THE ECONOMIC POTENTIAL OF THE LOWER HARTSHORNE COAL ON PINE MOUNTAIN, HEAVENER, OKLAHOMA

By

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PREFACE

This study concerns itself with economic potential and geology of the Lower Hartshorne coal on Pine Mountain, near Heavener, Oklahoma. Core and drill hole data, coal analyses and field data were used to prepare the text and maps that comprise this study.

I wish to thank my in-fact adviser, Dr. John W. Trammell, for his suggestions, expertise and criticism during this study, and Dr. Gary F. Stewart, my secondary adviser, for his assistance in preparing and refining this paper. Inasmuch as Dr. Trammell resigned from the faculty before he finished guiding this research, Dr. Stewart technically served as faculty adviser. Dr. Alex R. Ross served as my third committee member and made helpful suggestions.

Data and support for this thesis came from Arkoma Coal Corporation. My deepest gratitude goes out to Mr. Ben G. Henneke, Jr., President of Arkoma, for releasing the data to me and teaching me about the coal business. My thanks also go to my team mates, Mr. Thomas J. Harkness and Mrs. Laura Evans. A special thanks goes to Dr. William F. Berry of W. F. Berry and Associates, for technical services provided and teaching me about coal petrology. I would like to thank Mr. S. A. Friedman for introducing me to both coal in

Oklahoma and to Mr. Henneke. Partial financial support for my first two years of study was subsidized by a Cities Service Fellowship. Another thank you goes to Mildred Lee for typing this paper.

Through trying times, my progress was aided by the moral support that Robin Keasler and Peg and Val Kranak provided. Finally, I would like to offer my sincere gratitude to my wife, Debbie, for her patience and understanding and for giving me that final push to make the finish line.

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CHAPTER I

INTRODUCTION

Location

The study area of this report is Pine Mountain in parts of sections 25, 26, 27, 28, 33, 34, 35 and 36, T. 5 N., R. 25 E. It is approximately four square miles, bordering the southwest edge of Heavener, Oklahoma in LeFlore County (Fig. 1).

The Lower Hartshorne coal bed lies within the Hartshorne Formation, Krebs Group, Desmoinesian Series of the Pennsylvanian System. The McAlester Formation of the Krebs Group and the Atoka Formation of the Atokan Series bound the Hartshorne Formation above and below, respectively.

A generalized stratigraphic column representative of the Arkoma basin is shown in Figure 2. A generalized geologic map of the surrounding area is shown in Figure 3.

Statement of the Problem

The principal objective of this study was to determine the economic potential of the Lower Hartshorne coal on Pine Mountain, Heavener, Oklahoma. The secondary objective was to interpret the origin and depositional environment of the coal and coal-bearing strata.

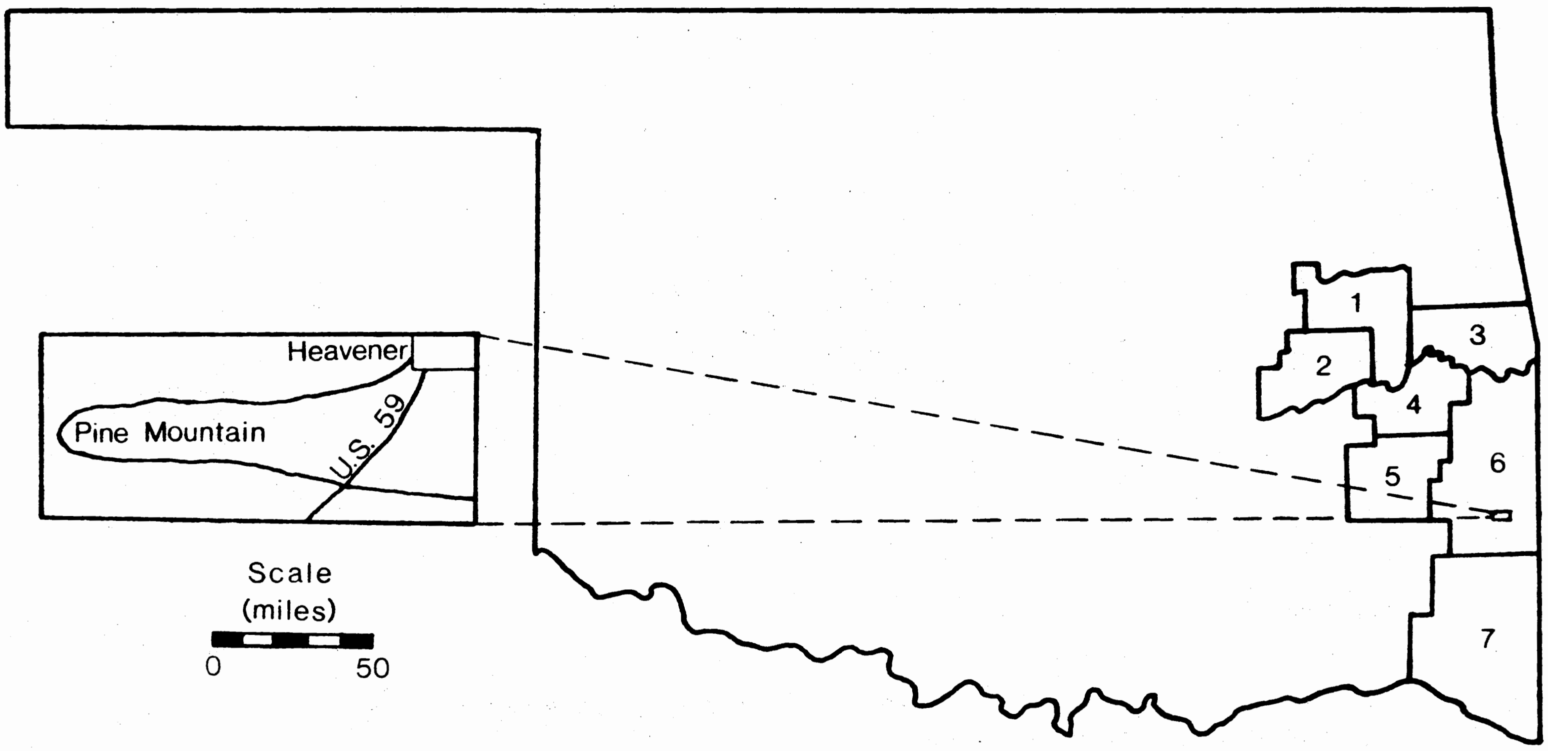

Fig. 1.-Location of the study area. Counties: 1) Muskogee, 2) McIntosh, 3) Sequoyah, 4) Haskell, 5) Latimer, 6) LeFlore and 7) McCurtain.

system	series	group	formation	member	coal	coal[1]
PENNSYLVANIAN	DESMOINESIAN	Krebs	Boggy	Bluejacket ss	Secor Lower Witteville	Secor
			Savanna		Cavanal	Lower Witteville Cavanal
			McAlester	Keota ss Tamaha ss Cameron ss Lequire ss Warner ss McCurtain sh	Stigler(?) McAlester	Upper McAlester McAlester (Stigler)
			Hartshorne	Upper Hartshorne ss Lower Hartshorne ss	Upper Hartshorne Lower Hartshorne	Upper Hartshorne Lower Hartshorne
	ATOKAN	Atoka	Atoka		unnamed coals	

Fig. 2.-Generalized stratigraphic column of Arkoma basin.

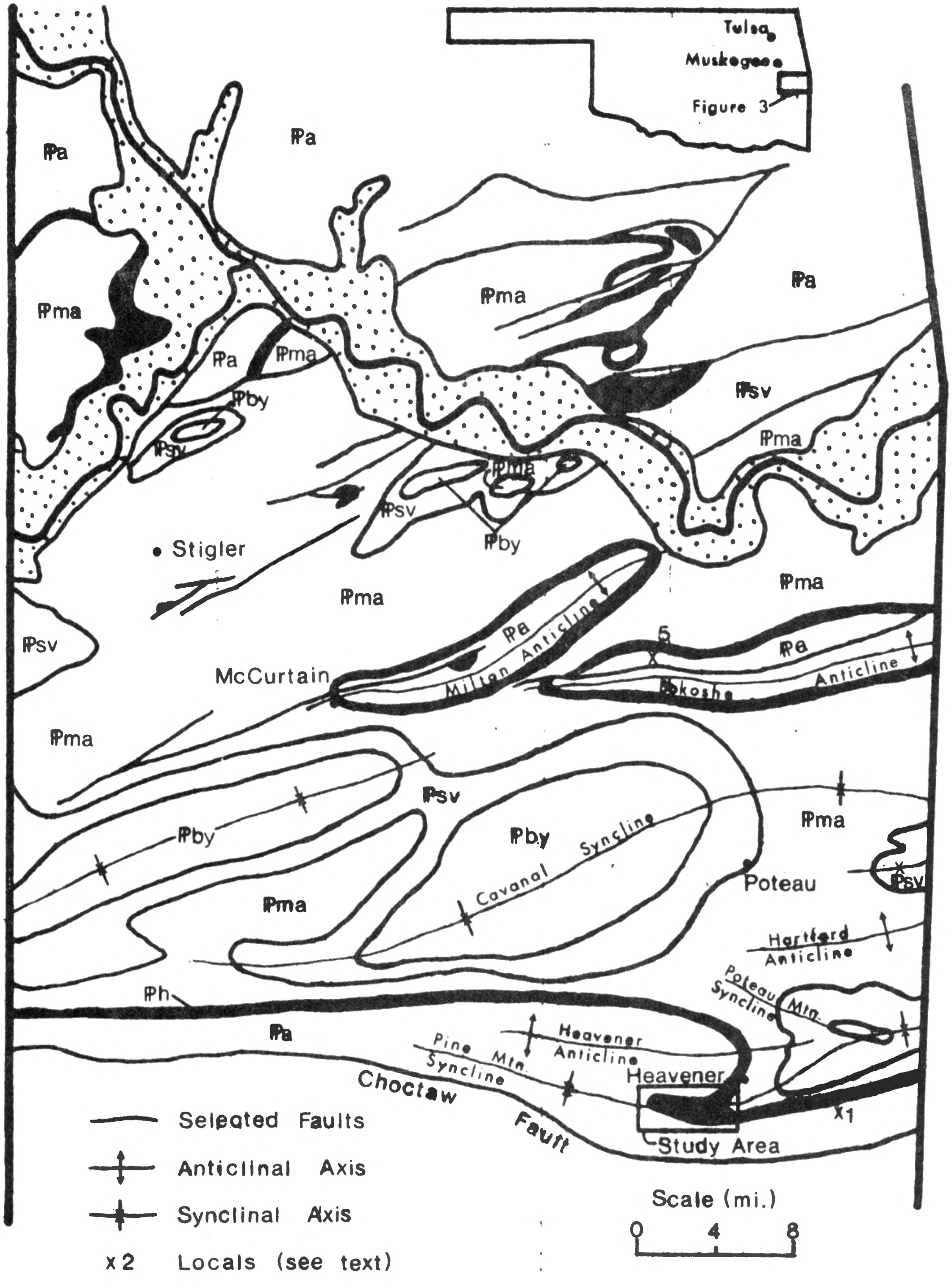

Fig. 3.-Generalized geologic map of Arkoma basin in vicinity of Pine Mountain.

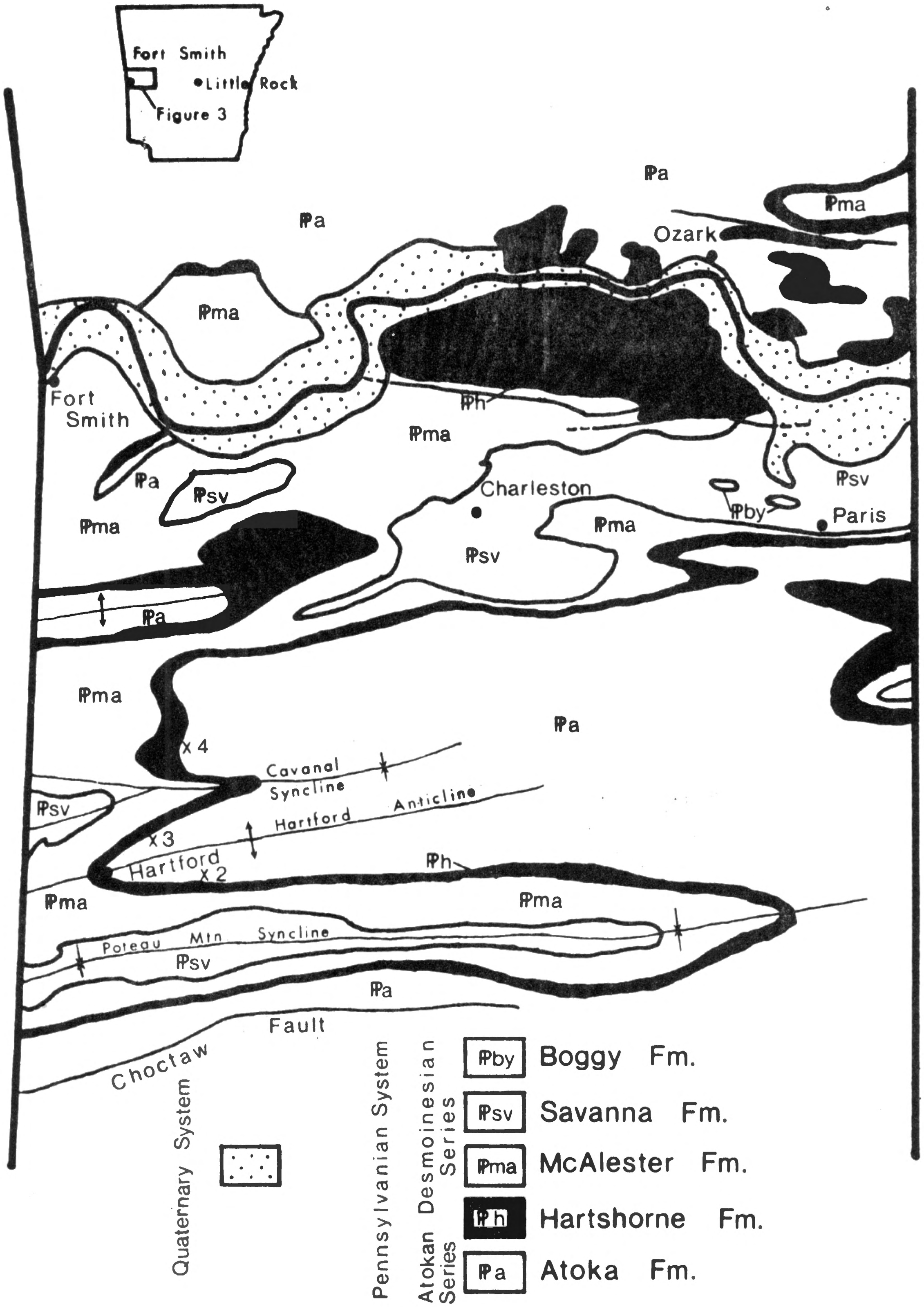

Fig. 3.-(continued)

Method of Solution

Data for this study were principally derived from 203 drill logs and numerous analyses of coal provided by several private companies, 21 graphic gravity logs and six petrographic-maceral-compositions analyses provided by Arkoma Coal Corporation and done by W. F. Berry and Associates, Pittsburg, Pa., 18 coal exploration pits, aerial photographs, outcrop descriptions, examination of fossils and field mapping. Data points are on Plate 1.

Previous Investigations

The first compilation of geologic work done in the Pine Mountain area was by Hendricks (1939). His publication also included a geologic map and description of the areal geology.

Oakes and Knechtel (1948) and Knechtel (1949) mapped the geology of adjacent Haskell County and northern LeFlore County and discussed the local Pennsylvanian nomenclature. Hendricks (1950), Haley (1966) and Haley and Hendricks (1968) mapped and discussed the general geology of coal-bearing strata of the Hartshorne Formation in adjoining Arkansas.

The definition of the Hartshorne Formation has been discussed by Taft (1899), Taft and Adams (1900), Oakes and Knechtel (1948), Knechtel (1949), Branson (1956) and McDaniel (1961). Trumbull (1957) and Friedman (1975) reported on the coal reserves and resources in Oklahoma.

CHAPTER II

STRUCTURE

The study area is on the southern edge of the Arkoma basin, 9 miles west of the Arkansas state line and 2.5 miles north of the Choctaw fault (Fig. 3). The structural style in that region of the Arkoma basin is characterized by east-west trending open folds. Dips along the flanks of the folds generally are less than 30°. High-angle dips, overturned strata and associated faults are present along some of the major folds. Thrust and reverse faults are compressional and are related genetically to the more severe folds. Some of the faults have been mapped for tens of miles, parallel to the fold axes. Pine Mountain is on the axis of the eastward plunging Pine Mountain syncline (Fig. 3).

Dip on the south flank of the Pine Mountain syncline is maximally 45° in the vicinity of the Choctaw fault, and is less than 5° on Pine Mountain. Dip measurements from the strip mines of the Hartshorne coal on the south side of Poteau Mountain are north, ranging from 16° to 24°. North of the Pine Mountain axis, in the vicinity of the axis of the Heavener anticline, dips exceed 60°. The Hartshorne coal on the north limb of the Heavener fold has a 10° to

25^{o} dip.

The Choctaw thrust is the only fault that has been mapped in the immediate area; however, another fault with a north-northwesterly trend may be present on the western half of Pine Mountain (Pl. 2). Irregular contours on the Hartshorne coal suggest a displacement of up to 11 feet. An alternative explanation of the irregularity is mapping and surveying error.

CHAPTER III

STRATIGRAPHY

The rock units on Pine Mountain are of the Atoka, Hartshorne and McAlester Formations. The Atoka Formation belongs to the Atoka Group of the Atokan Series and the Hartshorne and McAlester Formations belong to the Krebs Group of the Desmoinesian Series. Figure 4 is a columnar section of the area.

The Atoka-Hartshorne contact is defined as the base of the lowest sandstone of the Hartshorne Formation. The contact is generally gradational but, according to Hendricks (1939), in some "exposures the contact is sharp and irregular, indicating that a minor unconformity separates the two formations." (p. 264) Subsequent investigations have suggested that these local unconformable relationships are actually caused by channeling and changes in the depositional thickness of the Hartshorne sandstone (McDaniel, 1961 and 1968).

The Hartshorne Formation typically consists of a lower sandstone unit, a shale member containing the Lower Hartshorne coal, an upper sandstone unit and a shale member containing the Upper Hartshorne coal. Branson (1956) applied the name Tobucksy sandstone member to the lower

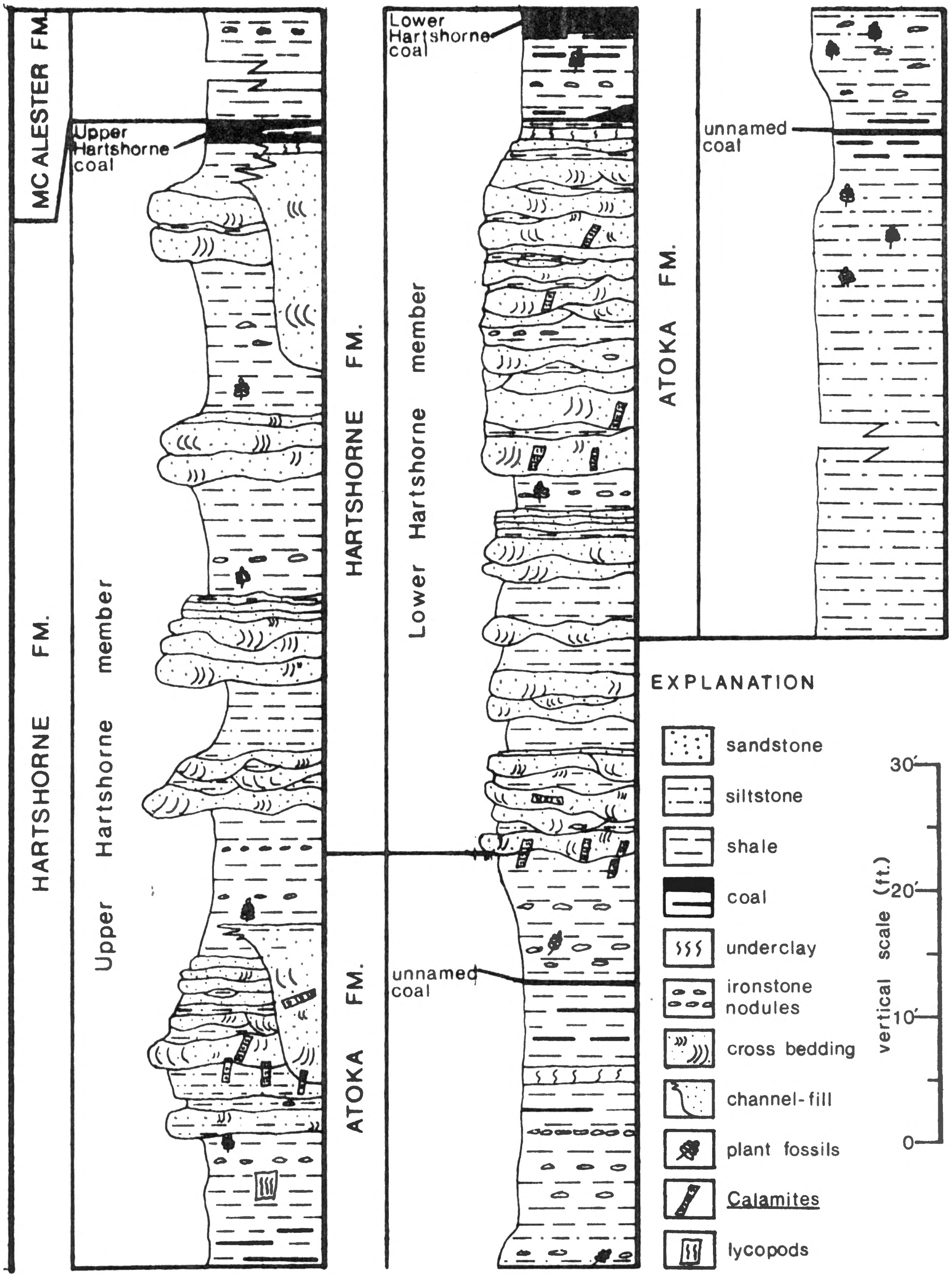

Fig. 4.-Stratigraphic columnar section of study area.

sandstone unit. McDaniel (1961) replaced Tobucksy sandstone with Lower Hartshorne sandstone and adopted Upper Hartshorne sandstone for the upper sand unit. He further refined the nomenclature by "using the top of the Lower Hartshorne coal to divide the Hartshorne Formation into . . . the Upper and Lower Hartshorne members" (p. 68). McDaniel's terminology has been adopted in this report.

The Hartshorne-McAlester formational contact was defined originally as the top of the first sandstone below the Upper Hartshorne coal. Oakes and Knechtel (1948) noted the convergence of the Upper and Lower Hartshorne coals and absence of the Upper Hartshorne sandstone and adopted the top of the Upper Hartshorne coal as the formational contact. Their nomenclature has also been used by Knechtel (1949), Branson (1956) and McDaniel (1961, 1968). Frezon (1962), however, adheres to the earlier usage and considers the Upper Hartshorne coal and lower shale as part of the McAlester Formation.

Atoka Formation

Only the extreme upper portion of the Atoka Formation crops out on Pine Mountain. The formation is predominately interbedded black, carbonaceous shale and gray, coarse siltstone to very fine sandstone, exhibiting horizontal bedding less than 2 mm thick and small-scale cross-bedding. The lower portion of the exposed formation is barren of fossils and burrows. The upper portion contains carbonized plant remnants that grade upward into a splintery, black, carbonaceous shale with thin vitrain bands, and then into coal. Between this lowest coal and the Lower Hartshorne sandstone is a shale sequence containing a siltstone unit with well-preserved plant fossils, siderite beds and nodules, an underclay, vitrain lenses and bands and a thin coal bed, that are of disputable stratigraphic position.

The Atoka-Hartshorne contact could logically be drawn at either the base of the oldest unnamed coal deposited following prevailing marine conditions, or at the base of the first sandstone above the Atoka shale. Hendricks (1939, p. 264) identified the contact as the base of a localized 1.5-foot shaly sandstone lens beneath this lowest coal and wrote that "no coal is known to occur in the Atoka Formation" in that vicinity. Wilson and Newell (1937, p. 25) and Knechtel (1949, p. 14) have both reported coals in the upper Atoka section. I have seen coals that are undisputably Atoka in both Arkansas[1] and within 8 miles of the study area. Following the most common practice in the Arkoma basin the base of the sandstone has been chosen for this report.

The thickness of the two Atoka coals is variable. The lowest coal is present on the southeastern portion of the area, but grades westward into carbonaceous shale. The

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[1] One of these seams, although thin and unnamed, is a high quality, metallurgical coal being mined north of Ozark, Arkansas. I suggest it be named the White Oak seam after the community near which it was first mined.

youngest unnamed coal is 34 inches thick on the north side of the mountain and thins to 7 inches within 400 feet southward. The coal is 4 to 7 inches thick on the south side of the mountain. Analysis of the younger coal shows it contains 3 to 4% sulfur and 10 to 38% ash, qualifying it at best as a low grade steam coal. Complete analyses are tabulated in Table 1. Descriptions of the coal from exploration pits J, K, L and M are in Appendix A.

Hartshorne Formation

Lower Hartshorne Member

The basal contact is conformable, but is scoured into the Atoka and it is marked by upright Calamites extending across the contact. The member is a very fine- to fine-grained sandstone with 1 inch to 3 feet of shale and siltstone beds. Fossils of Calamites are abundant and are generally either upright or have an east-west orientation. Bedding in the sandstone rarely exceed 3 feet in thickness and is characterized by medium-scale trough cross-bedding. Small-scale cross-bedding is evident in some of the flaser-bedded units and some of the thinner sandstone beds. The sandstones have scoured basal contacts. There is repetition near the base of the sandstone where flaser-bedded sandstone, siltstone and shale grade downward into sandstone beds 2 to 4 feet in thickness. Stigmarian roots, not in place, are plentiful on the bench of Lower Hartshorne

Table 1.-Analyses of Atoka coal on Pine Mountain.

Sample ID	Ash	Sul	V.M.	F.C.	B.T.U.	FSI	H_2O
151/C	10.47	3.68	19.75	69.77		8½	
158/C	29.98	3.43					
573-1 Top 22"	18.42	3.86	19.07	62.51	12,388		.95
573-1 Bottom 7", Flt. 1.60	17.34	4.05	19.68	62.98	12,478		1.10
573-2	37.70	4.08			9,065		

sandstone that forms the rim of Pine Mountain. Siderite nodules occur in all lithologies except coal, but are more typical in shale, closely associated with plant remains.

The top of the Lower Hartshorne member is a black to gray fissile shale, containing plant fragments, siderite nodules and coal. There is an underclay at the base of the shale, overlain by a poorly developed coal discussed in the succeeding paragraph. The top of the shale contains abundant, vitrainized, flattened, striated tree trunks in chaotic array. The shale and vitrain lens grade up into the Lower Hartshorne coal. The Lower Hartshorne member is 65-70 feet thick on Pine Mountain.

The poorly developed coal beneath the Lower Hartshorne coal is composed of several 1-inch to 1.5-inch vitrain bands in the U.S. Highway 59 road cut (Pl. 1). Most of the drill holes were too shallow to encounter the coal elsewhere, but an underclay was recorded 6.9 feet below the Lower Hartshorne coal in 154/C (Pl. 1). In drill holes and a mine 0.5 miles east of the study area, the vitrain bands thicken into a 16 inch coal. A composite analysis with the Lower Hartshorne coal shows this to be of metallurgical grade. Based on field work in the area, I suggest that this coal is correlative with a 28-inch coal seam that occurs beneath the 50-inch Lower Hartshorne coal in the vicinity of Hartford, Arkansas, 18 miles northeast of Pine Mountain.

Upper Hartshorne Member

Above the Lower Hartshorne coal is a transitional black shale and vitrain-band sequence, which grades up into a gray shale. Siderite and claystone nodules are abundant. An upright tree cast more than 2 feet in diameter, with a vitrain coating, is visible in the U.S. 59 road cut. Smaller plant fragments are also visible. This shale unit is highly variable in thickness, ranging from zero, where sandstone and siltstone are in contact with the black shale, to 35 feet. The average thickness is 6 to 10 feet and in some places it contains a thin sandstone bed.

In most places the shale is overlain by a flaser-bedded unit of sandstone, siltstone and shale. The flaser-bedded rock is rippled, with small-scaled cross-bedding. In the old strip pit, in the SW¼ of Section 26 (Pl. 1), upright Calamites are spaced approximately 3 feet apart, in situ. They commonly extend beyond the upper contact into the overlying sandstone.

The basal sandstone contact is sharp and has some well developed channel-fill structures (Hendricks, 1939, Pl. 29-A). Upright Calamites and lycopod casts occur at the base of the sandstone, and larger, randomly oriented tree casts are in the upper portion. The beds are usually less than 3 feet thick and commonly are separated by thin shale beds.

As indicated by the driller's logs, alternating sandstone and shales comprise the remainder of the member and they are presumed to have the same lithologic character as the above units. Sandstone thicknesses range from 2 to 35 feet and the shales from 2 to 20 feet. The number of sandstone layers encountered in drill holes varies inversely with the interval thicknesses. The top of the formation is the Upper Hartshorne coal.

The complete upper member is present only in the eastern portion of the study area, where it is usually 85 to 90 feet thick. Less than a half mile east of the study area, where only 15 feet of sandstone is present, the complete member is only 54 feet thick.

The Upper Hartshorne coal was reported in 4 drill holes, but is not known to crop out in the study area. Core hole #8 (Pl. 1) recorded 18.5 inches of coal which contained 1.66% sulfur and 46.62% ash.

McAlester Formation

The McAlester Formation is present only in the eastern portion of the study area and is demarked by the Upper Hartshorne coal outcrop on Plate 1. The formation probably reaches a maximum of 80 to 100 feet of gray shale in the study area.

Depositional Environment of the Atoka, Hartshorne and McAlester Formations

Briggs and Cline (1967) suggested that the Upper Atoka and Desmoinesian lithofacies represent fluctuating shallow marine and continental conditions. Paleocurrent data revealed a southwesterly trend in the northern portion of the basin and a westward trend south of the Heavener anticline (Fig. 3). They also reported that sandstone, coal and plant fragments in the upper Atoka Formation and the Krebs group increase eastward and suggested "a more continental environment towards Arkansas as well as an eastward source of sediments" (p. 997). Merewether (1961, p. 87) concluded that the upper Atoka sediments, containing alternating marine shale units, channel sandstone units and coal beds, "were probably deposited near a shoreline."

An isopach map of the Hartshorne Formation in Arkansas (equivalent to the Lower Hartshorne sandstone of this report) indicated maximum deposition in a strike-oriented basin in the central portion of the Arkoma basin, with sources to the north, east and south (Haley, 1961). McDaniel (1968) illustrated thickening along an east-west axis and a west to southwest current direction in the Lower Hartshorne member in Oklahoma and summarized the unit:

> 1. Lithologically, the unit grades from a sandstone to a shale (no carbonates).
> 2. The unit contains sedimentary features such as boring and churning, cut-outs, cross-bedding and ripple marks.
> 3. The unit is unfossiliferous with the exception of abundant plant material.
> 4. The thicker sandstone bodies are delta-distributary channels.
> 5. The unit is alluvial on the east and becomes progressively marine westward; it is a regressive unit. (p. 1696)

Wynn (1965), however, suggested that the Hartshorne sandstone in that part of Oklahoma represents a series of offshore bar deposits.

Haley (1961) concluded the following about the McAlester Formation in Arkansas:

1. The McAlester Formation exhibits the same longitudinal thickness trends as the Hartshorne Formation.
2. The thickness of the Lower Hartshorne coal varies inversely with the thickness of the underlying Hartshorne sandstone.
3. Some of the Hartshorne sandstone beds were deposited contemporaneously with the Lower Hartshorne coal and during the time the McAlester Formation of Arkansas was deposited.

Karvelot (1973) studied the McAlester Formation 30 miles north of Pine Mountain and concluded that it was primarily shallow marine and secondarily prodelta, interdistributary marsh and swamp.

Atoka Formation

The Atoka sequence exhibited in Fig. 4 indicates a shallow-water to swamp environment. The lower portion of the unit was deposited in a moderately low-energy regime receiving a steady influx of fine-grained sediments. The clear association with coal establishes it as shallow water. Megascopically, the beds are similar lithologically to the fine-grained laminated rocks found in many continental-margin environments, but lack the faunal burrows and glauconite of prodelta, interdistributary bay and tidal-flat environments described by Fisk (1961), Coleman and Gagliano (1964, 1965), Reineck (1972), Shelton (1973) and Reineck and Singh (1975). The occurrence of well-preserved plant matter grading up into shale and vitrain bands and then coal above the section barren of fossils, represents the gradual attainment of a terrestrial environment, reduction in the hydraulic gradient and the subsequent establishment of swamp conditions. The organic shales, laminated siltstones, ironstone nodules and plant remnants indicate that the swamp environment existed until deposition of the Hartshorne sandstone, a conclusion consistent with observations made in a modern environment, the Mississippi delta (Coleman and Gagliano, 1965). Abundant siderite nodules and beds and high sulfur content in the uppermost Atoka coal suggest the influence of marine to brackish water. The occurrence of underclay, coal, vitrain bands and lenses and carbonaceous plant matter are the results of an active hydraulic gradient and fluctuating water level.

The Atoka rocks described here probably are deltaic. The lower portion suggests laminated, delta-front or delta-fringe clastics deposited in a prograding delta. Fisk (1961) found only sparce fossil fauna in the delta-front facies of the Mississippi delta. The upper portion represents marsh and swamp deposits of the deltaic plain.

Hartshorne Formation

The Hartshorne sandstone was deposited in a fluvial environment. The regional geometry of the formation as described by Haley (1961) and McDaniel (1968) shows thickening along an east-west axis. The scour contacts, channel-fill features, medium- and small-scale cross-bedding, flute casts and prod marks, all indicate a flow regime. The immature texture and fabric of the sandstone indicate minimal reworking and winnowing. The occurrence of 1) upright Calamites at the base and elsewhere in the formation, 2) Stigmarian roots, 3) lycopod trunks and 4) coal and vitrain bands require a continental facies. Although the lack of glauconite in this section does not exclude a marine environment, it suggests continental conditions. The abundance of siderite in the sandstones and shale are criteria used by Shelton (1973) to differentiate siderite-bearing deltaic facies from nonsideritic alluvial facies.

The above indicates either an alluvial deposit, or deltaic deposit. The internal features of a distributary channel and alluvial plain are often very similar. To qualify as a deltaic deposit, two requirements must be met: 1) it must be a "subaerial and submerged contiguous sediment mass deposited in a body of water" (Moore and Asquith, 1971, p. 2566), and 2) the deposition must be primarily due to, and take place where a river system bifurcates (Pettijohn et al., 1972).

The close proximity of the Hartshorne Formation to a marine environment is evident. Merewether (1961), Briggs and Cline (1967) and Karvelot (1973) have interpreted the Desmoinesian and Atoka shales bounding the Hartshorne to be marine. Locale 1 (Table 2 and Figure 3) indicates that a swamp built upon marine shales was directly south of the sandstone trend of Pine Mountain during deposition of the upper and lower members. Locale 2 indicates the east-northeast extension of the sandstone trend or a local branch parallel to it. Locale 3 delineates the northern limits of this channel system and indicates an aqueous environment. Locale 5 suggests a shallow, brackish to marine milieu at the onset of Hartshorne deposition as does the described Atoka Formation on Pine Mountain.

The bifurcation of Hartshorne channels is not readily apparent, but at least the upper sandstone member occurs in discrete channels. The clearest case is the isolation of the upper sandstone member on Pine Mountain by locales 1 and 3 as stated above. Reference to locales 4 and 5 shows the sandstone recurs further north. Isolated sand bodies are also apparent from the mapping of Haley (1966).

McDaniel (1968) mapped a major Lower Hartshorne distributary channel 18 miles north of Pine Mountain and considered the upper portion of the lower member on Pine Mountain as alluvial. The nature of the formation at locale 1 suggests a deltaic environment for the whole member.

The upright <u>Calamites</u> and <u>Lepidodendron</u> at the base of

Table 2.-Locale description (for locations refer to Figure 3).

Locale 1: Sec. 26, T. 5 N., R. 26 E., Oklahoma, eight miles east of Pine Mountain along the Hartshorne coal outcrop south of Poteau Mountain. The formation is predominately swamp and marine. The total thickness is 25 to 35 feet and comprised of shale, siderite nodules and coal and vitrain beds of varying thicknesses. The Upper Hartshorne sandstone is absent and the Upper Hartshorne coal is present only as a coaly-shale interval above the Lower Hartshorne coal. The Lower Hartshorne sandstone occurs only as local sandstone lenses a few feet thick.

Locale 2: Sec. 14 and 15, T. 4 N., R. 31 W., in Arkansas, 22 miles northeast on the Hartshorne coal outcrop north of Poteau Mountain. Both the upper and lower sandstone members (Oklahoma nomenclature) are present. The boundaries of each are undetermined due to a splitting of the Lower Hartshorne coal into 4 or more coal beds separated by sandstone, all within a 30-foot interval. Both sandstones are relatively thin and have a fluvial nature.

Locale 3: Sec. 2, T. 6 N., R. 32 W., Arkansas, north of the Hartford anticlinal axis. The Upper Hartshorne sandstone is a laminated siltstone and shale similar to the lower Atoka section on Pine Mountain and was probably marine influenced. The Lower Hartshorne member is sandstone, less than 100 feet thick.

Locale 4: Sec. 20, T. 5 N., R. 31 W., Arkansas, north of the Cavanal synclinal axis. The lower sandstone is more than 200 feet thick and the upper sandstone is in excess of 50 feet. Both are fluvial.

Locale 5: Sec. 5, T. 8 N., R. 25 E., Oklahoma, north of the Bokoshe anticlinal axis. The Lower Hartshorne member is laminated siltstone and shale. The higher sulfur content in the bottom 5 inches of the Lower Hartshorne coal suggests that the laminated sediments below were deposited in brackish or marine water. The upper member is 40 feet thick, 20 feet of which is sandstone.

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the Upper Hartshorne sandstone indicate fairly rapid sedimentation with a relatively low current velocity. The laminated character of the siltstone and shale indicates pulsating sedimentation. Greensmith (1966) reported lepidodendroid tree trunks in place in a finely-laminated, delta-plain siltstone. He suggested their preservation was due to "an abnormally high rate of crevasse-splay silt deposition" (p. 193).

I judge that the Hartshorne Formation is part of a deltaic plain deposit formed during the regression that marked the end of Atokan time. The sandstones are minor distributaries and interdistributary channels. Evidently some of the laminated siltstones and shales are overbank deposits such as crevasse-splays, but their full extent is unknown. This would account for the preservation of the numerous upright plant casts. The shale and coal deposits are swamp facies influenced by varying degrees of submergence, salinity and hydraulic gradients.

McAlester Formation

The limited exposure of shale of the McAlester Formation of Pine Mountain makes any environmental interpretation difficult. From Karvelot (1973), Briggs and Cline (1967) and Haley (1961) it appears to be a shallow-marine shale.

CHAPTER IV

GEOLOGY OF THE LOWER HARTSHORNE COAL

Geometry

The outcrop of the Lower Hartshorne coal is different than that shown on the geologic map of the Howe-Wilburton District (Hendricks, 1939) and that determined by two private companies.[1] Hendricks, without benefit of the extensive, post-1946 drilling, mapped the coal west of the center of sections 27 and 34, more than one mile east of the westernmost outcrop examined during this study. Errors by the private companies were the result of confusing a stratigraphically lower, unnamed coal with the Lower Hartshorne.

The actual outcrop of the coal generally follows the sides of the mountain. Two important deviations are along the northern outcrop in sections 25 and 26 and along the southern outcrop in section 36 (Pl. 1). In these areas the outcrop of the Lower Hartshorne coal recesses toward the synclinal axis of the mountain. This recession is well displayed on aerial photos by the ridge formed by the overlying sandstone.

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[1] Because the data provided by the private companies is proprietary, the two names will not be mentioned.

Plate 2 is a structural contour map based on the top of the Lower Hartshorne coal. Pine Mountain is an eastward plunging syncline. The fold axis closely follows the center of the mountain and, on the western half, maintains a plunge of less than 1 degree. On the eastern half, the plunge increases to over 2 degrees. The maximal dip on Pine Mountain is 6 degrees.

As shown by the isopachous map of the overburden (Pl. 3), the depth of the coal ranges from outcrop to over 100 feet in W½, section 25. The deepest drill hole on the mountain penetrated the coal at 113 feet. A maximal depth of 180 to 200 feet is suggested by projecting the plunge of the syncline to the eastern edge of the study area.

The depth to coal is fairly uniform in sections 26, 27, 28, 33, 34, and 35; the overlying sandstone acts as a cap rock and the topography follows the structural contour. The shallow overburden depths parallel to the axis of the mountain reflect the major drainage system. The decrease in overburden east of the strip pit in section 26 is the result of the drainage system coinciding with a leveling-off of the axial plunge. The increase in overburden in the NE¼, NE¼, section 35 is topographic and reflects an increase in sandstone thickness. In sections 25 and 36 the overburden thickness is structurally controlled.

Plate 4 is an isopach map of the Lower Hartshorne coal. The thicknesses are highly variable, with a maximum and minimum of 50.4 and 11.5 inches, respectively, and an average thickness of 28.4 inches.

The variation in thickness is both depositional and tectonic in nature. The former is exemplified by the U.S. Route 59 road cut in N½, NW¼, section 36 (Pl. 1). The coal at that location can be seen to thin and thicken from 24 inches to 18 inches to 33 inches within 200 feet. There is a 16-inch to 18-inch band that can be identified along most of the exposure. The thickness variations are due to lithologic changes above and below this 18-inch band; the rocks are transitional from coal through shaley coal to shale. Where the coal is thinner, only the middle 18-inch band is present and the top and bottom contacts are sharp, coal against shale. In the thicker areas, either the top or bottom or both show a transition to coal.

Tectonic effects were well illustrated in outcrop hole 0 by coal thicknesses measured on different sides of the 8-foot by 3-foot hole:

South side	21 inches
Southeast side	16 inches
East side	18 inches
North side	11 inches
West side	13 inches

The 10-inch variation was caused by folding and small-scale faulting. Bedding planes were discontinuous and slickened sides were abundant. In some places the top of the coal was shaley; in others non-shaley coal had been brought to the top of the bed along distinct thrust planes.

The coal has two well-developed cleat faces. They are N. 75° E. to East-West and N. 25° W. to North-South. These are sub-parallel and sub-perpendicular, respectively, to the fold axis.

Coal Analysis

Selected analyses are in Table 3. The Lower Hartshorne coal of the study area ranges from 22 to 30% volatile matter (dry, ash-free or d.a.f.). The rank of coal, based on USBM standards, ranges from the low-volatile/medium-volatile bituminous border at 22% volatile matter or V.M. (d.a.f.) to a lower rank medium volatile bituminous coal. Average vitrinoid reflectance values of 1.29%, 1.28% and 1.24% are in agreement with the above.

The heat energy given off by each pound of run-of-mine coal will naturally vary depending upon the ash content. BTU values of a dry, ash-free product range from 15,000 to 16,000 and average around 15,500 BTU. The calculated heat value of a dry 12% ash steam coal product is 13,700 BTU.

The coal of this study has low inherent moisture, .8 to 4.95%; and an average of less than 1.5%. This is beneficial for two reasons: 1) it effectively increases the BTU/T of the run-of-mine product from that of a high-moisture coal with an equivalent dry, ash-free heating value, and 2) it is well below the maximum penalty-free moisture allowed in some metallurgical coal contracts.

Separate analysis of the top, middle and bottom portion

Table 3.-Selected analyses of the Lower Hartshorne coal.

Hole No.	Coal Thickness (In.)	Top Segment						Middle Segment						Bottom Segment					
		In.	Ash	S	V.M.	F.C.	FSI	In.	Ash	S	V.M.	F.C.	FSI	In.	Ash	S	V.M.	F.C.	FSI
152	27.0	6.6	30.6	3.68	16.6	52.8	4.5	20.4	8.8	1.71	20.2	71.0	+9						
153	21.8	6.0	7.9	.53	20.3	71.8	+9	15.8	6.7	.68	20.8	72.5	+9						
154	13.6	7.6	15.0	3.77	20.9	64.1	+9	6.0	8.1	.65	22.1	69.8	+9						
155	29.0	6.2	27.9	5.91	17.6	54.5	8	22.8	11.3	1.67	20.0	68.7	+9						
156	30.0	6.4	23.8	2.74	22.5	53.7		18.2	10.9	.96	26.1	63.0		5.4	28.9	.77	23.9	47.2	
157	30.0	6.4	35.7	3.22	22.9	41.4		17.8	7.7	1.24	25.0	67.3		5.9	15.8	.75	23.4	60.8	
159	31.2							31.2	13.16	1.53									
160	38.4	7.2	28.97	5.15				28.8	10.06	1.58				2.4	46.62	1.18			
161	31.8	6.2	20.9	7.73	24.4	54.7	8.5	18.5	9.5	1.64	25.9	64.6	9.0	7.1	21.0	1.16	23.2	55.8	8.5
162	19.5	6.2	11.8	1.99	23.5	64.7	9.0	7.3	11.7	1.0	26.1	62.2	+9	6.0	15.3	.75	23.1	61.6	9
163	28.8	3.6	23.65	6.19				25.2	12.38	1.33									
165	16.8							16.8	14.8	.9	22.1	63.1	9						
166	30.0	6.0	10.5	1.35	22.7	66.8	+9	18.0	8.0	.81	22.3	69.7	9	6.0	5.5	.88	23.7	70.8	+9
167	11.5	7.32	12.5	2.66	23.4	64.1	+9	4.2	23.6	1.86	21.0	55.4	7.5						
168	28.8	5.4	30.1	5.25				16.8	7.0	1.21	23.3	69.7	+9	6.6	43.1	1.13			
169	34.2	6.6	29.2	4.47	18.5	52.3	5.5	21.0	11.9	1.18	23.0	65.1	+9	6.6	12.3	.91	22.4	65.3	9
170	22.8	6.0	35.4	4.34	18.6	46.0	7	10.2	12.9	2.86	22.1	65.0	8	6.6	14.4	1.15	21.6	64.0	8
172	27.0	5.8	20.78	7.46	23.36	55.86	8.5	15.2	8.96	1.07	26.45	64.86	8.5	6.0	9.35	.75	26.0	64.65	8
173	22.4	6.5	27.27	6.8	23.3	49.43	7.5	10.2	12.5	2.32	26.6	60.8	8	5.8	7.92	.71	36.56	65.52	8
174	27.6	6.6	18.71	4.89	26.82	54.47	8.5	14.9	10.87	2.37	23.48	65.65	8.5	6.1	19.86	.93	22.92	57.22	6.5
175	50.4	6.4	27.08	6.39	22.45	50.47	7.5	38.3	11.29	2.21	24.38	64.33	8.5	5.8	15.99	1.04	25.33	58.68	8.5
176	22.6	6.4	11.10	1.94	26.19	62.71	7	10.6	8.1	.69	27.3	64.6	7.5	5.6	21.8	.86	24.4	53.7	7.5
177	21.8	5.6	13.0	2.91	25.4	61.6	8.5	9.4	9.3	1.15	26.0	64.7	8.5	6.8	20.4	1.01	25.8	53.8	8
178	29.2	7.6	17.56	5.14	24.89	57.55	8	15.6	9.88	1.79	26.73	63.39	8.5	6.0	15.77	.85	27.23	52.00	8

S = Sulfur content
V.M. = Volatile matter
F.C. = Fixed carbon
FSI = Free swelling index

of the coal cores show significant trends with respect to sulfur (Fig. 5) and ash. These trends can be observed in the core profiles in Appendix B. The top 6 inches of coal is usually high in sulfur content, normally in the 2% to 6% range. The ash in the top is typically above 12%, less than 30% and averages more than 20%. The middle, where most of the coal is situated, has a sulfur range of .6 to 2.3% and has an ash content generally less than 12%. The bottom six inches is always low in sulfur, exhibiting a maximum of 1.2%. Unfortunately, the ash is commonly high, due to a fissile, coal-shale mixture. The full-seam average of most recent cores, including the high-sulfur top, is approximately 2% sulfur and 14% ash. The average, excluding the top 6 inches, is 1.36% sulfur and 12% ash.

Generally sulfur increases from east to west along the mountain. This trend is evident in Tables 5 and 7, by comparing the percent of metallurgical coal yields versus the steam coal yields of each property.

The coal is strongly agglomerating as indicated by free-swelling indices greater than 7. Only core segments with very high ash content, which are unacceptable as metallurgical coal, have indices less than 7.

Coal Petrology

The petrologic nature of the coal was studied using two methods. Twenty-one cores were logged megascopically (Appendix B, Ten Selected Verbal Gravity Logs), and six coal

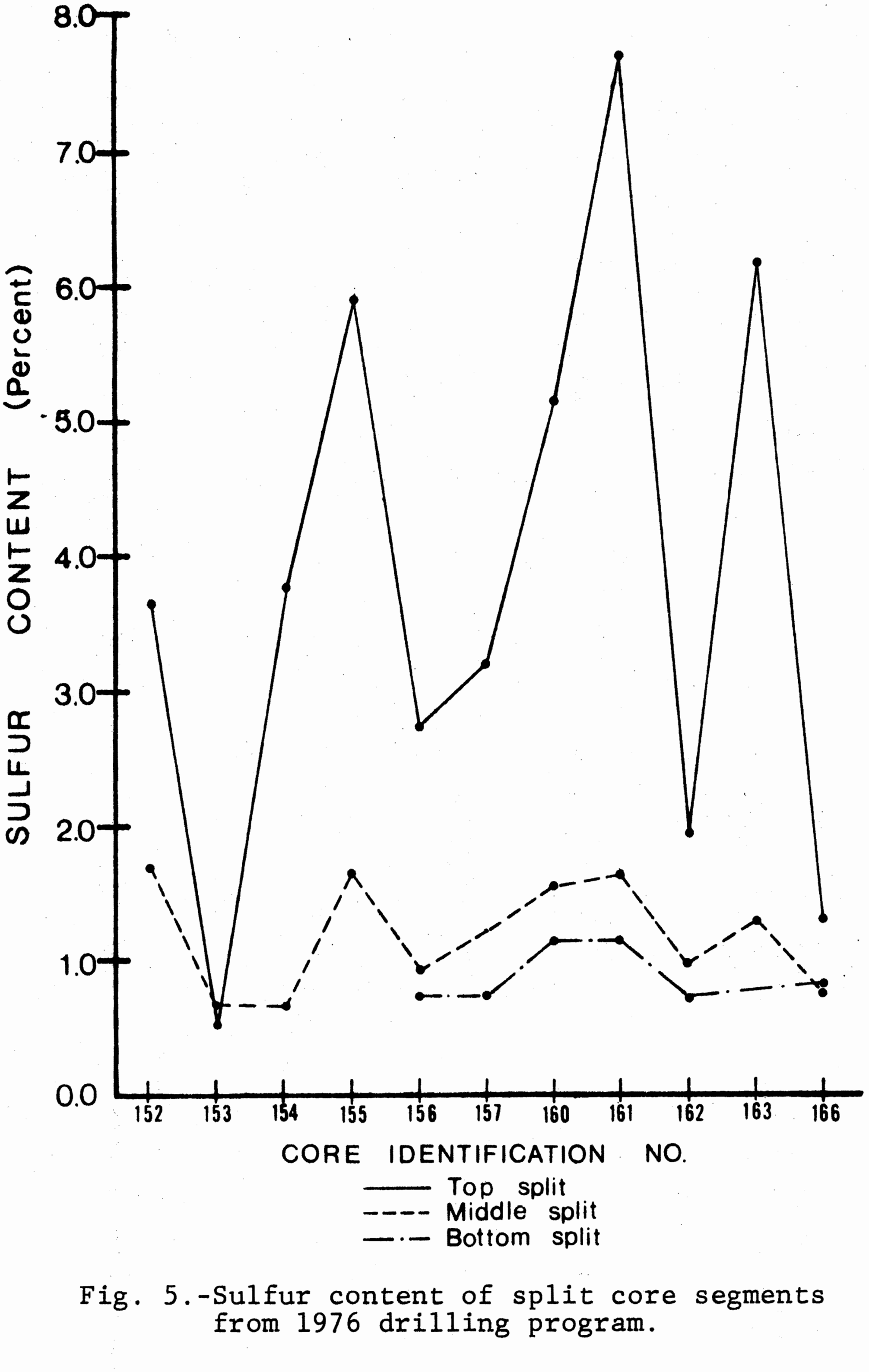

Fig. 5.-Sulfur content of split core segments from 1976 drilling program.

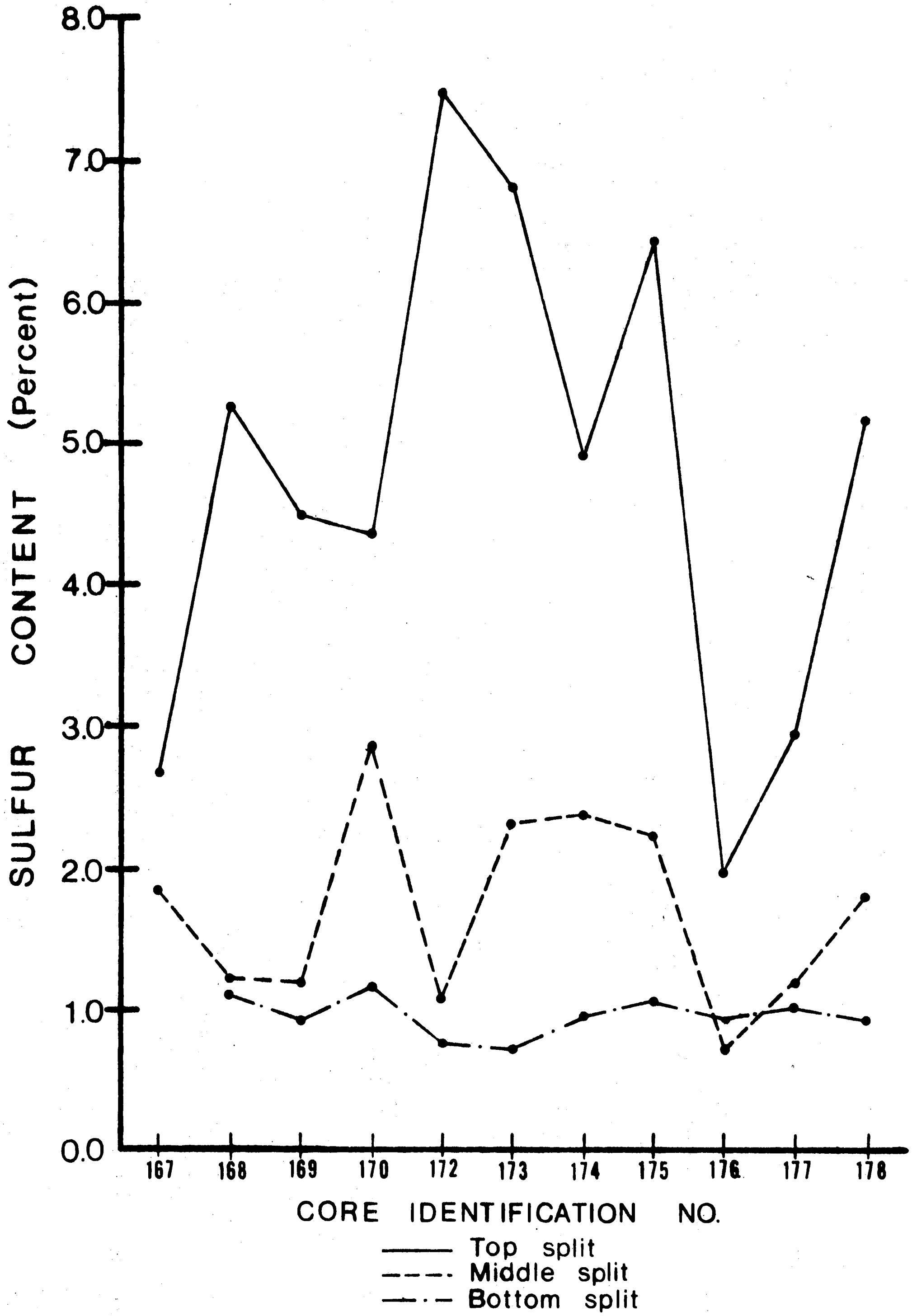

Fig. 5.-(continued)

samples were analyzed microscopically for maceral composition and reflectance (Table 4, Petrographic-maceral composition of indicated coal samples).

The graphic gravity logs contain a description of the luster, lithotype, accessories and specific gravity of a specified thickness of the core. The thicknesses vary, dependent on natural breaks, i.e., bedding planes and changes in coal character. The lithotypes clarain and durain can be inferred from the description; clarain has bright to intermediate luster and has recognizable, though thin, vitrain bands; and durain is dull with less than 1.40 s.g. Durain can be differentiated from boney coal[2] by both specific gravity and fissility: the shale gives the bone high specific gravity and a splintery texture. In the following paragraph, I have translated the data from the graphic gravity logs into the lithotypes of the Stopes-Heerlen System.

The predominant lithotype on Pine Mountain is clarain. It occurs with both bright and intermediate luster, the former being the more abundant. The luster of the clarain differs with the amount of vitrain bands, durain, fusain and mineral impurities present. Vitrain occurs as bands in the clarain, ranging from sparse to abundant, and as separate bands. Although none of the cores showed vitrain bands thick enough to qualify them as lithotypes by Stach's (1975,

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[2] Boney coal is an intimate mixture of black carbonaceous shale and coal in which neither is clearly recognizable macroscopically. It commonly exhibits the fissility of shale and the cleat structures of coal.

Table 4.-Petrographic-maceral composition of indicated coal samples.

Reactive Macerals (%)	156/C	166/C	172/C	101/CS	135/CS	100/S
Vitrinoid Type 11		12.6	0.8			
12	54.7	70.4	57.2			2.4
13	25.7	0.8	19.9	23.9	26.9	55.2
14	2.5		1.6	55.3	53.8	22.4
15				3.3	.8	
Exinoids	-	-	-	-	-	-
Resinoids	-	-	-	-	-	-
Semifusinoids	1.0	0.6	1.5	0.4	0.5	0.8
Total	83.9	84.4	81.0	82.9	82.0	80.8
Inert Macerals (%)						
Semifusinoids	1.9	1.2	2.9	1.5	2.1	1.5
Micrinoids	6.0	6.7	6.9	7.1	7.5	5.7
Fusinoids	1.9	3.5	4.0	4.3	4.3	3.6
Mineral matter	6.3	4.2	5.2	4.2	4.1	8.4
Total	16.1	15.6	19.0	17.1	18.0	19.2
Composition Balance Index	.75	0.62	0.89	1.19	1.24	1.19
Rank Index	5.14	4.65	5.11	6.70	6.64	6.18
Average Vitrinoid Reflectance, %	1.29	1.24	1.28	1.43	1.42	1.38
Calculated Stability Factor	64	62	64	+65	+65	+65

p. 133) definition, some are present in outcrop. Durain is usually present in the upper portion of the seam, but can occur in the lower and center portions. It is usually closely associated with dull coal having a higher specific gravity. The relationship between the durain and mineral impurities within these high specific-gravity, dull coals is unclear. Fusain usually occurs as lenses within the other lithotypes and rarely as distinct bands.

The macroscopic accessories are pyrite, shale and calcite. Pyrite generally occurs as lenses, fine particles, in cleats and rarely in distinct bands. It is megascopically visible throughout the seam. Carbonaceous shale is present in a range of forms: from distinct shale bands to a boney-coal-shale mixture, to a high specific gravity dull coal, to microscopic impurities. The shaley material appears throughout the seam, but is usually in the upper 1/3 of the seam and less often in the lower 1/4. There is a distinct shale-bone band less than 1 foot from the bottom of the seam that can be correlated through 7 coal cores representing the south-central portion of the mountain. Calcite is rare and is found in the cleats.

Graphic gravity logs have been used to correlate seam sections over many tens of square miles (W. F. Berry, W. F. Berry and Associates, Pittsburg, Pa., personal communication, 1976). The only clear correlation within the coal is the aforementioned shale band. This suggests a highly variable environment.

The petrographic-maceral composition analyses are classified according to the Spackman System (Berry et al., 1967, p. 11). The terminology includes vitrinoids, exinoids, resinoids as reactive components and fusinoids, semifusinoids, micrinoids and mineral matter as inert components. Vitrinoids correspond to vitrinite of the Stopes-Heerlen system. They are broken down into 20 V-types based on percent reflectance and are designated V-4, V-5, V-6 . . . V-24. V-12, for example, includes all the vitrinoids that have reflectance values between 1.150 and 1.249%. Exinoids and resinoids correspond to the exinite maceral group, exinoids representing the macerals sporite, cutinite, and alginite and resinoids representing resinite. Fusinoids corresponding to fusinite, and micrinoids, corresponding to micrinite and fine detrital coal such as inertodetrinite, represent the inertinite group. Semi-fusinoids, though showing the characteristics of semi-fusinites, are classified as 1/3 reactives and 2/3 inerts. This is because of their semi-reactive nature. The reactive and inert components are determined and tabulated accordingly. The totals and the different V-type categories then become the basis for calculating the Composition Balance Index, Rank Index, average vitrinoid reflectance and the calculated stability factor. For details on the use and calculation of these data, refer to Appendix C.

Of the six samples analyzed, 3 represent washed fractions. Sample 166/C represents a composite of the top, middle and bottom core sections washed at 1.40 s.g. Sample 101/CS is of a full-seam channel sample washed at 1.50 s.g. and sample 135/CS is a full-seam channel sample washed at 1.55 s.g. Samples 156/C and 172/C represent the raw middle core section and composite middle and bottom sections, respectively. Sample 100/S is of a stockpile sample.

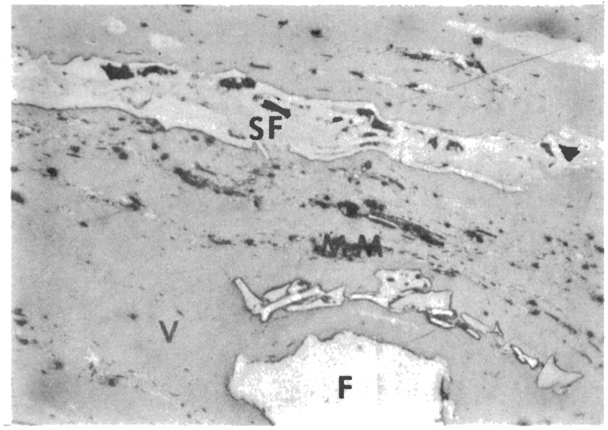
The vitrinoid types range from 11 to 15, average 12.9, and have average vitrinoid reflectance values ranging from 1.24 to 1.43 for the six samples. Vitrinoids comprise between 79.5 and 83.8% of the samples. There is a bi-modal distribution centering on 12 and 14. Samples 166 and 172, from the west half of the mountain, and 156, from the south-central, are centered around 12, whereas 101/CS and 135/CS, taken from the Heavener strip mine in the northeast portion, are centered around 14. This suggests an increase in rank in the east portion of the mountain, which is the same trend recognized throughout the Arkoma basin. The same trend is also evident by comparing the volatile matter of the different coal-cores. This evidence should shift the boundary that separates areas of medium- and low-volatile coals (Trumbull, 1957) to the east to bisect the eastern portion of Pine Mountain.

There are no exinoids or resinoids in any of the microscopic samples. As rank increases and the V.M. yield decreases to about 28%, the coal passes through the coalification jump, and the tars and gasses within the exinite macerals become volatile and are emitted. Below 28% V.M., the exinite reflectance increases until it becomes indistinguishable from vitrinite (Stach, 1975, pp. 68, 95). This obliterates traces of sporite, cutinite, resinite and alginite that could otherwise be used to determine the coal's origin.

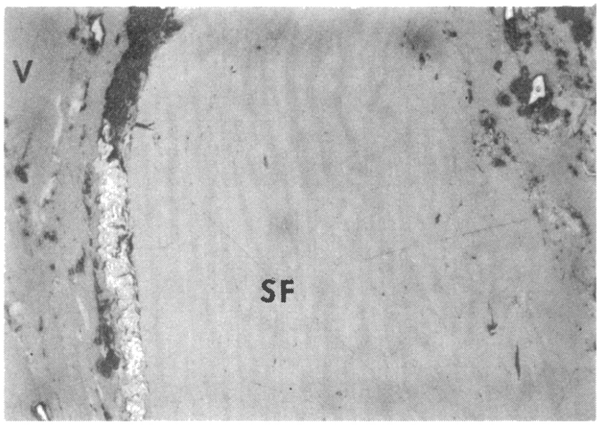
Semi-fusinoids comprise 1.8 to 4.4% of the coal samples. A common practice is to distribute 1/3 of them to the reactive components and 2/3 to the inert (Mackowsky, et al., 1967). Figures 6A and 6B (cores 172/C-A and 166C-B) show semi-fusinoids to be gradational and closely associated with vitrinoids and fusinoids.

Micrinoids account for between 5.7 and 7.5% of the coal and are characterized by high reflectance and small size. The micrinoids identified in the photomicrographs in Figure 6C are comprised of the macerals inertodetrinite and micrinite and are commonly associated with high mineral matter concentrations. Some of the inertodetrinite appears to be very fine fusinite and semi-fusinite particles. Teichmüller (Stach, 1975, p. 229) suggests that micrinite is related to and has possibly formed from exinite macerals and that they are preferential to the sapropelic facies. Micrinite, though traditionally classified with the inert components, is actually high in volatile matter.

The fusinoid content ranges from 1.7 to 4.3% of the petrographically analyzed coal samples. Based on the abundance of fusain lenses within the bright coal, the occurrence of "bogen" or "star" structure signifying cell

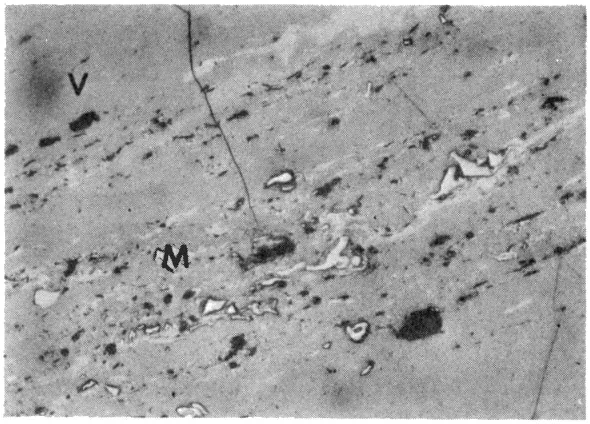


A. 172/C

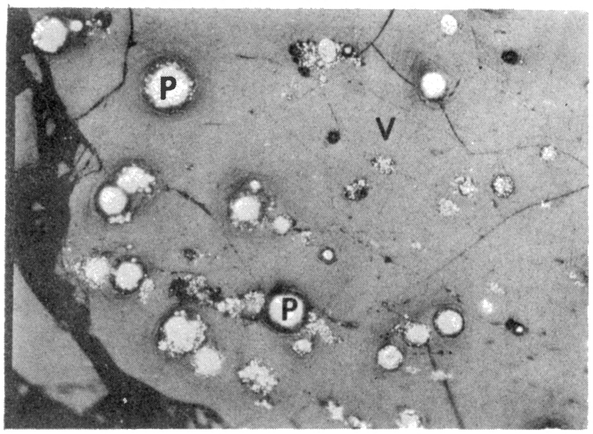


B. 166/C

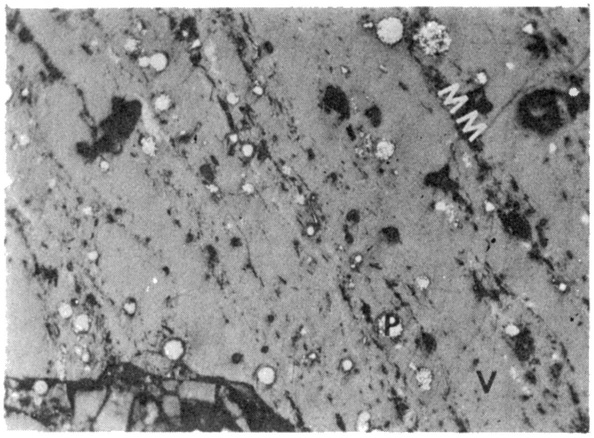
Fig. 6.-Photomicrographs of selected coal samples. V = vitrainoids, F = fusinoids, SF = semifusinoids, M = micrinoids, MM = mineral matter, P = pyrite. (Reflected light, oil, X400).



C. 156/C



D. 101/CS Raw Coal



E. 101/CS Washed ¼" x 0

Fig. 6.-(continued)

structures and the lack of any other evidence against it, the fusinite probably is pyrofusinite or degradofusinite.

Mineral matter ranges from 4.1 to 8.4%. Samples 166, 101/CS and 135/CS were all washed and show the lowest percentages. Photomicrographs show the mineral matter to be pyrite and clay-size particles. The pyrite typically occurs as fine disseminated framboids ranging from 20 microns to sub-micron in size (Fig. 6D). Framboidal texture is thought by many to indicate bacterial genesis (Park and MacDiarmid, 1970, p. 133). The mineral matter occurs in boney coal and also as fine particles throughout the vitrinoids. Figure 6E shows disseminated pyrite and mineral matter retained after being washed at a specific gravity of 1.55. Washing has little effect on the removal of such constituents.

Composition Balance Indices, or Inert Indices, range from .62 to 1.24. Coals taken from the Heavener strip pit all have C.B.I. values greater than 1.0 indicating slightly more inerts than the optimum. The other samples, being less than 1.0, have slightly less inerts.

The Rank or Strength Indices range from 4.65 to 6.70. Once again, the Heavener strip mine samples are clustered on the high end. This can be directly related back to the vitrinoid reflectance values. Vitrinoid types 14 and above have rank indices greater than 6, whereas vitrinoid type 13 will never reach 6, and V-11 and V-12 never exceed 5.

The range of the calculated stability factor is 62 to +65. These values are desirable in that they predict greater than 62% of the coke produced from the Lower Hartshorne coal in the study area will be retained on a 1-inch sieve after a standard tumbler test (ASTM D 294). This implies that the coke will remain in large pieces when transferred into a blast furnace; that it will provide the proper support needed to bear the weight of the overlying burden; and that it will have adequate permeability for transmittance of hot air blasts.

Origin of the Lower Hartshorne Coal

The origin of the Lower Hartshorne coal is due to the autochthonous accumulation of woody material and plant foliage in a stagnant, reducing, aqueous environment. Vitrinite (or vitrinoids), the most abundant constituent, is thought to be the coalification product of woody material and bark (Stach, 1975, p. 59, 61). This is supported by the bark striations in vitrain bands in the floor rock. Mackowsky (1968, p. 328) thought this preservation could only result from completely anerobic conditions, whereas the inertinite (inert) constituents usually undergo some degree of atmospheric exposure. The latter would stand true for both pyrofusinite or degradofusinite. Although no exinite macerals were identified, the flora present must have yielded some sort of spores, resin or cuticles. These are either unrecognizable due to the coal rank or they may have been destroyed by oxidation during formation (Chandra and Taylor, 1975, p. 144). The latter would be indicative of a highly fluctuating water table, because any prolonged atmospheric exposure would also obliterate the vitrinites.

As shown by the fossils bounding the coal, Calamites, lycopods such as Lepidodendron and Sigillaria, and fern-like foliage like Neuropteris were the coal-forming plants. Calamites, related to the modern jointed grass Equisetum, are the most abundant tree-like fossils on Pine Mountain. Williamson (1967) thought they were aquatic plants that could reach heights of over 50 feet and could establish on a poorly-consolidated swamp substrate. I observed Calamites casts with diameters ranging from less than 1 inch to over 12 inches. These plants formed a very dense jungle-like swamp in which the trunks were as little as 3 feet apart.

Fossil tree trunks larger than 2 feet in diameter are in the road cut and Pine Mountain strip it. These are well within the 2-meter maximum for Lepidodendrons suggested by Delevaryas (1962, p. 36). Although these trunks have vitrainized periderms and are not readily identifiable, I think they are lycopods. Tidwell (1975, p. 51), noted the structure of Sigillarian and Lepidodendron roots and aerating tissue and concluded they were fresh to brackish water plants. Williamson (1967) suggested they needed a firmer substrate than Calamites. These observations are supported by the absence of lycopod genera in the Atoka section and the abundance of Stigmarian roots at the top of the non-marine Lower Hartshorne sandstone.

Coleman and Gagliano (1965) observed that the most extensive swamps on the Mississippi Delta were best developed on the upper delta and that smaller swamps were found in isolated basins within the active delta. The geographic extent of the Lower Hartshorne coal and the occurrence of lycopods suggest an upper delta origin.

Sulfur in Coal

Investigation into the cause of the sulfur trend is warranted because of its economic importance on Pine Mountain and its potential application elsewhere. Numerous workers have associated high-sulfur coals with marine influences (Mackowsky, 1968, p. 316; 1975, p. 128; Teichmüller and Teichmüller, 1975, p. 27). Altshuler (1978) studied Florida peats and reported high sulfur contents associated with marine peats and low sulfur contents with non-marine peats. Williams and Keith (1963) concluded that the Lower Kittaning coal of Pennsylvania exhibited higher sulfur where overlain by marine overburden than where overlain by continental rocks. Karvelot (1973) reported that the Stigler coal in Oklahoma was higher in sulfur where overlain by marine sediment than where associated with non-marine sediments. Studying the Charleston coal near Charleston, Arkansas, I have determined that the bottom 4 to 6 inches of coal has a much higher sulfur content than the upper portion. The high-sulfur bottom can be traced for over 10 miles, the limit of control, from a zone in the lower portion of the coal, to a distinct band separated from the upper portion by a 1 mm-thick shale band, to a definite coal bed separated from the rest of the coal by a 5 inch shale layer. This lower portion contains 2 to 3 times more sulfur than the upper portions. Although no fossils are evident in the shale band and the nature of the underlying shale is unknown, the break in coal deposition and contrast in sulfur contents are significant. Other work that I have done with Arkansas coals has shown both high sulfur-marine and low sulfur-continental correlations.

From the above, I believe that the sulfur trend in the Lower Hartshorne coal on Pine Mountain is influenced by the salinity of the swamp environment. The low-sulfur, shaley bottom was probably controlled by fresh water in-flow. Deposition of the middle portion of the coal represents a low-hydraulic gradient and fresh to slightly brackish water. The "boney" high-sulfur top is the result of a marine transgression.

Origin of Rank

The rank of coal as determined through volatile matter content generally follows "Hilt's law"; the volatile matter decreases with increasing depth. Rather than being a function of increased pressure with depth, this relationship is due to increased temperature with depth, the geothermal gradient (Teichmüller and Teichmüller, 1968).

The rank of coal in the Arkoma basin ranges from high-volatile to semi-anthracite, from west to east, respectively. A comparison of formational thickness and rank indicates that this is primarily a function of a higher geothermal gradient to the east rather than depth of burial. For example, the Krebs Group is maximally 8000 feet thick near Poteau, Oklahoma (Fig. 3) (Oakes, 1953), the McAlester Formation is approximately 2500 feet (Knechtal, 1949) and the Lower Hartshorne coal nearby contains 20% volatile matter (d.a.f.). Near Paris, Arkansas (Fig. 3), the thickness of the Krebs Group is unknown, but the McAlester Formation is about 1000 feet thick (Haley, 1961). If the thickness of the McAlester Formation is any indication of sedimentation rates and total depth of burial, then the Lower Hartshorne coal should have a higher rank than the Upper Savanna, Paris coal. In fact, the Paris coal has only 18% volatile matter (d.a.f.).

The eastward increasing rank is probably due to the Ouachita Orogeny and post-tectonic igneous intrusions. Goldstein (1975) reported metamorphism of Late Cambrian or Early Ordovician rocks to greenschist facies in an exploratory well in McCurtain County (Fig. 1). Isotopic ages ranged from 267 to 303 million years, establishing the age of deformation as Late Pennsylvanian to Early Permian. In Arkansas two suites of intrusive igneous rocks have been recognized: 1) a diabase-diorite of Late Triassic to Early Jurassic age and 2) a diverse alkalic, usually silica deficient, mid-Cretaceous suite (Denison, et al., 1977). I think that the low-volatile coals in Oklahoma are due to the low-grade metamorphism ending in the Early Permian and that the higher rank of Arkansas coals is the result of Mesozoic igneous activity.

CHAPTER V

ECONOMIC POTENTIAL

Reserves

The resources and reserves of the Lower Hartshorne coal on Pine Mountain were calculated using the coal thickness isopach map. The results are in Table 5. All tonnages, resources and reserves were calculated assuming 1800 tons of coal per acre foot. No minimum thickness for economical coal recovery was used because the extent of the thin areas is unknown and it will not be realized until the overburden has been removed. Tonnage calculations of the mined-out areas were figured using their surface area and average thickness of coal calculated for the respective mine property. The mineable block tonnage and net recoverable reserves were based on the following criteria:

1. a 100 feet overburden is the maximum economic depth;
2. a 200 foot unmineable barrier exists on both sides of U.S. Highway 59;
3. within 50 feet horizontally of the outcrop, the coal becomes oxidized and unusable[1]; and

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[1] Fifty feet is used as an average. Much of the outcrop follows the sloping sides of the mountain so that very little down-dip mining is necessary before the coal is under sufficient cover and is unoxidized.

Table 5.-Resources and reserves of the Lower Hartshorne coal.

Item	Property	Measured	Indicated
Original Resources	Freeman United	2481	
	Cari International	1312	
	Rock Island	2534	107
	Total	6327	107
Remaining Resources	Freeman United	2469	
	Cari International	1301	
	Rock Island	2318	107
	Total	6088	107
Mineable Block Tons	Freeman United	2409	
	Cari International	1206	
	Rock Island	1754	
	Total	5369	
Net Recoverable Reserves	Freeman United	1927	
	Cari International	965	
	Rock Island	1403	
	Total	4295	

4. the net recoverable reserved are 80% of the mineable block tonnage (Averitt, 1969, p. 30).

The coal rights belong to three different companies: Freeman United Coal Mining Company, Cari International Mining Company and Rock Island Improvement Company. As part of the economic evaluation, each tract was analyzed separately. Tract boundaries are shown on Plate 1.

Pine Mountain contains a total of 1260 acres and 5.37 million block-tons of mineable coal with less than 100 feet of overburden. Statistics for each property tract are:

Freeman United	
Total Block tonnage	2,409,000 tons
Total coal-bearing acreage	599 acres
Average coal thickness	26.8 inches
Cari International	
Total Block tonnage	1,206,000 tons
Total coal-bearing acreage	386 acres
Average coal thickness	28.4 inches
Rock Island	
Total Block tonnage	1,754,000 tons
Total coal-bearing acreage	378 acres
Average coal thickness	31 inches
Combined Properties	
Total Block tonnage	5,369,000 tons
Total coal-bearing acreage	1,260 acres
Average coal thickness	28.4 inches

Effects of Coal Preparation

The following tests were performed to determine both the effects of various coal preparation methods on the coal and the feasibility of upgrading the mined product:

1. Stage grinding from 1 inch X 0 to 1/8 inch X 0 and washing at 1.55 specific gravity (s.g.).
2. Detailed washabilities from float 1.30 s.g. to sink 1.90 s.g.[2]
3. Detailed washabilities from float 1.30 s.g. to sink 1.90 s.g. with two size fractions.
4. Limited s.g. float-sink tests ranging from 1.45 to 1.60 using one to two size fraction, and
5. Froth floatation on -28 mesh sample fraction.

The results of selected tests are in Appendix D.

None of the above methods was effective in substantially decreasing the sulfur content. Samples with less than 1.1 sulfur can be upgraded to less than 1% sulfur at 1.60 s.g., but meet metallurgical coal specifications without beneficiation. Samples with higher sulfur show both increases and decreases of sulfur content in the float fractions, but never are reduced to metallurgical specifications of less than 1.25 sulfur. These results are consistent with

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[2] Coal is washed or prepared by segregating the lower s.g., purer coal from the higher-s.g. impure, coal in a bath of a certain specific gravity. If a bath of 1.50 s.g. is used then the "clean" coal that is retained for use would be the float 1.50 fraction and the reject coal would be the sink 1.50 fraction.

the petrographic analysis. The pyrite is finely disseminated throughout the coal rather than occurring in lenses or cleats or being associated specifically with shale bands.

Ash can be reduced through washing without necessitating stage grinding. Between 1.4 and 1.65 s.g., ash contents below 14% can generally be reduced by 1/3 to 1/2. Removal of ash is dependent on the occurrence. Where the ash is derived from well-defined bands, it is easily removed. Boney coal, an intimate association of coal and shale, has a specific gravity near that of which coal preparation plants wash coal and will often report to the float yield.

Prepared coal yields vary with the type and amount of ash present. Coals with less than 10% ash have yields over 95% at 1.50 to 1.60 s.g. Yields for coal with an ash content between 10 and 15% are better than 83%. Samples with very high ash (greater than 30%) should yield between 41% and 59%.

Mineable Coal Quality

Analysis of vertical segments of the coal cores have shown that the top 6 inches is generally high in sulfur and that both the top and bottom 6 inches may be high in ash content. Because the seam is strippable, the troublesome top and bottom portions can be controlled through selective mining, e.g., scraping off the high sulfur top before removal. The remaining center portion of the coal falls into one of two categories, metallurgical grade or high-grade steam coal, based on the following criteria:

	Ash	Sulfur
metallurgical coal	< 12%	< 1.25%
steam coal	12%-18%	> 1.25%

Using the above mining practice and the prediction that the numerous coal cores on which segmentation was done are an accurate representation of the quality of the reserve, the percentages of mineable metallurgical and steam coal were calculated. These figures were made for both raw coal and assuming the presence of a coal preparation plant. The results are presented in Tables 6, 7 and 8.

In the case of a raw coal product, quality control will be a matter determining the extent and amount of sulfur in the upper portion of the seam. If the full seam has high sulfur throughout, the upper portion must be scraped to remove all of the visual high ash coal. The remainder can be mined for steam coal. If the middle section has metallurgical potential, then the top should be scraped to remove the high ash and sulfur portion. The remaining portion can then be mined down to the visual high ash coal. In some cases, where the coal is thick enough and is comprised of both thick metallurgical and steam portions, the top high-ash coal will be scraped, the upper low-ash/high-sulfur portion will be mined as steam coal and the remaining portion will be mined as metallurgical coal. Calculations of sale of coal tonnages include approximately 20% coal-loss due to removal of the top and bottom low grade coal, 20% mining

Table 6.-Qualities and quantities of raw coal.

Item	Metallurgical Coal	Steam Coal	Total Coal
Average Specifications			
Sulfur	.89	1.78	
Ash	8.20	11.40	
Percent of Block			
Freeman United	31.8	45.4	77.2
Cari International	37.6	43.8	81.4
Rock Island	62.1	21.0	83.1
Total	43%	37%	80%
Sale Coal Tonnage			
Freeman United	613,000	1,192,000	1,805,000
Cari International	363,000	591,000	954,000
Rock Island	871,000	568,000	1,439,000
Total	1,847,000	2,351,000	4,198,000

Table 7.-Predicted qualities of coal assuming a preparation plant.

Item	Metallurgical Coal	High Grade Steam Coal	Low Grade Steam Coal
Sulfur Specifications (Raw)			
Freeman United	1.00	1.44	3.58
Cari International	.83	1.65	3.45
Rock Island	.87	1.42	3.60
Average	.91	1.50	3.55
Ash Specifications (Raw)			
Freeman United	9.9	16.1	16.7
Cari International	8.1	10.6	22.6
Rock Island	8.5	17.9	28.5
Average	8.9	15.0	19.8
Prepared Coal Specifications and Yield			
Sulfur	<1.00	<1.50	<3.00
Ash	<9.0	<10.0	<13.0
Yield	95%	80%	55%

Table 8.-Predicted quantities of coal assuming a preparation plant.

Item	Metallurgical Coal	High Grade Steam Coal	Low Grade Steam Coal
Percent of Block			
Freeman United	37.7	31.7	30.6
Cari International	38.1	41.7	20.2
Rock Island	62.2	27.6	10.2
Total	45.8	32.6	21.6
Block Tonnages			
Freeman United	908,000	764,000	737,000
Cari International	459,000	503,000	244,000
Rock Island	1,091,000	484,000	179,000
Total	2,458,000	1,751,000	1,160,000
Recoverable Tonnages			
Freeman United	726,000	862,000	553,000
Cari International	367,000	547,000	183,000
Rock Island	873,000	624,000	134,000
Total	1,966,000	2,033,000	870,000
Sale Coal Tonnages			
Freeman United	690,000	690,000	304,000
Cari International	349,000	438,000	101,000
Rock Island	829,000	499,000	74,000
Total	1,868,000	1,627,000	479,000

loss of metallurgical coal that reports to steam coal and a 5% mining loss of the steam coal. The above mining technique is currently being used with much success in Arkansas.

For the most part, if the coal is put through a preparation plant, the same mining procedures must be followed. The exceptions are that:

1. the high-ash top will not have to be removed if the full seam is to be mined for steam coal,
2. careful control of the high-ash bottom during mining will not be as critical, and
3. the low-quality tops and bottoms can be saved for sale.

The criteria for determining the three different coal qualities expected are based only on sulfur percentage:

	Sulfur Content
Metallurgical	< 1.25%
High Grade Steam	1.25 to 2.00%
Low Grade Steam	> 2.00%

The following formulas were used to figure the recoverable tonnages:

Metallurgical Coal[3]:

Block tonnage X .80 (pit recovery met)

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[3] There are no visible differences between the low sulfur met coal and high grade steam coal. The probability of contamination (and therefore loss) of met coal accounts for the 80% pit recovery.

High Grade Steam Coal[4]:

Block tonnage X .95 (pit recovery) + .15 X met yield

Low Grade Steam Coal[5]:

Block tonnage X .75 pit

Sale-coal tonnages reflect loss during preparation. Conservative wash yields for the different coal products are:

	Yield
Metallurgical Coal	95%
High Grade Steam Coal	80%
Low Grade Steam Coal	55%

A comparison of the raw and washed products suggests that the coal need not be prepared. Although the total recoverable tonnage of cleaned coal is greater than that of the raw-sales coal (4,869,000 versus 4,198,000 tons), loss in the preparation plant reduces the tonnage of clean coal to 3,974,000 tons. The yield of metallurgical coal, though slightly greater when cleaned, is not enough to warrant the high capital cost of the preparation plant, i.e., $3 - $5 million.

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[4] Losses of met coal should report to the high-grade steam coal, therefore 75% of the amount lost (20% X .75 = 15%) is added back. 95% pit recovery is assumed since top and bottom losses will report to low grade steam coal.

[5] Keeping the gradational coal and shale that bounds the seam separate from the coal accounts for 75% pit recovery of low grade steam coal.

The segregated mining practice is important in that it allows for maximizing yield of metallurgical coal. The feasibility lies in numerous daily samples and increased loading costs, offset by a 50 to 100% increase in sale price, FOB mine, for increased production of metallurgical coal. The daily production of a 200,000 ton per year mine is 750 to 800 tons per day. On Pine Mountain, this is equivalent to a 90 X 100 foot area. With a quality-control budget of $50,000 per year (or $200 per day), over 10 samples can be analyzed each day for ash and sulfur. Through careful visual examination of the coal seam before loading, the top and bottom high-ash areas can be identified, and vertically segmented channel-samples of the remainder will be taken. This is supported by the split-core analyses and verbal-gravity logs. On a practical basis, daily production will usually be either met or steam grade. If an area is identified as high in sulfur, metallurgical yields and prices will have to be forfeited. The actual analysis of mining costs of the projected operation has assumed all of the above.

Overburden

Plate 3 is a total-overburden isopach map, and Plate 5 is an isopach map of the Upper Hartshorne sandstone member. The overburden thicknesses and virgin mining ratios[6] for

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[6] Virgin mining ratio is the ratio of overburden (yd.^{3}) to tons of coal; for bituminous coal it is equivalent to the ratio of overburden thickness (ft) to the coal thickness (ft).

each property tract were calculated and tabulated in Table 9. Table 10 shows the average thickness and percent of overburden of the Upper Hartshorne sandstone member.

Table 9.-Overburden thicknesses and virgin mining ratios by property.

Item	Freeman United	Cari	RI
Overburden (in ft)			
Maximum	57	77	100
Average	43	42	77.6
Virgin Mining Ratio	19.25:1	17.75:1	30.04:1

Table 10.-Average thicknesses and percents of "hard" and total sandstone, by property.

Item	Freeman United	Cari	RI[2]
"Hard" Sandstone			
Average thickness (ft)	16.0	14.4	38.5
% of overburden	37.2	34.3	49.6
Total sandstone			
Average thickness (ft)	23.5	18.9	42.2
% of overburden	54.7	45.0	54.5

[1] "Hard" sandstone as described by drillers on logs.

[2] RI figured to a 100 ft high wall.

Coal Utilization

Two and possibly three different coal products are expected from Pine Mountain: metallurgical coal, high-grade steam coal and low-grade steam coal. All three grades are currently being mined in Oklahoma and Arkansas and marketed intrastate, interstate or export.

The metallurgical market is interstate or export. At present, low- to medium-volatile metallurgical coals from Oklahoma and Arkansas are being sold to steel manufacturers in Colorado, Texas and Indiana, at prices ranging from $30 to $50, F.O.B. railroad cars. The price is dependent on both quality and marketing prowess.

Except for problems of expansion and low-ash fusion temperatures, low-volatile coals from this area are of excellent quality when the ash and sulfur are within specifications (less than 9% and 1.25% respectively). During the coking processes the reactive components in the coal soften, become plastic and expand. As the volatile matter is driven off, the coal then contracts and solidifies into coke. Coals with average vitrinoid reflectance above 1.6% usually exhibit excessive coking pressure, above 10 psi, and become coke after a net expanion. When these coals are coked alone, two things can happen: 1) the expansion pressure may be enough to crack or burst the walls of the coke oven, and 2) net expanion makes removal of the coke from the oven extremely difficult and troublesome. These problems can be overcome by using a low proportion of low-volatile coal (less than 30%) with a low-expansion, net-contracting, high-volatile metallurgical coal in a blend.

Low-ash fusion temperatures cannot be corrected or compensated. Coke oven temperatures range from 1650° F. to 2000° F. (McGannon, 1971, p. 105). Any ash with fusion temperatures below the maximum oven temperature can have three detrimental effects. At temperatures high enough, when the coke is plastic, the ash can agglomerate and stick to the bottom of the oven. This causes fractionation of the coke into an upper normal coke and a lower high-ash coke that has undesirable characteristics in steel making. Secondly, the ash can fuse and stick to the oven wall. This process, unfortunately, is additive, so that when too much low-ash-fusion coal has been put through the oven, it must be shut down and overhauled. The third problem is similar to the second, but more drastic. The ash can also fuse the coke to the oven walls making it extremely difficult to remove. In this circumstance, the oven wall can be severely damaged; the inner walls can be ripped out, causing loss of coke cake, uneven heating, and need for an oven overhaul.

The Hartshorne coal on Pine Mountain is medium-volatile, has an expansion pressure of less than 7 psi and has a net contraction of 7%. The ash fusion temperature ranges from 1900° to 2370° F. The coal in the study area is a suitable blending coal with either a high-volatile coal alone or in a high-, medium-, and low-volatile blend. Blend ratios will depend on the other coals and on which vitrinite-reflectance mode is being produced on Pine Mountain; V-12 and V-13 coals can be blended at 1:1 or even 1:2 in a high-volatile blend, whereas the V-14 coal would probably be in the order of 1:5. The advantage of using a medium-volatile coal in a low/high-volatile blend is that it minimizes the use of scarce low-volatile coals, without adversely affecting the quality of coke. The ash-fusion temperature suggests that the coal can be safely coked if the oven temperature does not exceed 1900° F. Pine Mountain coal meeting 1.25% sulfur and less than 9% ash specification is worth \$35-\$50/ton in today's market--a value that should increase in following years.

The high-grade steam coal can be sold to cement or utility plants. Although most current production from the area is interstate, there are a few Oklahoma cement plants consuming Oklahoma coal. Two of the main reasons that local utilities have not been using this coal are 1) the ambient-air quality codes set up by the EPA in 1969, and 2) the stack-gas emissions standards. These regulate the amount of sulfur and particulate matter that is permissable as discharge. Under current restriction, Oklahoma cannot emit any more pollutants than it was at the time these laws were enacted. Because Oklahoma was burning natural gas, these laws severely limit the use of high-sulfur coal.

The market value of high-grade steam coal ranges from \$15 to \$25/ton F.O.B. mine. Many of the low-price coals were contracted when coal prices were depressed; others have over 3% sulfur and have high ash.

Pine Mountain high-grade steam coal meeting less than 2% sulfur and less than 12 ash specifications should be very marketable. High BTU values (13,700 for a 12% ash product, and relatively low sulfur) should be worth between $20 and $25/ton F.O.B. mine.

The low-grade steam coal has two possible markets, charcoal and drill-hole cement aggregate. The specifications for charcoal production are not very stringent as they will accept over 20% ash and 3% sulfur. The price for such coal is usually below $22 per ton. Drill-hole cement aggregate is a low-tonnage market but has a high net worth. The coal is used because of its low specific gravity as an aggregate to plug holes in highly permeable zones. Specification for this product is only that it be stage-crushed to the rigorous specification of the user. The crushed product in 70-pound bags is valued at over $60/ton with a maximum yearly production of 3000 tons. Although 3000 tons/year is not enough to warrant a large operation, it could be an added side line by using the "free" labor at the mine during equipment "down time." Pine Mountain low-grade coal could fit into either of these markets.

CHAPTER VI

CONCLUSIONS

The following are the principal conclusions that may be drawn from this study:

1. Pine Mountain is an eastward-plunging syncline.
2. The rocks belong to the Atoka, Hartshorne and McAlester Formations.
3. The sedimentary rocks are deltaic: the Atoka being delta fringe and swamp, Hartshorne being interdistributary and swamp and McAlester being shallow marine.
4. The thickness of the Lower Hartshorne coal ranges from 50.4 to 11.5 in. and averages 28.4 in. with variations due to depositional and tectonic activity.
5. There are 1260 acres and 5.37 million block tons of strip-mineable coal with less than 100 feet of overburden.
6. The overburden averages 53 feet to a 100-foot high wall of which 52% is sandstone.
7. There is a significant vertical trend with respect to sulfur and ash, the former increasing upward and the latter concentrated in the top and bottom of

the seam.

8. The coal is low- to medium-volatile bituminous indicating that the medium/low-volatile demarkation line passes through the study area.
9. Petrographic-maceral analysis shows the coal to have suitable coking characteristics for use as a low- or medium-volatile blend component in a coke oven.
10. Coal preparation reduces the ash content but will not reduce sulfur enough to make all of the coal a metallurgical grade.
11. The coal can be mined for either steam coal, using normal mining practice, and/or both steam and metallurgical coal using selective mining techniques.

REFERENCES CITED

Altschuler, Z. S., C. S. Zen, M. Rubin, and J. H. Medlin, 1978, Profile of coal-forming swamp--the Everglades: AAPG Annual Convention Program Ab.

Averitt, Paul, 1969, Coal resources in the United States, January 1, 1967: U.S. Geol. Survey Bull. 1275, 116 p.

Berry, W. F., A. R. Cameron, and B. N. Nardi, 1967, Development of coal petrology in North American, <u>in</u> Symposium on the Science and Technology of Coal: Dept. of Energy, Mines and Resources, Ottawa, Canada, p. 6-29.

Branson, Carl C., 1956, Hartshorne Formation, Early Desmoinesian, Oklahoma: Oklahoma Geology Notes, v/ 16, no. 9, p. 93-99.

Briggs, Garrett, and L. M. Cline, 1967, Paleocurrents and source areas of late Paleozoic sediments of the Ouachita Mountains, southeastern Oklahoma: J. Sed. Pet., v. 37, p. 935-1000.

Chandra, D., and G. H. Taylor, 1975, Gondwana coals, <u>in</u> Stach's Textbook of Coal Petrology (2nd ed.): Berlin and Stuttgart, Gebrüder Borntraeger, 428 p.

Coleman, James M., and Sherwood M. Gagliano, 1964, Cyclic sedimentation in the Mississippi River Deltaic Plain: Trans. Gulf Coast Assoc. of Geological Societies, v. 14, p. 67-80.

________ and ________, 1965, Sedimentary Structures and Their Hydrodynamic Interpretation: Soc. Econ. Paleontologists and Mineralogists Spec. Pub. No. 12, p. 133-141.

Delevoryas, Theodore, 1962, Morphology and Evolution of Fossil Plants: Holt, Rinehart and Winston, N. Y.

Denison, R. E., W. H. Burke, J. B. Otto, and E. A. Hetherington, 1971, Age of igneous and metamorphic activity affecting the Ouachita foldbelt, <u>in</u> Symposium on the Geology of the Ouachita Mountains: Ark. Geol. Comm., p. 25-41.

Fisk, H. N., 1961, Bar finger sands of Mississippi Delta, *in* Geometry of Sandstone Bodies--A Symposium: AAPG, p. 29-52.

Frezon, Sherwood E., 1962, Correlation of Paleozoic rocks from Coal County, Oklahoma, to Sebastian County, Arkansas: Oklahoma Geological Survey, Circular 58, p. 1-52.

Friedman, S. A., 1975, Investigation of the coal reserves in the Ozarks section of Oklahoma and their potential uses: Final Report to the Ozark Regional Commission, 117 p.

Goldstein, August, Jr., 1975, Geologic interpretation of Viersen and Cochran's 25-1 Weyerhaeuser well, McCurtain County, Oklahoma: Okla. Geol. Notes, v. 35, no. 5, p. 167-181.

Greensmith, J. Trevor, 1966, Carboniferous deltaic sedimentation in eastern Scotland: a review and reappraisal, *in* Deltas and Their Geologic Framework: Houston Geological Society, p. 189-211.

Haley, Boyd R., 1961, Thickness trends in the Hartshorne sandstone and McAlester Formation in northwestern Arkansas: U.S. Geol. Survey Prof. Paper 424-C, p. 80-81.

________, 1966, Geology of the Barber quadrangle, Sebastian County and vicinity, Arkansas: Ark. Geol. Comm. Info. Circular 20-C, 76 p.

________, 1976, Geologic Map of Arkansas, USGS.

________, and T. A. Hendricks, 1968, Geology of the Greenwood quadrangle, Arkansas - Oklahoma: Ark. Geol. Comm. Info. Circular 20-F, 15 p.

Harrison, J. A., H. W. Jackman, and J. A. Simon, 1964, Predicting coke stability from petrographic analysis of Illinois coals: Ill. State Geol. Survey Circular 366.

Hendricks, T. A., 1939, Geology and fuel resources of the southern part of the Oklahoma coal field; Part Four, the Howe-Wilburton district, Latimer and LeFlore Counties: U.S. Geol. Survey Bull. 874-D, p. 255-300.

________, 1950, Geology of the Fort Smith district, Arkansas: U.S. Geol. Survey Prof. Paper 221-E, p. 67-94.

Karvelot, Michael D., 1973, The Stigler coal and collateral strata in parts of Haskell, LeFlore, McIntosh, and Muskogee Counties, Oklahoma: Shale Shaker, v. 23, no. 5, p. 108-119; no. 6, p. 128-141.

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

Mackowsky, M. T., 1968, Mineral matter in coal, in Coal and Coal-bearing Strata: Edinburgh and London, Oliver and Boyd Ltd., 418 p.

________, 1975, Minerals and trace elements occurring in coal, in Stach's Textbook of Coal Petrology (2nd ed.): Berlin and Stuttgart, Gebrüder Torntraeger, 428 p.

________, B. Alpern, and G. H. Taylor, 1967, The behavior during carbonization of inertinite - with special reference to vitrinite/semifusinite transition: Fuel, v. 46, p. 431-441.

McDaniel, Gary A., 1961, Surface stratigraphy of the Hartshorne Formation, LeFlore, Latimer and Pittsburg Counties, Oklahoma, in Guidebook, Arkoma Basin and North Central Ouachita Mountains: Tulsa Geol. Soc., 78 p.

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

McGannon, H. E., ed., 1971, The Making, Shaping and Treating of Steel (4th ed.): Pittsburg, Pa., Herbick and Held.

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

Miser, H., 1954, Geologic Map of Oklahoma: Okla. Geol. Survey.

Moore, G. T., and D. O. Asquith, 1971, Delta: term and concept: Geol. Soc. Am. Bull., v. 82, p. 2563-2568.

Oakes, Malcolm C., 1953, Krebs and Cabaniss groups, of Pennsylvanian age, in Oklahoma: Am. Assoc. Petroleum Geologists Bull., v. 37, p. 1523-1526.

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

Park, Charles P., Jr., and R. A. MacDiarmid, 1970, Ore Deposits (2nd ed.): San Francisco, W. H. Freeman and Co.

Pettijohn, F. J., P. E. Potter, and R. Siever, 1972, Sand and Sandstone: Berlin-Heidelberg, Springer-Verlag, 618 p.

Reineck, Hans-Erick, 1972, Tidal flats, in Recognition of Ancient Sedimentary Environments: Soc. Econ. Paleontologists and Mineralogists Spec. Pub. No. 16, p. 146-159.

________, and I. B. Singh, 1975, Depositional Sedimentary Environments: Berlin-Heidelberg, Springer-Verlag, 439 p.

Schapiro, N., and R. J. Gray, 1964, The use of petrography in coke making: Science and Technology, v. 11, no. 30.

________, ________, and G. R. Eusner, 1961, Recent developments in coal petrography: Proc. Blast Furnace, Coke Oven and Raw Materials Committee, AIME, v. 20, p. 89-112.

Shelton, J. W., 1973, Models of sand and sandstone deposits: a methodology for determining sand genesis and trend: Okla. Geol. Survey Bull. 118, 122 p.

Stach, E., 1975, The macerals of coal, in Stach's Textbook of Coal Petrology (2nd ed.): Berlin and Stuttgart, Gebrüder Borntraeger, 428 p.

Taft, Joseph A., 1899, Geology of the McAlester-Lehigh coal field, Indian Territory: U.S. Geol. Survey, 19th Annual Report, Pt. 3, p. 423-456.

________ and G. I. Adams, 1900, Geology of the eastern Choctaw coal field, Indian Territory: U.S. Geol. Survey 21st Annual Report, Pt. 2, p. 257-311.

Teichmüller, M., and R. Teichmüller, 1968, Geological aspects of coal metamorphism, in Coal and Coal-bearing strata: Edinburgh and London, Oliver and Boyd Ltd., 418 p.

________ and ________, 1975, The geological basis of coal formation, in Stach's Textbook of Coal Petrology (2nd ed.): Berlin and Stuttgart, Gebrüder Borntraeger, 428 p.

Tidwell, W. D., 1975, Common Fossil Plants of Western North America: Brigham Young University Press, Provo, Utah.

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

Williams, E. G., and M. L. Keith, 1963, Relationship between sulfur in coals and the occurrence of marine roof beds: Econ. Geol., v. 58, p. 720-729.

Williamson, Iain A., 1967, Coal Mining Geology: Oxford University Press, London.

Wilson, C. W., Jr., and N. D. Newell, 1937, Geology of the Muskogee-Porum district, Muskogee and McIntosh Counties, Oklahoma: Okla. Geol. Survey Bull. 57, 184 p.

Wynn, L. I., 1965, Gas fields from Hartshorne sand of Arkoma Basin: AAPG Bull., v. 49, p. 1561.

APPENDIX A

PROSPECT PIT DESCRIPTIONS AND THICKNESSES

Pine Mountain Prospect Pit Description

Hole #			
A	31.5"	Top	0-10" coal
		Middle	10-16" coal
			16-18" shale parting
			18-22" coal
		Bottom	22-29" coal
			29-31.5" coaly shale
B	28.5"	Top	0-3" coal
			3-3.2" shale
			3.2-5" coal
		Middle	5-10" coal
			10-24.5" coal, contorted
		Bottom	24.5-28.5" coal with shale interbed
C	17.5"	Top	0-2.5" coal
			2.5-4.5" shale
			4.5-5" coal with shale
		Middle	5-11" coal
		Bottom	11-17.5" coal with shale
D	30.0"		Sandy concretionary shale
			9" black coaly shale
		Top	0-4.25" coal
			4.25-7" shale
		Middle	7-22" coal
		Bottom	22-30" coal, contorted with 3 small shale partings
D-E	29.5"	Top	0-2" boney coal
			2-3" shale
			3-5.5" coal
		Middle	5.5-26" coal
		Bottom	26-29.5" coal with shale
E	23.0"	Top	0-6" mixed coal and shale
		Middle	6-18" coal
		Bottom	18-23" coal (with possible high sulfur)
F	34.0"	Top	0-7" mixed coal and shale
		Middle	7-28.5" coal
		Bottom	28.5-34" coal with shale increasing towards bottom
G	31.0"	Top	0-6" coal, boney
		Middle	6-25" coal
		Bottom	25-31" coal interbedded with shale
H	35.5"	Top	0-10" coal, highly vitrinized
		Middle	10-24" hard solid coal

Hole #			
H (cont.)		Bottom	24-24.25" shale parting
			24.25-35.5" shale interbedded with coal
I	28.0"		(seam full of roots)
		Top	0-7" coal, shaley
		Middle	7-22" coal
		Bottom	22-28" coal interbedded with shale
J	22.0"		5-6" coaly shale (non-economic)
		Top	0-3.25" shaley coal
		Middle	3.25-18" coal
		Bottom	18-22" coal with shale
J-I	31.5"	Top	0-3" boney coal
			3-5" shale
			5-6.5" coal (boney)
		Middle	6.5-28" coal
		Bottom	28-30.25" coal with shale
			30.25-30.5" shale band
			30.5-31.5" coal with shale
K	22.5"		4" coal
			12" shale
		Top	0-5" coal
		Middle	5-13.25" coal
		Bottom	13.5-22.5" coal
L	34.0"	Top	0-7.75" coal highly weathered
			7.75-8" shale parting
		Middle	8-15.25" shaley coal
			15.25-18.75" parting
		Bottom	18.75-34" coal
M	25.0"		2" coal band
			12" highly contorted shale with interbedded coal (90% shale)
		Top	0-4" coal
			4-4.75" shale parting
		Middle	4.75-11" coal, dirty and shaley
		Bottom	11-25" coal
N	34.0"	Top	0-3" coal, weathered and oxidized
			3-6.5" shale band with interbedded coal (80% shale)
		Middle	6.5-18.25" coal, hard, fresh
			18.25-18.4" shale lens, 2" wide
			18.4-31.5" coal, hard, fresh
		Bottom	31.5-34" shale mixed with coal

Hole #			
O	16.0"	Top	0-4.5" coal
		Middle	4.5-10.5" coal
		Bottom	10.5-16" coal

The coal is 21" on the S side; 16" on the SE; 18" on E; 11" on N; and 13" on the W. Coal and associated shale is highly contorted. These contortions are the reason for the thickness variations. None of the beds is continuous, disruption has destroyed the continuity of the original bedding planes. In some places the top is shaley, in others, good coal has been forced to the top.

P	31.0"	Top	0-6" coal
		Middle	6-21" coal
		Bottom	21-31" coal
Q	30.0"		Top 16" has coal inbedded with shale
		Top	0-6" coal
		Middle	6-24" coal
		Bottom	24-30" coal

APPENDIX B

TEN SELECTED GRAPHIC GRAVITY LOGS

Graphic Gravity Log Explanation

Column 1 (L): Luster of coal or constituent

B = Bright coal	V = Vitrain
I = Intermediate coal	P = Pyrite
D = Dull coal	Sh = Shale
Bn = Boney coal	SS = Sandstone
F = Fusain	Blank = Indistinguishable

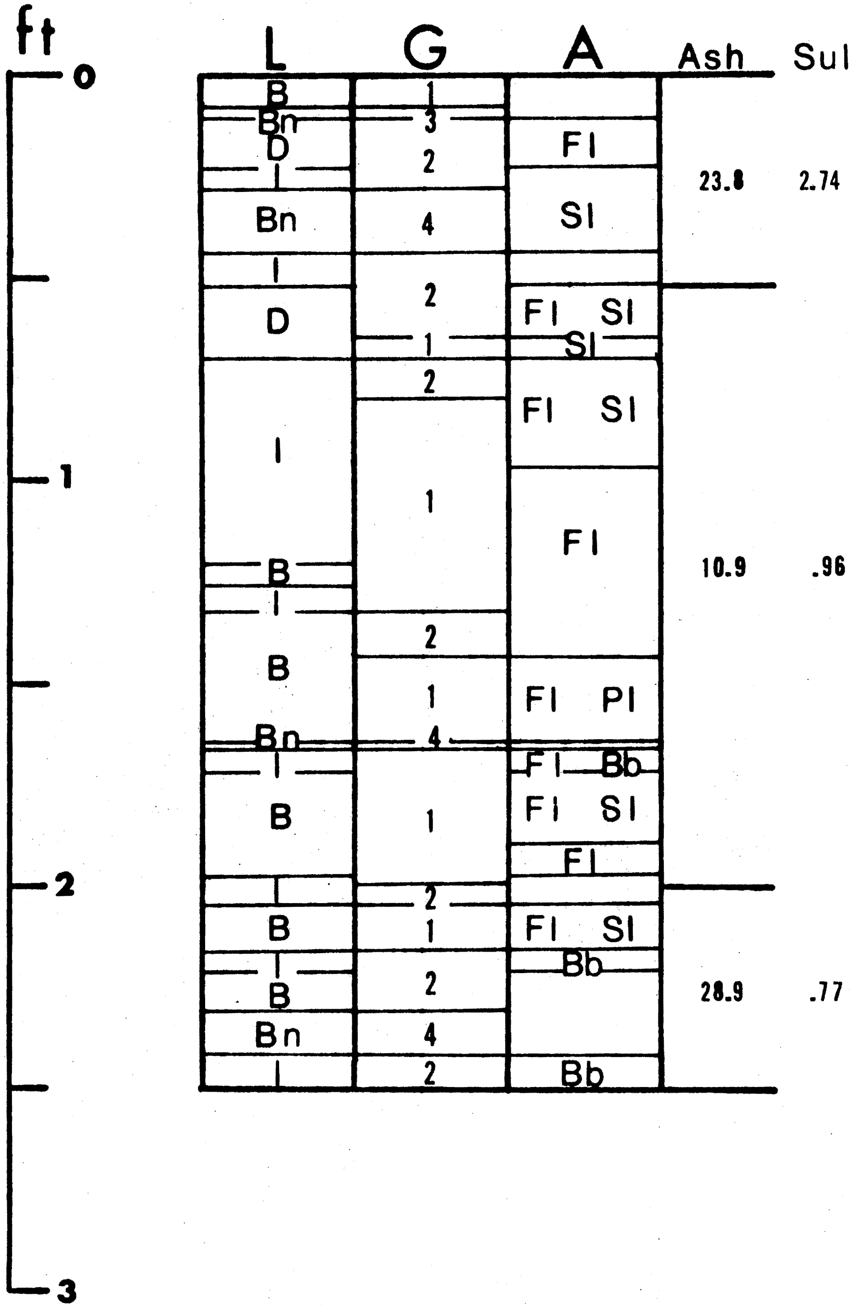
Column 2 (G): Specific gravity

1 = Float 1.30 and 1.35
2 = Float 1.40, 1.45, 1.50 and 1.55
3 = Float 1.60, 1.65 and 1.70
4 = Sink 1.70

Column 3 (A): Accessories

Cc = Calcite in cleats
Fl = Fusain lenses
Fb = Fusain bands
Bl = Boney lenses
Bb = Boney bands
Pl = Pyrite lenses
Pb = Pyrite bands
Pc = Pyrite in cleats
Pp = Pyrite along bedding plane
Sl = Slickensides

156/C


ft
0
1
2
3
L
G
A
Ash
Sul
B
Bn
D
I
Bn
I
D
I
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I
B
Bn
I
B
I
B
I
B
Bn
I
1
3
2
4
2
1
2
1
2
1
4
1
2
1
2
4
2
Fl
Sl
Fl Sl
Sl
Fl Sl
Fl
Fl Pl
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Fl
Fl Sl
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Bb
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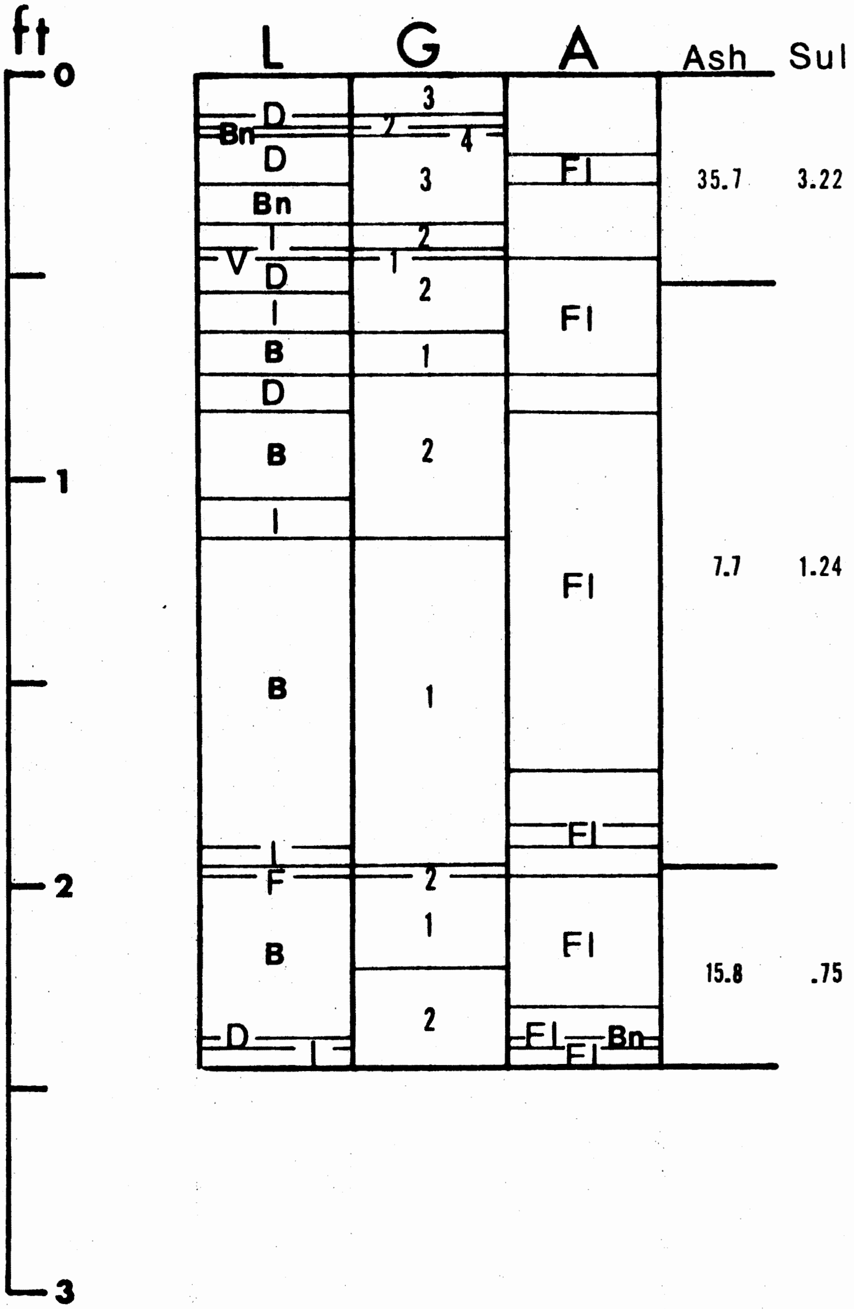
2.74
10.9
.96
28.9
.77

157/C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1
2
3
L
G
A
Ash
Sul
D
Bn
D
Bn
I
V
D
I
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D
B
I
B
I
F
B
D
I
3
2
4
3
2
1
2
1
2
1
2
1
2
Fl
Fl
Fl
Fl
Fl
Fl
Bn
Fl
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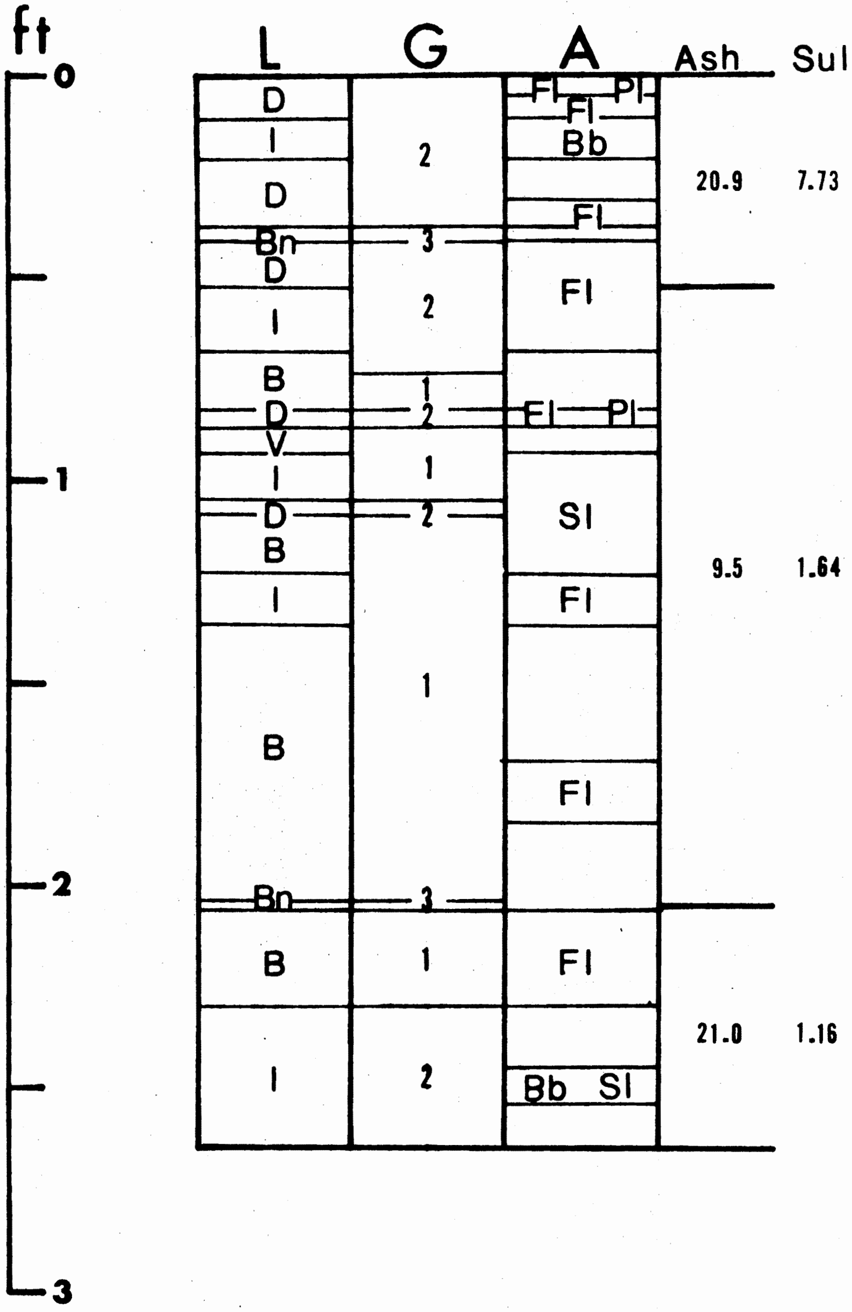
3.22
7.7
1.24
15.8
.75

161/C


ft
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L
G
A
Ash
Sul
D
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Bn
D
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V
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D
B
I
B
Bn
B
I
2
3
2
1
2
1
2
1
3
1
2
Fl Pl
Fl
Bb
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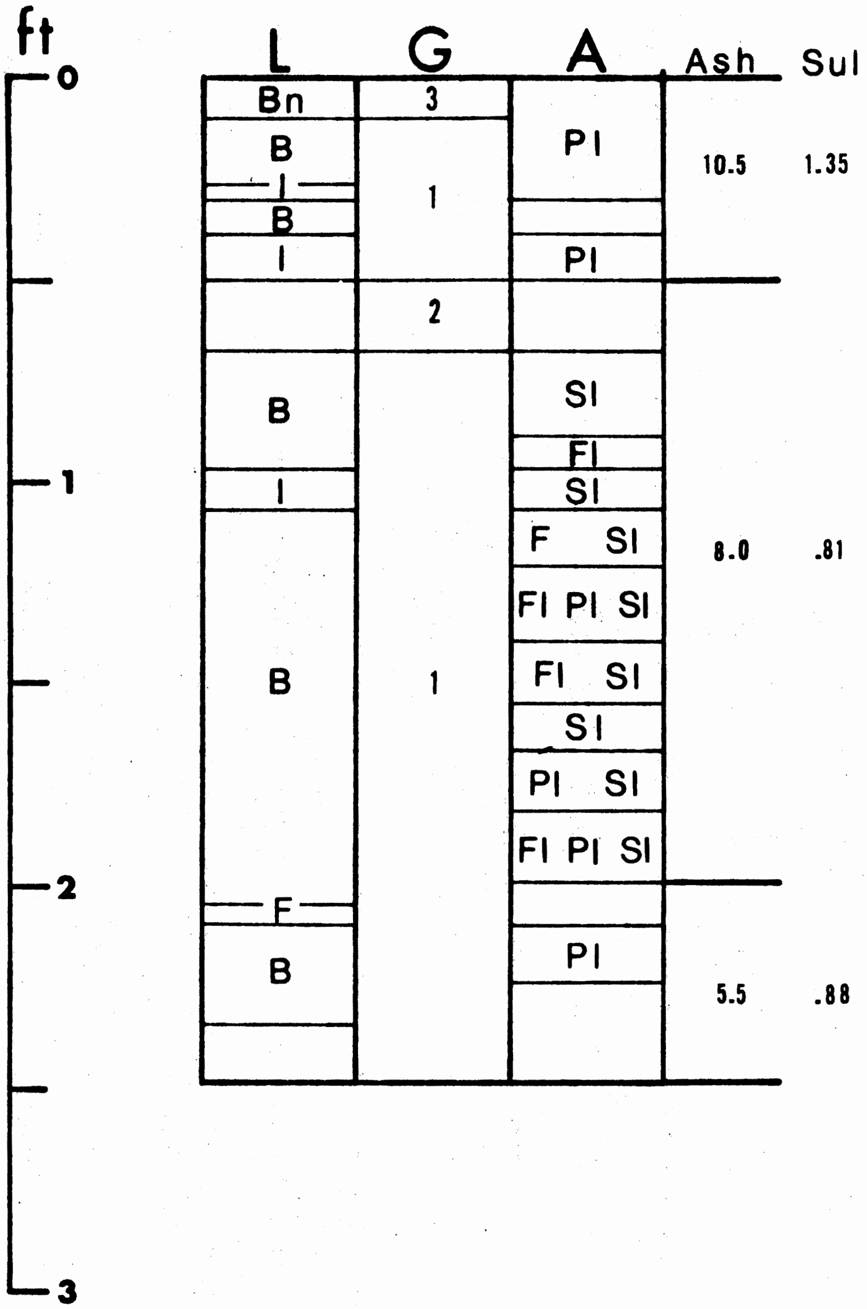
7.73
9.5
1.64
21.0
1.16

166/C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Ash
Sul
Bn
B
I
B
I
B
I
B
F
B
3
1
2
1
Pl
Pl
Sl
Fl
Sl
F Sl
Fl Pl Sl
Fl Sl
Sl
Pl Sl
Fl Pl Sl
Pl
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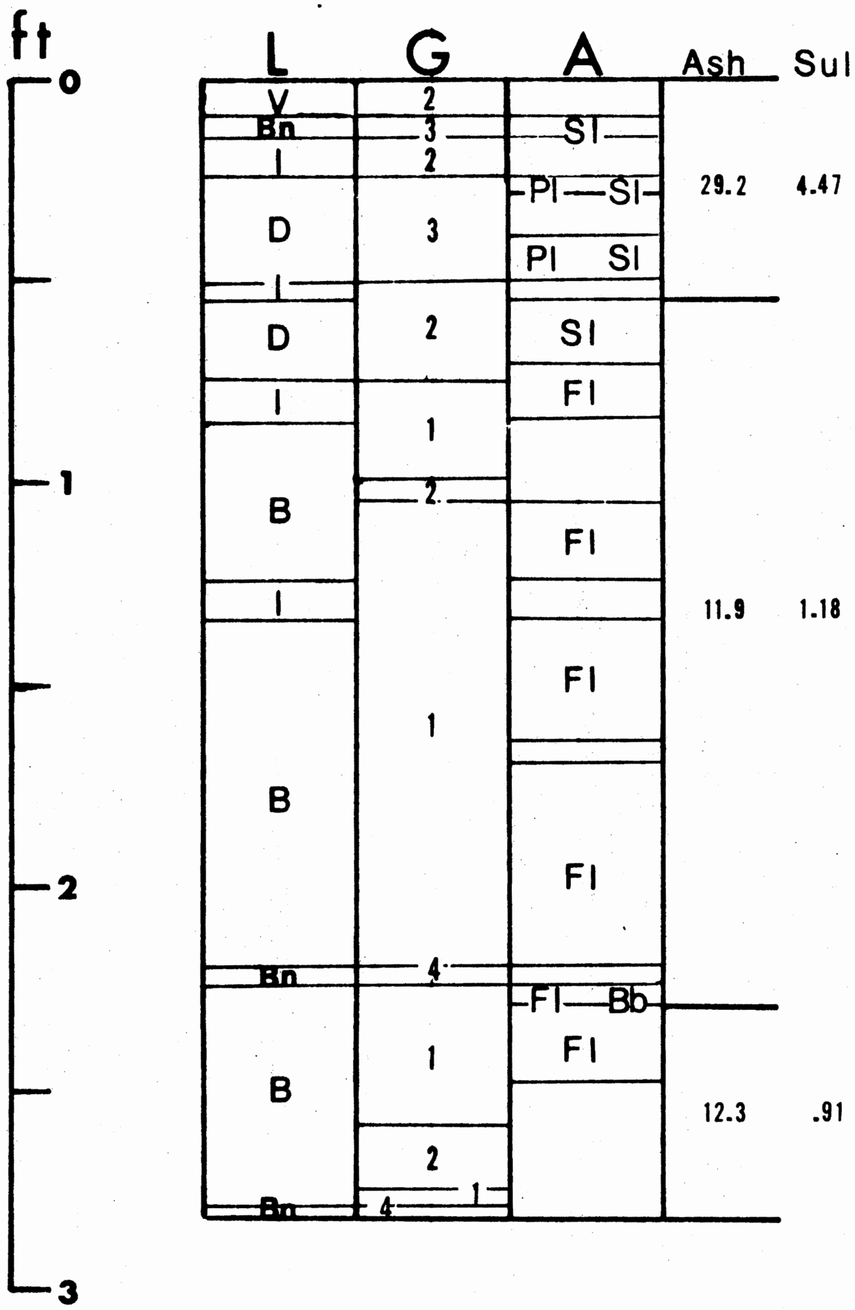
1.35
8.0
.81
5.5
.88

169/C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Ash
Sul
V
Bn
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D
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D
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B
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Bn
B
Bn
2
3
2
3
2
1
2
1
4
1
2
1
4
Sl
Pl
Sl
Pl
Sl
Sl
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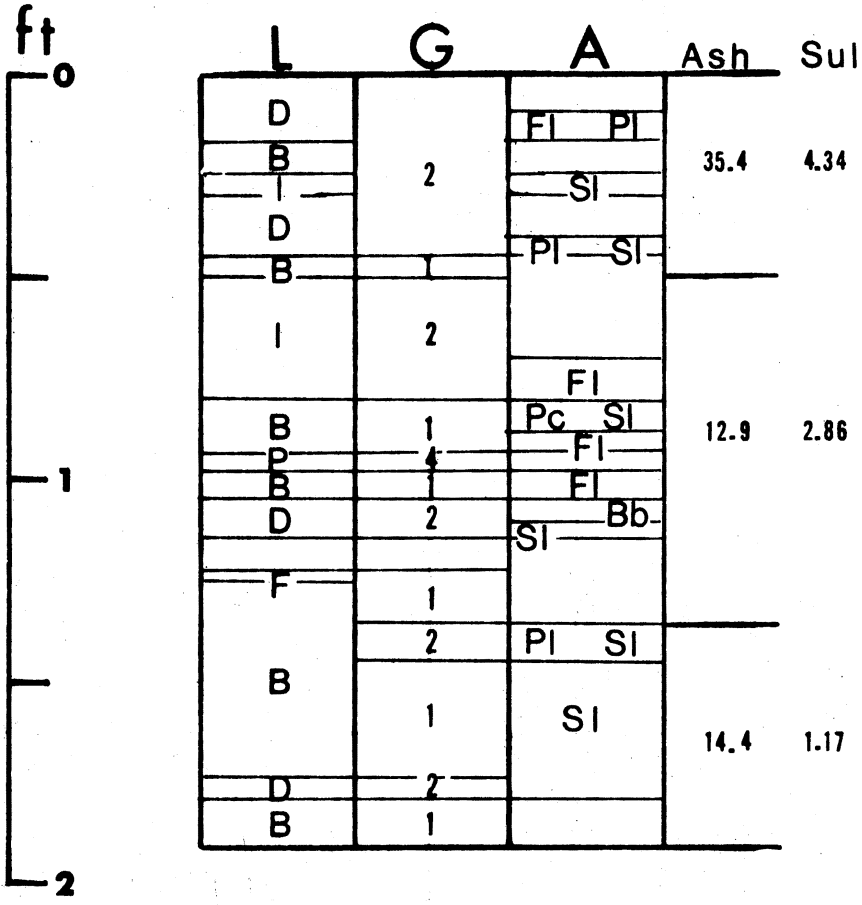
Fl
Fl
Fl
Fl
Bb
Fl
29.2
4.47
11.9
1.18
12.3
.91

170/C


ft
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L
G
A
Ash
Sul
D
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D
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P
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B
2
I
2
1
4
1
2
1
2
1
2
1
Fl
Pl
Sl
Pl
Sl
Fl
Pc
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Bb
Sl
Pl
Sl
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35.4
4.34
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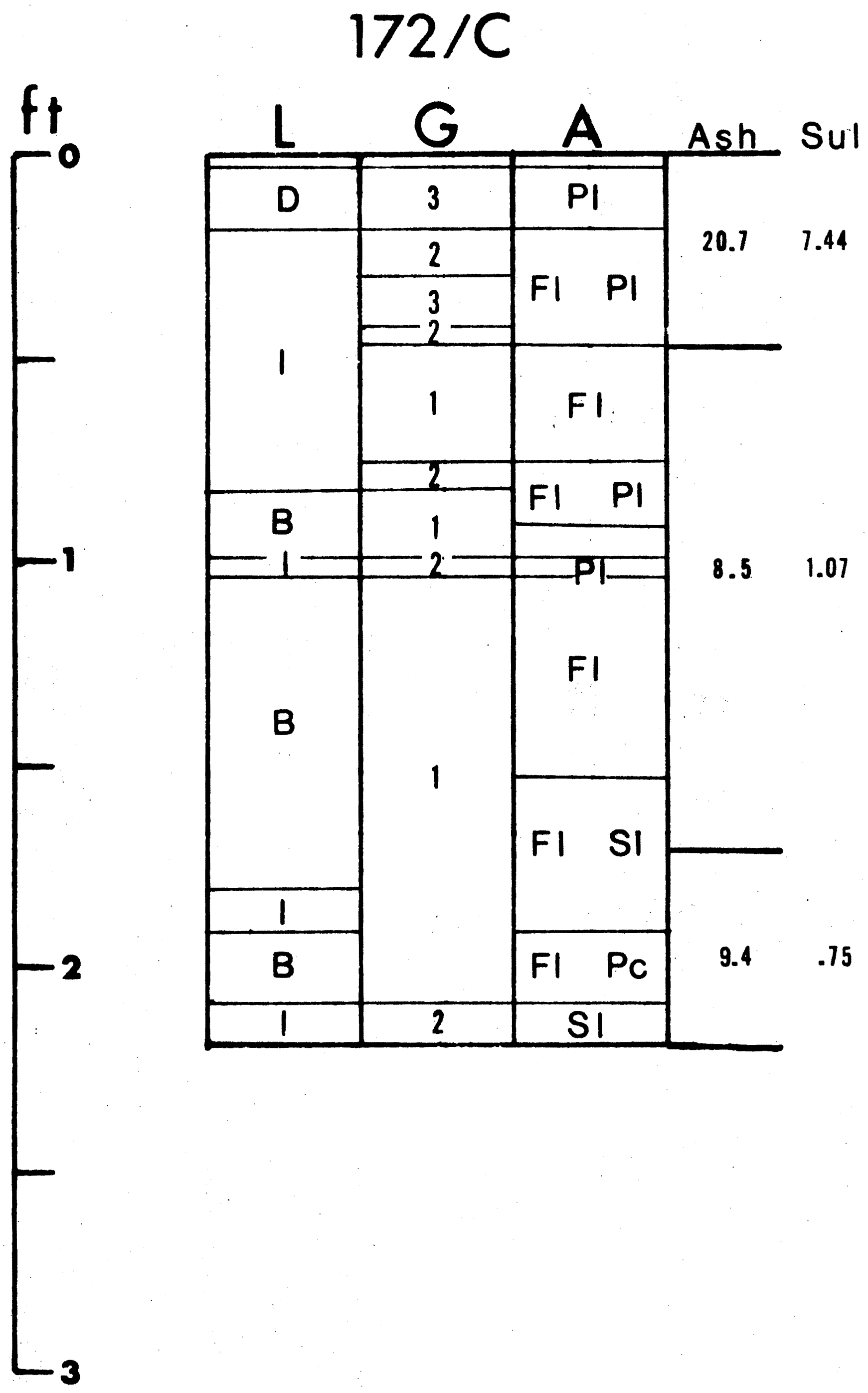
2.86
14.4
1.17


172/C
ft
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1
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Ash
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D
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Fl Pl
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1
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Fl Pl
B
1
I
2
Pl
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B
1
Fl
Fl Sl
I
B
Fl Pc
9.4
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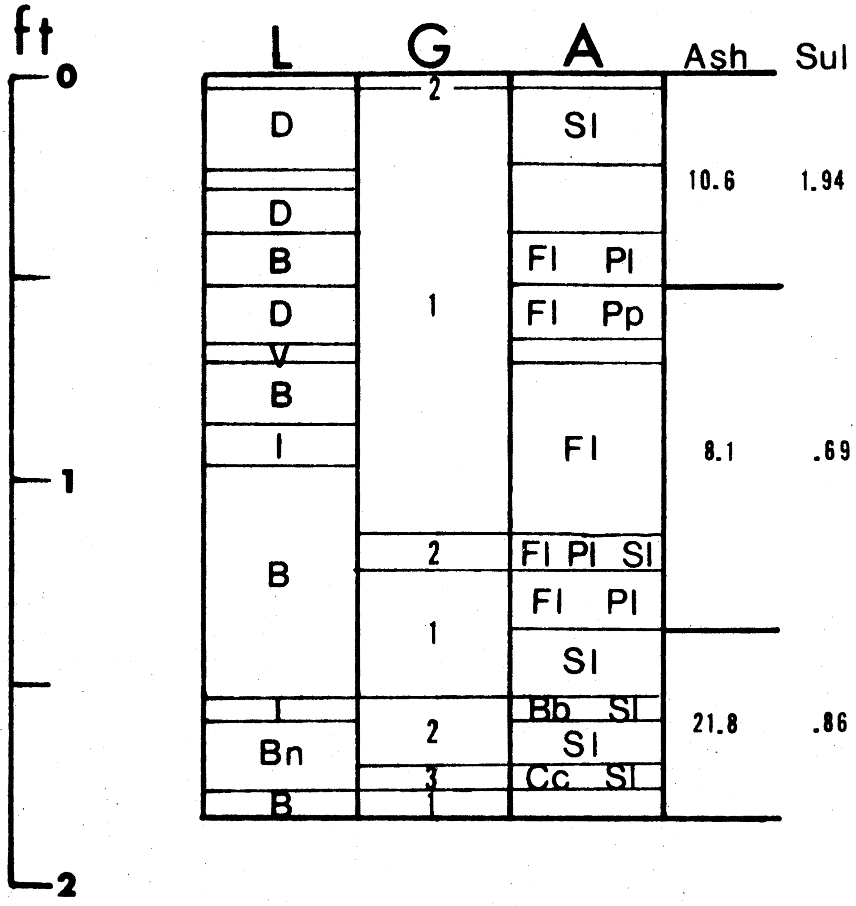
I
2
Sl

176/C


ft
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1
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Ash
Sul
D
D
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V
B
I
B
I
Bn
B
2
1
2
1
2
3
1
Sl
Fl Pl
Fl Pp
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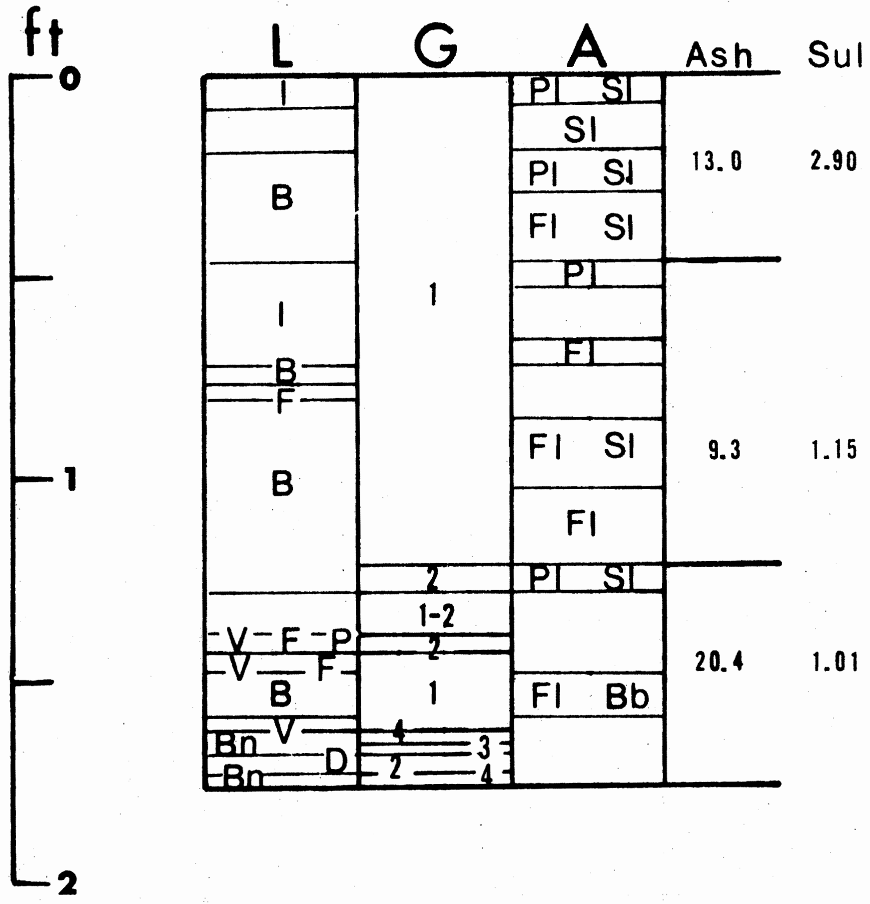
Fl Pl
Sl
Bb Sl
Sl
Cc Sl
10.6
1.94
8.1
.69
21.8
.86

177/C


ft
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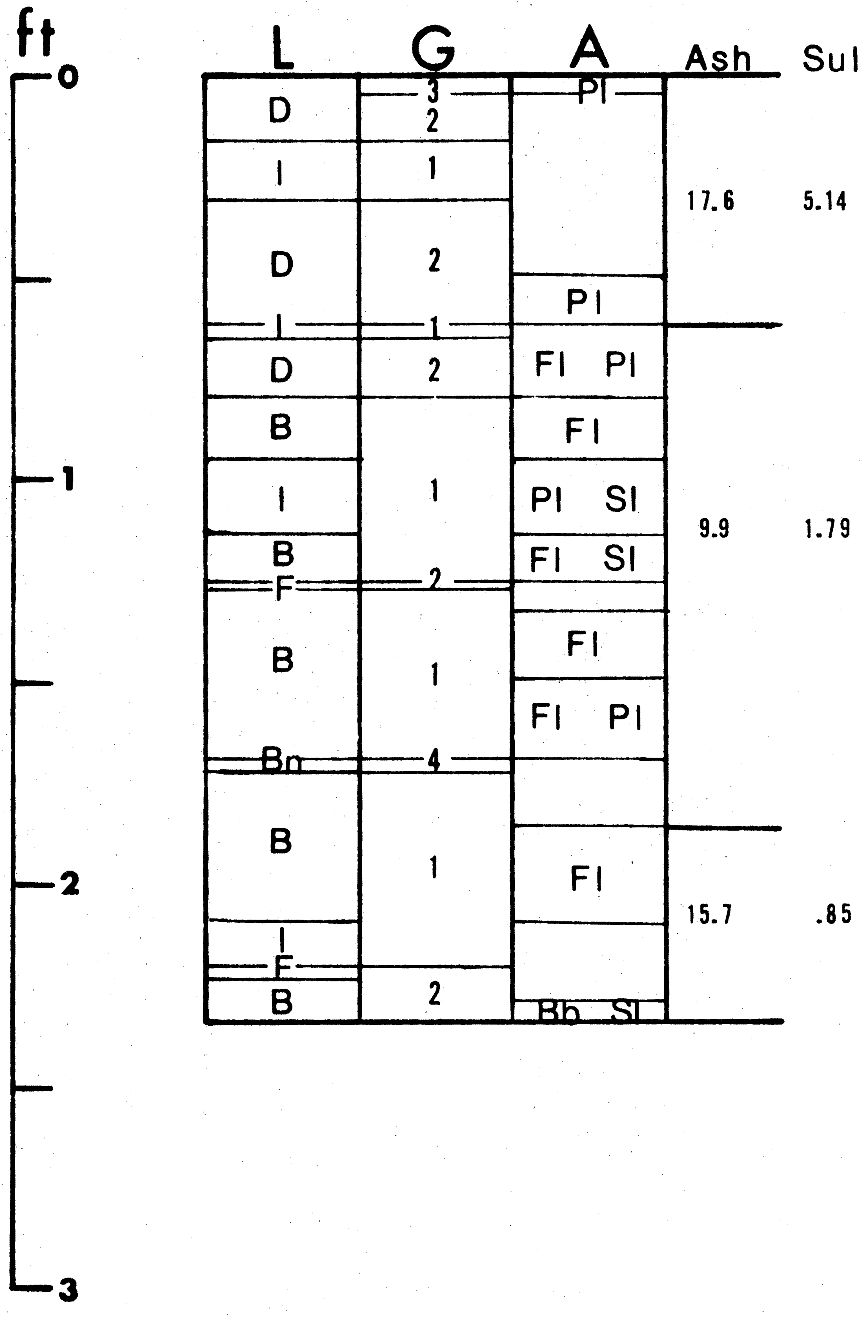
Ash
Sul
I
B
I
B
F
B
V F P
V F
B
Bn V
Bn D
1
2
1-2
2
1
4
3
2
4
Pl Sl
Sl
Pl Sl
Fl Sl
Pl
Fl
Fl Sl
Fl
Pl Sl
Fl Bb
13.0
2.90
9.3
1.15
20.4
1.01

178/C


ft
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Ash
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B
Bn
B
I
F
B
3
2
1
2
1
2
1
2
1
4
1
2
Pl
Pl
Fl Pl
Fl
Pl Sl
Fl Sl
Fl
Fl Pl
Fl
Bb Sl
17.6
5.14
9.9
1.79
15.7
.85

APPENDIX C

USE OF PETROGRAPHIC AND REFLECTANCE ANALYSIS

The use of petrographic and reflectance analysis in predicting coke stability has been discussed by Schapiro, et al. (1961), Schapiro and Gray (1964), Berry, et al. (1967) and Mackowsky (1975). The coke stability factor is the percentage of coke retained on a 1-inch sieve screen after the standard ASTM D 294 tumbler test. A high stability factor is a much sought after characteristic in that it means coke will remain in large pieces during transfer to the blast furnace, a necessity for high production rates in an iron ore blast furnace.

Determination of the coke stability factor is a multistep operation. After the reflectance maceral composition has been determined (Table 3, text), the Composition Balance Index and Rank Index are calculated.

The Composition Balance Index (CBI), also called the Inert Index, is based on the observation that for every vitrinoid reflectance class, there is a ratio of inert to reactive macerals that will make an optimum coke. The formula for the calculation of CBI follows:

$$CBI = \frac{Q}{\frac{P_1}{M_1} + \frac{P_2}{M_2} + \ . \ . \ . \ + \frac{P_{21}}{M_{21}}}$$

CBI = Composition Balance Index

Q = total percent of inerts in sample

P_{1-21} = percent of reactive macerals in each reflectance class (V-1,V-2...V-21)

M_{1-21} = ratio of reactives to inerts for optimum coke in each reflectance class

M_{1-21} have been derived empirically and can be read from Figure 7.

A CBI value of 1.0 is the optimum. Values less than 1.0 indicate less inert material than required for an optimum coke, and values greater than 1.0 indicate too many inerts.

The Rank or Strength Index is calculated from the following formula:

$$KT = \frac{(K_1 \times P_1 + (K_2 \times P_2) + \ldots (K_{21} \times P_{21})}{PT}$$

KT = Rank Index

PT = total percent reactives in sample

K_{1-21} = rank indices of reactives in each reflectance class

P_{1-21} = percent of reactives in reflectance class

K_{1-21} are also empirical values, to be read from Figure 8.

Rank Index takes into account the difference in reactivity during coking of each reflectance class. Vitrinoid types less than 8, coals of high volatile bituminous B rank and less, react weakly, expand little and produce a weak coke. V-9 to V-13, high-volatile A and lower rank medium-volatile coals, react very well and exhibit good expansion characteristics and coke strengths. V types 14 through 19, high rank medium-volatile and low-volatile coals, are strong coking coals but commonly exert excess expansion pressures that are considered unsafe in a coke oven. Coals with reflectance values greater than 19, semi-anthracite to

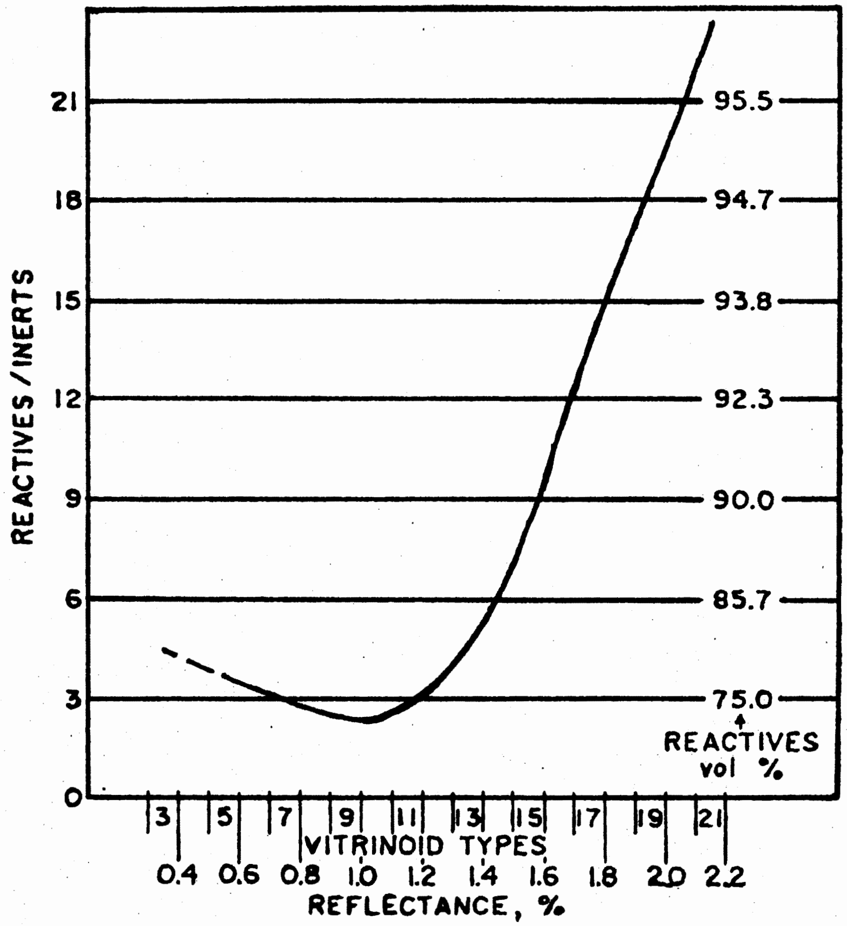


Fig. 7.-Composition Balance Index chart. Ratio of reactives to inerts for optimum coke in each reflectance class (M_{1-21}) is determined by plotting the vitrinoid type with empirically derived ratio line.

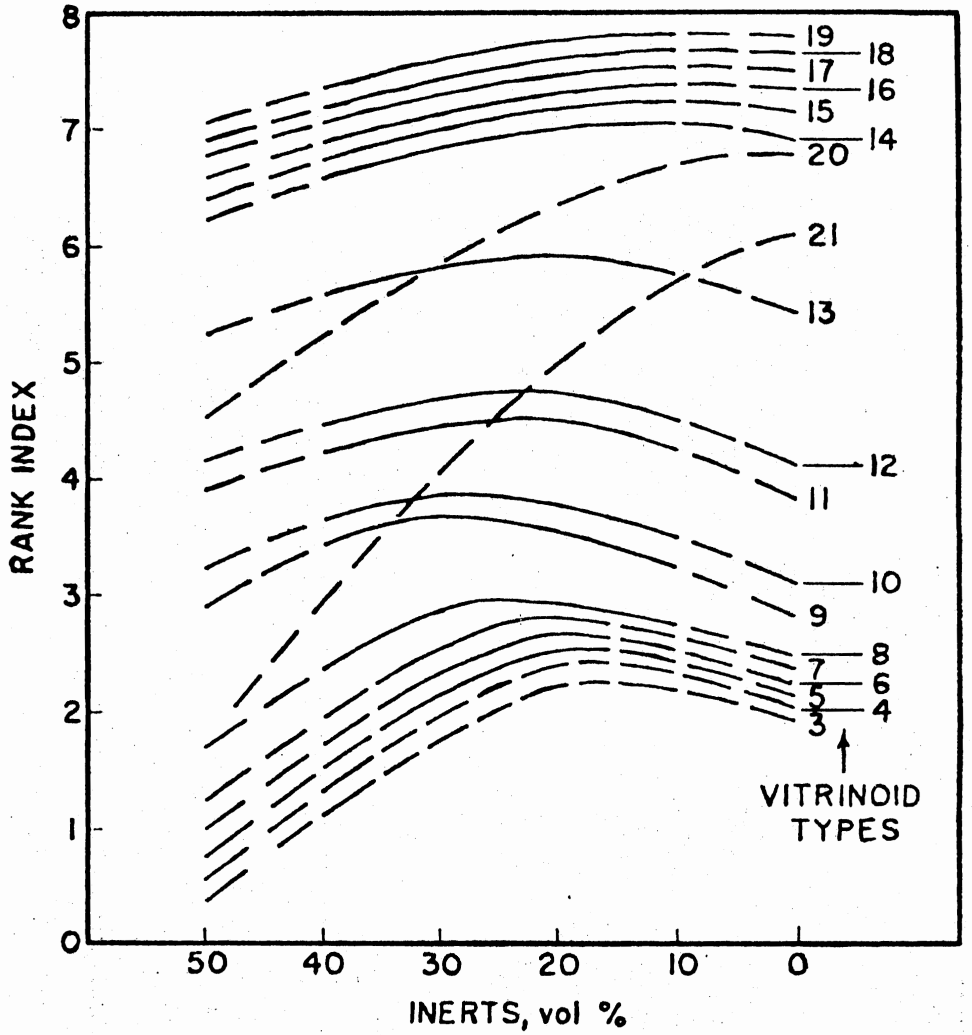
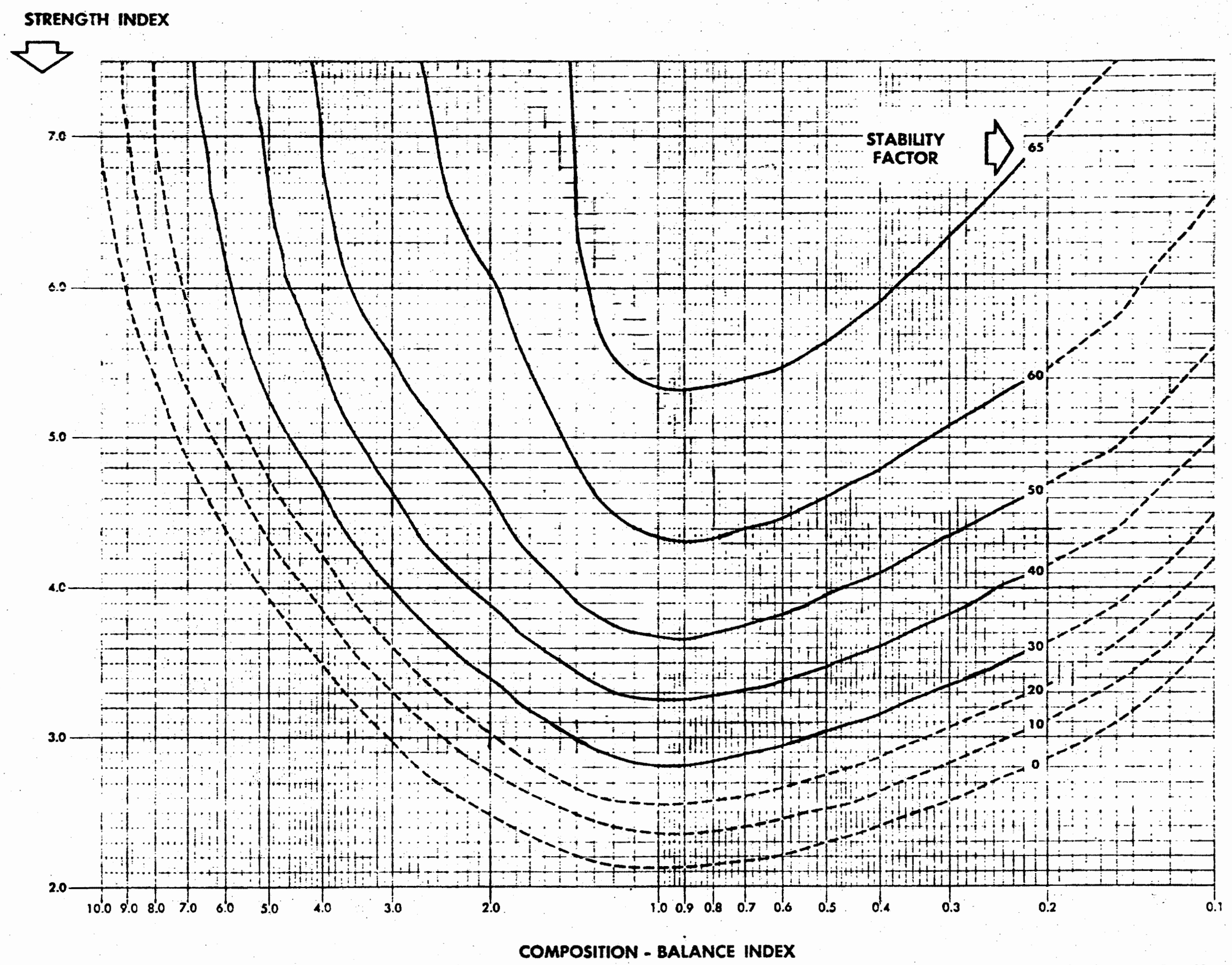


Fig. 8.-Rank Index chart. Indices of individual reflectance classes (K_{1-21}) are obtained by plotting the total inerts of sample with each vitrinoid type.

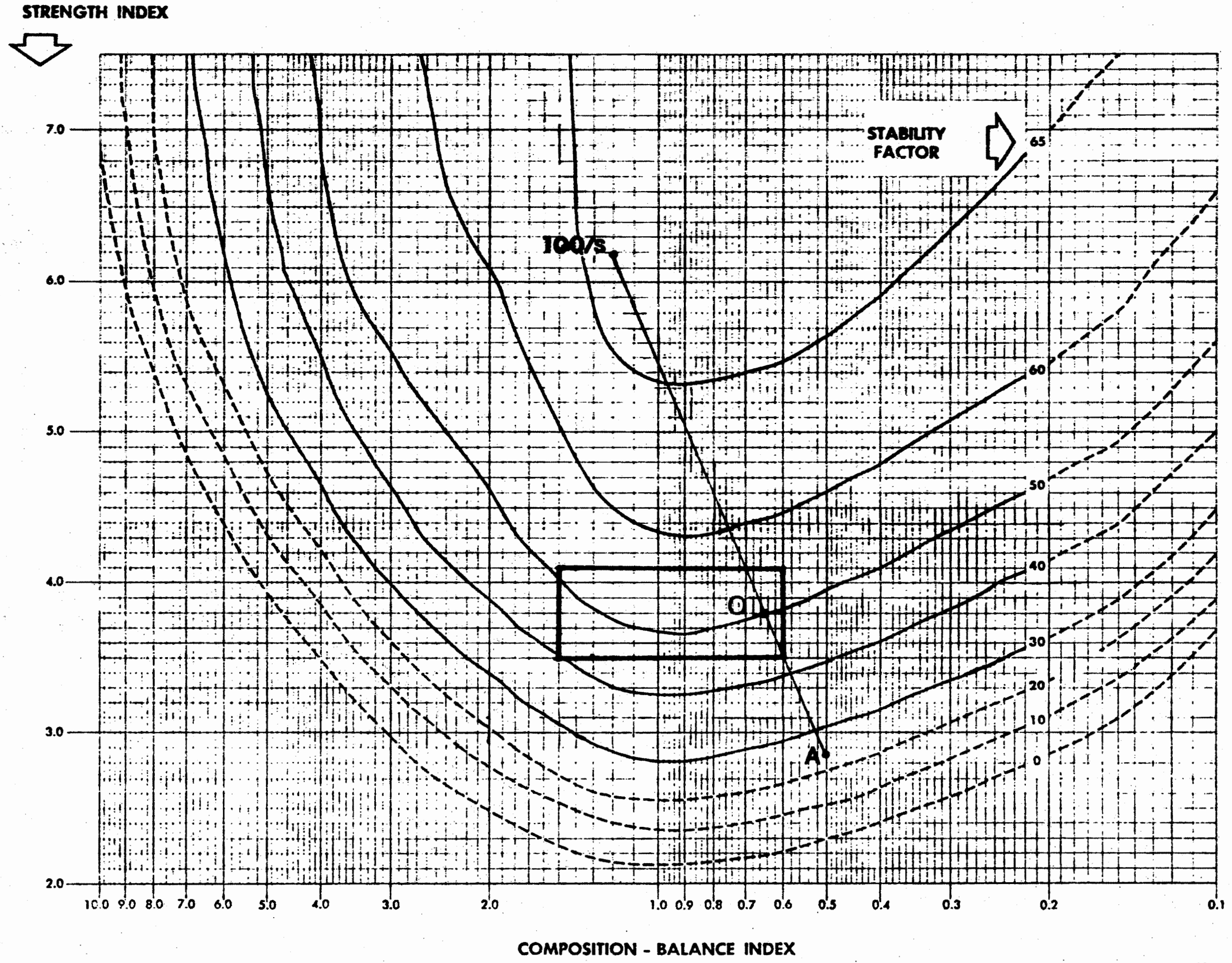
anthracite, decrease in coke strength and once above 22 act like the inert constituents.

The Calculated Stability Factor is obtained by plotting the CBI and Rank Index on Figure 9. An optimum metallurgical coal should fall between CBI 1.5 and .6, and Rank Index 3.5 and 4.1. Because few coals lie within this range, this chart can also be used to predict blendable coals and blend ratios. If two coals were to be tested for blend compatibility, they would each be plotted on the same Calculated Stability Factor Chart (example: Pine Mountain sample 100/s and high-volatile sample A with CBI=.50; RI= 2.86; CSF=24). If a line drawn connecting the two points passes through the optimum metallurgical coal zone, then the two can be blended to produce such a coal. The blend ratio is inversely proportional to the length of each line segment to the center of the optimum zone, that is if 100/s to point O (Figure 10) is 2.8 inches and point A to point O is 1.12 inches, then the blend ratio should be 5:2 (coal A:coal 100/s). If the line does not intersect the optimum zone, they are not blendable by themselves to produce an optimum coal. The system can be used to calculate multiple blends and hence for the latter example, suggest a third coal or combination of coals to blend with the original blend to produce an optimum metallurgical coal.



Shapiro and Gray - 1964

Fig. 9.-Stability Factor and coal blending chart.



Shapiro and Gray - 1964

Fig. 10.-Hypothetical blend of sample 100/s and coal A.

APPENDIX D

WASHABILITY DATA

Table 11.-Washability data of Lower Hartshorne coal.

					Individual Wt Percent			Cumulative Wt Percent		
Hole	Sample	Size	Size Percent	Specific Gravity	Yield	Ash	Sul	Yield	Ash	Sul
155/C	A	+28	86.4	Float 1.45	88.4	8.08	1.48			
				1.45 x 1.60	4.5	24.21	3.18			
				Sink 1.60	7.1	56.20	.96			
		-28	13.6	Float 1.45	88.3	9.02	1.40			
				1.45 x 1.60	4.7	17.02	2.31			
				Sink 1.60	7	57.36	2.96			
165/C	A			Float 1.55	90.8	9.67	.97	90.8	9.67	.97
				Sink 1.55	9.2	52.26	.98	100.0	13.59	.97
167/C	A,B & C			Float 1.55	53.5		1.45			
				Sink 1.55	46.5	62.35	1.82			
168/C	A			Float 1.55	41.6	18.38	.97	41.6	18.38	.97
				Sink 1.55	58.4	58.62	.98	100.0	41.88	.98
	B			Float 1.55	99.6	8.37	1.40	99.6	8.37	1.40
				Sink 1.55	.4	36.3	4.34	100.0	8.48	1.41
	C			Float 1.55	59.1	22.63	5.13	59.1	22.63	5.13
				Sink 1.55	40.9	42.62	5.06	100.0	30.81	5.10
	A & B	- ¼"		Float 1.45	86.9	8.5	1.44			
				Sink 1.45	13.1	23.53	5.17			
170/C	B			Float 1.45	90.4	10.07	2.40			
				Sink 1.45	9.6	36.86	10.46			

Table 11.-(continued)

					Individual, Wt. Percent			Cumulative, Wt. Percent		
Hole	Sample	Size	Size Percent	Specific Gravity	Yield	Ash	Sul	Yield	Ash	Sul
152/C	A	+28 mesh	89.96	Float 1.30	13.47	3.78	0.93	13.47	3.78	0.93
				1.30 x 1.35	46.71	7.44	1.37	60.18	6.62	1.27
				1.35 x 1.40	28.58	11.25	3.12	88.76	8.11	1.87
				1.40 x 1.45	6.19	14.94	4.10	94.95	8.56	2.01
				1.45 x 1.50	2.29	19.23	7.58	97.24	8.81	2.14
				1.50 x 1.55	1.60	26.39	4.00	98.84	9.09	2.17
				1.55 x 1.60	0.40	29.82	10.41	99.24	9.18	2.20
				1.60 x 1.65	0.11	30.20	8.86	99.35	9.20	2.21
				1.65 x 1.70	0.11	31.32	8.87	99.46	9.23	2.22
				1.70 x 1.90	0.25	34.42	12.79	99.71	9.29	2.24
				Sink 1.90	0.29	39.31	17.17	100.00	9.37	2.29
		-28 mesh	10.04	Float 1.30	29.64	3.02	0.71	29.64	3.02	0.71
				1.30 x 1.40	53.29	7.20	1.14	82.93	5.71	0.99
				1.40 x 1.50	7.49	13.67	2.41	90.42	6.36	1.10
				1.50 x 1.60	2.99	15.79	3.53	93.41	6.67	1.18
				1.60 x 1.70	1.80	19.72	5.78	95.21	6.91	1.27
				1.70 x 1.90	1.20	38.71	9.69	96.41	7.31	1.37
				Sink 1.90	3.59	57.71	15.36	100.00	9.12	1.88
		Composite All Sizes		Float 1.30	15.10	3.63	0.88	15.10	3.63	0.88
				1.30 x 1.40	73.08	8.77	1.96	88.18	7.89	1.78
				1.40 x 1.50	8.38	15.88	4.80	96.56	8.58	2.04
				1.50 x 1.60	2.10	25.47	5.03	98.66	8.94	2.10
				1.60 x 1.70	0.38	25.53	7.40	99.04	9.01	2.12
				1.70 x 1.90	0.34	35.93	11.70	99.38	9.10	2.15
				Sink 1.90	0.62	49.99	16.12	100.00	9.35	2.24

Table 11.-(continued)

					Individual, Wt. Percent			Cumulative, Wt. Percent		
Hole	Sample	Size	Size Percent	Specific Gravity	Yield	Ash	Sul	Yield	Ash	Sul
154/C	B + C Composite	+28 mesh	91.49	Float 1.30	8.84	3.48	0.71	8.84	3.48	0.71
				1.30 x 1.35	40.23	6.55	0.89	49.07	6.00	0.86
				1.35 x 1.40	18.75	10.90	1.79	67.82	7.35	1.12
				1.40 x 1.45	7.26	15.16	3.43	75.08	8.11	1.34
				1.45 x 1.50	4.38	20.59	4.35	79.46	8.79	1.51
				1.50 x 1.55	2.30	28.51	3.65	81.76	9.35	1.56
				1.55 x 1.60	1.80	32.13	4.13	83.56	9.84	1.62
				1.60 x 1.65	6.18	32.14	6.76	89.74	11.38	1.97
				1.65 x 1.70	3.45	33.16	10.04	93.19	12.18	2.28
				1.70 x 1.90	3.23	40.25	9.22	96.42	13.12	2.51
				Sink 1.90	3.58	64.34	5.96	100.00	14.96	2.63
		-28 mesh	8.51	Float 1.30	4.67	6.24	1.17	4.67	6.24	1.17
				1.30 x 1.40	64.67	6.43	1.10	69.34	6.42	1.11
				1.40 x 1.50	12.00	12.81	2.38	81.34	7.36	1.29
				1.50 x 1.60	5.33	16.50	3.26	86.67	7.92	1.41
				1.60 x 1.70	4.67	23.51	4.12	91.34	8.72	1.55
				1.70 x 1.90	3.33	30.10	5.64	94.67	11.62	1.70
				Sink 1.90	5.33	60.51	6.29	100.00	12.19	1.94
		Composite All Sizes		Float 1.30	8.48	3.61	0.72	8.48	3.61	0.72
				1.30 x 1.40	59.47	7.79	1.17	67.95	7.27	1.11
				1.40 x 1.50	11.67	16.82	3.66	79.62	8.67	1.49
				1.50 x 1.60	4.20	28.64	3.80	83.82	9.67	1.60
				1.60 x 1.70	9.21	32.12	7.77	93.03	11.89	2.21
				1.70 x 1.90	3.24	39.37	8.91	96.27	12.82	2.44
				Sink 1.90	3.73	63.88	6.00	100.00	14.72	2.57

Table 11.-(continued)

					Individual, Wt. Percent			Cumulative, Wt. Percent		
Hole	Sample	Size	Size Percent	Specific Gravity	Yield	Ash	Sul	Yield	Ash	Sul
166/C	A B +C	3/4" x 28 m	92.82	Float 1.30	16.07	3.62	0.73	16.07	3.62	0.73
				1.30 x 1.40	75.47	7.99	0.95	91.54	7.22	0.91
				1.40 x 1.50	3.16	9.95	1.81	94.70	7.31	0.94
				1.50 x 1.60	0.90	23.84	3.75	95.60	7.47	0.97
				1.60 x 1.70	0.90	36.92	3.49	96.50	7.74	0.99
				1.70 x 1.90	3.21	46.65	3.89	99.71	9.00	1.08
				Sink 1.90	0.29	60.42	6.49	100.00	9.15	1.10
		-28 mesh	7.18	Float 1.30	3.65	3.60	0.71	3.65	3.60	0.71
				1.30 x 1.40	79.73	7.98	0.83	83.38	7.79	0.82
				1.40 x 1.50	11.63	13.41	1.12	95.01	8.48	0.86
				1.50 x 1.60	1.33	13.78	2.79	96.34	8.55	0.89
				1.60 x 1.70	1.33	31.68	3.20	97.67	8.86	0.92
				1.70 x 1.90	1.00	43.36	3.99	98.67	9.21	0.95
				Sink 1.90	1.33	60.14	6.84	100.00	9.89	1.03
		Composite All Sizes		Float 1.30	15.18	3.62	0.73	15.18	3.62	0.73
				1.30 x 1.40	75.77	7.99	0.94	90.95	7.26	0.90
				1.40 x 1.50	3.76	10.71	1.66	94.71	7.40	0.93
				1.50 x 1.60	0.94	22.77	3.65	95.65	7.55	0.96
				1.60 x 1.70	0.94	36.36	3.46	96.59	7.83	0.99
				1.70 x 1.90	3.05	46.57	3.92	99.64	9.01	1.08
				Sink 1.90	0.36	60.34	6.59	100.00	9.20	1.10

Table 11.-(continued)

					Individual, Wt. Percent			Cumulative, Wt. Percent		
Hole	Sample	Size	Size Percent	Specific Gravity	Yield	Ash	Sul	Yield	Ash	Sul
169/C	A + B	3/4" x 28 m	94.53	Float 1.30	14.10	3.91	0.73	14.10	3.91	0.73
				1.30 x 1.40	75.85	8.73	0.94	89.95	7.97	0.91
				1.40 x 1.50	5.25	18.87	1.31	95.20	8.58	0.93
				1.50 x 1.60	0.75	30.42	1.93	95.95	8.75	0.94
				1.60 x 1.70	0.60	39.19	2.14	96.55	8.94	0.94
				1.70 x 1.90	0.90	52.90	2.54	97.45	9.34	0.96
				Sink 1.90	2.55	64.68	3.37	100.00	10.75	1.02
		-28 mesh	5.47	Float 1.30	3.63	4.33	0.66	3.63	4.33	0.66
				1.30 x 1.40	80.31	7.61	0.91	83.94	7.81	0.90
				1.40 x 1.50	5.70	13.83	1.34	89.64	7.87	0.93
				1.50 x 1.60	3.11	15.61	1.88	92.75	8.13	0.96
				1.60 x 1.70	1.55	34.42	2.72	94.30	8.56	0.99
				1.70 x 1.90	1.55	46.26	3.57	95.85	9.17	1.03
				Sink 1.90	4.15	64.86	5.04	100.00	11.48	1.20
		Composite All Sizes		Float 1.30	13.53	3.92	0.73	13.53	3.92	0.73
				1.30 x 1.40	76.09	8.66	0.94	89.62	7.94	0.91
				1.40 x 1.50	5.28	18.57	1.31	94.90	8.54	0.93
				1.50 x 1.60	0.88	27.56	1.92	95.78	8.71	0.94
				1.60 x 1.70	0.66	38.61	2.21	96.44	8.91	0.95
				1.70 x 1.90	0.93	52.33	2.63	97.37	9.33	0.96
				Sink 1.90	2.63	64.70	3.51	100.00	10.79	1.03

Table 12.-Froth flotation tests.

Sample: 155/C A Float 1.45 fraction

Size: -28 mesh

	Dry Basis		
	% Wt.	% Ash	% Sulfur
Concentrate	92.39	7.43	1.25
Tails	7.61	19.57	1.75
Feed	100.00	8.35	1.29

Sample: 155/C B raw coal

Size: -28 mesh

	Dry Basis		
	% Wt.	% Ash	% Sulfur
Concentrate	75.00	19.44	4.64
Tails	25.00	50.83	7.09
Feed	100.00	27.29	5.25

APPENDIX E

MEASURED STRATIGRAPHIC SECTIONS AND CORE DESCRIPTIONS

1. U.S. Highway 59 roadcut, E½, NW¼, sec. 36, T. 5 N., R. 25 E.

Description of Unit	Thickness in Feet
Hartshorne Formation	
Upper Hartshorne Sandstone Mbr., sandstone, gray weathers tan, very fine-grain, angular, 99% quartz with traces of carbonaceous material, feldspar and fe mags; small-scale cross-bedding and groove casts; broken silty layers 9 to 18" present. Bottom contact sharp.	11.7
Claystone, weathers light gray to tan, claystone and siderite nodules and plant fragments present, blocky texture.	11.7
Sandstone, gray weathers tan, fine- to very fine-grain, 90% quartz with fe mags, mica and feldspar; allocthonous plant cast with vitrain coating; medium-scale trough cross-bedding; upper portion massive, lower shaley.	7.0
Siltstone, light gray to dark gray, laminated; flaser, wavy and lenticular bedding.	1.2
Silty shale, light gray with ironstone nodules.	.9
Sandstone, weathers light gray to tan, fine-grain to siltstone, laminated, small-scale cross-bedding.	1.4
Shale, gray, clay and ironstone nodules, plant fragments including 2 ft + diameter tree trunk with vitrainized periderm.	5.1
Shale, dark gray to black, with thin vitrain bands and lenses, plant fragments, gradational with coal.	2.8
Coal, Lower Hartshorne.	2.0
Shale, light gray to black, fissile with ironstone concretions, lenses and beds, top gradational with coal, bottom contains several 1-1.5" coal bands.	7.4
Underclay, light gray.	.4
Sandstone, gray weathers tan, coarse silt to fine sand, quartz abundant with minor weathered feldspar, siderite, muscovite, traces of chloritized biotite; quartz cement dominates with traces of hematite; quartz grains sub-angular and sub-rounded, plant	

Description of Unit	Thickness in Feet
fragments, thin interbedded shale beds, ironstone concretions, flaser and wavy bedding, vertical tree casts at bottom, some replaced with siderate.	25.7
Shale, gray, fissile at top, ironstone concretions and plant fragments.	2.0
Sandstone, gray weathers tan, very fine-grain to coarse silt, top foot contains 2-3" beds, bottom massive 2-3 ft. medium-scale cross-bedding, scoured basal contact.	3.5
Siltstone, dark gray medium to coarse silt, micaceous with trace of feldspar, quartz cement with minor secondary siderite and trace of hematite, grades down to fine-grain sandstone.	3.0
Sandstone, gray weathers tan, very fine-grain, scoured basal contact.	2.0
Siltstone, dark gray, with ironstone concretions.	2.0
Sandstone, gray weathers tan, coarse silt to fine sand, quartz subangular to subrounded; quartz cement with trace of siderite and minor clay; minor muscovite.	3.5
Siltstone, dark gray with ironstone concretions.	1.5
Sandstone, dark gray weathers tan, with interbedded siltstone; bimodal quartz, very fine-grained sand to coarse silt and fine to medium silt, both angular and sub-rounded; minor muscovite feldspar, clay, and secondary siderite; quartz cement; graded bedding, fines upward to siltstone; small- and medium-scale cross-bedding, scoured base with flute and groove casts; upright and NE-SW oriented Calamites and lycopods; siderite nodules, often association with plant fragments, up to 4" thick; gradational with lower shale.	8.0
Atoka Formation	
Shale, dark gray weathers light gray, with iron and claystone nodules.	6.1
Shale, black, carbonaceous with vitrain bands; ironstone nodules, along bedding planes, with leaf imprints; dewatering structures.	2.8

Description of Unit	Thickness in Feet
Coal.	.5
Shale, black, interbedded coal from vitrain bands to intimate mixtures giving shale a well-developed cleat, secondary native sulfur on weathered surface.	6.8
Underclay, gray.	.8
Shale, black, carbonaceous with coal bands.	4.0
Ironstone nodule bed, burnt red with plant casts.	.3
Shale, dark gray; clay and ironstone nodules; blocky texture.	7.9
Siltstone, light and dark gray, medium to coarse silt, angular and subrounded; clay matrix with quartz cement; carbonaceous with well-preserved plant remains; bedding laminated, horizontal to wavy.	7.8
Shale, dark gray, with ironstone nodules.	.7
Shale, black, carbonaceous, fine and fissile, with interbedded coal bands.	.8
Coal.	.6
Shale, black, carbonaceous, fissile with fine coal bands.	3.8
Siltstone, light to dark gray, coarse silt, angular and subrounded; laminated, flaser, wavy and lenticular bedding; graded, coarser laminae quartz cemented, finer have clay matrix; quartz grains show pressure solution; muscovite, and minor chlorite after biotite(?); bedding planes highly micaceous well-preserved plant fossils in top 15'; fossils below 15' grade from sparce to absent.	+50.0

2. Core hole 155/C, N½, SE¼, SE¼, Sec. 26, T. 5 N., R. 25 E.

Description of Unit	Thickness in Feet
Hartshorne Formation	
Sandstone, weathered tan, very fine-grain, quartz,	

Description of Unit	Thickness in Feet
angular and subrounded, weathered unidentifiable plant mold, minor mica, small-scale cross-bedding, carbonaceous material concentrated along bedding planes.	8.0
Shale, light to dark gray, with carbonaceous plant remnants.	5.0
Shale, black, carbonaceous	.6
Siltstone, light to dark gray, shaley, flaser, wavy and lenticular bedding.	1.0
Shale, dark gray, minor carbonaceous plant fossils.	.4
Shale, dark gray, abundant broken carbonaceous plant fossils.	6.0
Siltstone, light to dark gray, shaley, flaser, wavy and lenticular bedding.	1.0
Sandstone, light gray, fine-grain, quartz cement with minor siderite in small- and medium-scale cross-bedding, lower portion of unit is flaser bedded grading down to horizontal bedding and then to sandy shale.	2.0
Sandstone, light to dark gray, fine-grain, quartz; small- to medium-scale cross-bedding; horizontal lamination of sandstone, siltstone and shale in bottom 3 feet.	7.0
Shale, dark gray, well-preserved carbonaceous leaf fossils.	5.0
Shale, black, carbonaceous, trace of coal bands.	.6
Coal, Lower Hartshorne.	2.3

3. Core hole 159/C, E½, NE¼, SE¼, Sec. 26, T. 5 N., R. 25 E.

Description of Unit	Thickness in Feet
Hartshorne Formation	
Sandstone, gray weathered tan, very fine-grain quartz, medium-scale cross-bedding, in top 3 ft, bottom 1.5 has horizontal bedding and dewatering structure; hard.	4.5

Description of Unit	Thickness in Feet
Clay, light brown to gray, weathered, sideritic concretions and minor carbonaceous plant fossils.	1.0
Sandstone, gray weathers tan, very fine-grained quartz, minor small- and medium-scale cross-bedding; hard; micaceous bedding planes.	11.0
Shale, dark gray, carbonaceous leaf imprints with some vitrain fossils abundant in bottom 8 feet, parallel to bedding.	17.0
Siltstone, light to dark gray, flaser and wavy bedding.	1.0
Shale, dark gray, sandy and silty.	3.0
Shale, dark gray, carbonaceous plant remnants.	3.0
Shale, black, carbonaceous.	.5
Coal, Lower Hartshorne.	2.5

4. Core hole 169, S½, SE¼, SW¼, Sec. 27, T. 5 N., R. 25 E.

Description of Unit	Thickness in Feet
Hartshorne Formation	
Sandstone, light brown, very fine-grain quartz, small-scale cross-bedding.	3.2
Shale, gray, soft.	3.0
Sandstone, gray, very fine-grain to coarse silt, angular, subrounded, clay matrix with muscovite and siderite, small-scale cross-bedding.	4.0
Shale, gray.	3.0
Sandstone, gray, very fine-grain, laminated, flaser and wavy beds, small-scale cross-bedding, sparse worm burrows 7' to 9'.	9.8
Shale, gray.	.4
Sandstone, gray, very fine-grain to coarse silt, with shale laminae, flaser bedded, carbonaceous *Calamites* remnants, small- and medium-scale	

Description of Unit	Thickness in Feet
cross-bedding, minor convolute bedding and dewatering structure, gradation basal contact with shale.	8.8
Shale, dark gray, hard at top, soft at bottom, bottom 1 ft rich in carbonized plant imprints with traces of vitrain.	7.0
Shale, black, fissile with vitrain bands.	.3
Coal, Lower Hartshorne.	2.8

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VITA

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