. grnd. quartz grains and carbonaceous streaks.	3.5
Shale, gray, covered.	2.5

Sandstone, silty, green-brown where fresh, tan where weathered; rippled; contains thin interbeds of siltstone; composed of fn. grad. quartz grains and abundant mica; well cemented.	3.0
Covered, probably shale and thin-bedded sandstone, as indicated by float; base not exposed.	30.0

3. Roadcut, Highway 82, SE ¼, SE ¼, SE ¼, sec. 29, T8N, R21E

Description of Unit	Thickness in Ft.
Lequire Sandstone Member, McAlester Formation	
Sandstone, dark gray where fresh, brown where weathered; hard, with some convolute bedding, very fn. grnd.; interbedded with a brown silty shale; max. thickness of beds is 5 in.; forms gently dipping cuesta.	8.0
Sandstone, gray where fresh, red-brown stain on weathered surface; hard, very fn. grnd.; rippled; composed primarily of well cemented quartz grains.	1.2
Shale, gray, fissile.	0.6
Sandstone, red-brown stain on weathered surface, gray where fresh; very fn. grnd. and resistant; ripple-bedded; composed of well cemented quartz grains with some mica.	2.2
Shale, brown, weathers gray; very fissile and well fractured.	0.4
Sandstone, red-brown where weathered, gray where fresh; ripple-bedded in top half, more nearly massive in bottom half; composed of well cemented, very fn. grnd. quartz grains with some limonite stains.	4.6
Shale, dark gray, covered; base of unit not exposed.	25.0

4. Top of ridge, county line road, NW ¼, NW ¼, NW ¼, sec. 18, T8N, R23E

Description of Unit	Thickness in Ft.
Tobucksy Sandstone Member, Hartshorne Formation	
Sandstone, gray where fresh, red-brown stain on weathered surface; ripple-bedded; composed of well cemented, med. grnd. qtz. grains; interbedded with thin (1 in.) shales.	4.0
Siltstone, gray where fresh, red where weathered; quite weathered.	2.0
Sandstone, tan to gray where fresh, red-brown where weathered; composed of well cemented fn. grnd. quartz grains; ripple-bedded; evenly spaced shale partings (1 cm thick); rounded red clay balls, some as large as cobbles, at bases of sandstone beds; weathering-out of clay balls gives pitted appearance; beds continuous laterally; most sandstone beds thinner than 3 in.	12.5

5. Roadcut, Highway 26, NW ¼, NW ¼, SW ¼, sec. 23, T9N, R22E

Description of Unit	Thickness in Ft.
Keota Sandstone Member, McAlester Formation	
Sandstone, brown where fresh or weathered; thin-bedded, with individual beds cut-out; composed of med. grnd., well sorted, poorly cemented quartz grains with fragments of fossil wood at base of unit.	4.0
Siltstone, brown, covered; contains 0.6-ft.-thick sandstone; brown where fresh; composed of med. grnd., poorly cemented quartz grains with scattered fragments of fossil wood.	3.0
Sandstone, tan where fresh, red-stained where weathered; contains clay balls and fragments of fossil wood at base, with med.-scale crossbedding; slight fining-up in grain size; fn. grnd. and well cemented overall; thins laterally; cuts out underlying shale.	3.0
Shale, gray to brown where fresh; thickness variable owing to channeling before deposition of overlying sandstone.	0.8

Sandstone, brown where fresh or weathered; cuts into underlying unit; composed of fn. grnd., well cemented quartz grains; thins laterally.	1.5
Sandstone, silty, brown where fresh; composed of very fn. grnd., poorly cemented quartz grains; rippled; interbedded with brown shale (avg. 2 cm thick); thin-bedded near top.	2.4
Sandstone, brown to tan where fresh; thin-bedded; composed of fn. grnd., well cemented quartz grains; interbedded with thin gray shales (less than 1 inch thick).	1.5
Shale, gray, fissile, covered; base of unit not exposed.	15.0

6. Roadcut, Highway 26, C, NW ¼, NE ¼, sec. 15, T8N, R22E

Description of Unit	Thickness in Ft.
Warner Sandstone Member, McAlester Formation	
Sandstone, gray to tan where fresh, brown where weathered; well cemented, very fn. grnd. quartzose sandstone; very thin-bedded (less than 2 in. thick); a few thicker beds near top of exposure; ripple-bedded.	20.0
McCurtain Shale Member	
Shale, soft, black, fissile; base of unit not exposed.	10.0

VITA 2

Lee Edward Catalano

Candidate for the Degree of

Master of Science

Thesis: GEOLOGY OF THE HARTSHORNE COAL, McCURTAIN AND LAFAYETTE QUADRANGLES, HASKELL AND LEFLORE COUNTIES, OKLAHOMA

Major Field: Geology

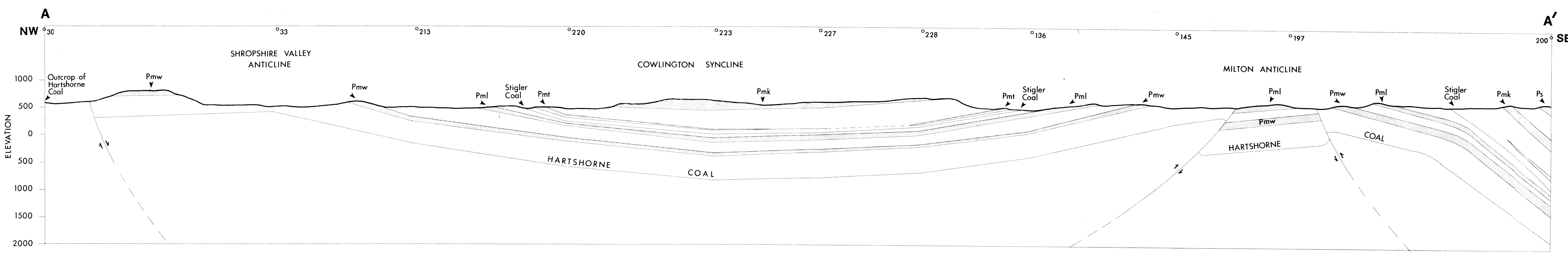
Biographical:

Personal Data: Born in San Diego, California, November 22, 1954, the son of Mr. and Mrs. Lee C. Catalano.

Education: Graduated from St. Joseph High School, Westchester, Illinois, in May, 1972; received the Bachelor of Arts degree in Earth Science from Adrian College, in May, 1976; completed requirements for Master of Science degree at Oklahoma State University in July, 1978, with a major in Geology.

Professional Experience: Junior Member of the American Association of Petroleum Geologists; Field geologist, Pamco Oil Corporation, August, 1977; Teaching Assistant, Department of Geology, Oklahoma State University, 1976-1978.

GEOLOGIC CROSS-SECTION, LAFAYETTE AND MC CURTAIN QUADRANGLES, HASKELL COUNTY, OKLAHOMA



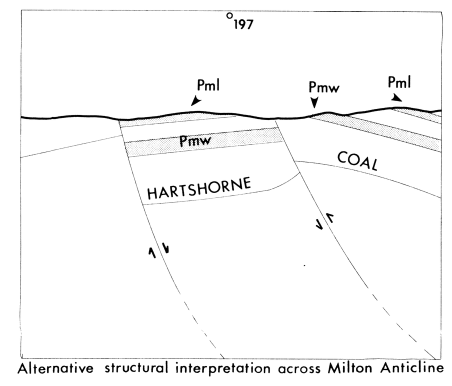
EXPLANATION

HORIZONTAL SCALE 1:24,000
VERTICAL SCALE 1:48,000

1 1/2 0 1 Mile
1 inch = 2,000 feet

Ps — Savanna Formation
Pmk — Keota Sandstone Member
Pmt — Tamaha Sandstone Member
Stigler Coal
Pml — Lequire Sandstone Member
Pmw — Warner Sandstone Member
(Keota through Warner: McAlester Formation)
Hartshorne Coal — Hartshorne Formation

Fault, showing relative displacement of beds.



Alternative structural interpretation across Milton Anticline

PLATE 1
GEOLOGIC MAP, LAFAYETTE AND
MC CURTAIN QUADRANGLES, OKLAHOMA
[ADAPTED FROM OAKES AND KNECHTEL, 1948]

EXPLANATION

QUATERNARY
- Qal — Alluvium
- Qt — Terrace Deposits

PENNSYLVANIAN
- Ps — SAVANNA FORMATION
- Pm — Unnamed Shale Member
- Pmk — Keota Sandstone Member
- Pm — Unnamed Shale Member
- Pmt — Tamaha Sandstone Member (not present everywhere)
- Pm — Unnamed Shale Member; Stigler Coal
- Pmc — Cameron Sandstone Member (not present everywhere)
- Pm — Unnamed Shale Member
- Pml — Lequire Sandstone Member (Pmlw where intervening shale is not present)
- Pm — Unnamed Shale Member
- Pmw — Warner Sandstone Member
- Pm — McCurtain Shale Member (contains local sandstone bed)

McALESTER FORMATION
- Ph — Upper and Lower Hartshorne Coals
- Pht — Tobucksy Sandstone Member

HARTSHORNE FORMATION
- Pa

ATOKA FORMATION

U/D Fault, dashed where concealed
U–Upthrow
D–Downthrow

Strike and dip of rock 5°

Coal bed outcrop

Area from which coal has been stripped.

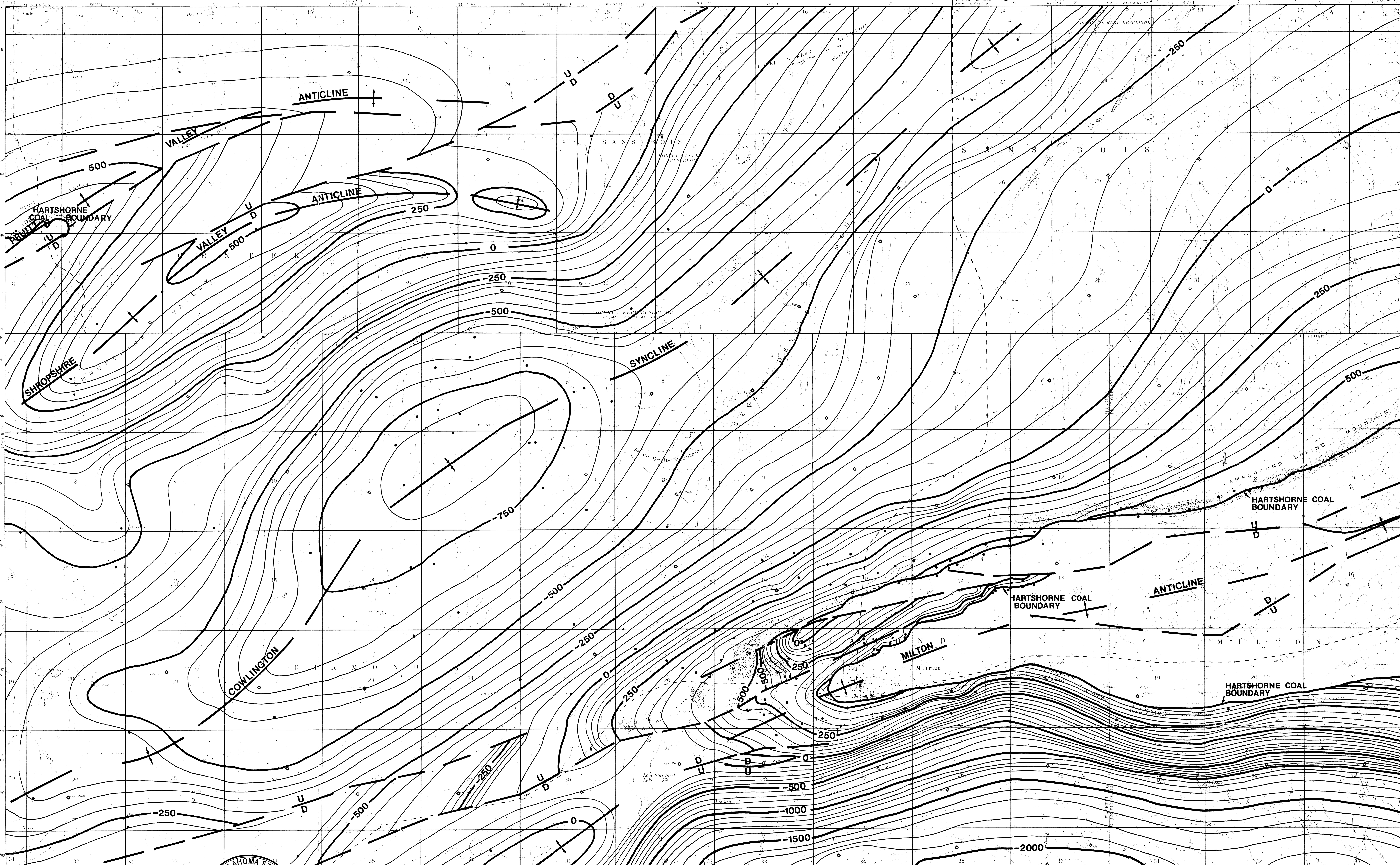
0 1/2 1 MILE
SCALE 1:24,000

LEE E. CATALANO, 1978

PLATE 2

CORRELATION SECTION B - B′

DATUM: TOP OF HARTSHORNE COAL



NOTE: CONTOUR INTERVAL CHANGES TO 100 FT.

PLATE 3
STRUCTURAL CONTOUR MAP TOP OF HARTSHORNE COAL

LAFAYETTE AND McCURTAIN QUADRANGLES, OKLAHOMA
CONTOUR INTERVAL: 50 FEET (EXCEPT WHERE SPECIFIED OTHERWISE)

EXPLANATION

- • Coal-test boring
- ○ Gas-well
- ◇ Dry-hole

FAULT
U-Upthrow
D-Downthrow

SYNCLINAL AXIS

ANTICLINAL AXIS

0 1/2 1 MILE
SCALE 1:24,000

N

LEE E. CATALANO, 1978

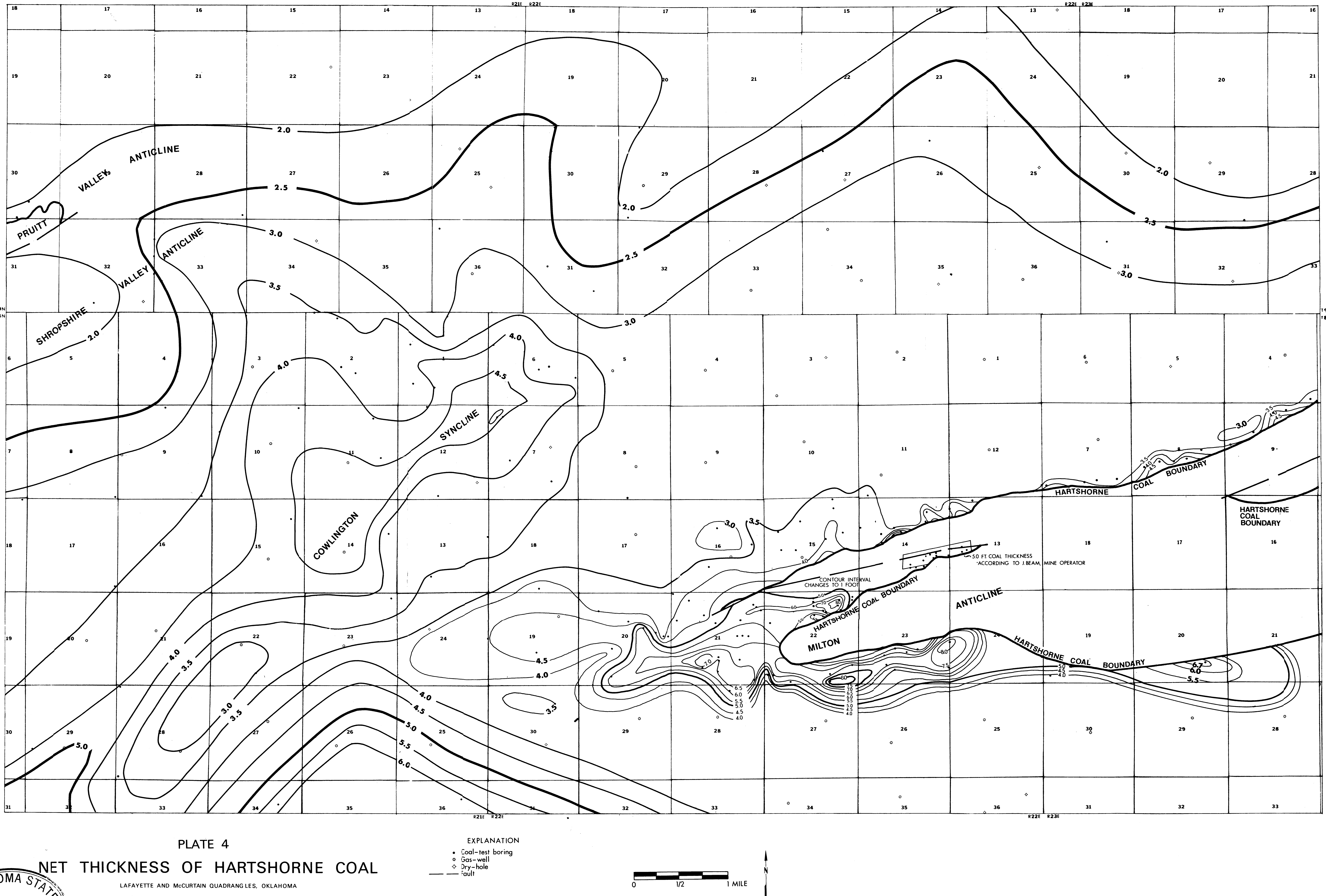


PLATE 4

NET THICKNESS OF HARTSHORNE COAL

LAFAYETTE AND McCURTAIN QUADRANGLES, OKLAHOMA

CONTOUR INTERVAL: 0.5 FEET

LEE E. CATALANO, 1978

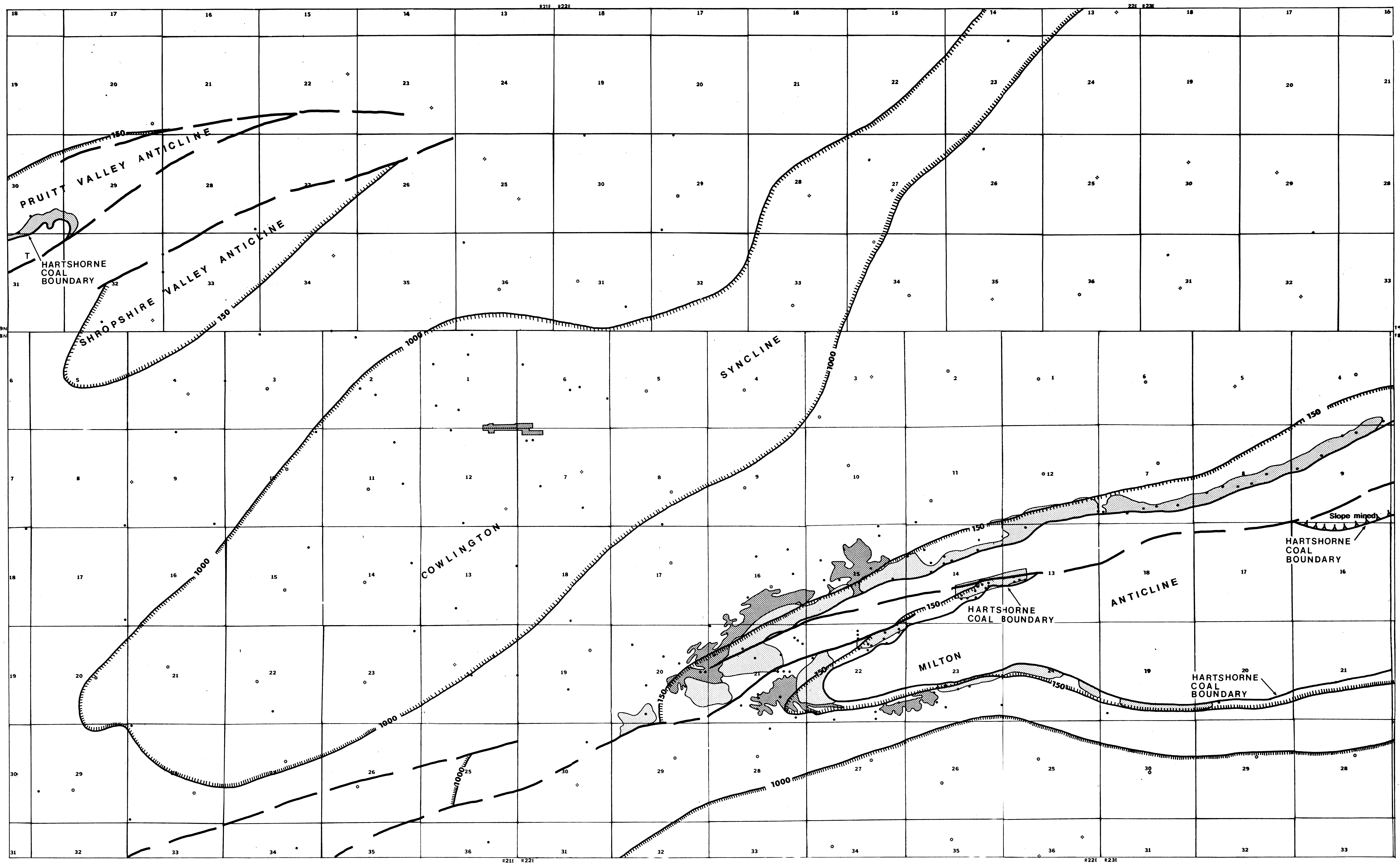


PLATE 5

OVERBURDEN THICKNESS MAP

LAFAYETTE AND McCURTAIN QUADRANGLES, OKLAHOMA

EXPLANATION

- Coal-test boring
- Gas-well
- Dry-well

150 ≤150 Overburden

1000 ≥1000 Overburden

Underground mine

Strip mine

Slope mine

Fault

0 1/2 1 MILE

N

LEE E. CATALANO, 1978

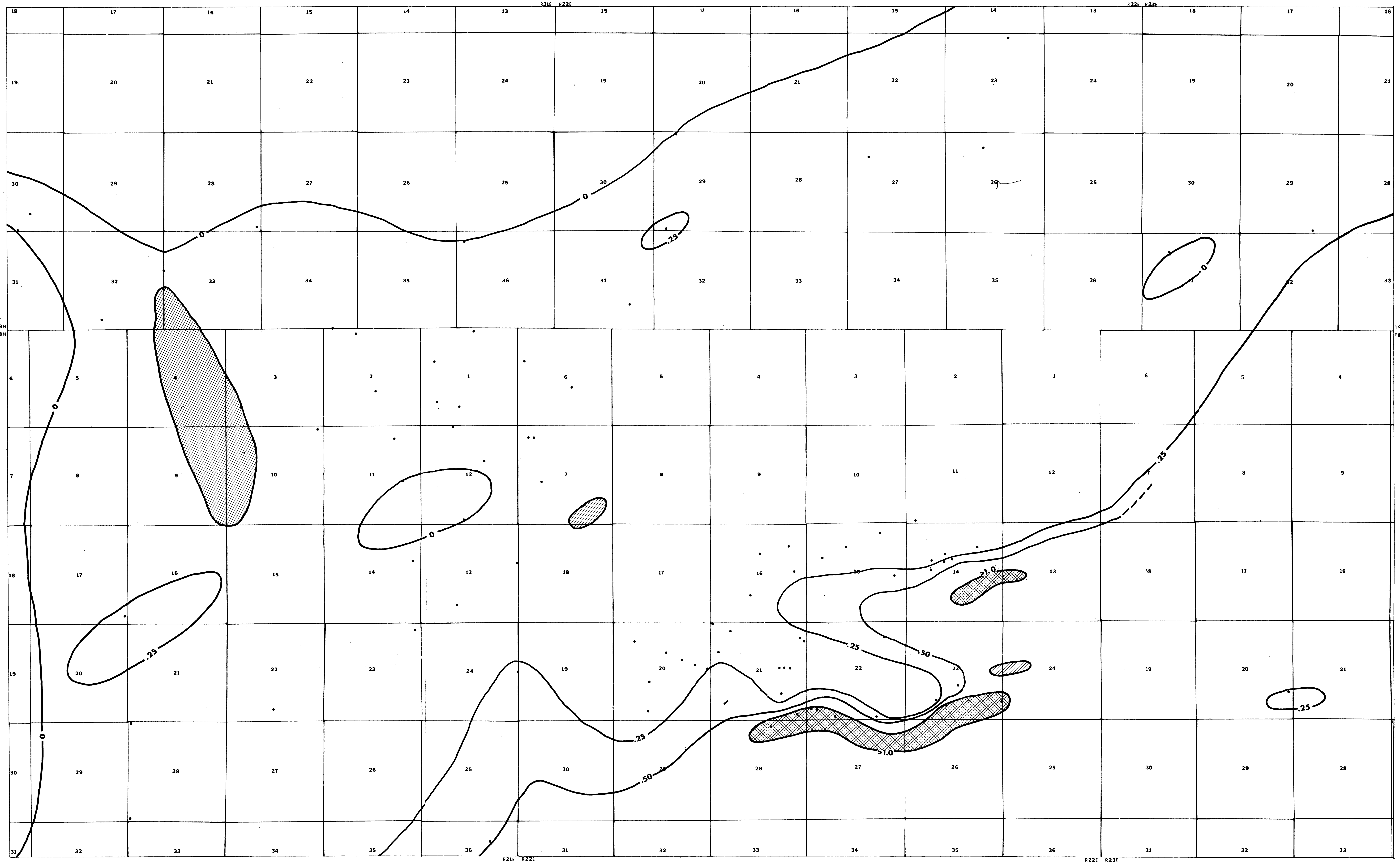


PLATE 6

THICKNESS OF HARTSHORNE COAL PARTING

LAFAYETTE AND McCURTAIN QUADRANGLES, OKLAHOMA

EXPLANATION

- Coal-test boring
- ≥1.0 Foot-split
- Multiple shale partings

0 1/2 1 MILE

N

LEE E. CATALANO, 1978

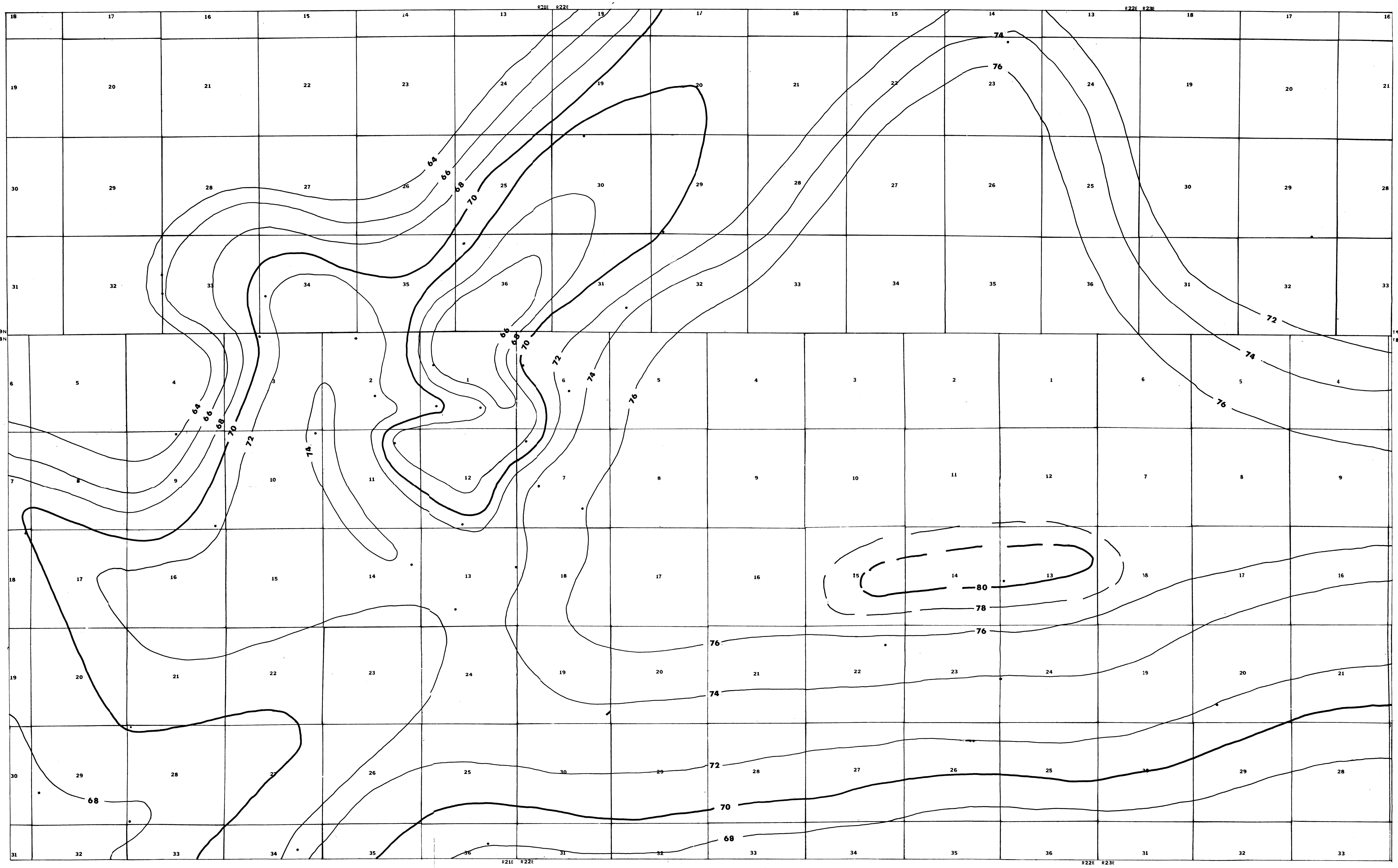


PLATE 7
ISOPLETH MAP OF FIXED CARBON

LAFAYETTE AND McCURTAIN QUADRANGLES, OKLAHOMA

CONTOUR INTERVAL: 2 PERCENT

CONTOUR LINES DASHED WHERE INFERRED

EXPLANATION

• Coal-test boring

0 1/2 1 MILE

N

LEE E. CATALANO, 1978

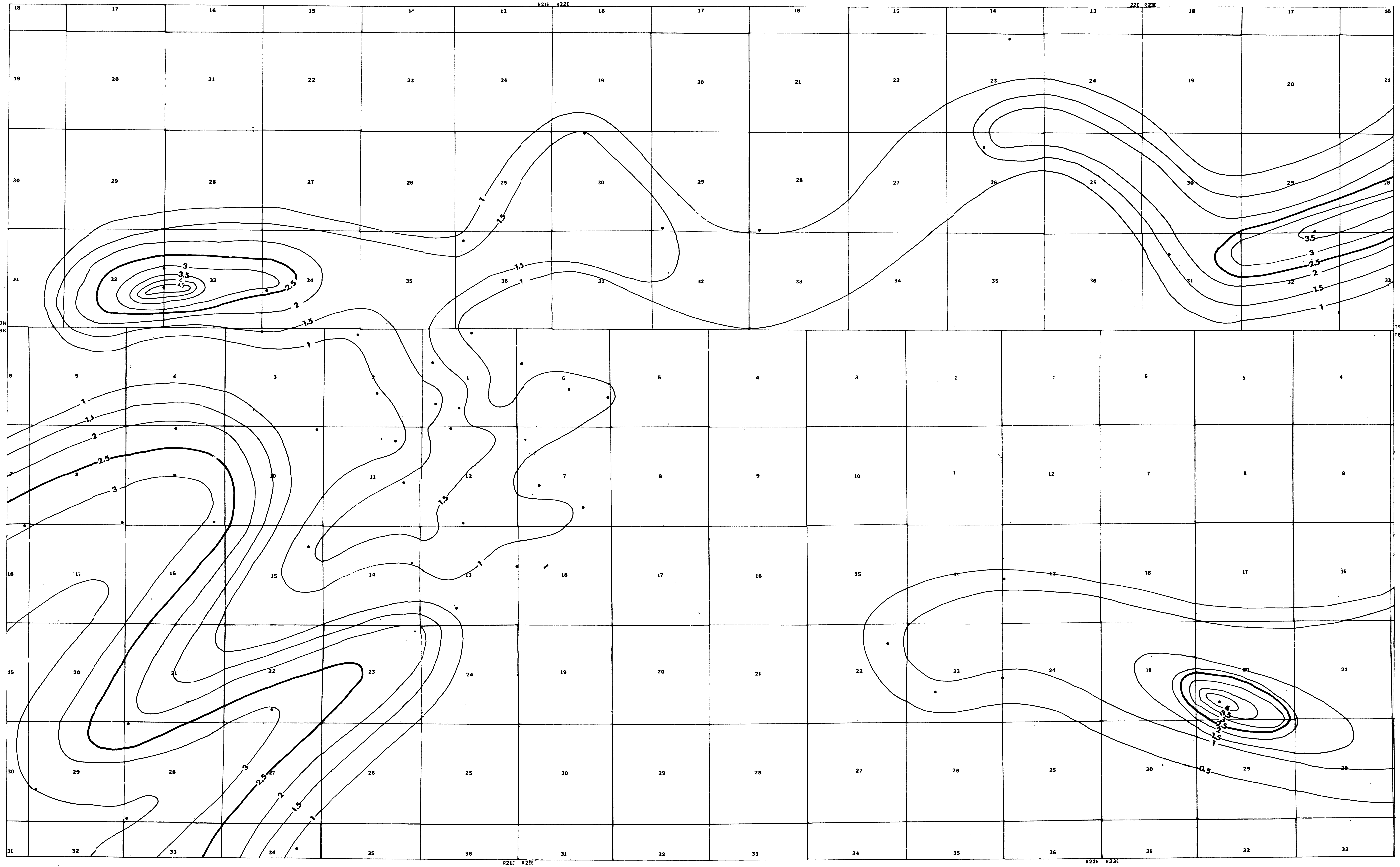


PLATE 8

ISOPLETH MAP OF SULFUR

LAFAYETTE AND McCURTAIN QUADRANGLES, OKLAHOMA

CONTOUR INTERVAL: 0.5 PERCENT

EXPLANATION

• Coal-test boring

0 1/2 1 MILE

N

LEE E. CATALANO, 1978

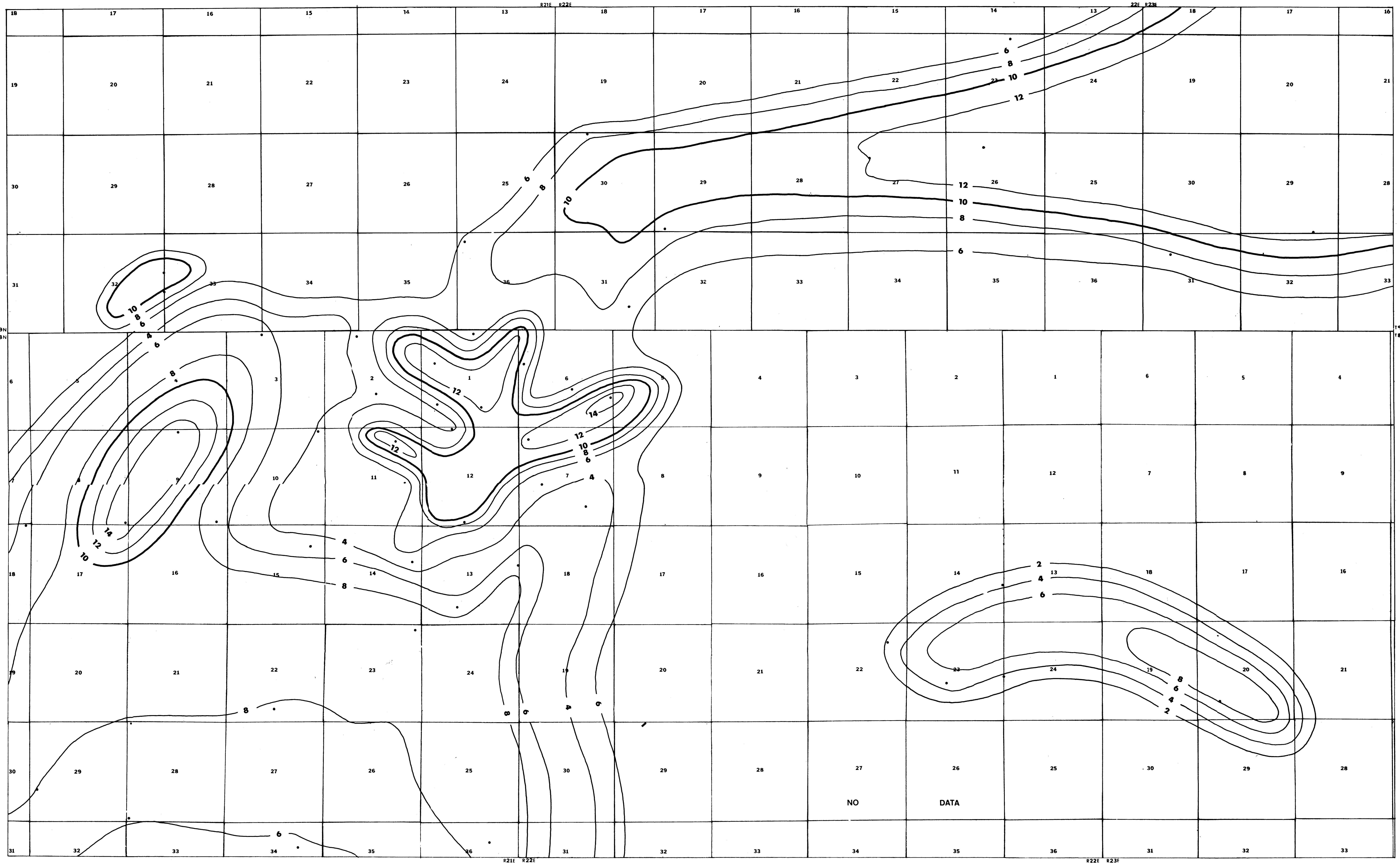


PLATE 9

ISOPLETH MAP OF ASH

LAFAYETTE AND McCURTAIN QUADRANGLES, OKLAHOMA

CONTOUR INTERVAL: 2 PERCENT

EXPLANATION

• Coal-test boring

0 1/2 1 MILE

N

LEE E. CATALANO, 1978

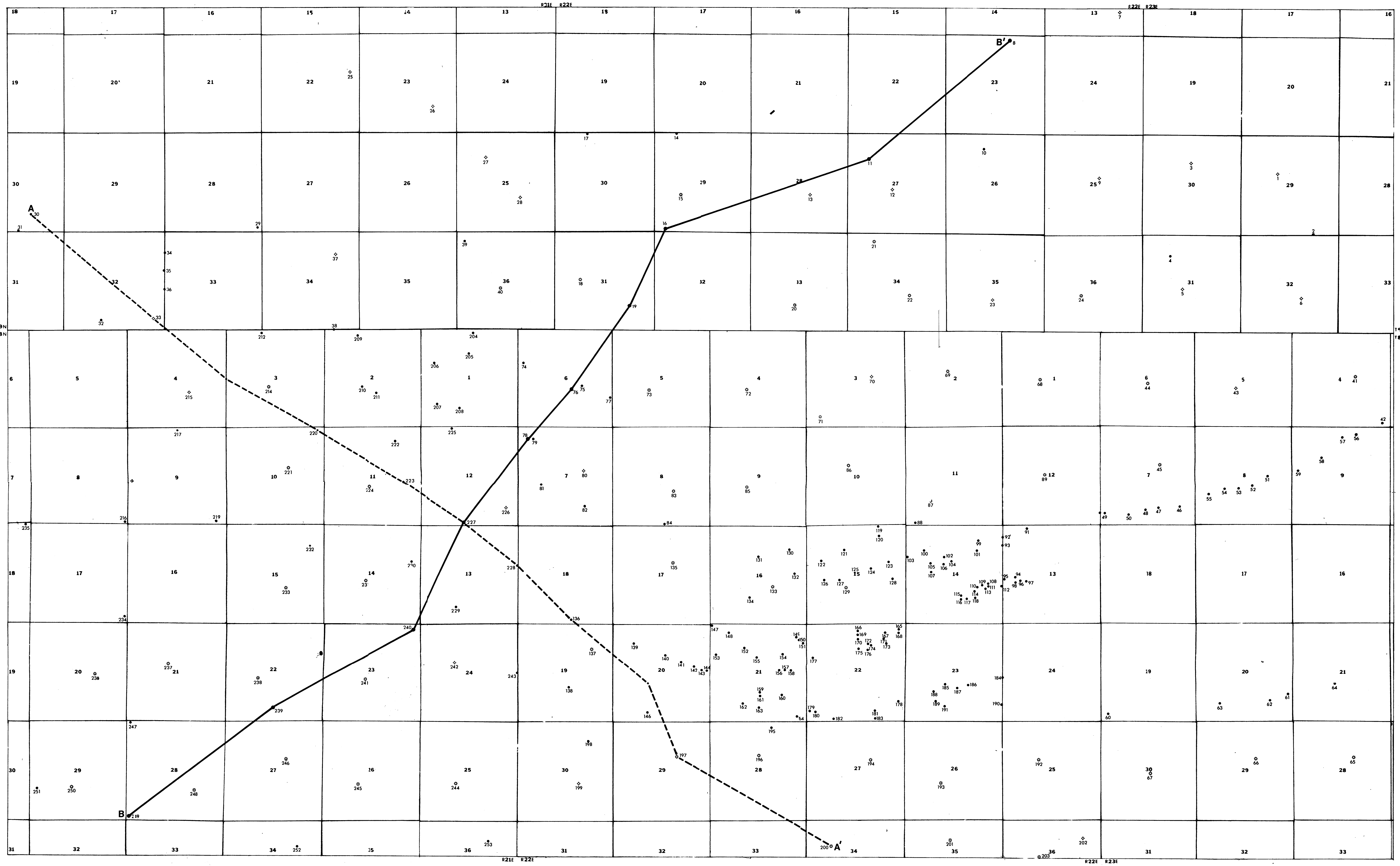


PLATE 10

INDEX MAP SHOWING DATUM POINTS AND LINES OF CROSS - SECTIONS

LAFAYETTE AND McCURTAIN QUADRANGLES, OKLAHOMA

EXPLANATION

- Coal test boring
- Gas-well
- Dry-hole

0 1/2 1 MILE

LINE OF CORRELATION SECTION

LINE OF GEOLOGIC CROSS-SECTION

LEE E. CATALANO, 1978

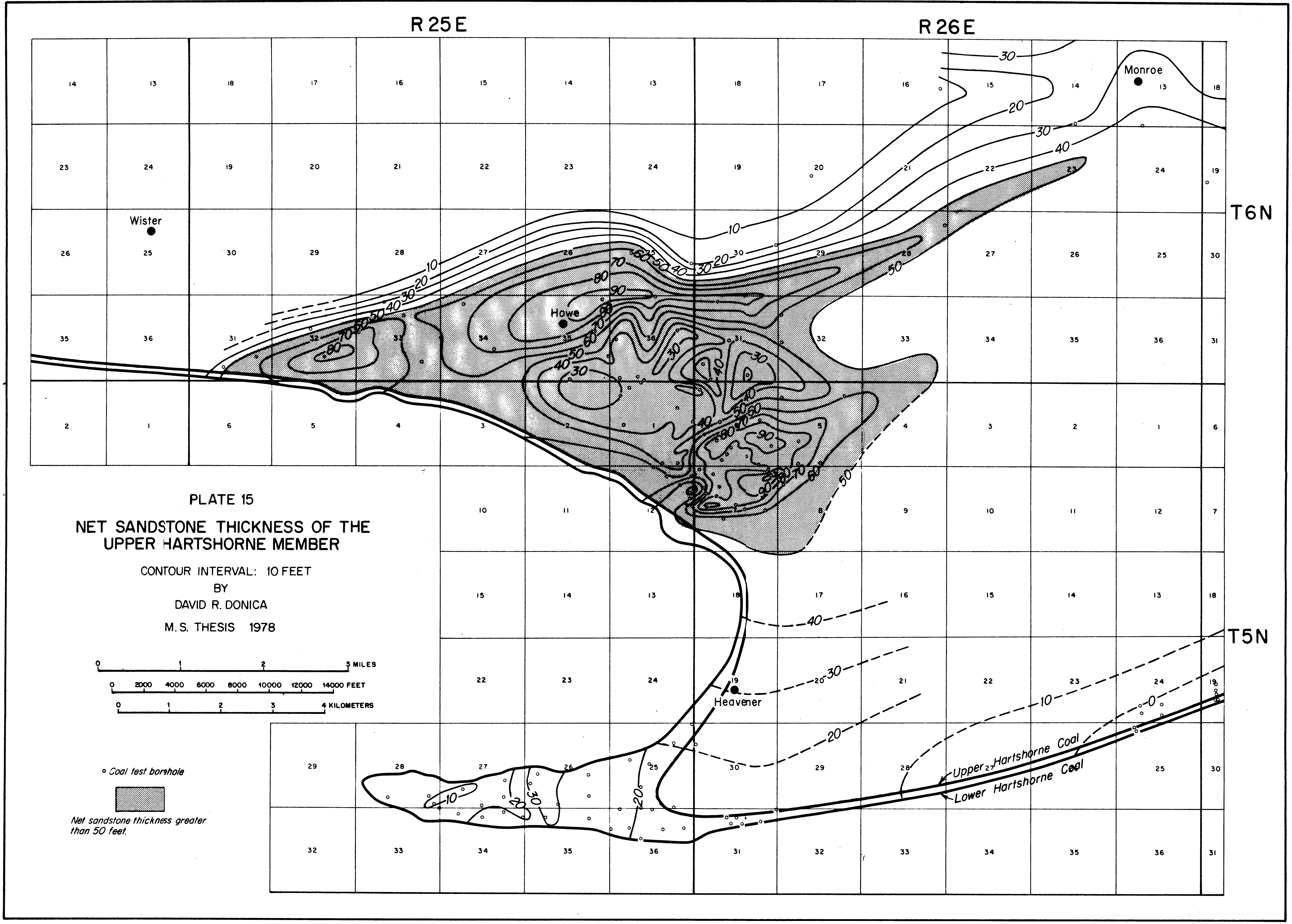


PLATE 15

NET SANDSTONE THICKNESS OF THE UPPER HARTSHORNE MEMBER

CONTOUR INTERVAL: 10 FEET

BY

DAVID R. DONICA

M.S. THESIS 1978

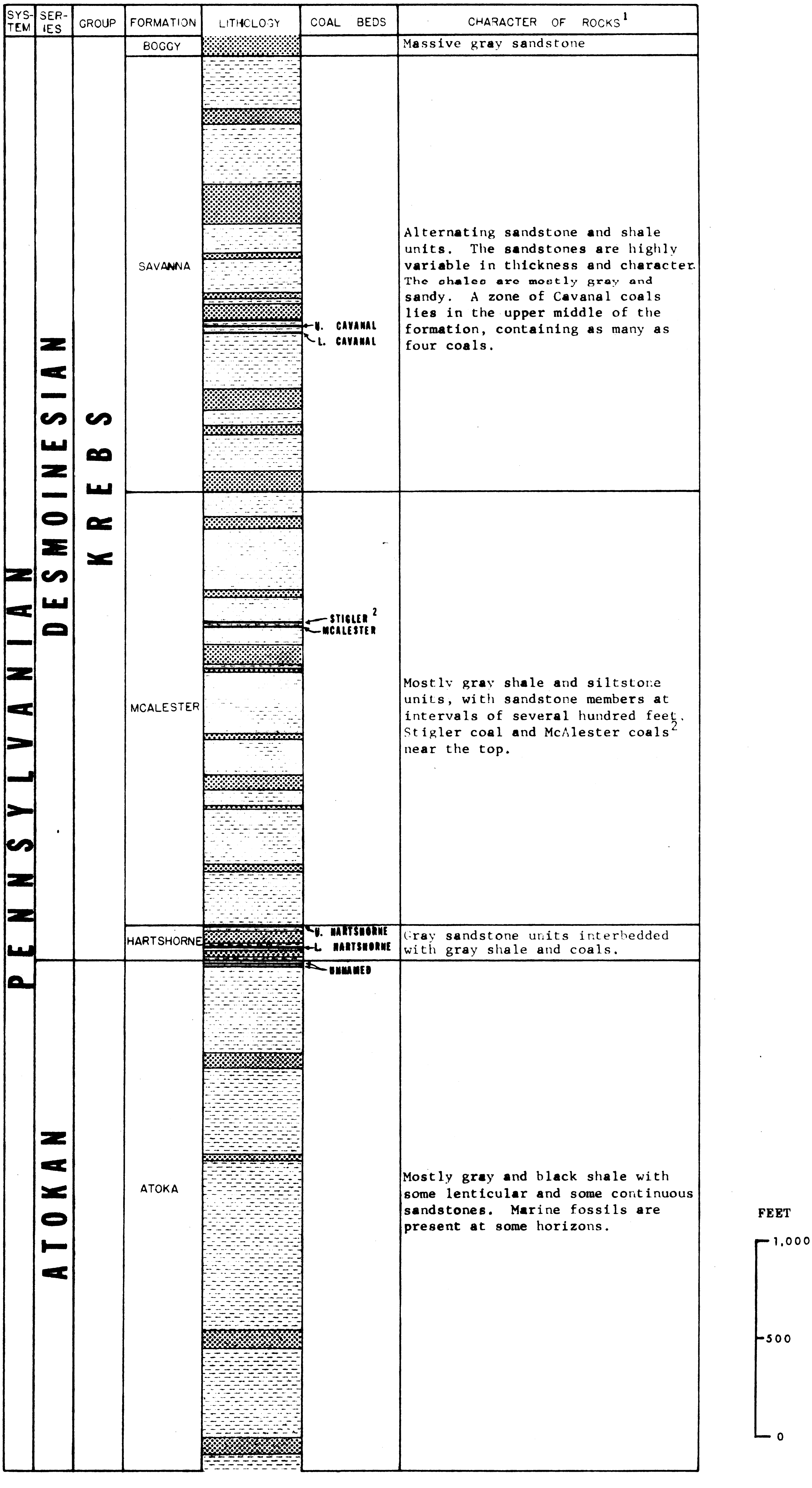


PLATE 16

Composite Geologic Column

showing strata exposed in the map area

[1] ADAPTED FROM HENDRICKS (1939) AND KNECHTEL (1949)

[2] STIGLER MAY CORRELATE WITH MCALESTER COAL. THIS MAY BE UPPER MCALESTER COAL AND NOT STIGLER COAL.