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COAL-BED METHANE POTENTIAL OF THE MINERAL COAL BED (SENORA FORMATION, DESMOINESIAN SERIES) OKMULGEE COUNTY, OKLAHOMA

FIELD TRIP GUIDEBOOK

By
Samuel A. Friedman

**PREPARED FOR
THE MID-CONTINENT SECTION BIENNIAL MEETING
OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS (AAPG)
ENERGY MINERALS DIVISION
TUESDAY FIELD TRIP, SEPTEMBER 13, 2005**

**Field Trip Leader
Samuel A. Friedman
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and the Oklahoma City Geological Society
Hosted by the Oklahoma City Geological Society
Coordinated by the Energy Mineral Division of the
American Association of Petroleum Geologists

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LIST OF ILLUSTRATIONS

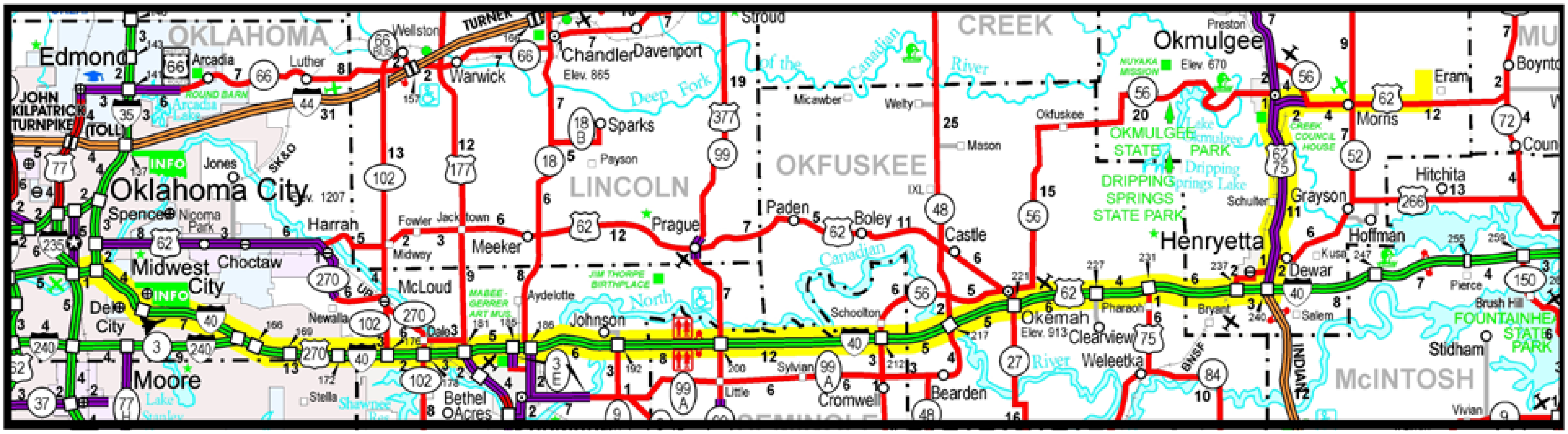

Fig. 1. Route of field trip on the 2005 Oklahoma State Highway Map, highlighted from downtown Oklahoma City to the Metropolis mine, near Eram.

INTRODUCTION

PURPOSE

The purpose of the field trip to a small surface coal mine is to evaluate the potential for coal-bed methane (CBM) exploration and production of the Mineral coal in Okmulgee County, by examining the coal geology in the mine, with emphasis on the coal bed, and then projecting this geology westward. This guidebook contains a brief sketch of the county's coal geology in relation to other counties in the Northeast Oklahoma Shelf.

The route map (Fig. 1) shows that the mine we will visit is 120 miles (a two-hour drive) from downtown Oklahoma City, the location of the present (2005) Biennial Meeting of the AAPG Mid-Continent Section. The mine is 1.5 miles northwest of Eram, Okmulgee County, which is located in the Eastern Sandstone Cuesta Plains subsection of the Sandstone Hills Section (Johnson and others, 1972) of the Central Lowlands Physiographic Province (Fenneman, 1931).

COAL GEOLOGY SETTING

Approximately 8 billion short tons of identified bituminous coal resources (Table 1) are present in 25 coal beds in 19 counties (Fig. 2) in the Oklahoma coalfield (Friedman, 2003). This coalfield includes about 8,000 square miles and is in the southern part of the Western Region of the Interior Coal Province of the United States (Campbell,1917). The Oklahoma coalfield has been divided into the Arkoma Basin and the Northeast Oklahoma Shelf (Friedman 1974, p. 6 and fig. 5, p. 10). The coal beds, for which coal resources have been determined, occur mostly in the Desmoinesian Series and in part of the Missourian Series of the Pennsylvanian System. The coals are 0.8-10.0 ft thick, contain low sulfur (0.4%) to high sulfur (6.5%),and average 2-3% sulfur by weight. Low- to high-volatile bituminous in rank (ASTM 1994), these coals contain 11,500-14,500 Btu/lb (Friedman, 2003).

The thickest coal beds, along with some thin ones, are present in the Arkoma Basin. Thin coal beds are common in the Shelf. Some of these coals may be too thin (< 1 ft thick) and discontinous to consider as good targets for exploration and production for coal-bed methane (CBM). The stratigraphically lower coals are present in the Basin and the higher coals are present in the Shelf (Fig. 3).

ACKNOWLEDGMENTS

I greatly appreciate the efficient assistance of my wife Evelyn Friedman and my son Aaron Friedman in field work and preparation of this guidebook. Special thanks to Claren Kidd, University of Oklahoma Geology Librarian Emerita, for helpful editorial suggestions. I thank Jim Anderson and Brian Cardott of the Oklahoma Geological Survey (OGS) for their advice and support. I am grateful to Alan Churchill, President of Joshua Coal Co., for enabling us to map and study coal geology at the Metropolis Mine. The Oklahoma City Geological Society paid for the printing and binding (at the OGS) of the unedited copies of this guidebook that were distributed for the field trip.

STRATIGRAPHY

The Hartshorne, McAlester, Savanna, Boggy, and Calvin formations of the Desmoinesian Series, Pennsylvanian System, are present in the Arkoma Basin. The Boggy is also present in the Northeast Oklahoma Shelf. In the Shelf the Boggy is overlain conformably by the Senora Formation, which is overlain conformably by the Ft.Scott Limestone or the Calvin Sandstone (Friedman, 1974). This guidebook focuses on the Senora Formation and its coal beds in the Shelf, especially in Okmulgee County.

THICKNESS AND STRATIGRAPHY OF THE SENORA FORMATION

NORTHEAST OKLAHOMA SHELF

In 10 counties in the Northeast Oklahoma Shelf the Senora Formation is150-900 ft in thickness, contains seven coal beds of which six contained identified coal resources some of which had been

Table 1. Remaining Identified Bituminous Coal Resources in Oklahoma, January 1, 1999 (from Friedman, S. A., 2003).

County	Short Tons (thousands)
Atoka	29,619
Coal	292,875
Craig	*640,092
Creek	**15,573
Haskell	1,513,681
Latimer	841,968
Le Flore	1,973,362
Mayes	*31,094
McIntosh	****36,319
Muskogee	****95,557
Nowata	*29,645
Okfuskee	***155,964
Okmulgee	***340,124
Pittsburg	1,383,833
Rogers	*361,821
Sequoyah	27,146
Tulsa	**169,974
Wagoner	**128,955
Washington	**23,450
TOTAL	8,091,052

*Revised in 1986,**Revised in 1991.
Revised in 1994,*Revised in 1998

mined (Friedman, 1974, p. 9, fig. 4). Friedman identified four of the coals--- the Croweburg, Mineral, Morris, and Eram while stating that the Morris in Okmulgee County may be the same as the Mineral in the other counties. A field-trip guidebook (Friedman, 1976) shows that some 300 ft of strata are present in the Senora Formation in parts of Craig, Nowata, and Rogers counties in the Shelf. It also shows surface-mined areas and identified remaining coal resources of three major coals (including the Mineral coal) on a township map.

Another map shows mined areas and identified, remaining strippable coal resources of the Croweburg, Morris, and Eram coal beds 0-100 ft in depth in Okmulgee County (Friedman, 1982, pl. 2). A generalized stratigraphic column indicates that these coals are present in the Senora Formation, which is 300 ft in thickness.

Subsequently, detailed stratigraphic mapping indicated that eight coals occur in the Senora Formation, which is 102-298 ft in thickness. Five of the coals were mined and contained identified remaining resources 0-100 ft or more in depth in Craig and Nowata counties (Hemish, 1986, p. 8, fig. 4). Mapping farther south showed that the Senora Formation is 143-457 ft in thickness, contains four out of six coals that were mined and contained identified remaining resources 0-100 ft or more in depth in Rogers and Mays counties (Hemish, 1989, p. 8-9, fig. 2). Further detailed mapping showed the Senora Formation 245-470 ft in thickness, including six coals of which four contain identified, remaining resources 0-100 ft or more in depth in Creek, Washington, Tulsa, and Wagoner counties (Hemish, 1990, pl 1). Thus the Senora thickens, but contains fewer coal beds more than one foot thick, progressively southward in the Northeast Oklahoma Shelf.

OKMULGEE COUNTY

Dunham and Trumbull (1955, pl. 22) indicated that the Senora Formation increased in thickness from 500 ft in the northern part of Okmulgee County to more than 720 ft in the southern part. These writers assigned the name Morris coal bed to a coal that is less extensive than the Henryetta (Croweburg) coal in the Henryetta Mining District (1955, p. 197). They indicated that the Morris coal cropped out and had been surface mined in the vicinity of Morris, a few miles east of the city of Okmulgee. Forty years later, detailed 7.5' quadrangle mapping in Okmulgee County (Hemish, 1994) showed that the Senora is 332-757 ft or more in thickness, thus confirming that this formation is thickest in the southern-most part of the Northeast Oklahoma Shelf (Fig. 2).

The present writer suggested a research project to determine why the Senora Formation shown on the Oklahoma State Geologic Map (Miser, 1954) extended over an abnormally wide east-west area in Okmulgee County. The result of the project included detailed cross sections with faults bordering tilted half-grabens with vertical displacements from a few ft to almost 450 ft (Hemish, 1988). This

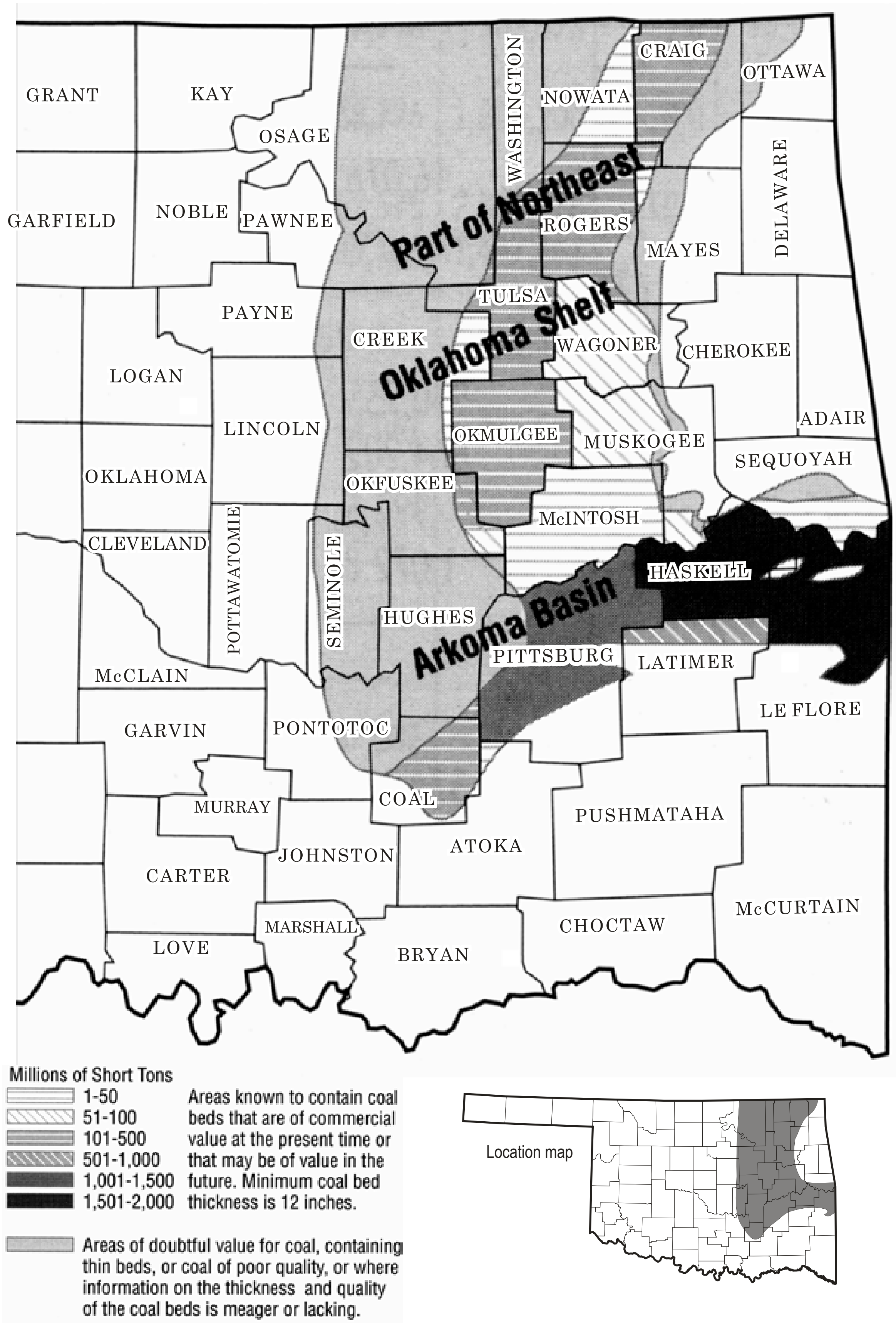

Fig. 2. Map showing the distribution of coal resources by county in Oklahoma. (Modified from Friedman, 2003 Keystone Coal Industry Manual).

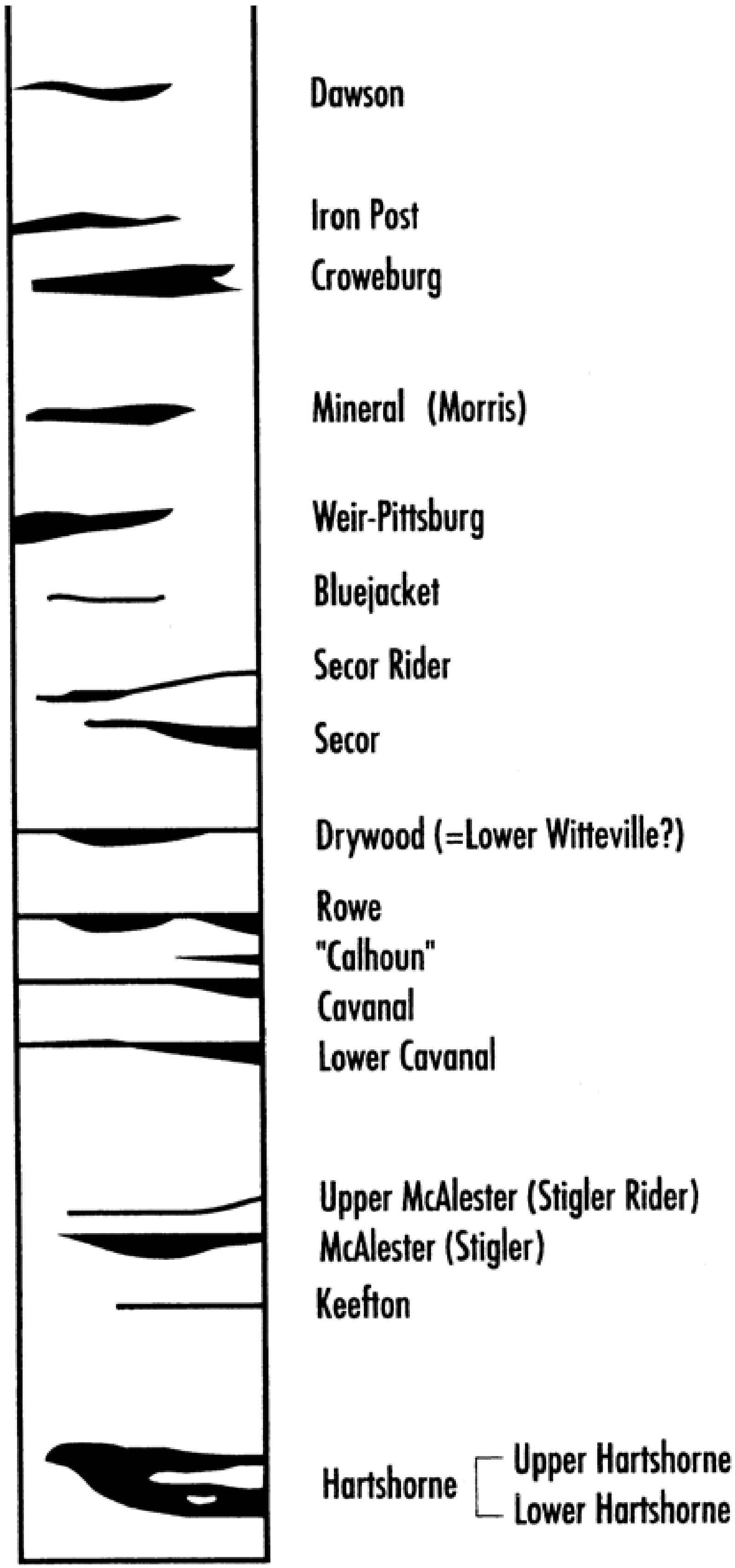

Fig. 3. Skeletal stratigraphic column showing bituminous coals of Oklahoma that contain identified quantities if coal resources and unknown quantities of coal-bed methane resources (Modified from Friedman, 2003 Keystone Coal Industry Manual).

Fig. 4. Map showing location of the Metropolis surface coal mine and abandoned coal mines in a narrow graben that is tilted northwestward west of Eram. (Modified from Hemish, 1988). Additional small faults are present parallel or oblique to the major eastern fault in blocks of strata containing pockets of the Mineral coal. In places the Mineral coal bed is 60 feet deep.

extensional faulting resulted in northeast-trending repetitions of the Senora from Henryetta eastwards to Eram, thus widening its present surface exposure (Hemish 1988). These grabens align with the Seneca faults (graben) (Hemish 1980), and they may be part of a rift system. Just east of Henryetta, again at Morris, and finally near Eram these repetitions of parts of the Senora Formation contain the Mineral coal bed. In the graben area near Eram (Fig. 4) the Mineral coal bed is present in places at depths of 0-60 ft. Thus the Mineral coal bed at Morris was correlated with the Eram coalbed (Hemish, 1988). Previously the Mineral coal bed had been correlated with the coal bed at Morris.(Friedman, 1974, p. 9, fig.4; p. 32; and 1982a).

The Senora Formation in Okmulgee County is composed mostly of shale, sandy or silty shale, and sandstone. The Formation also includes other coals that are underlain by underclaystones and are overlain by dark-gray to black shales, which in some places are overlain by thin fossiliferous limestones (Fig. 5). The present writer believes that these lithologically similar sequences each belongs to a separate cyclothem.

COAL RESOURCES AND MINING

First mined on a commercial scale in 1902, mostly by underground methods, the Henryetta (Croweburg) is the most important coal bed in Okmulgee County (Dunham and Trumbull, 1955). This coal bed contains ~303 million tons of remaining identified coal resources in the county (Hemish, 1994, table 2). The Croweburg may contain CBM resources, but this coal bed is not the focus of this guidebook, which is centered on the Mineral coal bed. Later the present writer will indicate an area in which the Mineral coal bed may contain CBM resources.

THE MINERAL COAL BED

The Mineral is a high-volatile bituminous coal, high in sulfur (3-6%), 1.2-2.7 ft thick, averaging 1.8 ft in Craig, Nowata, Rogers, Tulsa, and Wagoner counties (Table 2). The Mineral coal is overlain by a thin, hard, impure limestone or gray shale in most places in Craig County. This limestone is absent in most places in Rogers County and is completely absent in Tulsa and Wagoner counties.

The Mineral coal bed lies 60-80 ft below the Croweburg coal bed in Craig, Nowata, and Rogers counties. This interval increases southward to about 100 ft in northern Okmulgee County, and it further increases to approximately 200 ft in the central part of this county (Fig. 5). Most of the mining of the Mineral coal bed in the county has been in the vicinity of Morris, and some has been mined just northwest of Eram (where it is known as the Eram coal) (Fig. 4). Most of the reported production has been by surface mining. Almost 35 million tons of identified remaining coal resources are present in this coal in Okmulgee County (Hemish 1994, table 2).

Earlier, Dunham and Trumbull (1955) described the Morris coal as 7-30 inches thick, averaging 16 inches in the Henryetta Mining District (mostly in Okmulgee County). Two small drift mines produced this coal in the 1940s in the vicinity of Morris. The Morris coal was mined by stripping methods in the early 1950s. Later during 1977- 1984, this coal was mined by stripping north of Morris, where it is 1-2 ft thick and is high (3.7-3.9%) in sulfur content (Table 2). Shaly limestone, 1-2 inches thick, overlies this coal in small areas in the vicinity of Morris. A small surface mine, north of Morris, uncovered a northeast-trending fault with a 3-foot vertical displacement. In this mine some of the coal contained 3-inch wide vertical fillings of calcite, which greatly increased the ash content, and the operation was closed in 1982. This coal was not mined from 1984 –1994.

About 31 million short tons of identified resources of Morris coal has been determined (Friedman 1974). Although adverse geologic and mining conditions are present in the faulted area north of Morris, additional resources of Morris coal are present down dip in other places in Okmulgee County. For example, some 9.7 million tons of Mineral coal occurs at depths greater than 100 ft but less than 500 ft in T. 12 N., R.13 E., in T. 13 N., R. 13-15 E., and in T. 14 N., R. 15 E. (Hemish, 1994, Appendix 1, p. 20, 22, 23, and 25).

STANDARD ASTM COAL ANALYSES

COAL BED (Former Name)	PROXIMATE ANALYSIS (Percent)				SULFER (Percent)	Btu/lb	FSI (Free Swelling Index)	Ash Softening Temp. (^{o}F)	No. of Analyses	Data Source
	M	VM	FC	ASH						
Mineral	3.6	39.4	49.6	11.0	3.6	12.730	-	1,990	2	USBM R.I. 7712
Mineral	4.8	36.2	46.0	14.0	4.8	12.022	-	-	4	TGS Guidebook 1976
Mineral	2.3	36.4	47.7	13.8	4.7	12.132	6.3	-	7	OGS SP 94-3
Mineral (Morris)	4.2	37.5	49.0	9.4	3.7	12.505	-	-	1	OGS SP 74-2
Mineral (Morris)	3.9	36.9	51.0	8.3	3.9	12.874	5.5	-	11	OGS SP 94-3
Mineral (Eram)	2.2	38.1	45.5	13.3	5.1	12.188	-	-	1	OGS SP 74-2 OGS SP 94-3
Mineral (Eram)	4.1	38.3	51.2	6.4	1.4	13.105	-	-	1	OGS OPL 1142
Mineral (Eram)	3.4	36.8	49.6	10.3	5.8	12.582	-	-	1	OGS (2005C1F)

Table 2. Table of some standard chemical analyses of the Mineral coal bed. One analysis is from a core sample and the others are from channel samples. All samples were collected by geologists of the Oklahoma Geological Survey, except the USBM sample, which was collected and analyzed by personnell of the U. S. Bureau of Mines. Analyses published in OGS SP 94-3 are from samples collected by L. A. Hemish. The analyses published in OGS SP 74-2 and the one designated as 2005C1F are from samples collected by S. A. Friedman.The analysis designated as OPL 1142 is from a sample collected by B. J. Cardott. The two most recent analyses (2000 and 2005) were done for OGS by Standard Laboratories, Inc., Van Buren, AR.

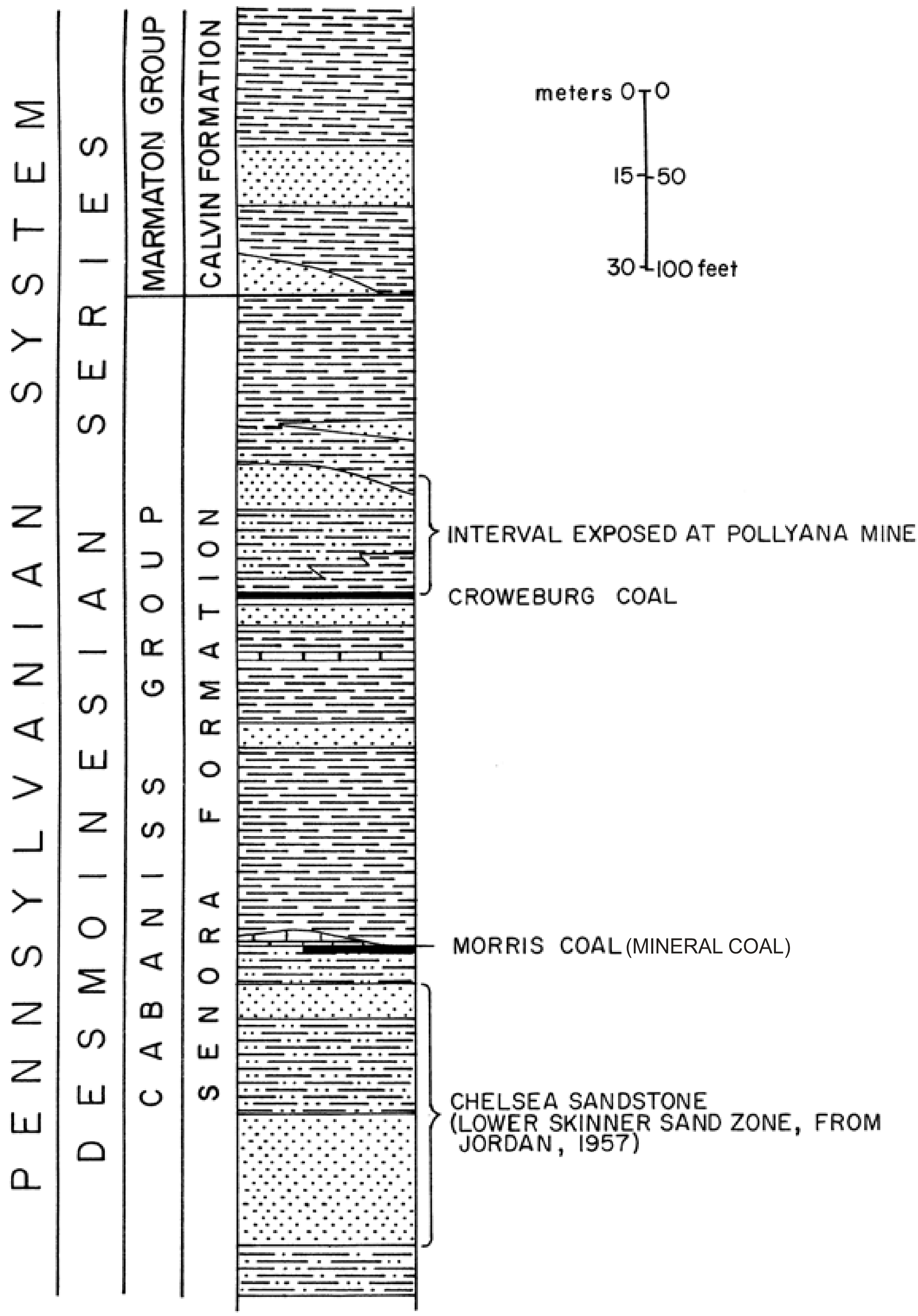

Fig. 5. Generalized stratigraphic column based upon a cross section by Dunham and Trumbull (1955, plate 22). (Modified from Friedman, 1978).

Approximately 41,000 tons of the Mineral coal bed was surface mined in the Metropolis mine near Eram, Okmulgee County, from November, 1995 through June 30, 2005 by Joshua Coal Co. This small, active mine is the destination of the field trip; it is located in the NE1/4NW1/4NE1/4 sec.1, T. 13 N., R. 14 E. (Fig. 6).

In most places in the graben near Eram (Fig. 4), medium light-gray shale that weathers light brown, overlies the coal. In the highwall of the Metropolis mine, medium light-gray shale,12-15 ft thick, overlies the Mineral coal bed, which is 1.5 ft thick (photograph on cover page of guidebook). Light-gray underclaystone, a few inches to a few ft thick, underlies the coal bed in the Metropolis mine and in many places in the county (Figs. 5 and 7).

DIRECTIONS TO THE METROPOLIS MINE

Going east on I-40, exit at the third exit in the Henryetta vicinity. The second exit leads to the Indian Nations Turnpike that takes you to McAlester---do not take this exit although it is tempting! The third exit should say Okmulgee; it is a clover leaf (270 degree) type of turn that lets you end up going north (on U.S. 75) to Okmulgee and, eventually, to Broken Arrow and Tulsa. Drive about 12 miles to Okmulgee and turn right (east) onto U. S. 62 at a traffic light. Go east to a stop sign in Morris. Notice the new water tower. The old water tower was destroyed by a tornado a few years ago. Continue on U. S. 62 for four miles to County Road 330. If you go too fast and are not watchful you will pass it (as I did). Turn north onto County Road 330. In one mile Pass Watts Road . Slowly go ½ mile farther. Turn east at a bushy tree cluster. See the Joshua Mine sign (Fig. 8). Continue about ½ mile to the mine office, which is in a trailer. Stop. This is a hard hat area by Federal and State rules. Follow the mine operator to the active pit. Take care.

CLEAT

The dominant vertical fracture system in coal beds is called cleat. There is face cleat and butt cleat. Face cleat are continuous through the coal bed, whereas butt cleat commonly terminate at almost right angles to the face cleat. The cleats are perpendicular to the coal bedding. The face cleat are the primary paths for water and CBM to move through coal beds. Therefore identifying the face cleat and measuring its orientation are important. Face cleat commonly are oriented almost at right angles to the regional structure. Looking down at the top of the coal bed shows the face cleat trending N 23° W (Fig. 9). This orientation conforms to numerous measurements by Friedman and Hemish (Fig. 10) in the Oklahoma coalfield (Cardott, 2002, p. 54, fig. 14). Face cleat commonly contains mineral fillings. A 10-inch- thick sample of the Mineral coal in the Metropolis mine contains (yellow) pyrite and (white) calcite on face cleat (Fig. 11).

Although the occurrence of sphalerite (ZnS) in cleat in the Mineral coal causes abnormal concentrations of zinc in the coal bed in places in Craig County (Joe Hatch, U.S.G.S., oral communication, 1983), no sphalerite has been identified in this coal bed in Okmulgee County. Anomalous trace concentrations of lead, zinc, and manganese have been mapped in this coal bed in Craig and Rogers counties (Friedman, 1986), but not in Okmulgee County. A Scanning Electron Microscope (SEM) image (thanks to Bill Chisoe) shows a pyrite framboid (Fig. 12) from a face cleat surface in a sample of an Oklahoma coal bed (collected by the present writer and Kurt T. Hollocher in 1978) from the Arkoma Basin.

These and other minerals on face cleat commonly decrease permeability and thus decrease the flow of water and CBM towards a well.

COAL-BED METHANE RESOURCES

All bituminous coals contain coal-bed methane (CBM) that develops during thermal coalification (maturation). Some coals also contain some biogenic methane. Coal beds 500-2,000 ft in depth contain 77% of the CBM resources in the Arkoma Basin (Iannaccione and Puglio, 1979). At least 3 trillion cubic ft of CBM has been estimated to be present in only five of the principal coals in this Basin (Rieke and Kirr, 1984). Other coals undoubtedly contain CBM in the Basin and in the

Shelf areas in Oklahoma (Figs. 2 and 3). Probably coal beds at the same depth range (500-2,000 ft) contain the greatest quantity of CBM in the Shelf.

The present writer previously had applied this depth range (500-2,000 ft) to determine CBM resources in some parts of the Arkoma Basin (Friedman, 1982), but not in the Shelf area. Coal resources for the Mineral (Eram) have been determined (Friedman, 1974, Hemish, 1994) for depths much less than 500 ft, but not for depths from 500-2,000 ft in Okmulgee County, which is in the southernmost part of the Shelf area. In the absence of reliable geologic coal resource estimates, reliable geologic estimates of CBM resources have not been determined and published.

Fig. 6. Aerial photograph showing location of the Metropolis mine in Sec. 1, T. 13 N., R. 14 E., Okmulgee County, Oklahoma.

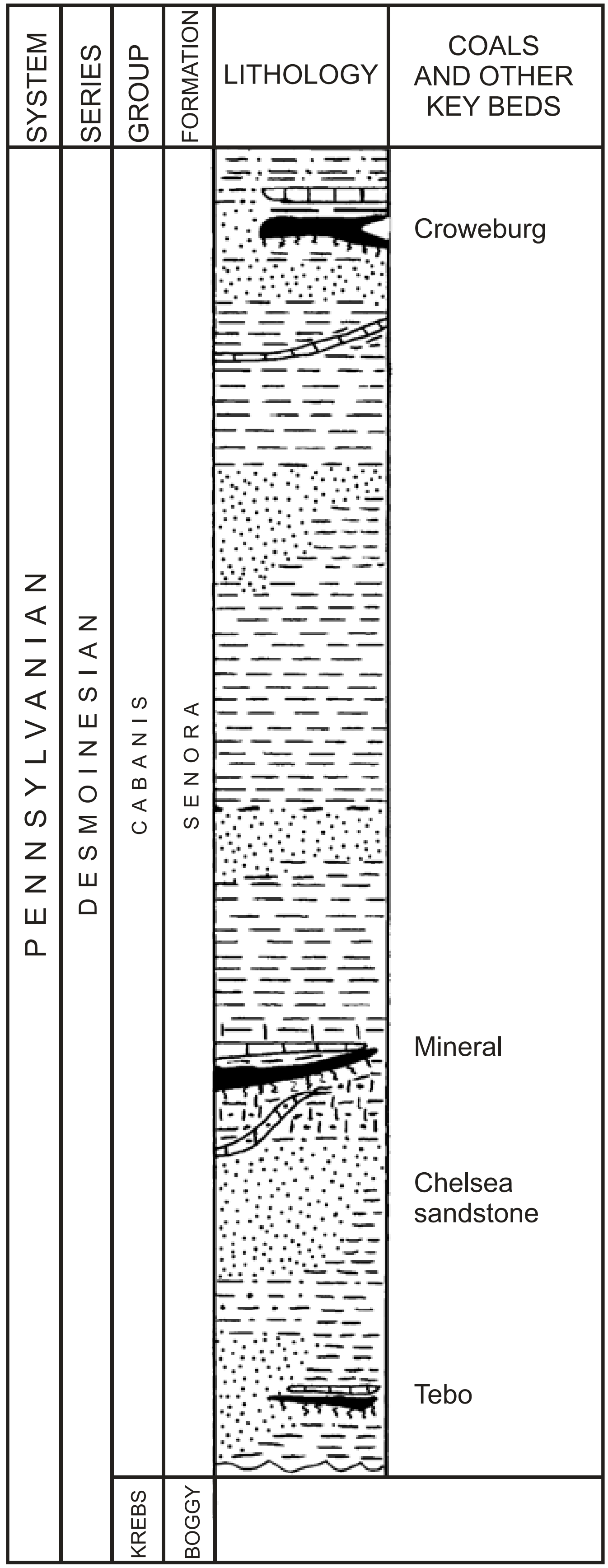

Fig. 7. Generalized stratigraphic column showing the Mineral coal and other key beds in the Senora Formation, Okmulgee County.

Fig. 8. Photograph of required sign at entrance to the Metropolis coal mine. Phone number and address have been deleted by computer by the present writer for security.

Fig. 9. Photograph, looking down, showing N. 23° NW. orientation of the face cleat (with compass) on top of the Mineral coal bed in the Metropolis mine.

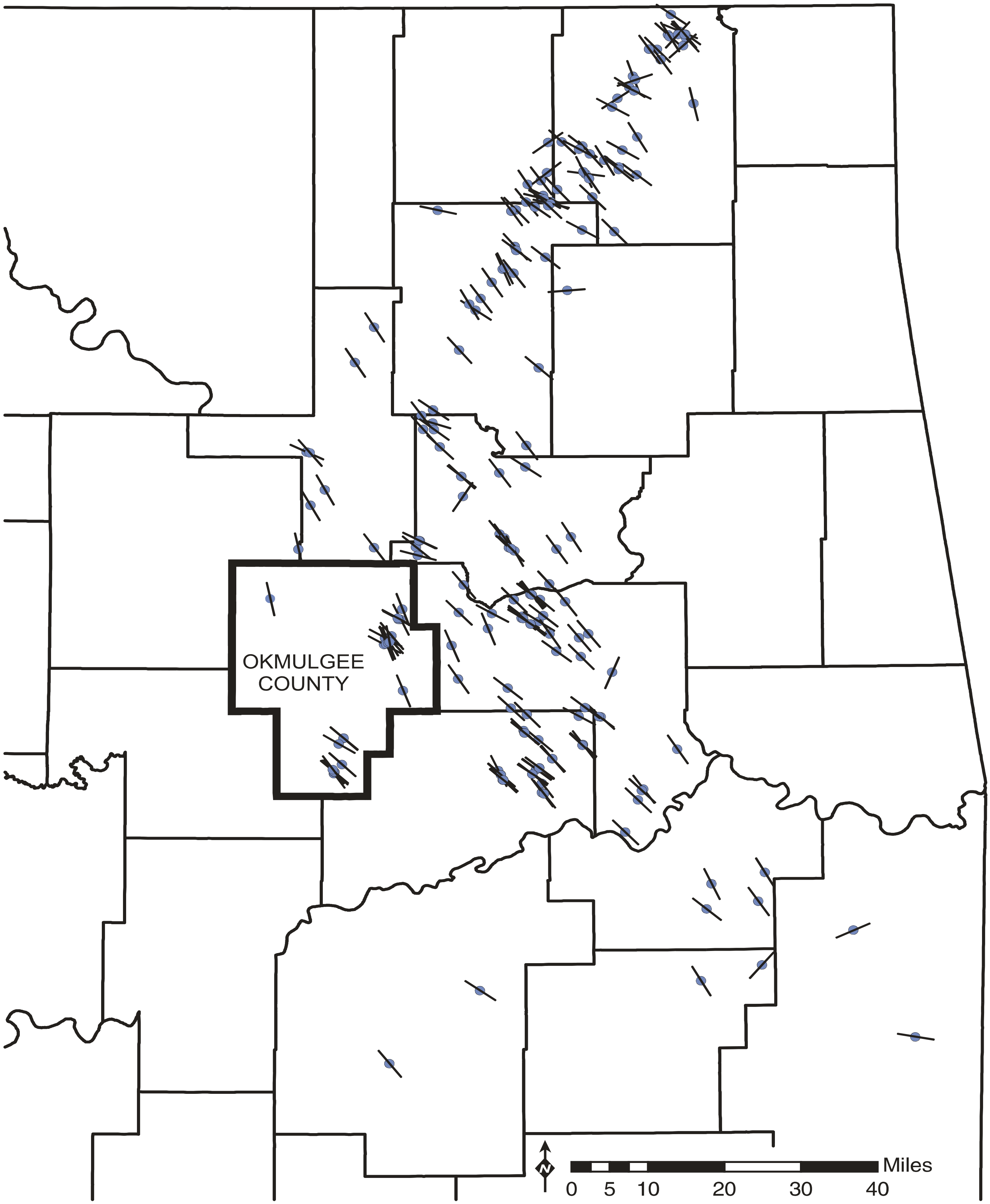

Fig.10. Map showing face cleat orientation of coal beds in the Oklahoma coal field as measured by Friedman and by Hemish in Cardott, 2002, p. 54, fig. 14. The orientation symbol east of the Y in Okmulgee County represents the cleat orientation shown in Fig. 9).

Fig.11. Photograph showing pyrite (yellow) and calcite (white) on the face cleat of the Mineral coal bed in the Metropolis mine. Only 10 inches of the total thickness of the coal bed is shown. The butt cleat is oriented almost 90° to the face cleat. Both cleats are perpendicular to the bedding.

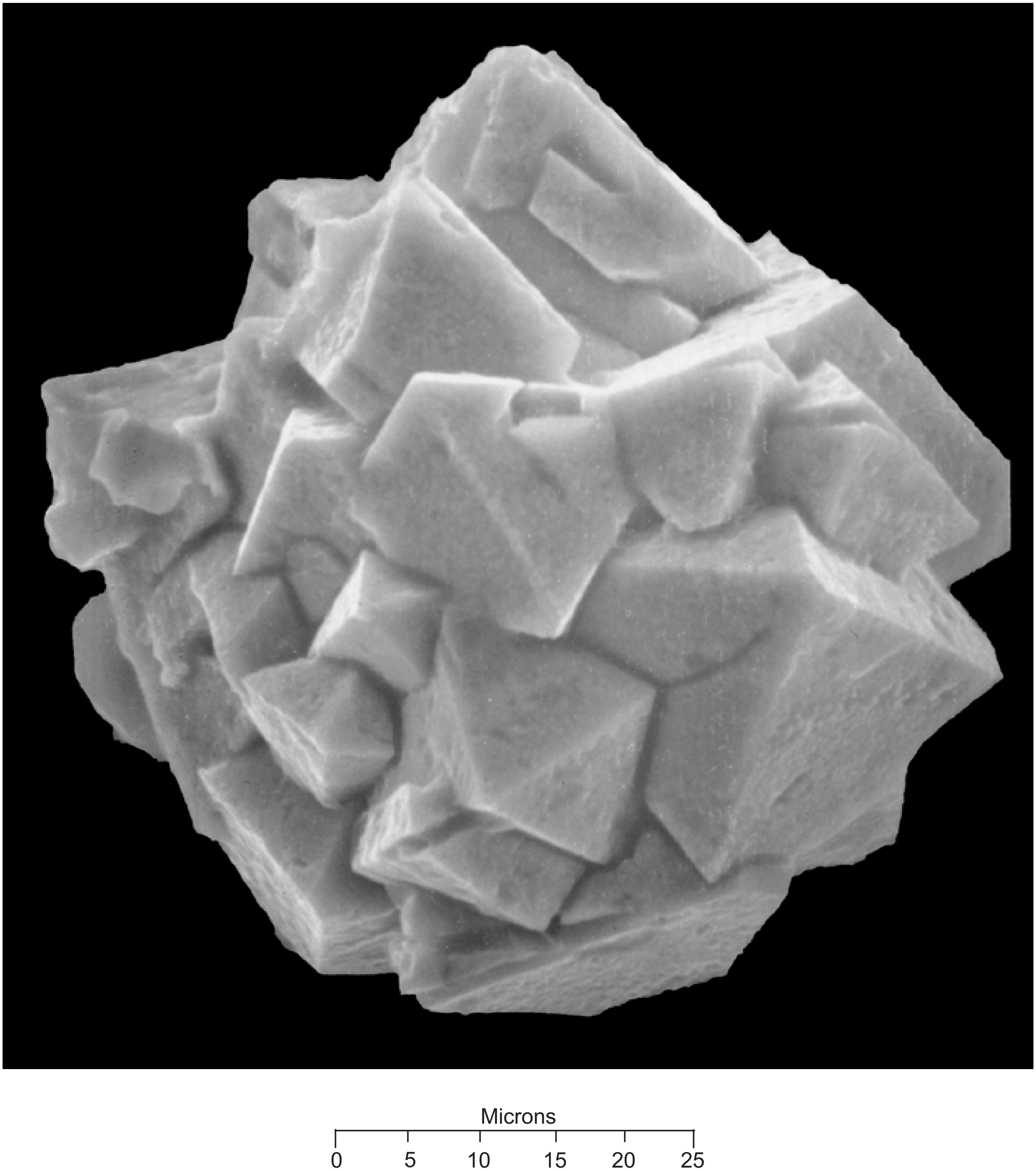

Fig.12. Scanning electron microscope (SEM) photomicrograph of a pyrite framboid from a face-cleat filling, collected by S. A. Friedman and Kurt T. Hollocher from a coal bed in LeFlore County, Oklahoma in 1978.

COALBED METHANE PRODUCTION

Annual CBM production accounts for 3 percent of the total annual natural gas production in Oklahoma (D. Boyd, personal communication). Approximately 79 billion cubic ft (Bcf) of CBM has been produced from wells in the Arkoma Basin from 1989-2003 (Cardott, 2005, p. 79).

A total of 45 billion Bcf of methane from coal beds has been produced from 844 CBM wells in the Northeast Oklahoma Shelf from 1994-2003 (Cardott, 2005). Companies have reported 1,577 wells completed in CBM in 13 coal beds in 7 counties in the Shelf. Companies also have reported the majority of completions in the Riverton, Rowe, Weir-Pittsburg, Mulky, and Iron Post (Ft. Scott) coal beds, averaging 31,000 cubic ft (31Mcf) per day per well of initial production of CBM (Cardott, 2005).

Oklahoma Corporation Commission records indicate that only a few CBM wells have been completed through 2003 in Okmulgee County, and they were in the western and northern-most part of the county. One well was reported to have penetrated the Mineral coal at 466-468 ft in depth in sec. 3, T.14 N., R.13 E. It was completed on 1/21/2002 as D & A (dry and abandoned).

This location is just east of the area in which the Mineral coal is projected to lie ≥500 ft in depth (Fig 13). Production data is uncertain for the few other completed wells.

POTENTIAL COAL-BED METHANE PRODUCTION FROM THE MINERAL COAL BED

The Mineral coal bed if present in the faulted northeast-trending grabens between Henryetta and Eram is most likely too shallow to contain significant CBM resources.

On the other hand, and based upon previous studies (Friedman, 1974 and Hemish, 1994) Okmulgee County has approximately 10,000 acres that contain 31 million short tons of the Mineral coal, which is 101-1,000 ft deep, 12-42 inches thick, and high-volatile bituminous in rank. If one assumes that only one half of these acres contain the Mineral coal bed at depths from 500-1,000 ft, then only 15.5 million tons of coal is present in the area shown in Fig. 13. This is not the ideal depth range in which high-volatile bituminous coal contains the maximum CBM. Nevertheless, a conservative estimate, employing the original U. S. Bureau of Mines standard (Iannacchione and Puglio, 1979), indicates that approximately 3,100,000,000 cubic ft of CBM resources are present in this coal bed in this county, assuming that a minimum of 200 cubic ft of CBM is present per ton of coal.

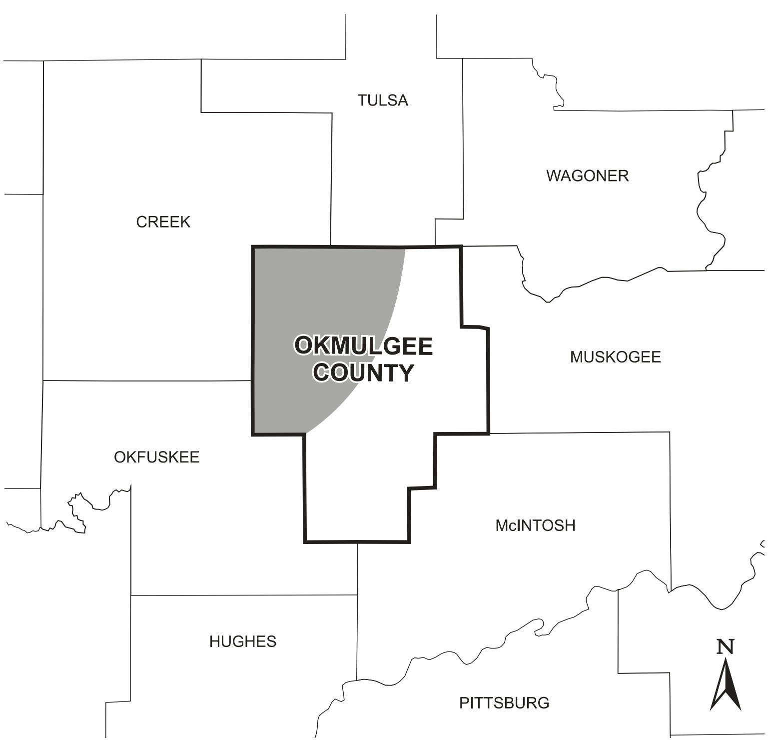

Fig.13. Map showing an area (gray) in Okmulgee County in which the Mineral coal or its stratigraphic position is approximately 500 ft or more in depth. The coal bed increases in depth northwestward, down dip.

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