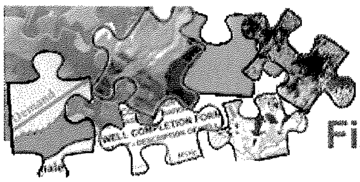

Mid-Continent Coalbed Methane and Gas Shale Symposium II

Figuring out the CBM & Gas Shale Puzzle

Field Trip

October 24, 2006

Overview of Coalbed Methane and Gas Shales in the Cherokee Basin, Northeastern Oklahoma

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[1]Oklahoma Geological Survey

[2]Kansas Geological Survey

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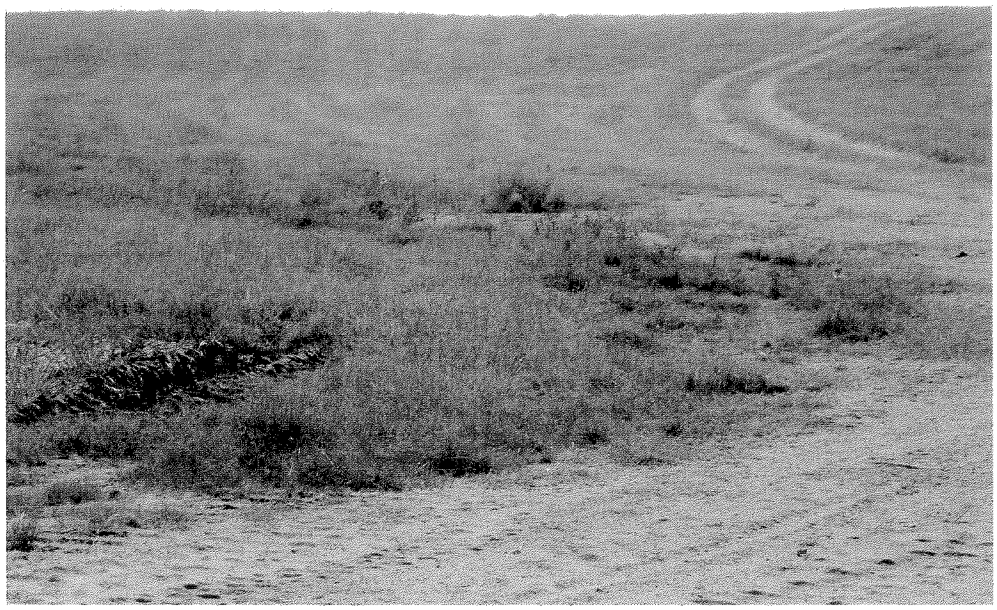
Road Log and Geological Guide

The field trip begins at the Renaissance Hotel (6808 S. 107th E. Ave, Tulsa).

Distance in miles

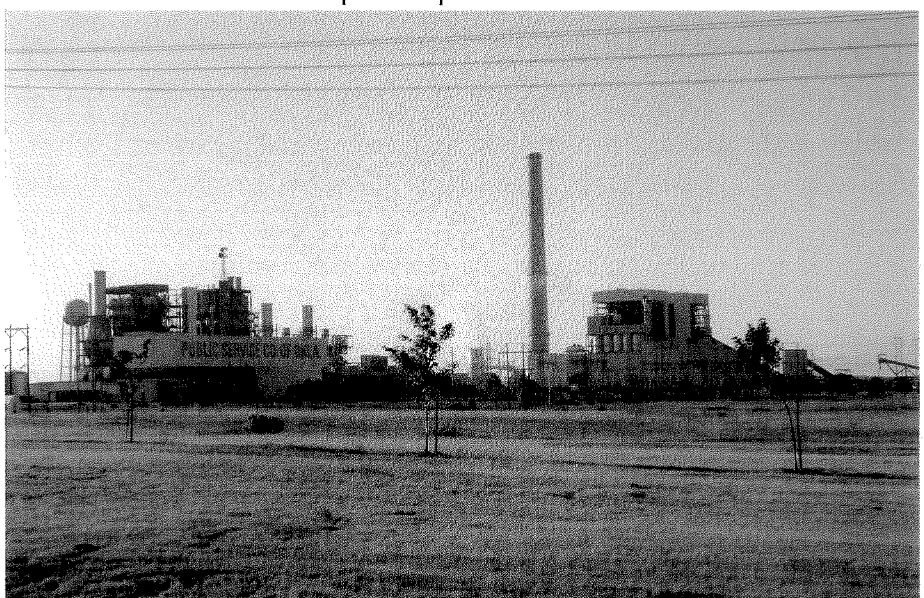
Cumulative/Interval		
0.0	0.0	Depart Renaissance Hotel driving south (right) on 107th E. Ave. (**Map 1**)
0.2	0.2	Turn right at stop sign on E. 109.
0.3	0.1	Turn right at stop light on E. 71st St.
0.4	0.1	Turn right at stop light onto U.S Highway 169 North
5.9	5.5	Enter ramp to Interstate 44 East.
13.4	7.5	Enter ramp to Will Rogers Turnpike (Interstate 44 East).
17.4	4.0	Bridge over Kerr-McClellan Navigation System.
26.9	9.5	Leave turnpike at Exit 255 (Claremore).
27.8	0.9	Turn left on State Route 20 W.
29.3	1.5	Turn right on State Route 66 E.
35.3	6.0	Entering Sequoyah, Oklahoma. Notice railroad tracks on left. Hemish and Chaplin (1999) described a new railroad spur connecting the Public Service Company of Oklahoma coal-fired power plant at Oologah with the Burlington Northern Santa Fe Railroad near Sequoyah.
48.5	13.2	Rest stop at Phillips 66 station on right. Turn left on State Route 28 W in Chelsea.
51.3	2.8	Cross outcrop of Croweburg coal at base of hill.
53.3	2.0	Abandoned surface coal mine in Croweburg coal on right with highwall. Croweburg coal is about 1.4 ft thick (see Hemish, 1989, plate 3, for map showing Croweburg coal from outcrop to depths >100 ft and mined-out areas in Rogers County).
55.0	1.7	Abandoned surface coal mine in Croweburg coal on east (right) side of road.
55.7	0.7	Abandoned coal mining equipment on east side of road.
55.9	0.2	Entering Nowata County (see Hemish, 1986, plates 1 and 2, for maps showing Iron Post and Croweburg coals from outcrop to depths >100 ft and mined-out areas in Craig and eastern Nowata Counties).
57.4	1.5	Turn left on rural road 28 (at Alluwe Baptist Church in New Alluwe).
57.9	0.5	Phoenix Coal Company Alluwe coal mine active pit is on south side of road.
58.4	0.5	Turn left at stop sign.
58.8	0.4	**STOP 1**: Phoenix Coal Company Alluwe coal mine (see **Maps 2 and 3**). Exit mine and drive north on rural road.
59.1	0.3	Turn right (east) at stop sign.
60.1	1.0	Turn left (north) on State Route 28 W.
60.5	0.4	Road crosses Panther Creek.
61.1	0.6	Turn right (east) on rural road 27.

61.3	0.2	Peabody Coal Company mine in Iron Post coal on both sides of road (reclaimed surface coal mine in 1988; permit 88/91-4161).
62.9	1.6	Reclaimed surface coal mine in Croweburg coal on right.
64.7	1.8	**STOP 2**: Phoenix Coal Company Kelley coal mine. Active surface coal-mine reclamation in Croweburg coal on right. Exit mine and drive west on rural road 27.



65.1	0.4	Reclaimed surface coal mine in Croweburg coal on right showing water-filled last cut.
68.4	3.3	Turn left (south) on State Route 28 E.
72.7	4.3	At fork in road, stay to the right on rural road NS 422.
73.2	0.5	Abandoned surface mine in Croweburg coal on left (east).
73.4	0.2	Turn right (west) at stop sign on rural road EW 32.
74.4	1.0	Turn left (south) on rural road NS 421. Reclaimed surface mine in Iron Post coal on left (see Hemish, 1989, plate 1, for map showing Iron Post coal from outcrop to depths >100 ft and mined-out areas in Rogers County).
77.5	3.1	Turn right (west) at stop sign on rural road E 350. Sign indicates direction to Oklahoma's first oil well.
79.7	2.2	Unreclaimed surface mine (spoil piles) in Croweburg coal on left.
80.7	1.0	Turn left (south) at stop sign on rural route NS 418.
81.6	0.9	Abandoned surface mine in Iron Post coal on both sides of road.
84.7	3.1	Abandoned surface mine in Croweburg coal on right (west).
85.2	0.5	Turn right (west) at stop sign on rural road EW 40.
87.2	2.0	View of Round Mound on left (south).
88.2	1.0	Turn left (south) at stop sign on rural route NS 415.

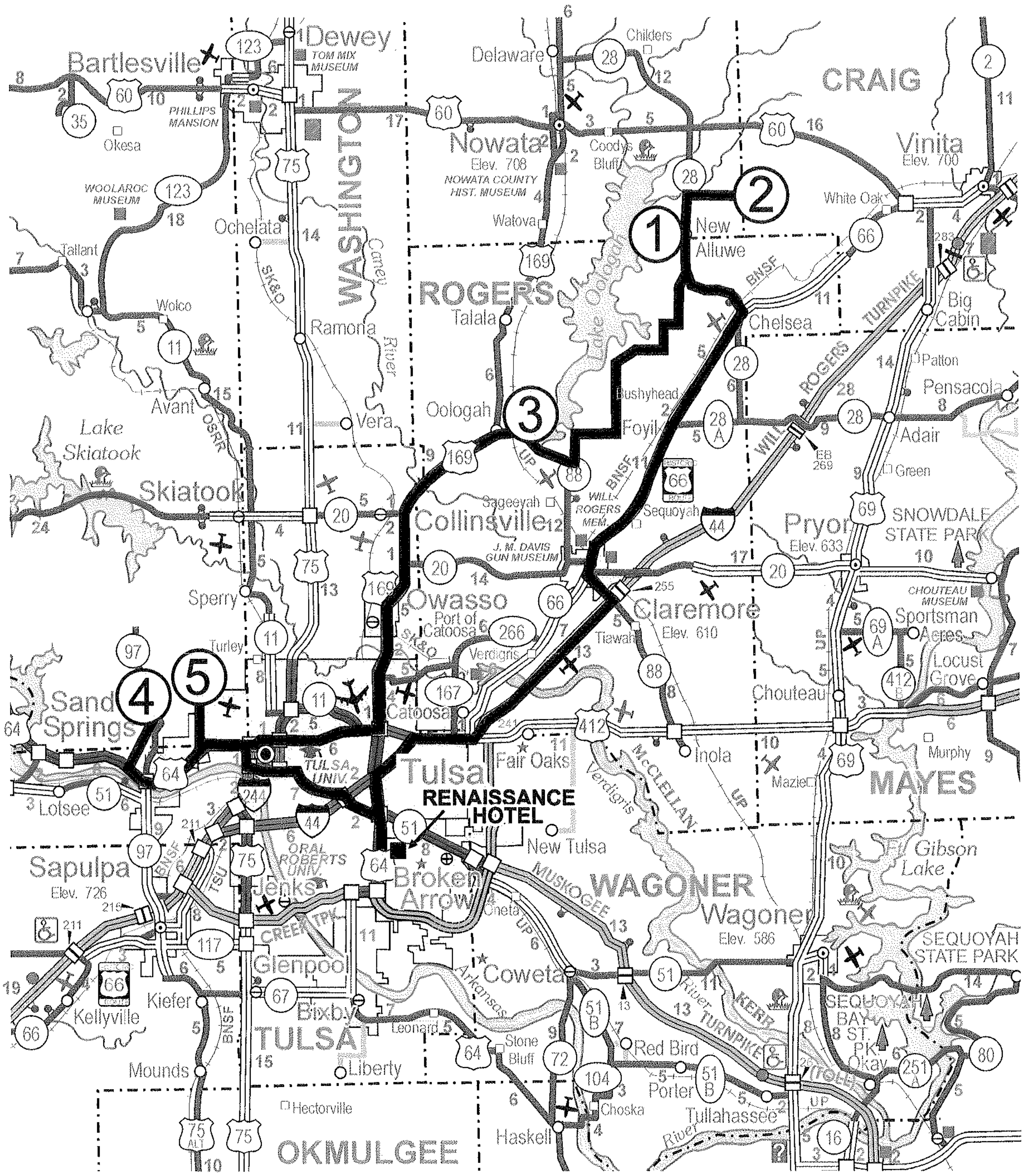
90.2	2.0	Turn right (west) on rural route EW 42.
91.2	1.0	Turn right (north) at stop sign on State Route 88.
92.0	0.8	Cross over Lake Oologah spillway.
93.9	1.9	Turn right (north) into Overlook. **STOP 3 AND LUNCH STOP**. Overlook of Public Service Company of Oklahoma (PSO) Northeastern coal-fired utility electric power plant at Oologah, Lake Oologah, and dam.
94.0	0.1	Turn right (west) on State Route 88.
94.9	0.9	Optional lunch stop at Hawthorn Bluff shelter on right.
96.6	1.7	View of PSO power plant on left.



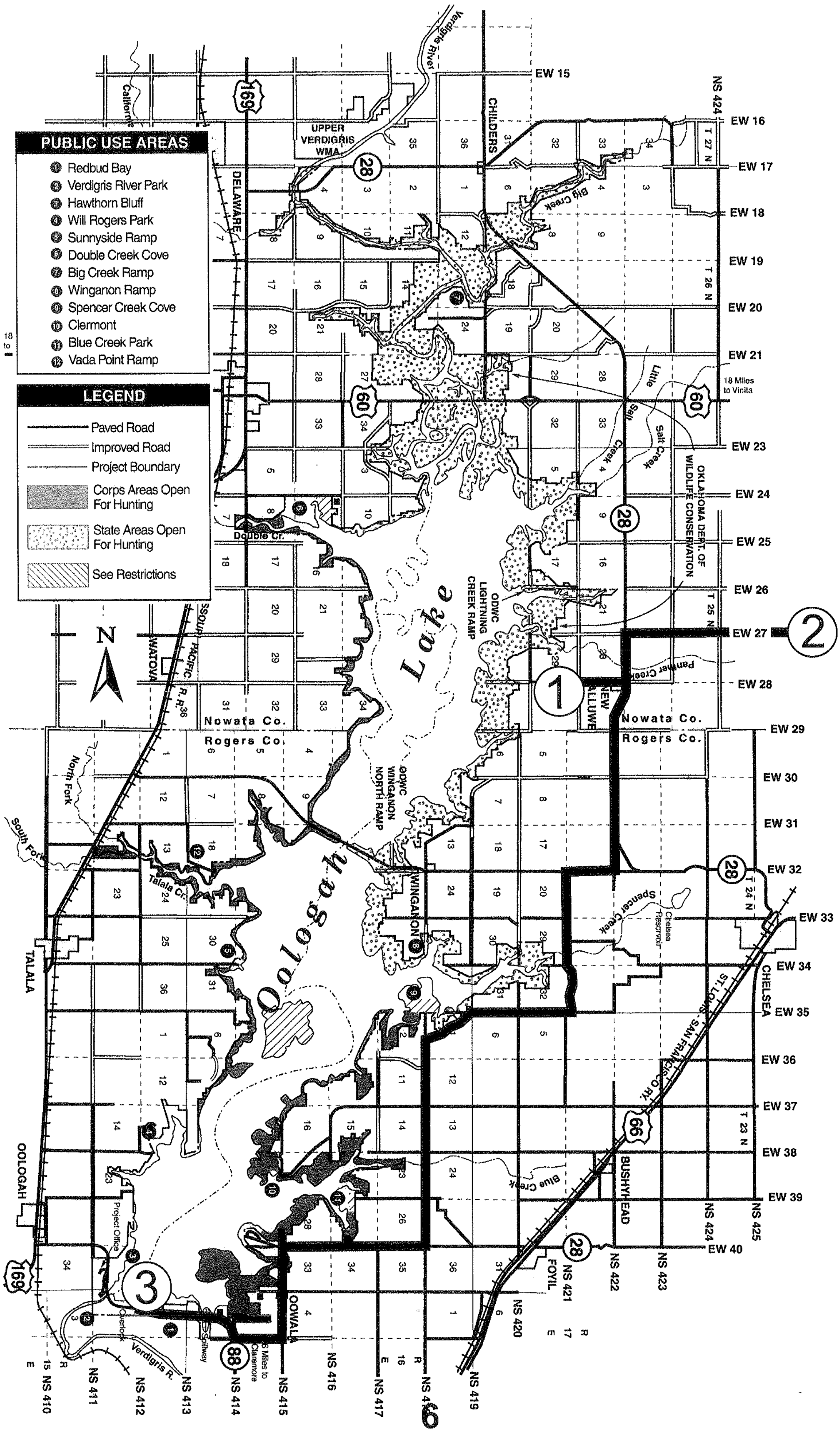
View of unit train with subbituminous coal from Wyoming for PSO power plant.

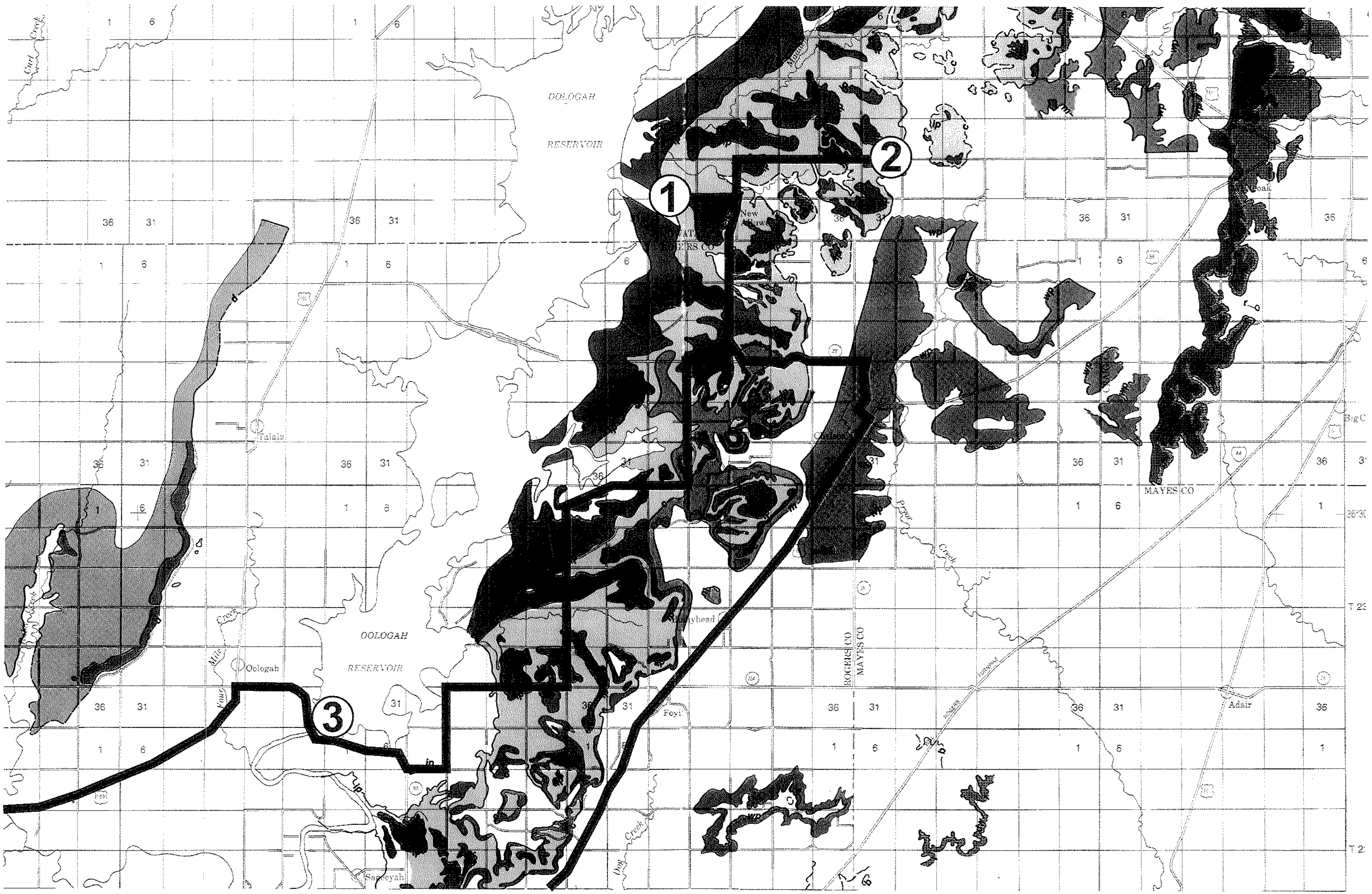
97.6	1.0	Turn left (south) at traffic light on U.S. Route 169 South.
117.4	19.8	Exit (right) on Interstate 244 West/U.S. Route 412 West.
125.5	8.1	Exit (left) on U.S. Route 412 West/U.S. Route 64 West.
133.6	8.1	Exit (right) on 129th West Avenue (State Route 97T).
137.0	3.4	Intersection with State Route 97 South (on right).
137.2	0.2	Turn right (east) on gravel road. **STOP 4**: Amvest Osage, Inc. CBM and SWD wells. When exiting, turn left (south) on State Route 97T.
140.8	3.6	Turn left (east) on U.S. Route 64 East.
144.8	4.0	Exit (right) on 65th W Avenue.
145.1	0.3	Turn left (north) on 65th W Ave.
145.4	0.3	At fork in road, stay to the right on Edison Street.
146.2	0.8	Turn left (north) on 57th W.
148.3	2.1	Turn right (east) on gravel road at gate. **STOP 5**: Amvest Osage, Inc. compressor station and gas sales point. When exiting, turn left (south) on 57th W.
150.4	2.1	Turn right (west) on Edison at stop sign.
151.0	0.6	At fork in road, stay left on 65th W Ave.
151.5	0.5	Turn left (east) on U.S. Route 64 East/U.S. Route 412 East.
155.1	3.6	Turn right (south) on Interstate 244 West.
155.9	0.8	Exit (LEFT) on U.S. Highway 75 East/64 East.
165.3	9.4	Exit (right) on U.S. Highway 169 south
167.8	2.5	Exit (right) and turn left at stop light on E. 71st Street.
168.5	0.7	Turn left at stop light on E. 109.
168.7	0.2	Turn left at stop sign on E. 69th St.
168.8	0.1	Renaissance Hotel (end of field trip).

Map 1. Road map showing field-trip route and stops



Map 2. Map showing detailed field-trip route from stops 1 to 3





Map 3. Map showing principal coal boundaries in the Tulsa area and vicinity, Nowata, Rogers, and Craig Counties (modified from Friedman and Woods, 1982, plate 1).

A Brief History of COAL MINING IN OKLAHOMA

Nuttall (1821, p. 146–177) recorded the presence of coal in what is now Oklahoma as early as 1821, but mining on a commercial scale did not begin until railroads were built in 1872. McAlester became the hub city for the Missouri–Kansas–Texas Railroad. Branch lines were built to haul coal from nearby mines to the main line at McAlester; similarly, commercial-scale mining in other parts of the coal field was made possible by the arrival of railroad lines (Trumbull, 1957).

In 1872, the Choctaw, Oklahoma, and Gulf Railroad was built eastward from McAlester through Hartshorne, Wilburton, Howe, and other points. Later, extension of the line eastward to Memphis, Tennessee, and westward across Oklahoma, widely increased the market for coal. The St. Louis–San Francisco Railway was built across the east side of Indian Territory (Oklahoma) about 1885. Building of the Kansas City Southern Railway followed, and the coal field was linked to the Gulf of Mexico at Port Arthur, Texas (Trumbull, 1957).

Statistics on the coal trade in Oklahoma (Indian Territory) in two of the early years, 1887–88, were published by Ashburner (1890, p. 124). He listed coal production as 685,911 short tons for 1887 and 761,986 short tons for 1888. In 1888, 1,700 men were employed by the industry in the Indian Territory, according to Ashburner (1890, p. 137), and the value at the mine for "soft coal" was $1.95 per ton.

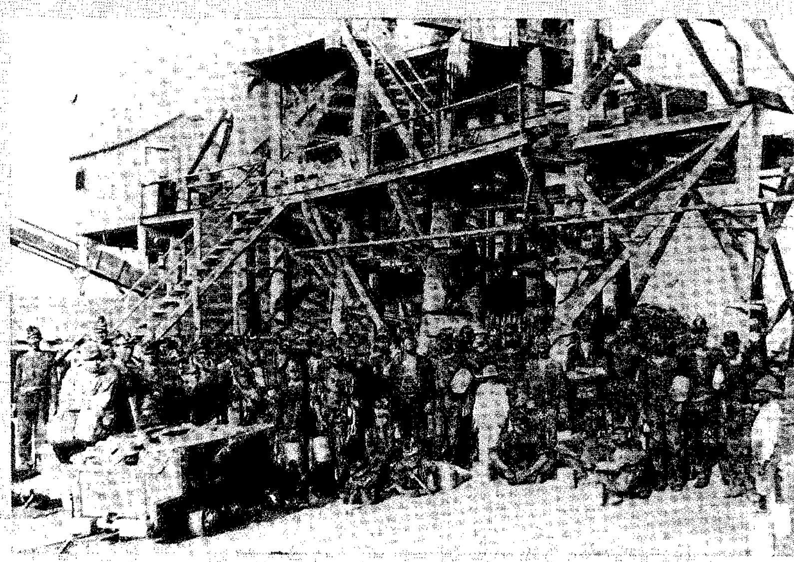
Even at that time, wages paid for mining coal were "the subject of an almost constant dispute between the employer and the employee" (Ashburner, 1890, p. 135). Wages were based primarily on the market price received for the product of the mine. If the employer did not meet wage demands—and mines could not be kept in active operation at a direct loss to the operator—miners would strike. Ashburner (1890, p. 135) eloquently expressed the difficulties of the times:

> The inevitable result of such a strike is that while the operator loses much money during these periods, in case there is a legitimate demand for his coal, yet the actual personal suffering is at all times infinitely greater to the miner and his family, whose distress for the want of proper food and clothing, and even at times shelter from the weather, is frequently heartrending.

Average wages in 1888 were 80¢ per net ton per miner. The coal miners worked an average of 300 days per year. Their work consisted of removing the coal from the bed and placing it on railroad cars and wagons at the mouth of the mine for shipment to market (Ashburner, 1890, p. 136–137).

As a result of the completion of the four new railroad lines in the late 1880s, and of the increased market for coal, coal production in Oklahoma had reached a million tons per year by 1891. By 1903, production from 117 mines throughout the coal field exceeded 3.5 million tons per year (Trumbull, 1957, p. 362).

Between 1873 and 1883, there were about 1,000 coal miners in the Indian Territory. Ten years later, there were twice as many, and, by 1904, the number of coal miners stood at more than 8,000. In the early history of coal mining in the Indian Territory, most of the miners were immigrants from the British Isles. However, around the turn of the century, more and more immigrants from southern and eastern Europe arrived to work in the coal mines and find a home (Hightower, 1985).



Deep-shaft coal mining in the Indian Territory lured three generations of immigrants to a life of coal dust, back-breaking labor, and constant danger. (Photograph courtesy of the Oklahoma Historical Society.)

From Suneson and Hemish (1994, p. 42-43)

In the early days of coal mining, miners used canaries to detect deadly gases. A dead bird meant extreme danger! (Photograph courtesy of the Oklahoma Historical Society.)

Mining towns in the Indian Territory were built to imitate those in Pennsylvania. Miners were paid in scrip that was used as legal tender and backed by the mining companies, most of which were owned by the railroads. The economic system has been described as semi-feudal. Communities were totally dependent on the production of coal. It was not until the 1920s that company stores began to decline in importance and a measure of free enterprise was introduced (Hightower, 1985).

From 1900 through WWI, Oklahoma was an important coal producer. Coal was a major fuel in Oklahoma and a major ingredient in steel production in adjacent states (Friedman, 1974, p. 44). During the past 120 years, coal production in Oklahoma has gone through a series of cycles, generally controlled by demands of steel manufacturing for fuel and coke.

Prior to 1920, production of coal by strip mining was insignificant. In 1920, 95% of all coal mined was produced by underground methods. Since then, the trend toward surface mining has increased steadily; at present, only one underground mine is operating.

Oklahoma's underground mines—where the men were surrounded by crude machinery and worked by maneuvering in near darkness—were among the most dangerous in the country. The bituminous coal produced a great deal of fine dust that was inhaled by the miners. Explosions were common. Gas seeps in mine shafts could be deadly, so miners used birds as an early-warning system.

The immigrant miners were thought of as no better than pit mules. They went into the coal mines at daybreak and came out after dark. There were no eight-hour days. It was not unusual for the miners to walk 2 or 3 miles to the mines, put in a day's work, then—sweaty and grimy—walk home. Beginning wages were $1.15 per day. Experienced miners were paid somewhat better (Hightower, 1985).

The coal mining industry in Oklahoma has had a history of disasters, in which a number of men have lost their lives. Much of the blame for coal mining accidents rests with mine operators whose lack of safety precautions contributed to hundreds of injuries and deaths in the early days of mining. Gas and dust explosions in underground mines were the primary cause of the disasters. The earliest records of deaths go back to 1885 when 13 men lost their lives in a mine at Krebs. Other disasters followed; a few of the major ones are listed here: in 1892 another underground mine explosion at Krebs killed 96 men; in 1912, 73 men were killed in a mine at McCurtain; and, in 1926, 91 men were killed in a mine at Wilburton (Oklahoma Department of Mines, 1988).

Earliest published mapping and discussion of coals in the field-trip area were by Chance (1890, p. 653–661). He wrote a description of the Choctaw coal field, which, in general, included the area from just west of McAlester to the Arkansas state line. It was bounded on the south by the Choctaw fault and, on the north, by the San Bois Mountains and Cavanal Mountain. As would be expected, subsequent, more detailed work revealed many errors in his mapping. Names he had given coal beds were changed or abolished as geologic work progressed. For example, the name "Grady" coal was dropped in favor of "Hartshorne" coal, and the "Mayberry" coal was shown to be equal to the "Secor" coal. The "Norman" coal could not be identified, and the name was never used again (Oklahoma Geological Survey, 1954).

In 1899, 1901, and 1903, the U.S. Geological Survey mapped the geology of parts of the Choctaw coal field. In 1900, the report, "Geology of the Eastern Choctaw Coal Field, Indian Territory," was published (Taff and Adams, 1900). A second report on the geology of coal in Indian Territory, Arkansas, and Texas, entitled "The Southwestern Coal Field," was published in Part III of the Twenty-Second Annual Report of the U.S. Geological Survey (Taff, 1902b).

Many familiar stratigraphic names, such as "Atoka Formation," "Hartshorne Sandstone," "McAlester Shale," "Savanna Formation," and "Boggy Shale," had their origins in these reports (Taff, 1902b; Taff and Adams, 1900). Considering the limited resources available at the time to aid field workers in their research, as well as the adverse working conditions in the region, the quality of this early work is truly remarkable.

OKLAHOMA GEOLOGICAL SURVEY
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2

Introduction to coal geology of Oklahoma

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Introduction to Coal Geology of Oklahoma

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Oklahoma Geological Survey

INTRODUCTION

The Oklahoma coalfield is in the eastern part of the State and occupies the southern part of the Western Region of the Interior Coal Province of the United States (Campbell, 1917; Friedman, 2002). The coal region continues northward into Kansas and eastward into Arkansas (Tully, 1996). The Oklahoma coalfield is bounded on the northeast, south, and southwest by the Ozark, Ouachita Mountain, and Arbuckle Mountain Uplifts, respectively, and on the west by noncommercial coal-bearing strata of Missourian to Wolfcampian age (**Figure 1**). Some noncommercial Pennsylvanian-age coal resources occur in the Anadarko Basin (Wood and Bour, 1988) and Ardmore Basin (Trumbull, 1957; Tomlinson, 1959), but these are not part of the Oklahoma coalfield.

Friedman (1974) divided the Oklahoma coalfield into the northeast Oklahoma shelf and the Arkoma Basin based on physiographic and structural differences (**Figure 2**). The commercial coal belt contains coal beds ≥ 10 in. (25 cm) thick that are mineable by surface methods at depths < 100 ft (30 m) and coal beds ≥ 14 in. (36 cm) thick that are mineable by underground methods (Hemish, 1986). The noncommercial coal-bearing region has limited information on coal thickness and quality or contains coals that are too thin, of low quality, or too deep for surface mining. The western boundary of the noncommercial coal-bearing region is uncertain. Coalbed methane (CBM) production has been developed in both the commercial coal belt and the noncommercial coal-bearing region.

Figure 3 shows coal outcrop and potentially strippable areas in the Oklahoma coalfield (Friedman, 1982b). Coal beds in the northeast Oklahoma shelf strike northeast in outcrop and dip as much as 2° westward and northwestward from the outcrop to depths > 2,500 ft (760 m; **Figure 4**). Coal beds in the Arkoma Basin are present at the surface and to depths > 6,000 ft (1,830 m)(Iannacchione and Puglio, 1979a); they are faulted and folded into narrow, northeastward-trending anticlines and broad synclines (Figure 4). Coal beds in the Arkoma Basin dip from 3° to nearly vertical (Friedman, 1982b, 2002). Major deformation of the Oklahoma coalfield occurred during the peak of the Ouachita orogeny (Middle to Late Pennsylvanian)(McBee, 1995).

COAL STRATIGRAPHY

The age of commercial coal-bearing strata in the Oklahoma coalfield is Desmoinesian (Middle Pennsylvanian). Thin, noncommercial coal beds occur in Morrowan, Atokan, Missourian, Virgilian, and Wolfcampian strata (Cardott, 1989). **Figures 5 and 6** are generalized stratigraphic columns of the northeast Oklahoma shelf and Arkoma Basin, showing about 40 named and several unnamed coal beds and their range in thickness measured from outcrops, mines, and shallow core samples. Coal beds are 0.1 to 6.2 ft (0.03 to 1.9 m) thick in the shelf and 0.1 to 7.0 ft (0.03 to 2.1 m) thick in the basin. The thickest known occurrence of coal in the Oklahoma coalfield is an exposure of the Hartshorne coal (10 ft) in Latimer County (sec. 35, T. 6 N., R. 18 E.; Wilson, 1970; Hemish, 1999). The thickest known occurrence of coal in the shelf is the Weir-Pittsburg coal (6.2 ft) in a coal-company drill hole at a depth of 408 ft (124 m) in Craig County (sec. 28, T. 29 N., R. 18 E.; Hemish, 1986, Plate 4; Hemish, 2002).

Hemish (2001, p. 78) described the following differences in the coal-bearing strata between the Arkoma Basin and the northeast Oklahoma shelf: "1) Coal-bearing rocks present above the Senora Formation in the shelf area are absent in the Arkoma Basin; 2) Stratigraphic units are generally much thicker in the Arkoma Basin; 3) Commercial coal beds in the northern shelf area pinch out to the south and are absent in the basin; conversely, certain well-developed commercial coals in the Arkoma Basin, such as the Hartshorne coal, pinch out to the north, or have no commercial value in the shelf area, owing to thinness; 4) Quality of the same coal in the two regions often varies because of different depositional environments. Additionally, strata in the Arkoma Basin are much more deformed than they are in the shelf area. Beds have been folded into broad, northeast-trending synclines and narrow anticlines, resulting in steep dips of the beds in some areas. Faulting is also common throughout the Arkoma Basin."

In ascending order, the coal beds yielding commercial methane in the northeast Oklahoma shelf include the Riverton and McAlester (McAlester Formation), Rowe and Drywood (Savanna Formation) and Bluejacket and Wainwright (Boggy Formation) in the Krebs Group; Weir-Pittsburg, Tebo, Croweburg, Bevier, Iron Post, and Mulky (Senora Formation) in the Cabaniss Group; and Dawson (Holdenville Formation) in the Marmaton Group of Desmoinesian age. Hemish (2002) correlated coals from the surface to subsurface in a 2,700-mi^2 area in the northeast Oklahoma shelf to assist operators in correctly identifying methane-producing coal beds. Two type logs were designated in the northern and southern parts of the study area. The northern type log is in **Figure 7.** Persistent marker beds are identified to correlate the coal beds.

The nomenclature of Oklahoma and Kansas coal-bearing strata and coal beds differ slightly. The Kansas Geological Survey includes the Krebs and Cabaniss Formations in the Cherokee Group (Brady, 1997), whereas the Oklahoma Geological Survey assigns the Krebs and Cabaniss to group level in the Desmoinesian Series. The Rowe coal of Kansas and Missouri is equivalent to the Keota coal of Oklahoma, whereas the Drywood coal of Missouri and Dry Wood coal of Kansas are equivalent to the Spaniard coal of Oklahoma (Hemish, 1990b).

The Mulky coal is one of the most important CBM reservoirs in the northeast Oklahoma shelf (Cardott, 2002b). The Mulky, the uppermost coal in the Senora Formation, occurs at the base of the Excello Shale Member and varies in composition from pure to impure coal with increasing amounts of mineral matter. (As defined by Schopf (1956), carbonaceous shale contains >50% mineral matter by weight or <30% carbonaceous matter by volume. According to the ASTM (1994), impure coal contains 25 to 50 weight % mineral matter as ash.) Hemish (1986, p. 18) recognized the Mulky coal in three drill holes in northern Craig County, where its maximum thickness is 10 in. Hemish (2002, p. 3) indicated that "The occurrence of the Mulky coal downdip to the west in Nowata, Washington, and Osage Counties has not been verified by the OGS from coring. It seems probable that the methane is being produced from the Excello black shale."

In ascending order, the methane-producing coal beds in the Arkoma Basin are the Hartshorne (undivided), Lower Hartshorne, and Upper Hartshorne (Hartshorne Formation), McAlester and "Savanna" (interpreted to be the McAlester coal, McAlester Formation; a CBM completion in Coal County reported to be in the "Lehigh" coal is equivalent to the McAlester coal), Secor (Boggy Formation), and unnamed coal in the Krebs Group of Desmoinesian age. The McAlester coal and Stigler coal are correlative (Friedman, 1974, p. 29).

The Hartshorne coals are the most important CBM reservoirs in the Arkoma Basin (Cardott, 2002b). The Hartshorne coal contains a thin claystone parting and splits into two beds (Upper and Lower Hartshorne coals) where the parting is thicker than 1 ft (Friedman, 1982a). The coal is a single bed north and west of the coal split line (**Figure 8**). South and east of the line, two beds are identifiable. The interval between the upper and lower coal beds increases southeastward to a maximum of 120 ft (37 m)(Friedman, 1978, p. 48; Iannacchione and Puglio, 1979a, p. 5). The top of the Hartshorne coal or Upper Hartshorne coal, where present, marks the top of the Hartshorne Formation in Oklahoma. The nomenclature of Oklahoma and Arkansas coal beds differ slightly. The Arkansas Geological Commission includes the Upper and Lower Hartshorne coals in the McAlester Formation (Prior and White, 2001), whereas the Oklahoma Geological Survey includes the Hartshorne coals in the Hartshorne Formation (Hemish and Suneson, 1997). The Paris and Charleston coals (Savanna Formation; Prior and White, 2001) of Arkansas are not present in Oklahoma.

COAL RESOURCES, RESERVES, AND PRODUCTION

Remaining identified bituminous coal resources (using measured, indicated, and inferred resource categories of reliability) in beds ≥ 10 in. (25 cm) thick total 8.09 billion short tons in 19 counties in eastern Oklahoma, an area of approximately 8,000 mi^2. Approximately 76% of these resources are in the Arkoma Basin and 24% are in the northeast Oklahoma shelf (Friedman, 2002).

Identified coal resources were determined by S.A. Friedman and L.A. Hemish of the Oklahoma Geological Survey. Friedman (1982b) showed the distribution of strippable coal resources to depths of 100 ft (30 m) or 150 ft (46 m), and areas where coal has been mined by surface methods. Friedman (1974) summarized the coal resources and reserves in 7 counties (Atoka, Coal, Haskell, Latimer, Le Flore, Pittsburg, and Sequoyah) in the Arkoma Basin. County coal reports with updated estimates of strippable coal resources and reserves in the northeast Oklahoma shelf are available for the following 12 counties: Craig and Nowata (Hemish, 1986), Rogers and Mayes (Hemish, 1989), Tulsa, Wagoner, Creek, and Washington (Hemish, 1990a), Okmulgee and Okfuskee (Hemish, 1994), Muskogee (Hemish, 1998a), and McIntosh (Hemish, 1998b).

The demonstrated reserve base (economically recoverable portion of identified coal resource from measured and indicated resource categories for beds ≥ 28 in. (71 cm) thick at depths to 1,000 ft) for Oklahoma is 1.57 billion short tons of coal (Energy Information Administration, 2002, table 33). Oklahoma ranks 19th of 32 coal-bearing states in the U.S. demonstrated reserve base.

From 1873–2001, 281.3 million short tons of coal were produced in Oklahoma (Federal and State data). Peak annual coal production was 5.73 million short tons in 1981, with smaller production peaks during and immediately following World War I and World War II (**Figure 9**). Coal was mined in Oklahoma exclusively by underground methods until 1915. The predominant mining method shifted from underground to surface in 1943. Oklahoma produced 1.59 million short tons of coal from 11 mines in 2000 (Oklahoma Department of Mines, 2001). Oklahoma imported 18.0 million short tons of low-sulfur, subbituminous coal from Wyoming in 2000 for electricity generation at five Oklahoma public-utility power plants (Energy Information Administration, 2002, tables 64, 65).

Abandoned underground coal mines are areas where coal has been removed by room-and-pillar type mining in Oklahoma. Coal mine methane migrates to mine workings and is vented to the atmosphere during mining (Diamond, 1994; Brunner, 2000). Mine and gob gas (in caved zone of mine) may be present in abandoned underground mines. Maps showing the location of abandoned underground coal mines in Oklahoma are in Hendricks (1937, 1939), Knechtel (1937, 1949), Dane and others (1938), Oakes and Knechtel (1948), Hemish (1990a), and Friedman (1978, 1979, 1994, 1996).

COAL STRUCTURE AND THICKNESS

Maps showing structure, overburden (to depths >100 ft (30 m)), coal isopach, and mined areas in the northeast Oklahoma shelf are in Hemish (1986, 1989, 1990a, 1994, 1998a, 1998b). **Figure 10** shows the regional structure on the top of the Hartshorne Formation. Additional structure and/or overburden maps of the Hartshorne Formation are in Dane and others (1938), Hendricks (1939), Oakes and Knechtel (1948), Knechtel (1949), Catalano (1978), Agbe-Davies (1978), Craney (1978), Donica (1978), Williams (1978), Iannacchione and Puglio (1979a, 1979b), Iannacchione and others (1983), and Gossling (1994). A structure map on the McAlester coal is in Knechtel (1937).

Hartshorne coal isopach maps of limited coverage are in Catalano (1978), Agbe-Davies (1978), Craney (1978), Donica (1978), Williams (1978), Iannacchione and Puglio (1979a, 1979b), Iannacchione and others (1983), Brady (1981a-c; 1983a,b), and Brady and Querry (1985a-i). Hartshorne coal isopach maps in parts of Haskell, Latimer, Le Flore, McIntosh, and Pittsburg Counties are in Gossling (1994). An isopach map of the Stigler (McAlester) coal is in Karvelot (1973).

RANK

Coal rank, generalized for all coals at or near the surface, ranges from high-volatile bituminous in the shelf and western Arkoma Basin to medium- and low-volatile bituminous in the eastern Arkoma Basin in Oklahoma (**Figure 11**). Rank increases from west to east and with depth in the Arkoma Basin, attaining semianthracite in Arkansas (Prior and White, 2001). For example, the Hartshorne coal is medium-volatile bituminous at 2,574 ft (785 m) in Continental Resources' 1-3 Myers well in Pittsburg County (sec. 3, T. 7 N., R. 16 E.) in the high-volatile bituminous area in Figure 11.

CLEAT

Cleat is a miners' term for the natural, opening-mode fractures in coal. Two orthogonal cleat sets, perpendicular to bedding, are the face cleat (primary, well developed; extends across bedding planes of the coal) and the butt cleat (secondary, discontinuous; terminates against face cleat). Cleats control the directional permeability of coal beds (Diamond and others, 1988). Vertical CBM wells drain gas from an elliptical area elongated in the face-cleat direction. Horizontal coalbed-methane wells drilled perpendicular to oblique to the face cleat drain more gas from a larger area than would a vertical well. Cleat spacing is closest in medium- and low-volatile bituminous coals (Close, 1993).

Coal beds in the northeast Oklahoma shelf exhibit average face-cleat directions of N39°–47°W and butt-cleat directions of N46°–56°E (Andrews and others, 1998; Hemish, 2002; **Figure 12**). Face and butt cleats in the Hartshorne coal beds in the eastern Arkoma Basin trend N17°–32°W and N52°–77°E, respectively (**Figure 13**). In general, face cleats are oriented parallel to the axis of compression and butt cleats are oriented subparallel to the structural fold axes (McCulloch and others, 1974). **Figure 14** is a map summarizing face-cleat direction in the Oklahoma coalfield.

Secondary mineralization (e.g., authigenic minerals) in cleats decrease the permeability of coal. Clay, carbonate, quartz, and sulfide minerals are common cleat-filling minerals (Close, 1993; Gamson and others, 1996). **Figure 15** illustrates the distribution of common cleat-filling minerals in Oklahoma coals.

CONCLUSIONS

The Oklahoma coalfield contains bituminous-coal resources in about 40 coal beds of Middle Pennsylvanian age in 19 counties. Commercial coal beds range from 10 in. to 7 ft thick from the surface to depths > 6,000 ft in the Arkoma Basin. Coal beds in the northeast Oklahoma shelf dip gently westward and northwestward, whereas coals in the Arkoma Basin are folded and faulted. Coal and coalbed-methane resources in Oklahoma are suitable and available for combustion, carbonization, and gasification.

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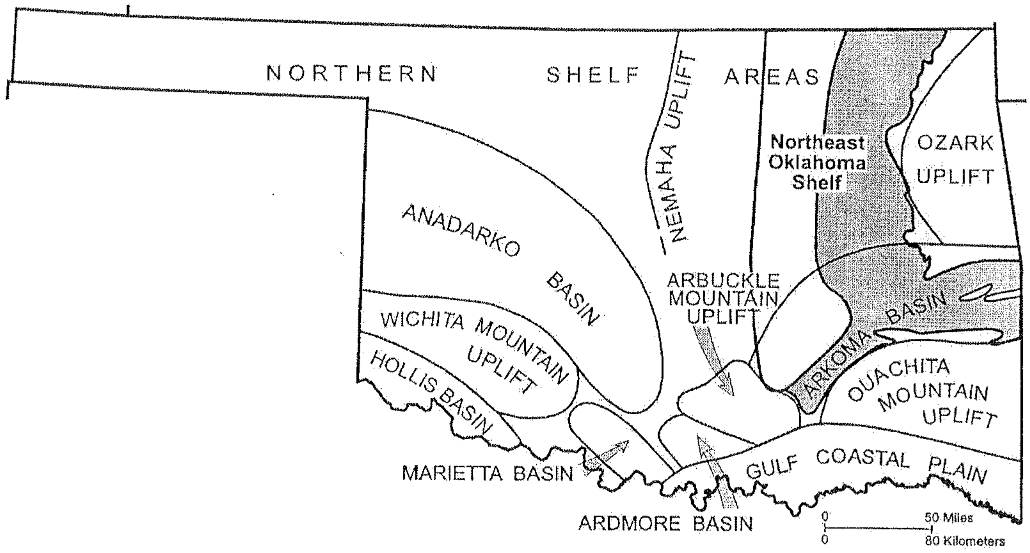


Figure 1. Map of Oklahoma coalfield (modified from Friedman, 1974) in relation to the major geologic provinces of Oklahoma (modified from Johnson and Cardott, 1992).

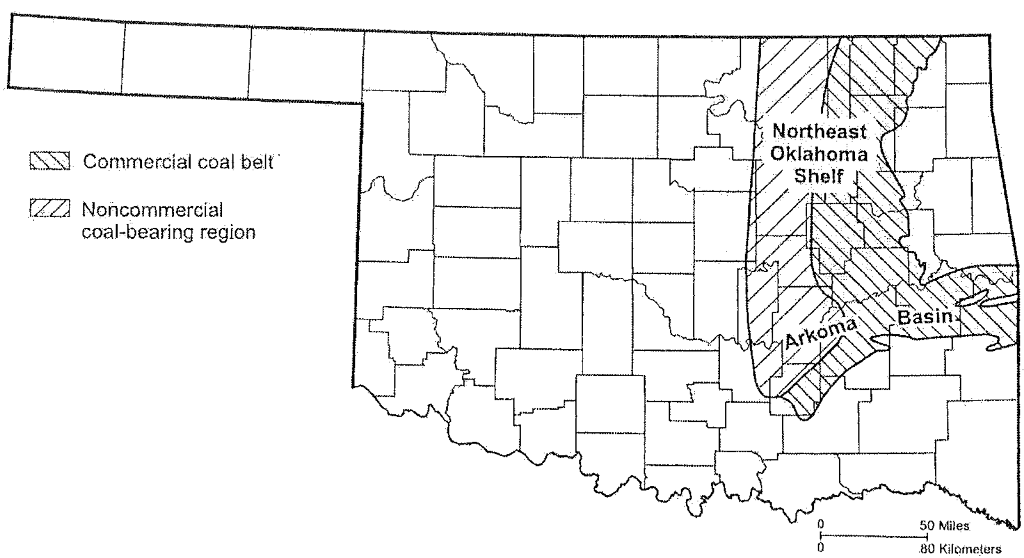


Figure 2. Map of Oklahoma coalfield. Modified from Friedman (1974).

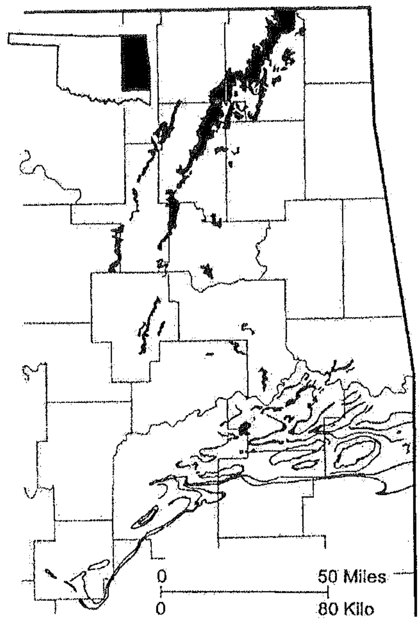


Figure 3. Map showing potentially strippable coal beds in eastern Oklahoma (modified from Friedman, 1982b).

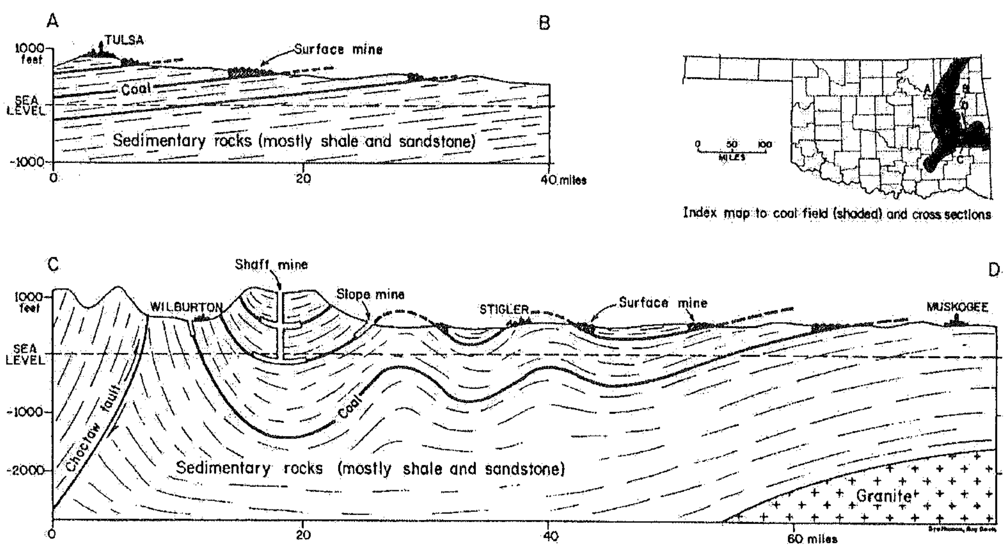


Figure 4. Schematic sections showing geologic structure and types of mines in the Oklahoma coalfield (from Johnson, 1974).

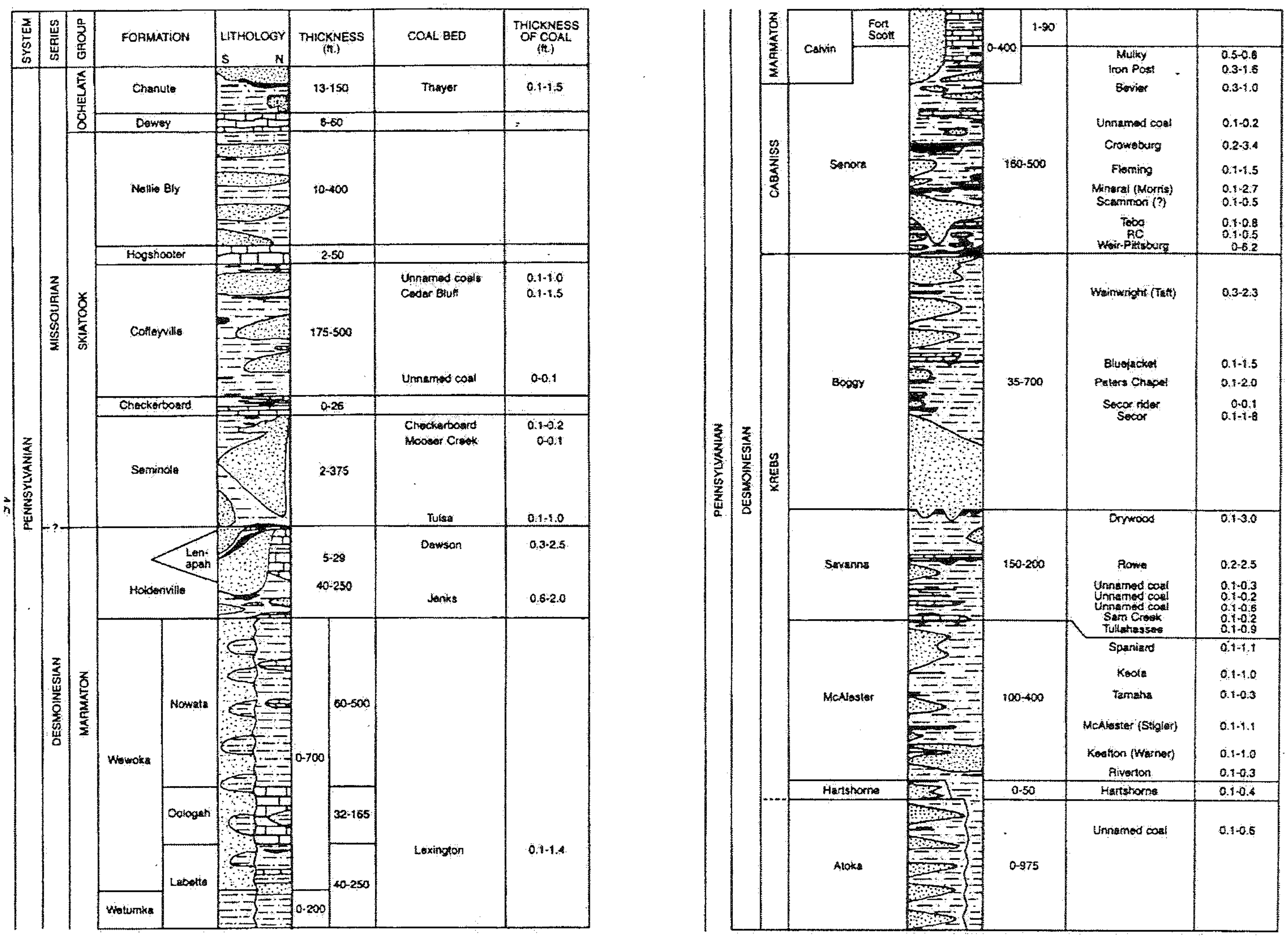


Figure 5. Generalized stratigraphy of coal-bearing strata of the northeast Oklahoma shelf (from Hemish, 1988).

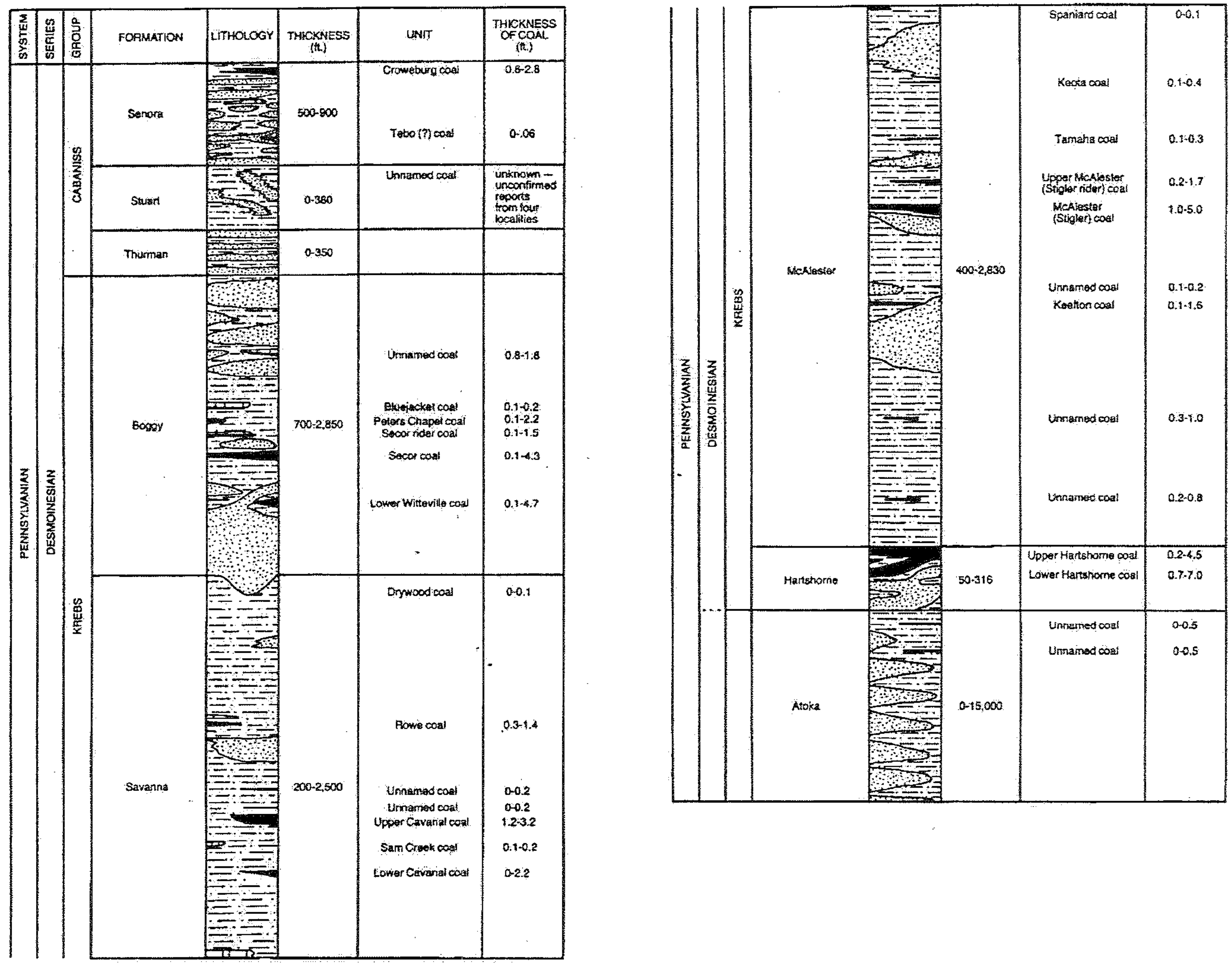


Figure 6. Generalized stratigraphy of coal-bearing strata of the Arkoma basin (from Hemish, 1988).

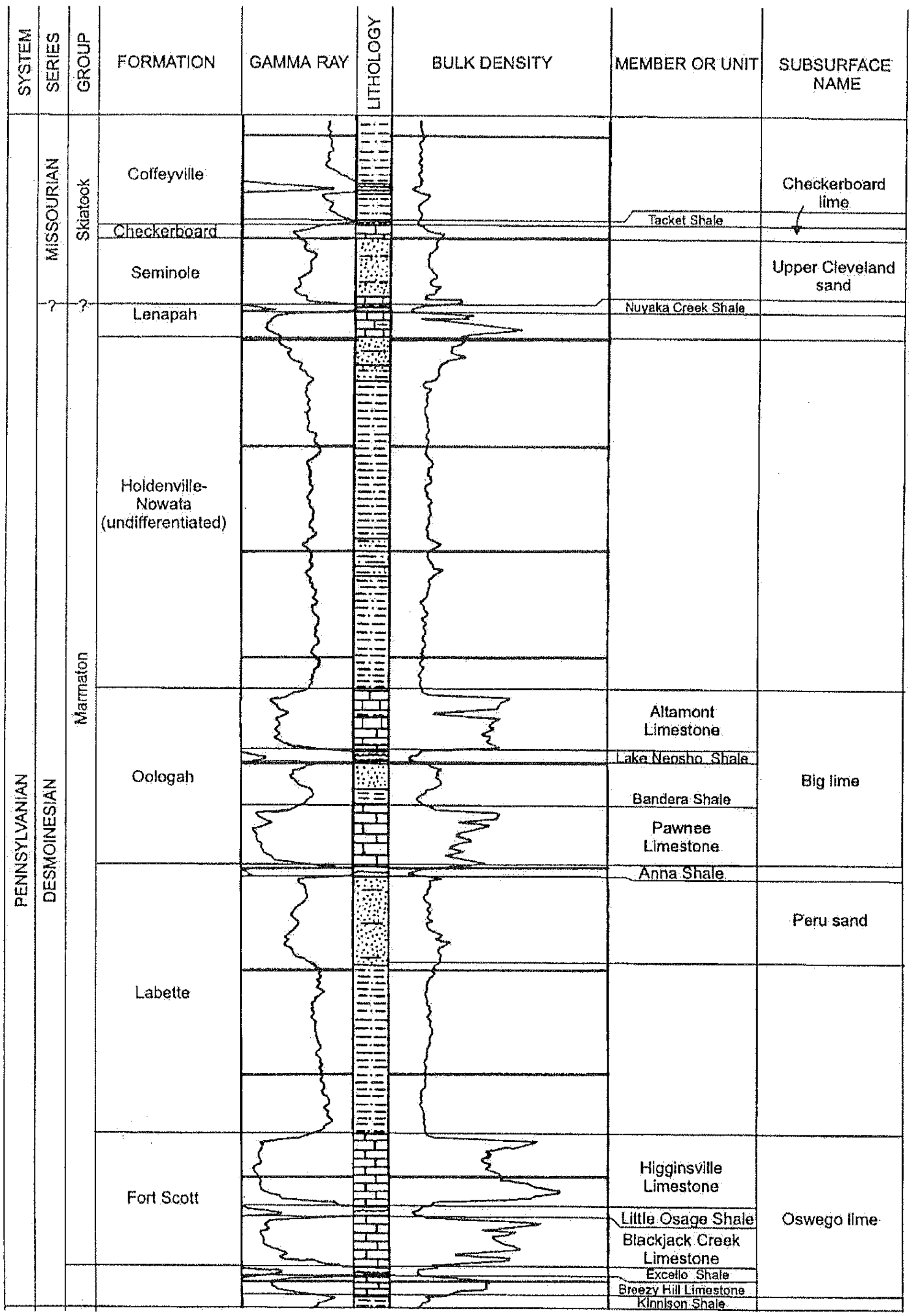
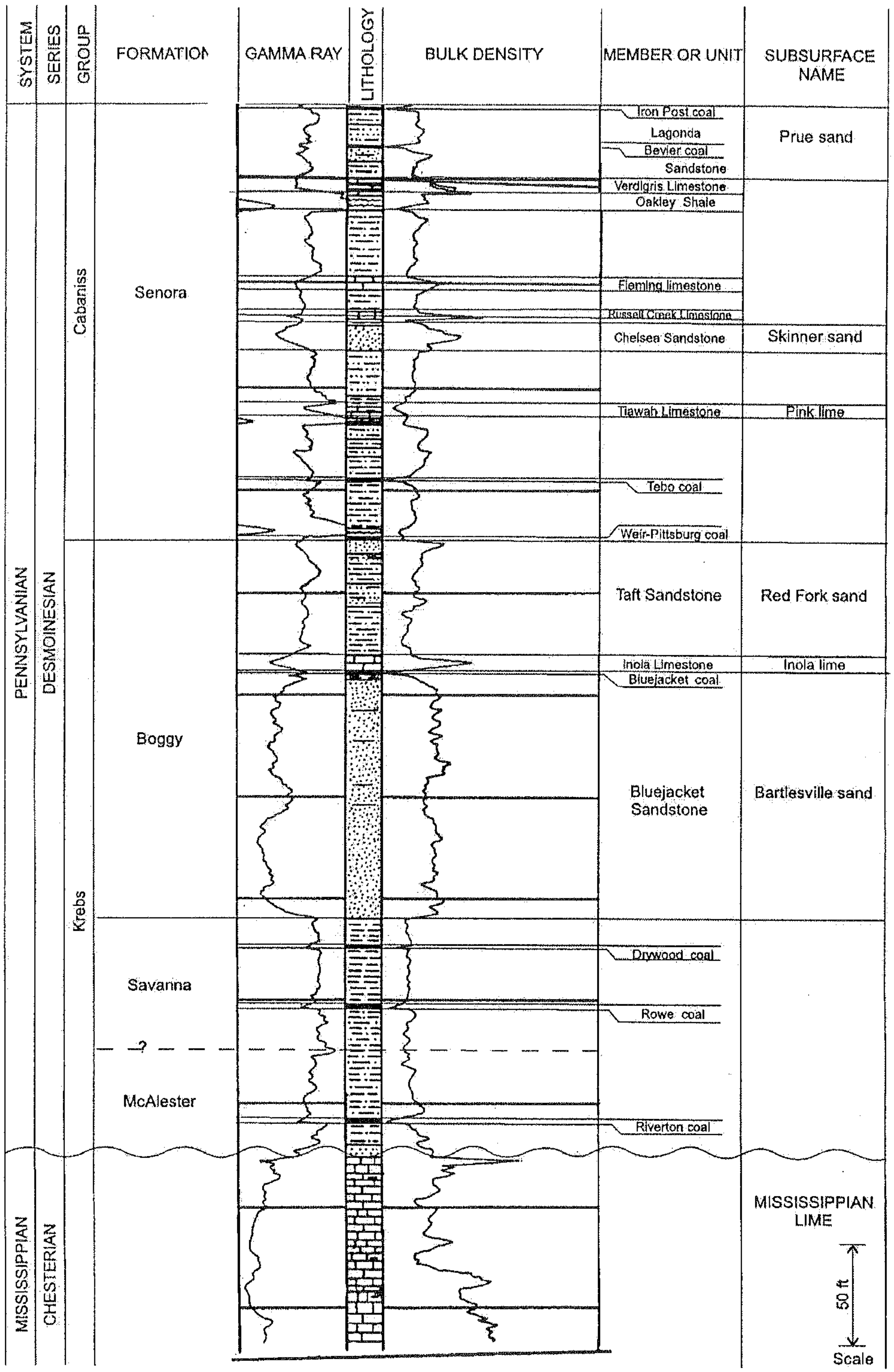


Figure 7. Type log for northern part of northeast Oklahoma shelf (from Hemish, 2002, fig. 18).
47


SYSTEM
SERIES
GROUP
FORMATION
GAMMA RAY
LITHOLOGY
BULK DENSITY
MEMBER OR UNIT
SUBSURFACE NAME
Iron Post coal
Lagonda
Bevier coal
Sandstone
Prue sand
Verdigris Limestone
Oakley Shale
Fleming limestone
Russell Creek Limestone
Chelsea Sandstone
Skinner sand
Tiawah Limestone
Pink lime
Tebo coal
Weir-Pittsburg coal
Senora
Cabaniss
Taft Sandstone
Red Fork sand
Inola Limestone
Inola lime
Bluejacket coal
Boggy
Bluejacket Sandstone
Bartlesville sand
PENNSYLVANIAN
DESMOINESIAN
Krebs
Savanna
Drywood coal
Rowe coal
?
McAlester
Riverton coal
MISSISSIPPIAN
CHESTERIAN
MISSISSIPPIAN LIME
50 ft
Scale

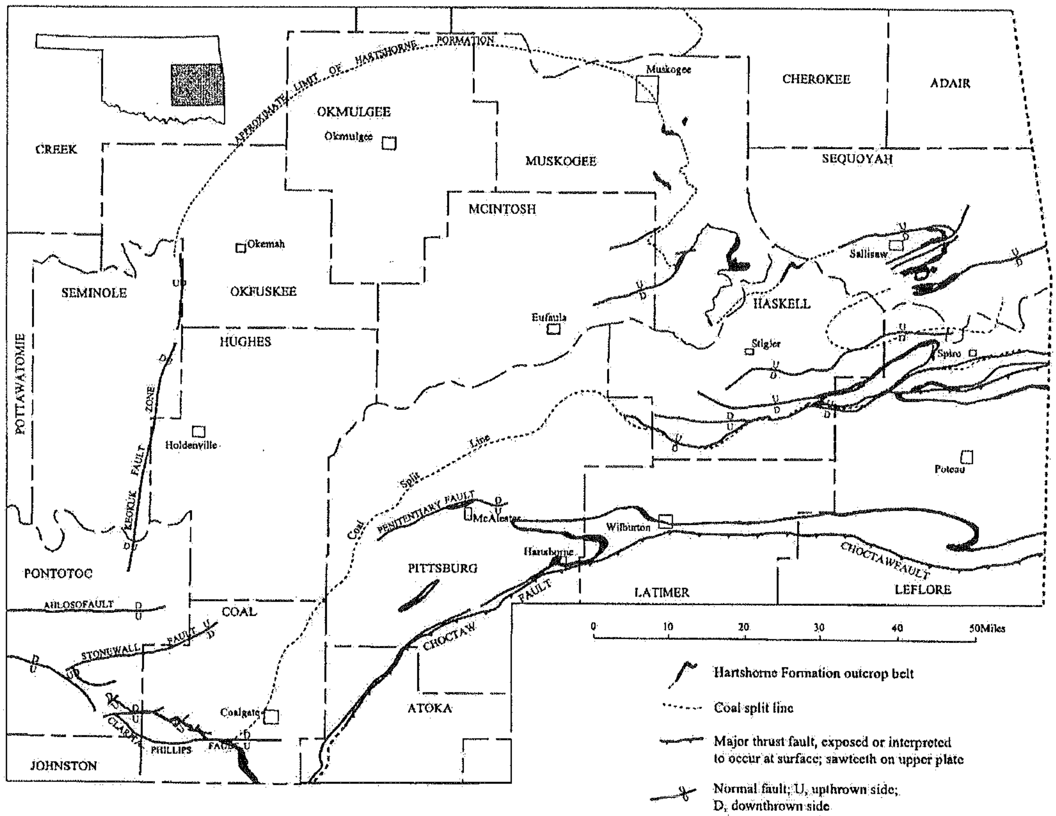


Figure 8. Distribution of the Hartshorne coal in the Arkoma basin, showing the coal split line (from Cardott, 2002a)

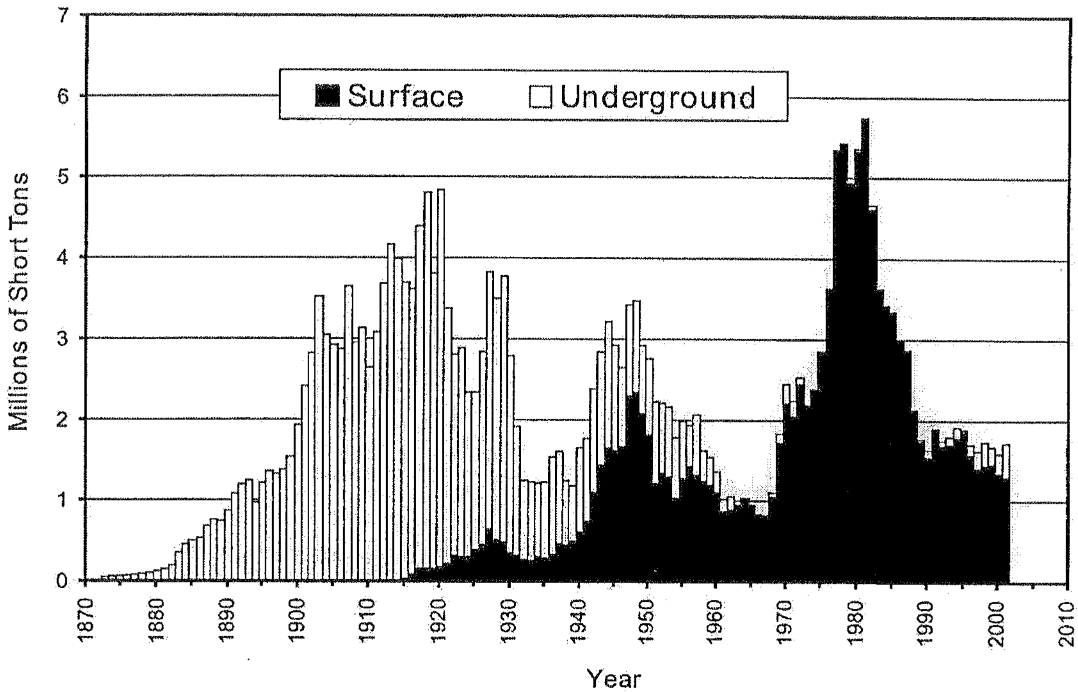


Figure 9. Coal production in Oklahoma, 1873-2001
(from Federal and State data).

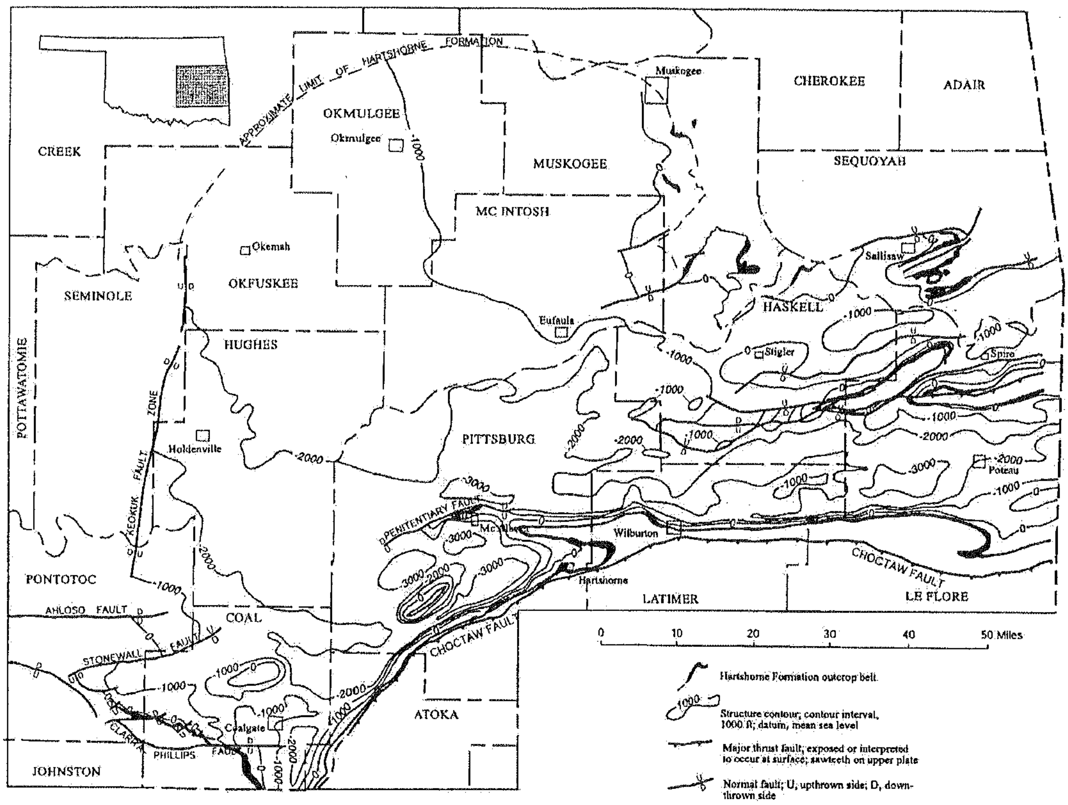


Figure 10. Regional structure on the top of the Hartshorne Formation (from Cardott, 2002a).

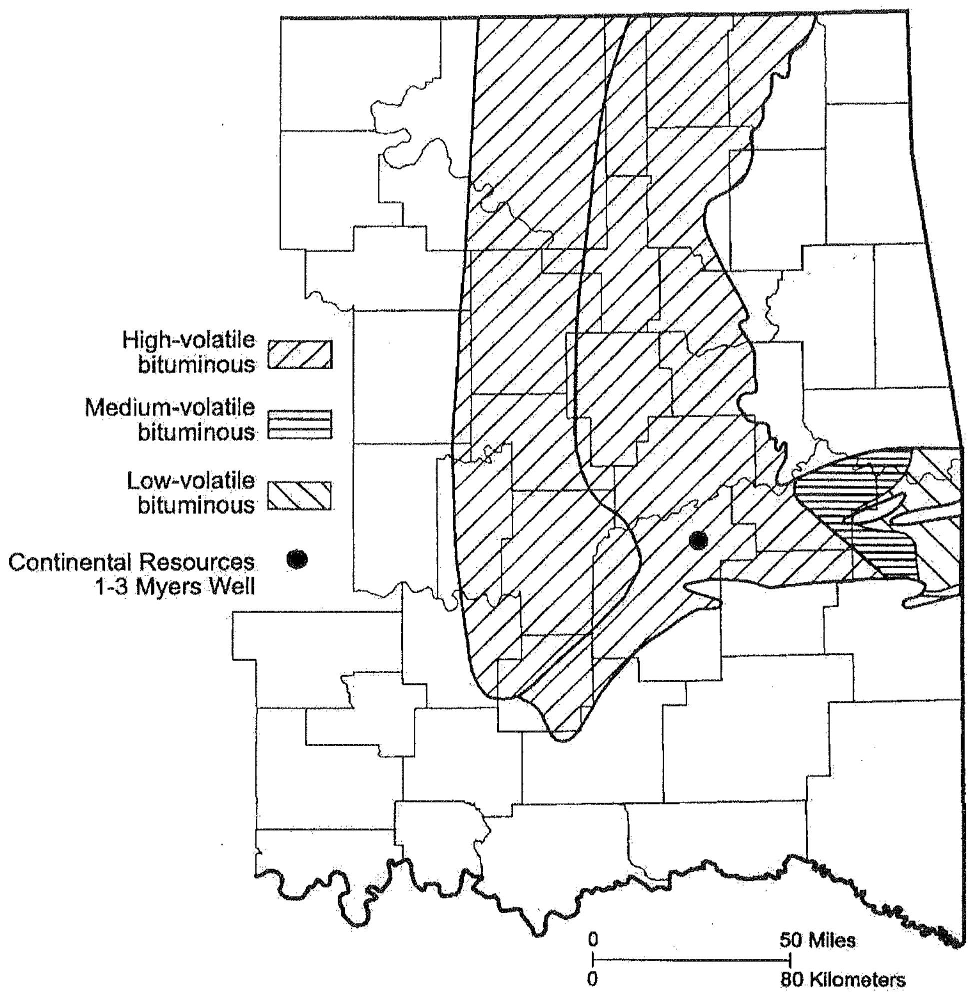


Figure 11. Generalized rank of all coal beds at or near the surface in the Oklahoma coalfield. Modified from Friedman (1974) and Andrews and others (1998).

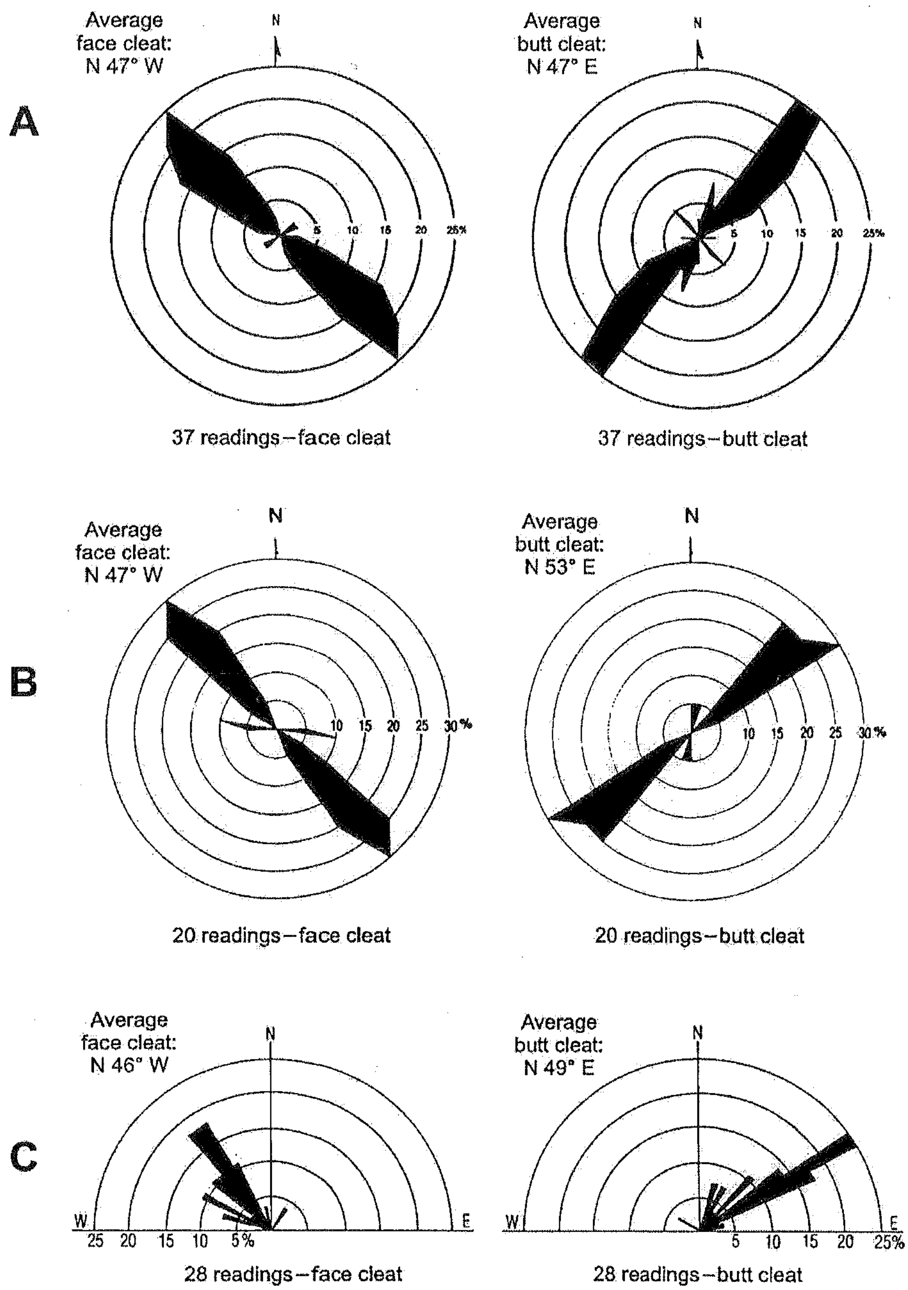


Figure 12. Rose diagrams of cleat orientations in coal beds (from Hemish, 2002). A. Craig and Nowata Counties. B. Rogers and Mayes Counties. C. Tulsa and Wagoner Counties.

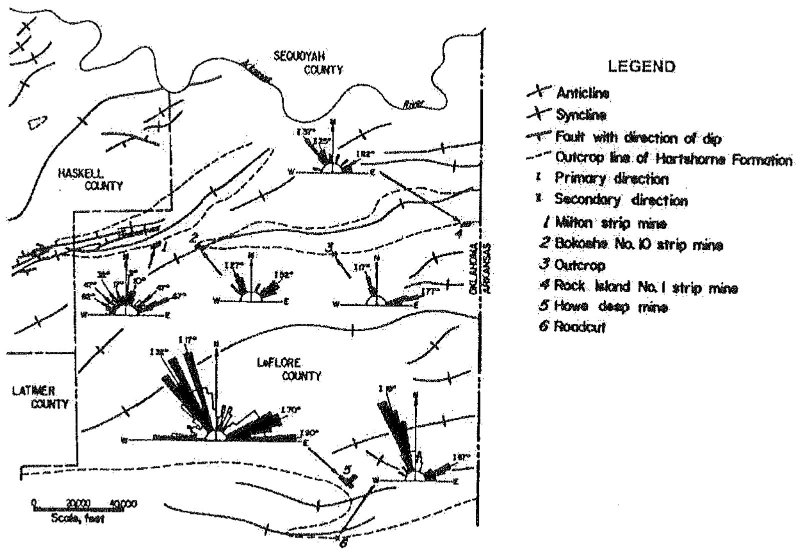


Figure 13. Coal cleat orientations of the Hartshorne coal, Le Flore County, Oklahoma (from Iannacchione and Puglio, 1979a).

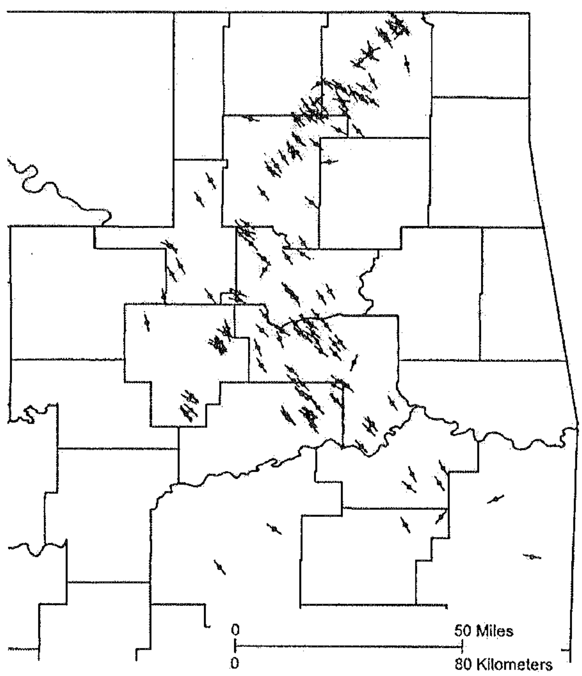


Figure 14. Map of face-cleat orientations in the Oklahoma coalfield from data in Hemish (1986, 1989, 1990a, 1994, 1998a, 1998b) and Friedman (unpublished).

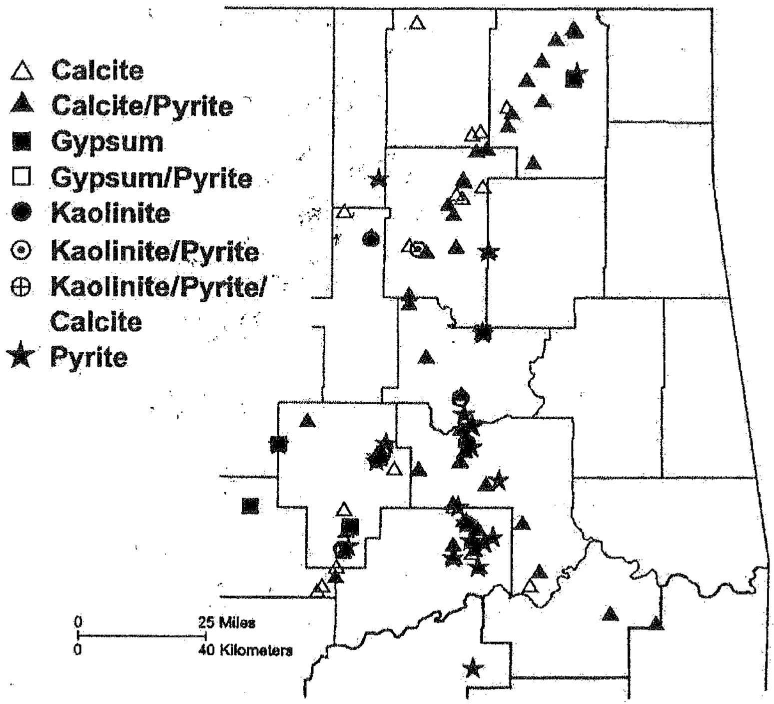
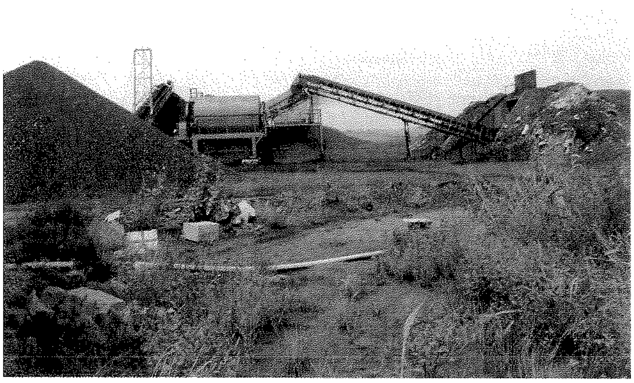


Figure 15. Map showing the distribution of cleat-filling minerals in northeast Oklahoma coal beds from data in Hemish (1986, 1988, 1989, 1990a, 1990b, 1994, 1997, 1998a, 1998b) and Friedman (unpublished).

Stop 1. Phoenix Coal Company Alluwe Mine

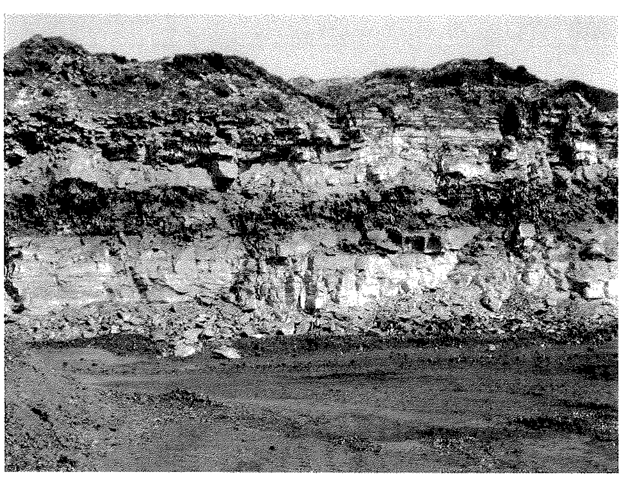
Location: E½ SE¼ Sec. 32, T.25N., R.17E., Nowata County, Oklahoma.
Winganon 7.5 minute quadrangle.

Introduction: The emphasis of this stop will be to view an active surface coal mine and reclamation, visualize the thickness of the Iron Post coal, Excello Shale, and overburden, and collect coal samples.

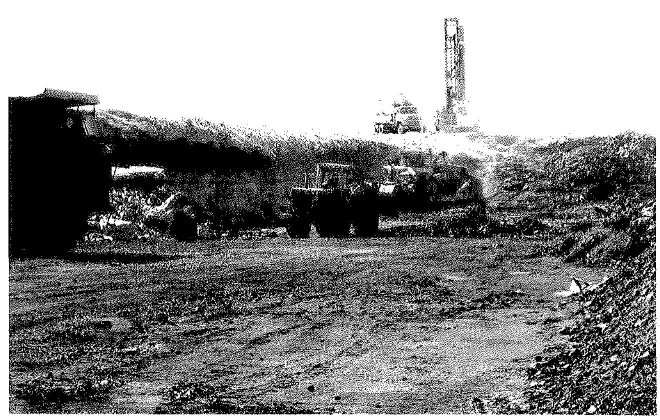


Coal crushing facility.

Coal is shipped by truck.



View of Blackjack Creek Ls, Excello Shale (@6 ft thick), and Breezy Hill Ls (top to bottom) in highwall, looking north. Highwall is @25 ft.



View of mining operation looking southeast.

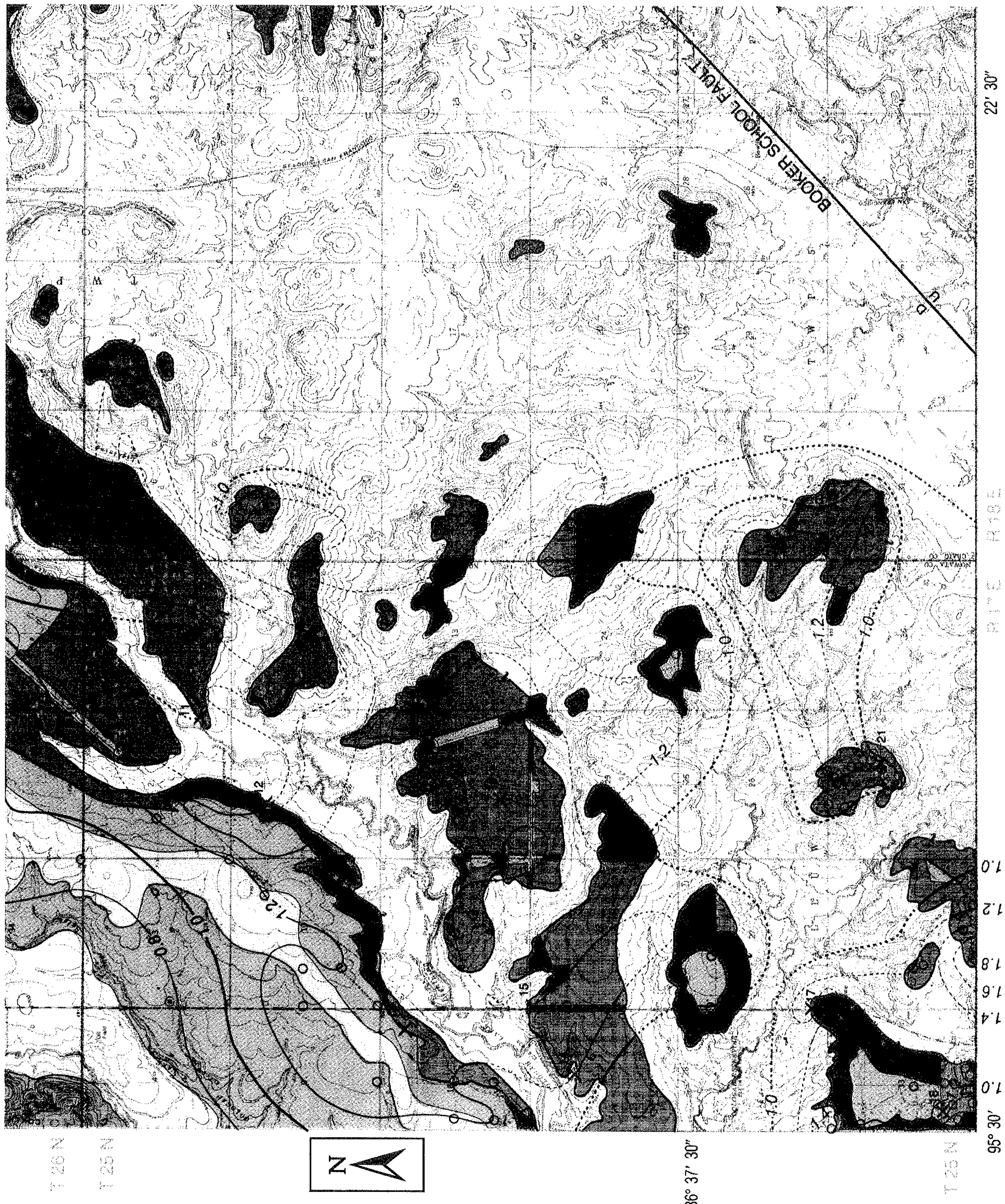
Iron Post coal (Cabaniss Group, Senora Formation; Desmoinesian, Middle Pennsylvanian)

~17 in. thick, dip ~2° NW.
Face cleat N26°W, 0.5 in. spacing; calcite and pyrite filling cleat.
Overburden: 18-25 ft (Kinnison shale above coal;
Breezy Hill limestone above shale)

Iron Post coal rank: high volatile B bituminous
[vitrinite reflectance (Rmax) = 0.58%].
Excello Shale thermal maturity: 0.59% Rrandom (well laminated; abundant pyrite)

Chemical analyses (as-received basis) of Iron Post coal:

Moisture	3.49%
Ash	4.89%
Volatile Matter	43.24% [47.19% dmmf]
Fixed Carbon	48.38% [52.81% dmmf]
B.T.U./LB	13,673 [14,562 moist, mmf; hvAb]
Sulfur	4.00%



Map of Iron Post coal showing coal thickness, overburden, and mined-out areas in the vicinity of the Alluwe mine (southwest corner of map, north is to the left; from Hemish, 1986, plate 1).

Measured Section 17

NW¼SW¼SW¼SW¼ sec. 27, T25N, R17E, Nowata County. Measured in road ditch just northeast of Alluwe along State Highway 28, by LeRoy A. Hemish. Field notebook designation CN-51-78-H. (Estimated elevation at top of section, 741 ft.)

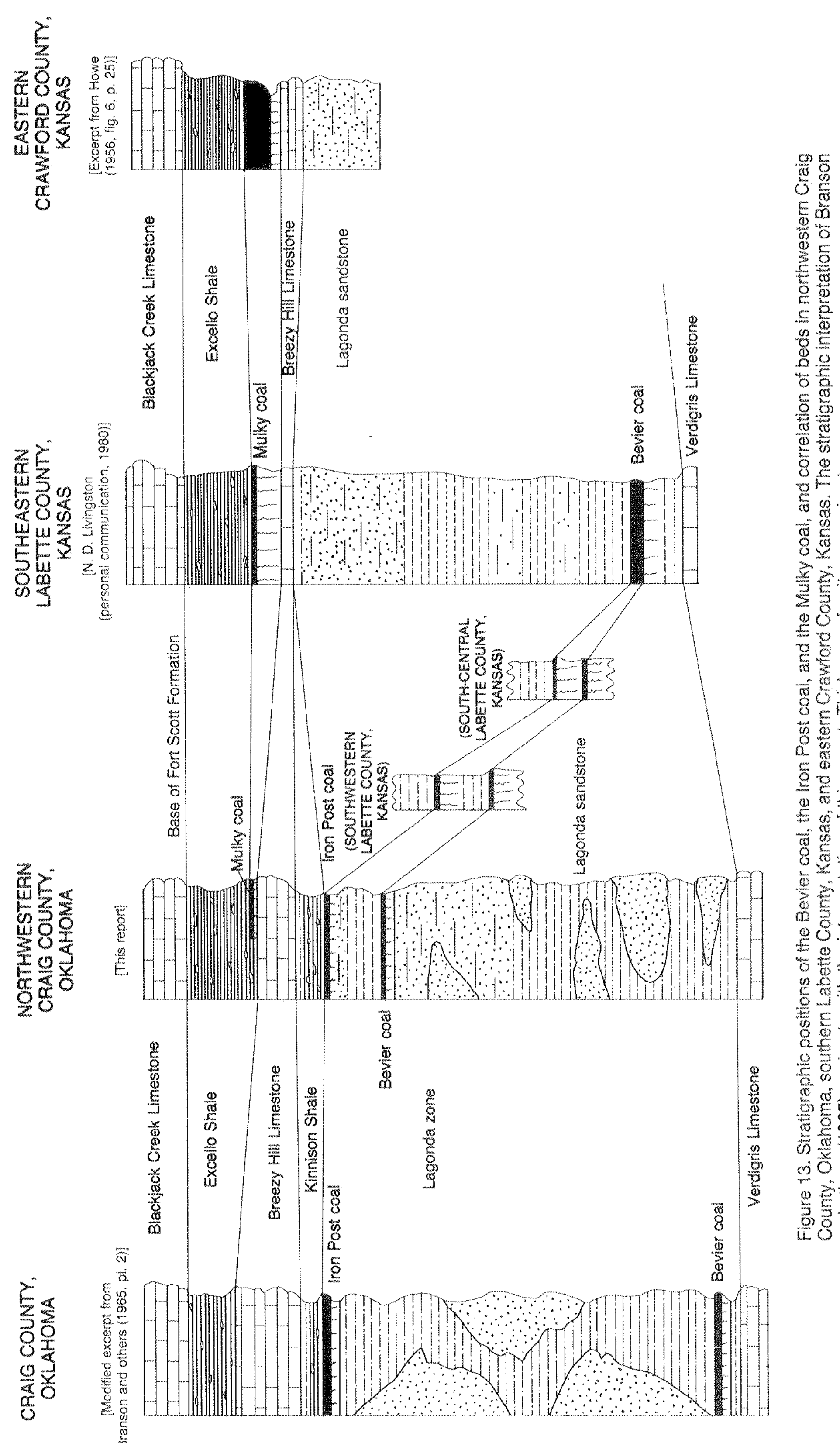
	Thickness (ft)
Undifferentiated:	
Clay, reddish-brown, oxidized (regolith)	0.5
CABANISS GROUP	
Senora Formation:	
Limestone, buff, silty, fossiliferous	0.5
Shale, medium-gray; contains black, carbonized plant fragments	3.0
Coal, black with reddish-brown iron-oxide staining on cleat surfaces (Iron Post)	1.1
Underclay, light-gray streaked with yellow, plastic; base not exposed	0.8
Total	5.9

Measured Section 18

NW¼SE¼SW¼ sec. 33, T25N, R17E, Nowata County. Measured in highwall of strip pit operated by Carbonex Coal Company, by LeRoy A. Hemish. Field notebook designation CN-42-78-H. (Estimated elevation at top of section, 735 ft.)

	Thickness (ft)
Undifferentiated:	
Clay, brown; weathered limestone boulders included (regolith)	2.0
MARMATON GROUP	
Fort Scott Limestone:	
Limestone, yellow-buff, silty, fossiliferous, weathered	1.0
CABANISS GROUP	
Senora Formation:	
Shale, yellow-gray, partly weathered	2.6
Shale, black, hard, slaty; contains phosphatic nodules; rectangularly-jointed, with reddish-brown staining on joint surfaces	2.9
Limestone, grayish-tan, dense, massive, fossiliferous	8.0
Shale, black, hard; bottom 1 ft includes the following: fossil tracks, trails, and burrows; a 6-in. zone of impure, shaly limestone containing brachiopod shells; black phosphatic nodules; and pyritized brachiopods and wood fragments	3.0
Coal, black with reddish-orange iron-oxide staining on cleat surfaces (Iron Post)	1.1
Shale, gray	0.3
Total	20.9

Measured sections 17 and 18 (from Hemish, 1986).



Cross section showing southern extent of Mulky coal in Oklahoma (from Hemish, 1986).

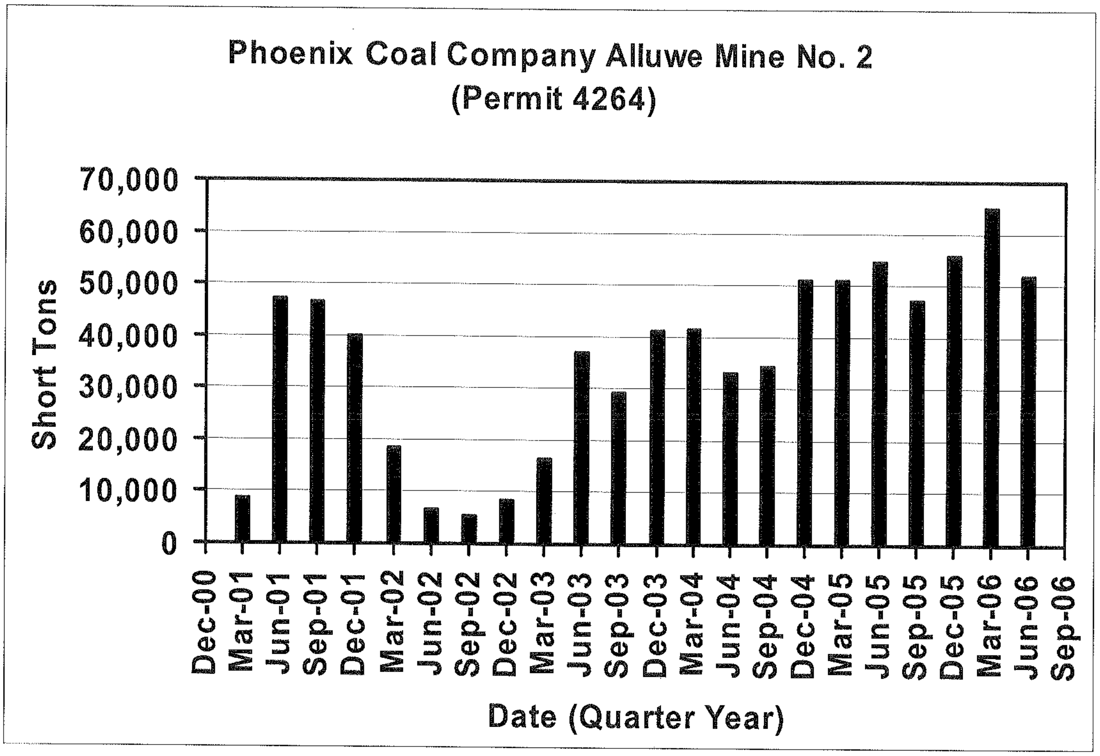
Close-up view of Excello Shale and Breezy Hill Limestone contact.

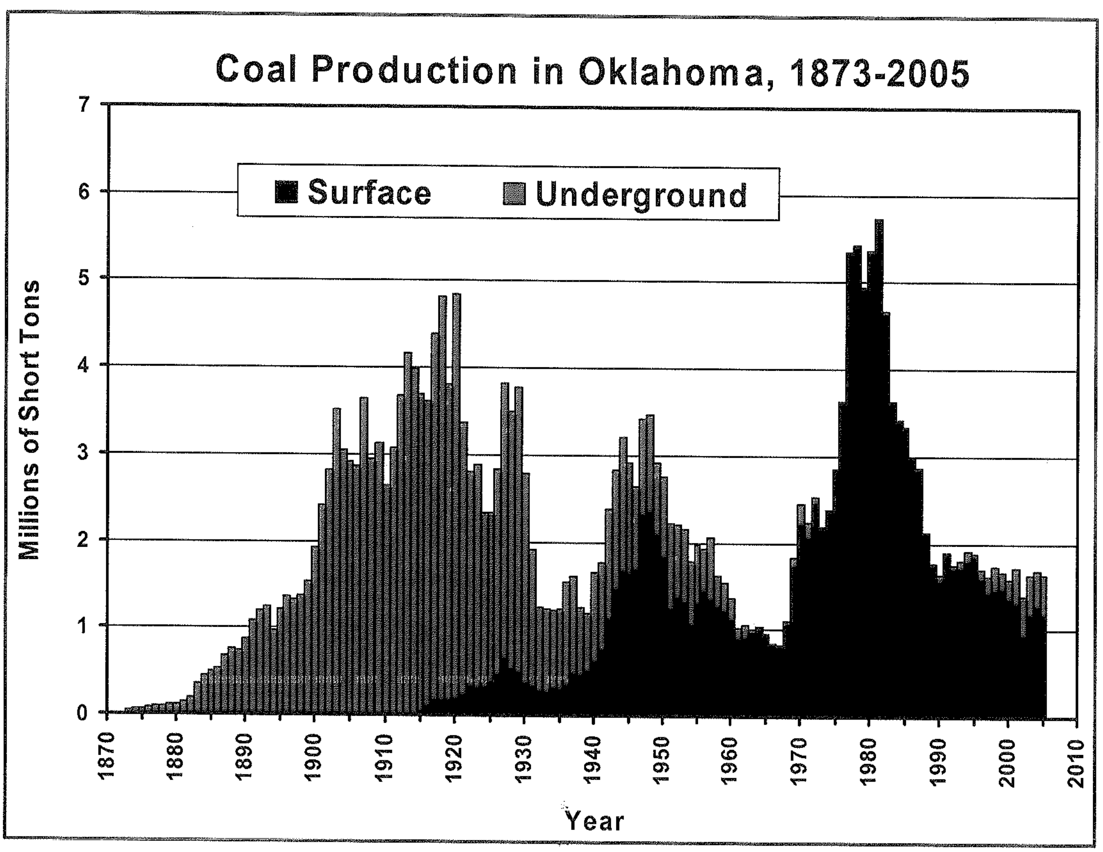
The Alluwe mine opened in March 2001. Year 2005 production was 208,358 short tons (12.7% of Oklahoma coal production; total Oklahoma coal production in 2005 was 1,638,210 short tons from 9 mines). Cumulative coal production from the Alluwe mine through June 2006 is 789,294 short tons.

From 1873–2005, 287,664,281 short tons of coal were produced in Oklahoma (see graph on next page). Coal was mined in Oklahoma strictly by underground methods until 1915. Peak annual coal production was 5.73 million short tons in 1981, with smaller production peaks during and immediately following World War I (4.85 million short tons in 1920) and World War II (3.46 million short tons in 1948). Five coal-fired utility electric power plants were built in Oklahoma from 1978–1982.

Much of the coal mined in eastern Oklahoma is shipped by truck to the Applied Energy Services (AES) Shady Point coal-fired cogeneration facility near Panama, Oklahoma (Le Flore County; SE¼ Section 3, Township 8 North, Range 25 East). Commercial operation of the plant began on January 15, 1991. The plant supplies electricity to Oklahoma Gas and Electric Company, food-grade carbon dioxide to Tyson Foods, and dry ice to Dixie Carbonics. The plant has four coal-fired circulating fluidized-bed (CFB) steam boilers and two turbine generators with a net electrical output of approximately 320 megawatts (enough electricity for about 230,000 homes). The CFB technology offers low sulfur dioxide and nitrogen oxides emissions while burning

Oklahoma high sulfur coal, and is a highly efficient combustion process at a low firing temperature. In the process of burning coal, there is a combustion gas reaction with limestone for sulfur dioxide capture. The plant uses about 3,000 tons of coal per day, and 1,000 tons of limestone per day.





COAL AND OIL POTENTIAL OF THE TRI-STATE AREA

Tulsa Geological Society Field Trip

April 30-May 1, 1976

Leaders:

Frederick N. Murray
Richard C. Norman
L. R. Wilson
Jack S. Wells
Allan P. Bennison
L. L. Brady
S. A. Friedman

Editor

Robert W. Scott

COAL GEOLOGY OF PARTS OF CRAIG, NOWATA, AND ROGERS COUNTIES, OKLAHOMA

S. A. Friedman
Oklahoma Geological Survey

This summary briefly indicates and illustrates the distribution, thicknesses, chemical analyses, resources and reserves, and mined areas of the Mineral, Croweburg, and Iron Post coals in the area of the junction of Craig, Nowata, and Rogers Counties, Oklahoma and vicinity (Fig. 1). The information presented is selected from coal geology projects in progress at the Oklahoma Geological Survey. The three counties (located between Tulsa and Kansas) contain 11 mines and 16 pits run by 10 companies, which produced 70 percent of the coal mined in 1975 in Oklahoma. The two Peabody mines led all others in production in 1975 in the State. Only 3 of the 11 operators have been mining coal for more than five years. The others are relatively new to the industry. At the 16 pits, the operators produce from four coal beds; namely, in ascending stratigraphic sequence, the Weir-Pittsburg, Mineral, Croweburg, and Iron Post. Some of the pits are shown on the preliminary coal map by the crossed picks symbol (Fig. 1). This map also shows the distribution and surface-mined areas of the Mineral, Croweburg, and Iron Post coals. All three coals are approximately 1 to 2 ft thick where mined, justifying the thin-coal reputation that northeastern Oklahoma has. The coals occur within a stratigraphic interval of about 160 ft, as shown on the generalized geologic column (Fig. 2) and the cross sections (Figs. 3 and 4). The interval thins by 40 to 50 ft northward from the Tulsa area to Kansas as suggested on cross section B-B' (Fig. 4). As many as three other thinner coals occur within this interval in parts of the area, but the Oklahoma Geological Survey does not have sufficient information to determine their coal resources.

Recent coal investigations by the OGS (Friedman, 1974) indicate that selected coal beds in Craig, Nowata, and Rogers Counties together contain resources and reserves classified as strippable (defined as 0-100 ft deep), shown in Table 1. Chemical analyses are given in Table 2.

TABLE 1. REMAINING COAL RESOURCES
(in Measured, Indicated, and Inferred categories of reliability combined)

Formal geologic name of coal	Thickness of coal bed	Sulfur content	Thousand short tons
Iron Post	10-28 inches	3.5-4.2%	64,000
Croweburg	10-28 inches	0.4-3.5%	157,000
Mineral	10-28 inches	3.5-5.1%	23,000
Total	10-28 inches	0.4-5.1%	244,000

TABLE 2. TYPICAL CHEMICAL ANALYSES[1] OF PRINCIPAL COALS MINED IN CRAIG, NOWATA, AND ROGERS COUNTIES, OKLAHOMA

COAL	COUNTY	PROXIMATE ANALYSIS As Received (percent)				SULFUR (percent)	Btu
		M.	V.M.	F.C.	Ash		
Iron Post	Craig	3.5	45.0	47.9	7.1	3.5	13,420
Iron Post	Craig	6.5	33.2	54.3	6.0	0.5	13,451
Iron Post	Nowata	7.0	37.7	50.7	4.6	2.2	12,582
Iron Post	Rogers	4.4	44.3	46.1	5.3	3.6	13,417
Croweburg	Rogers	6.0	37.1	55.2	4.8	0.6	13,547
Croweburg	Rogers	7.1	34.7	51.9	6.3	2.0	12,780
Mineral	Craig	4.4	36.4	46.8	12.5	5.0	12,321
Mineral	Craig	3.6	39.4	49.6	11.0	3.6	12,730
Mineral	Craig	4.8	34.3	43.6	17.3	5.0	11,427
Mineral	Craig	6.3	34.7	44.0	15.0	5.5	11,608

[1] David Foster, Chemical Analyst, Oklahoma Geological Survey

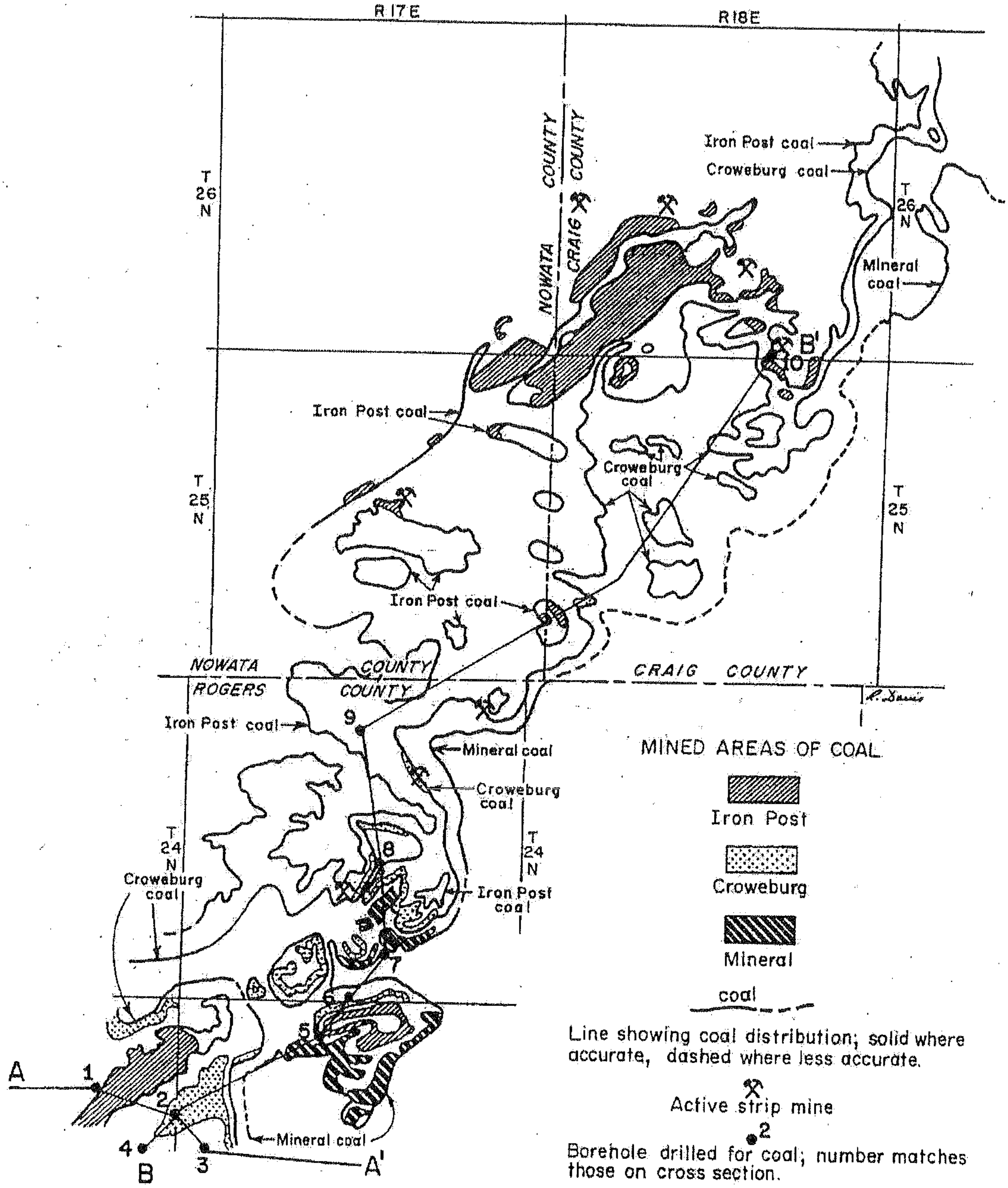


Fig. 1. Map showing distribution and surface-mined areas of principal coals in parts of Craig, Nowata, and Rogers Counties, northeastern Oklahoma. (Lines A-A' and B-B' indicate cross sections shown on Figs. 3 and 4.)

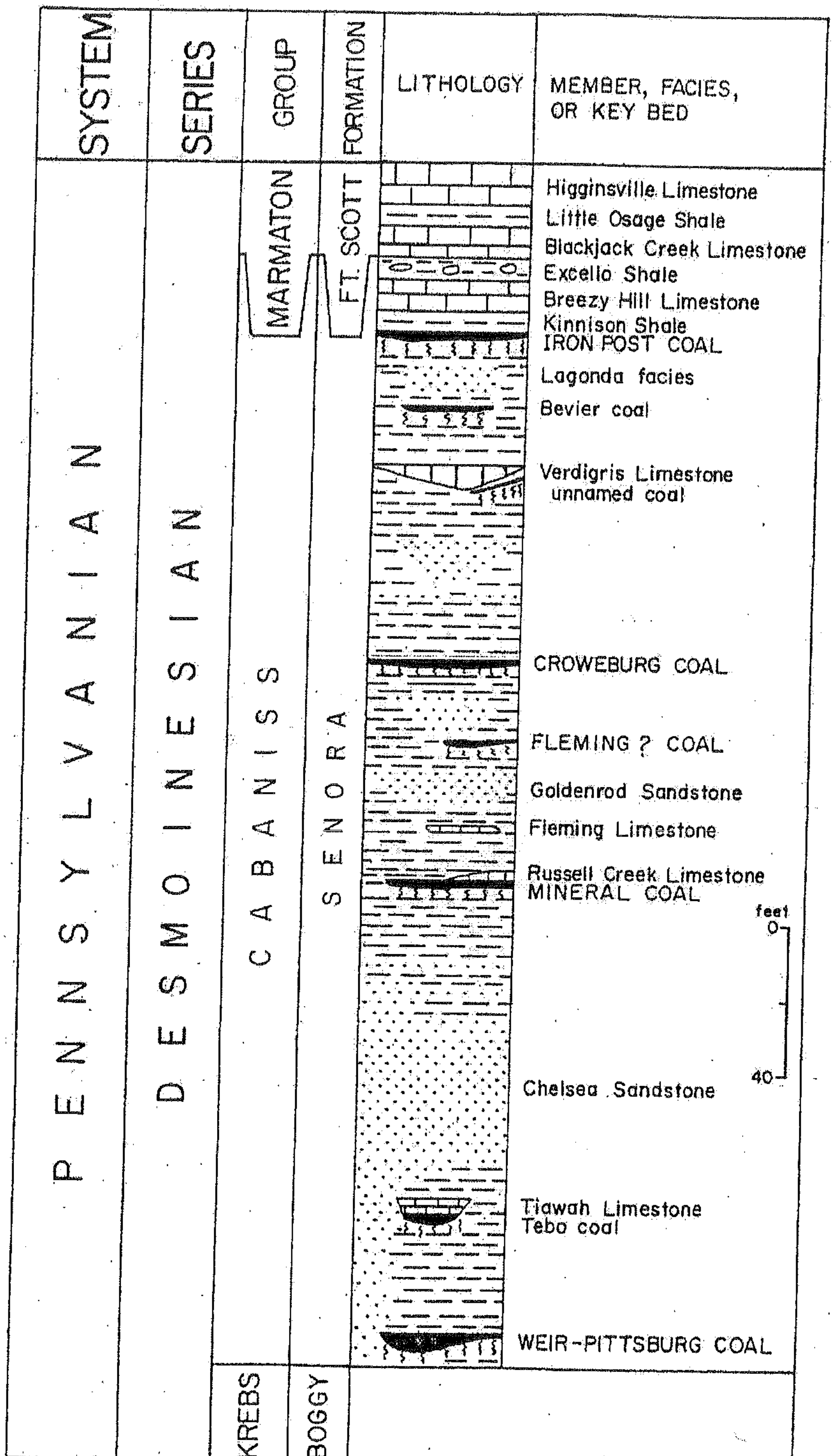


Fig. 2. Generalized geologic column showing the Senora and Ft. Scott Formations in the map area.

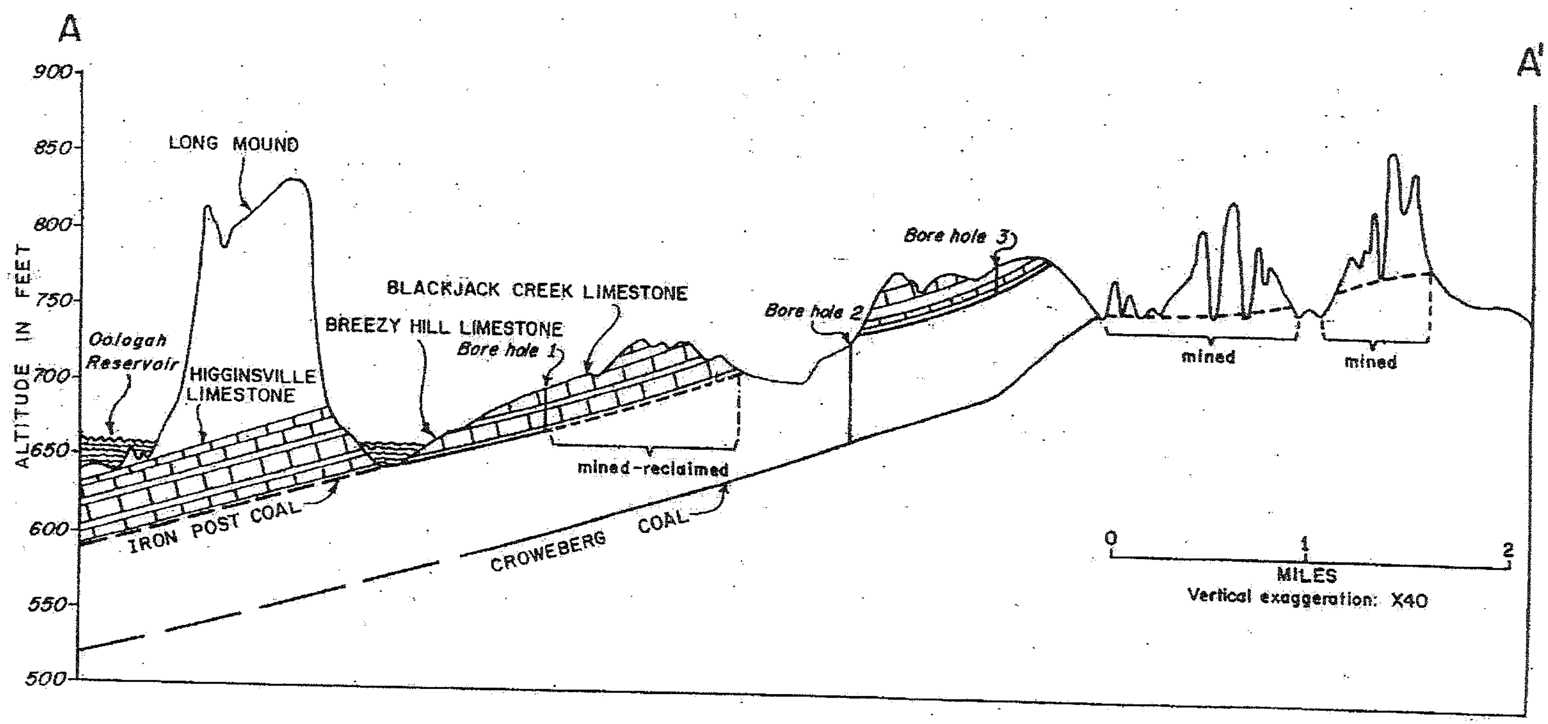


Fig. 3. Cross section along line A-A' (see Fig. 1) showing stratigraphic relationship of the Croweburg and Iron Post Coals and the Breezy Hill and Ft. Scott Limestones.

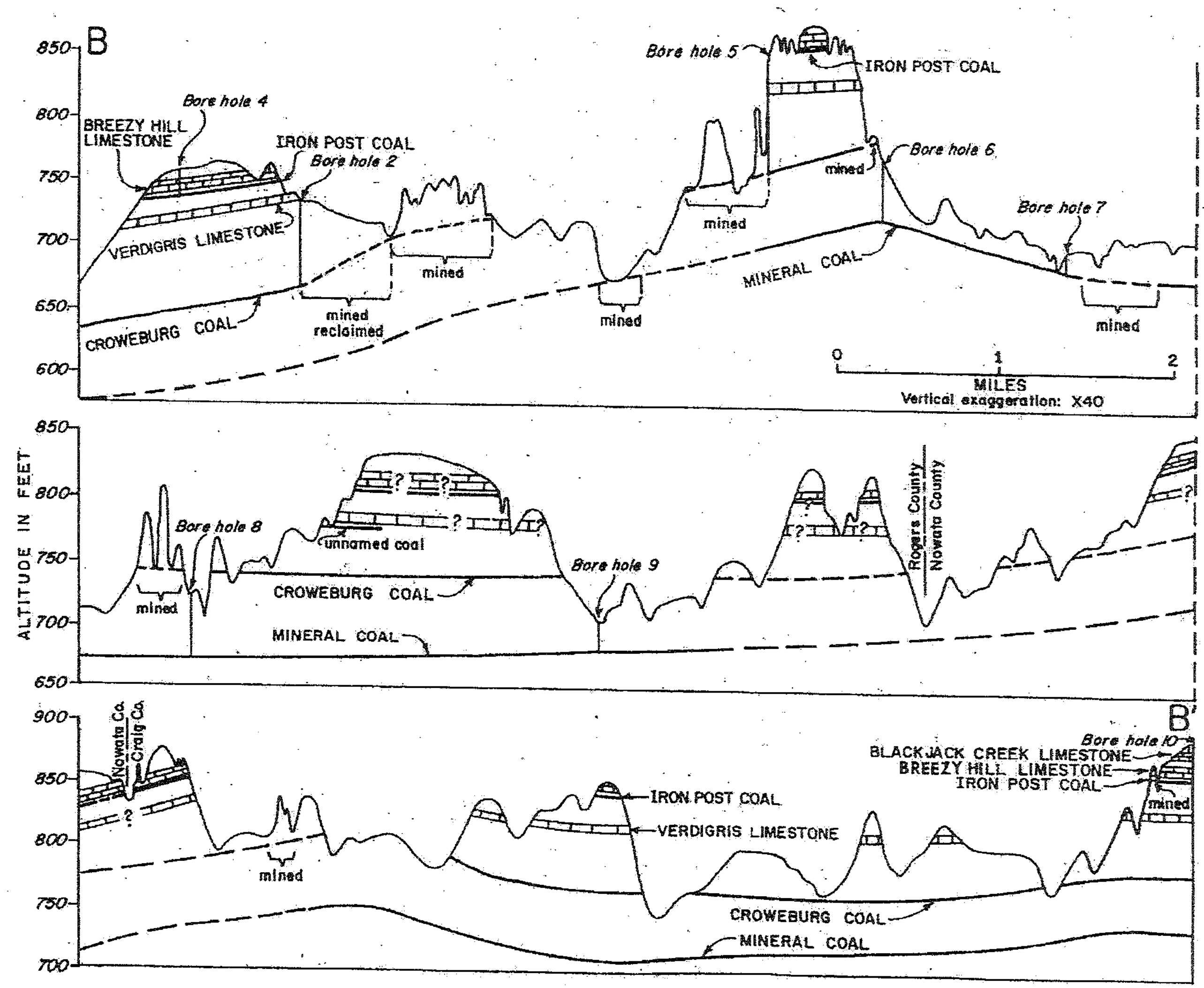


Fig. 4. Cross section B-B' showing stratigraphic relationship of the principal coals and limestones in the map.

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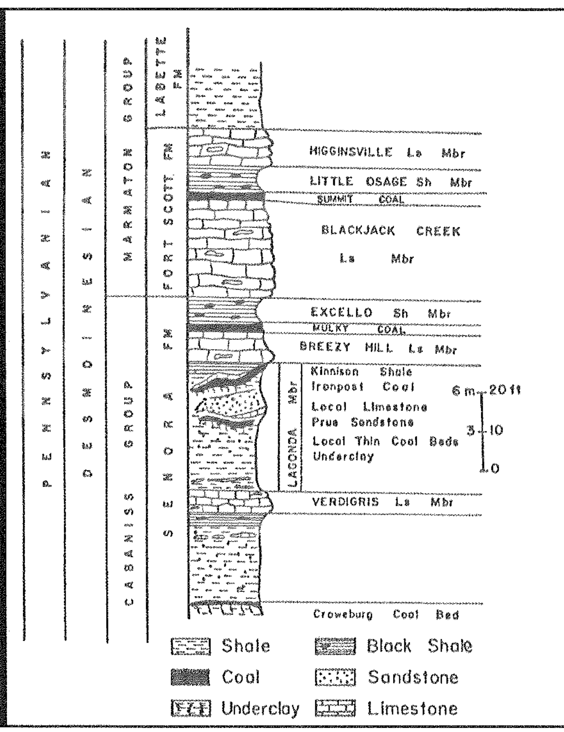
Excello Gas-Shale Play of Oklahoma

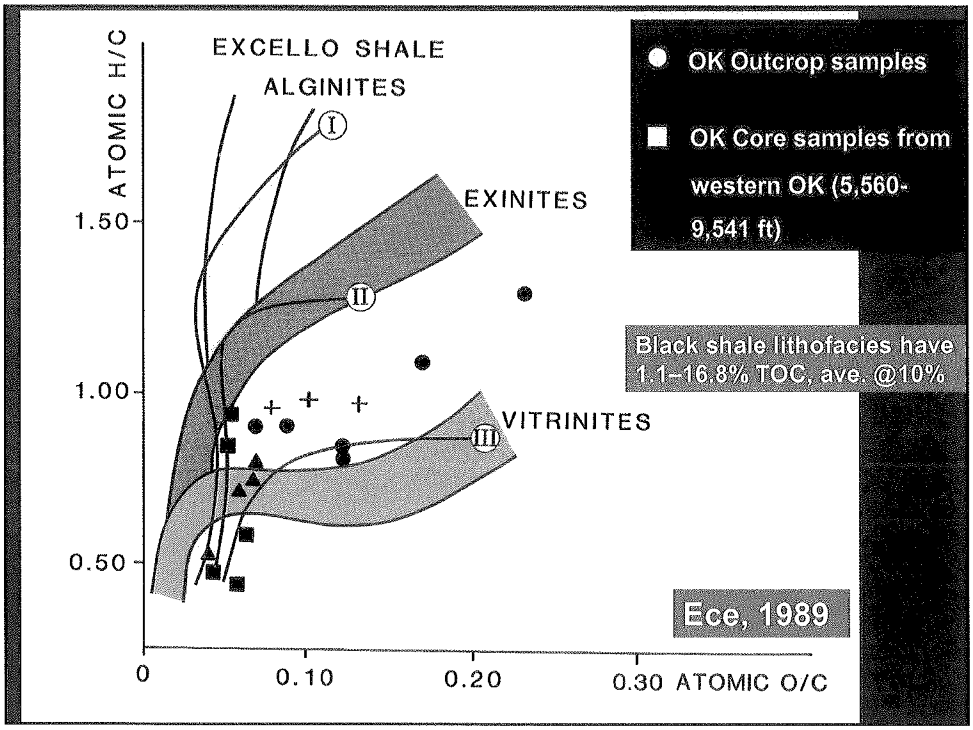
Brian J. Cardott
Oklahoma Geological Survey

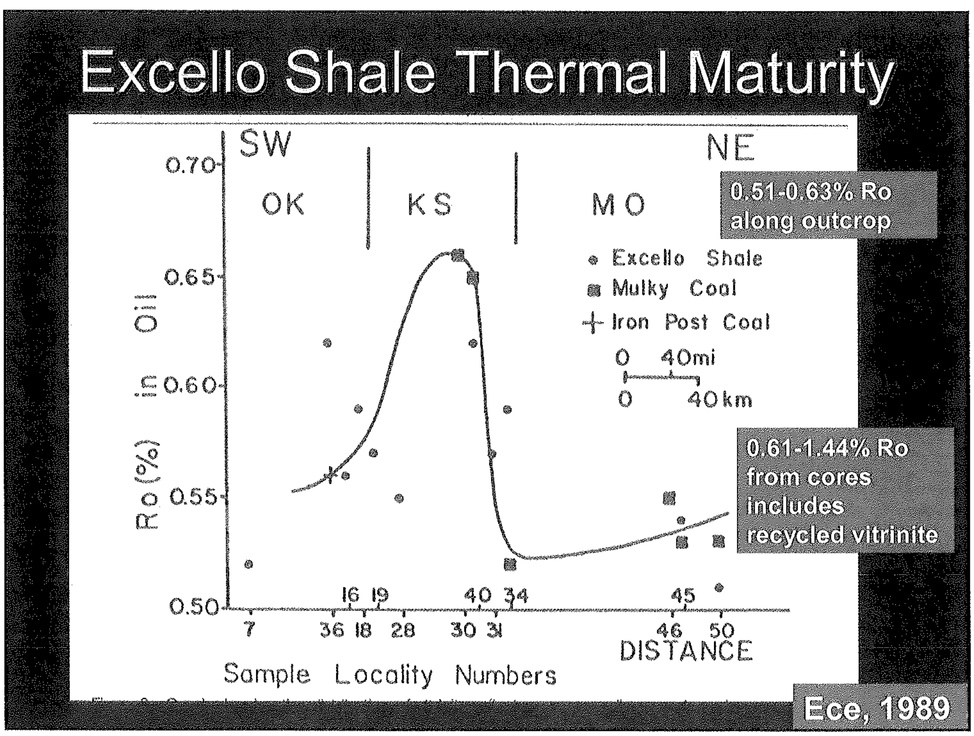


Excello Shale Stratigraphy

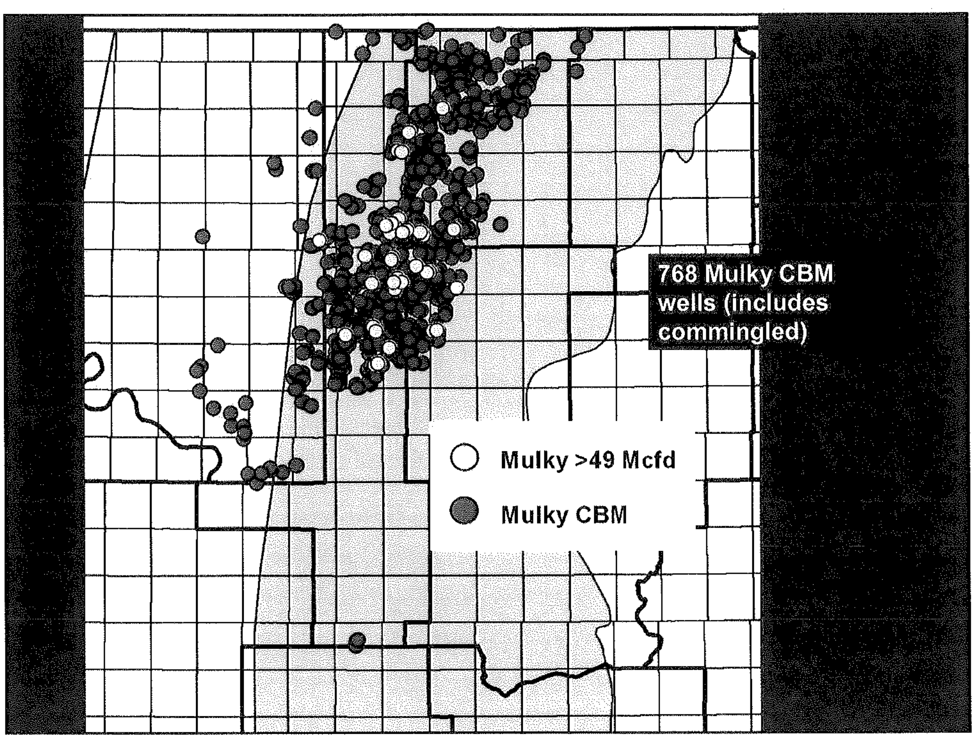
(<16 ft thick)

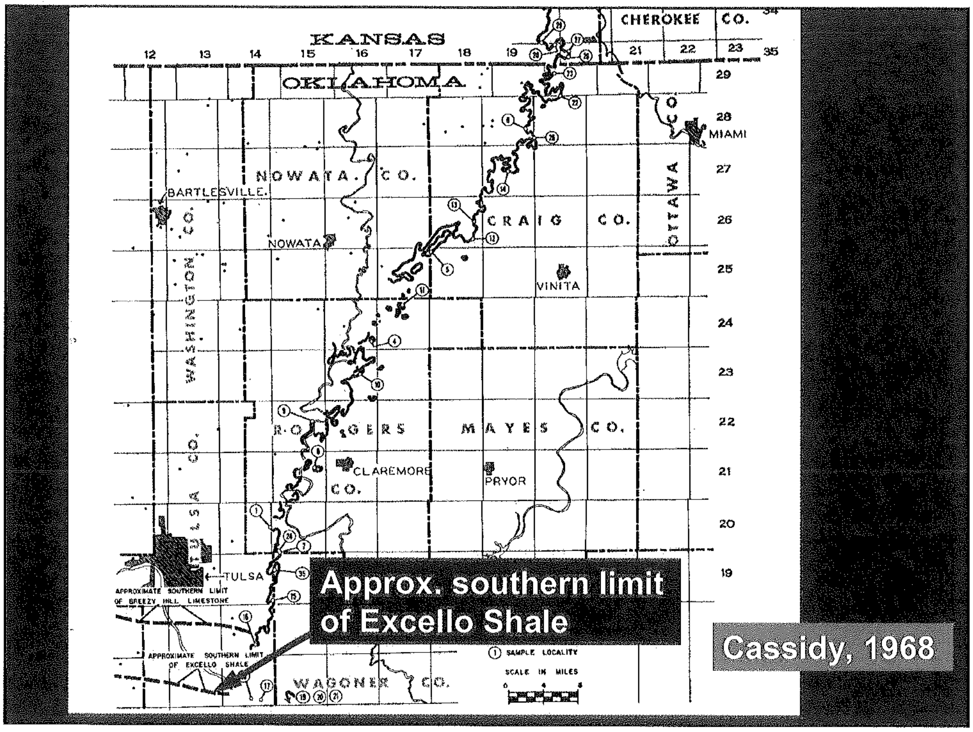
Ece, 1989


ATOMIC H/C
EXCELLO SHALE
ALGINITES
I
II
III
EXINITES
VITRINITES
1.50
1.00
0.50
0
0.10
0.20
0.30 ATOMIC O/C
OK Outcrop samples
OK Core samples from western OK (5,560-9,541 ft)
Black shale lithofacies have 1.1–16.8% TOC, ave. @10%
Ece, 1989


Excello Shale Thermal Maturity
SW
NE
OK
KS
MO
0.51-0.63% Ro along outcrop
Excello Shale
Mulky Coal
Iron Post Coal
0 40mi
0 40km
0.61-1.44% Ro from cores includes recycled vitrinite
Ro (%) in Oil
0.70
0.65
0.60
0.55
0.50
16 19
40 34
45
7
36 18 28
30 31
46 50
DISTANCE
Sample Locality Numbers
Ece, 1989

Excello Shale gas production is included with Mulky coalbed-methane production





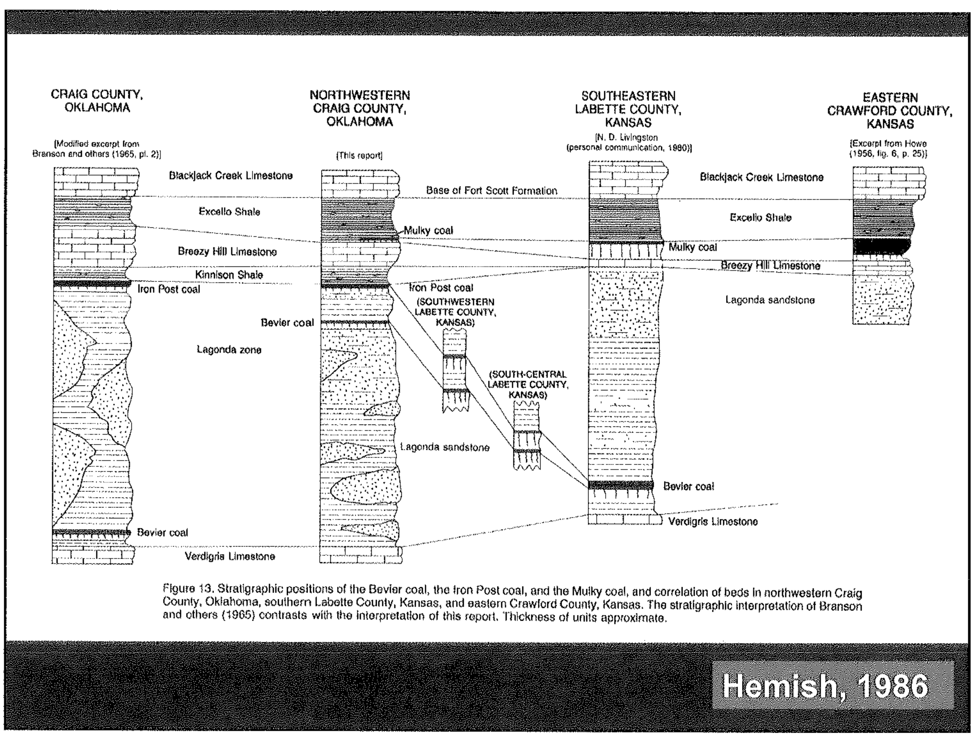
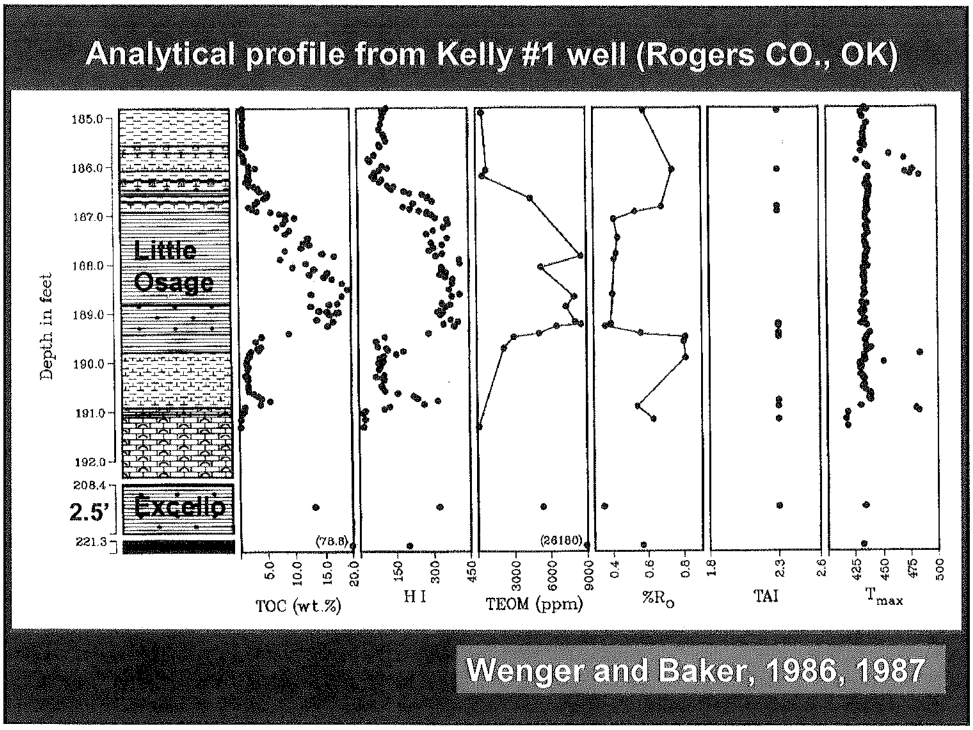
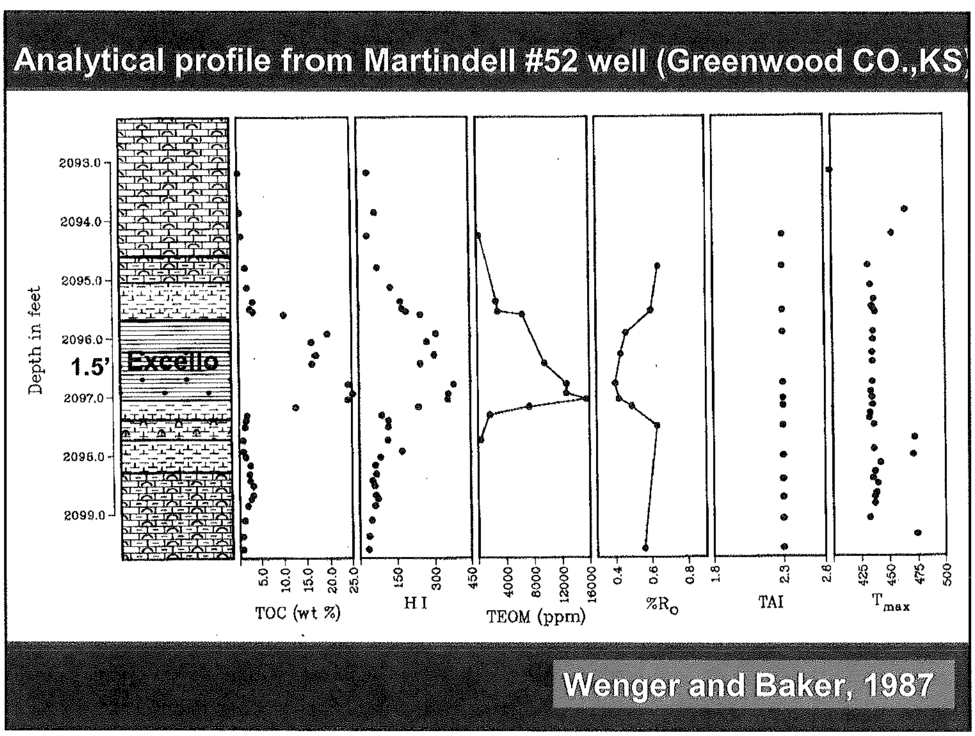


Figure 13. Stratigraphic positions of the Bevier coal, the Iron Post coal, and the Mulky coal, and correlation of beds in northwestern Craig County, Oklahoma, southern Labette County, Kansas, and eastern Crawford County, Kansas. The stratigraphic interpretation of Branson and others (1965) contrasts with the interpretation of this report. Thickness of units approximate.



Analytical profile from Kelly #1 well (Rogers CO., OK)
Depth in feet
Little Osage
Excello
2.5'
TOC (wt.%)
H I
TEOM (ppm)
%Ro
TAI
Tmax
Wenger and Baker, 1986, 1987



Analytical profile from Martindell #52 well (Greenwood CO.,KS)
Depth in feet
Excello
1.5'
TOC (wt %)
H I
TEOM (ppm)
%Ro
TAI
Tmax
Wenger and Baker, 1987

Stop 2. Phoenix Coal Company Kelley Mine

Location: NW¼ Sec. 19, T.25N., R.18E., Craig County, Oklahoma.
Chelsea NW 7.5 minute quadrangle.

Introduction: The emphasis of this stop will be to view an active surface coal mine and reclamation, visualize the thickness of the Croweburg coal and overburden, and collect coal samples from the coal storage pad.

Hydraulic front shovel has a 27 cubic yard bucket.
Caterpillar 789 haul truck (21 feet high, 24 feet wide) has 200 ton capacity.

Caterpillar track-type tractors move overburden across pit.
Drilling rig prepares holes to blast the overburden.

Collecting sample of Croweburg coal below 50 ft highwall.

View of mining operation on September 5, 2006.

View of mining operation on September 5, 2006. Highwall is about 60 ft high.

Croweburg coal (Cabaniss Group, Senora Formation; Desmoinesian, Middle Pennsylvanian)

~16 in. thick, dip ~2° NW.

Face cleat N34°W, 0.5 in. spacing; calcite and minor pyrite filling cleat.

Overburden: ~75 ft (shale above coal; capped by Verdigris limestone)

Map of Croweburg coal showing coal thickness, overburden, and mined-out areas in the vicinity of the Kelley mine (below center of map, north is to the left; from Hemish, 1986, plate 2).

Measured Section 29

SW¼NE¼NE¼NW¼ sec. 30, T25N, R18E, Craig County. Measured in highwall of strip pit operated by Solar Excavating, Inc., by LeRoy A. Hemish. Field notebook designation CN-53-78-H. (Estimated elevation at top of section, 813 ft.)

	Thickness (ft)
Undifferentiated:	
Clay, dark-gray-brown, silty (regolith)	2.0
Clay, orange-brown; contains weathered shale fragments (regolith)	4.0
CABANISS GROUP	
Senora Formation:	
Shale, yellow-gray, partly oxidized	5.0
Shale, light-gray; includes scattered, oblate, gray clay-ironstone concretions about 6 to 8 in. in diameter	22.0
Coal, black, hard (Croweburg)	1.2
Shale, gray; includes abundant, black carbonized plant fragments; base not exposed	0.6
Total	34.8

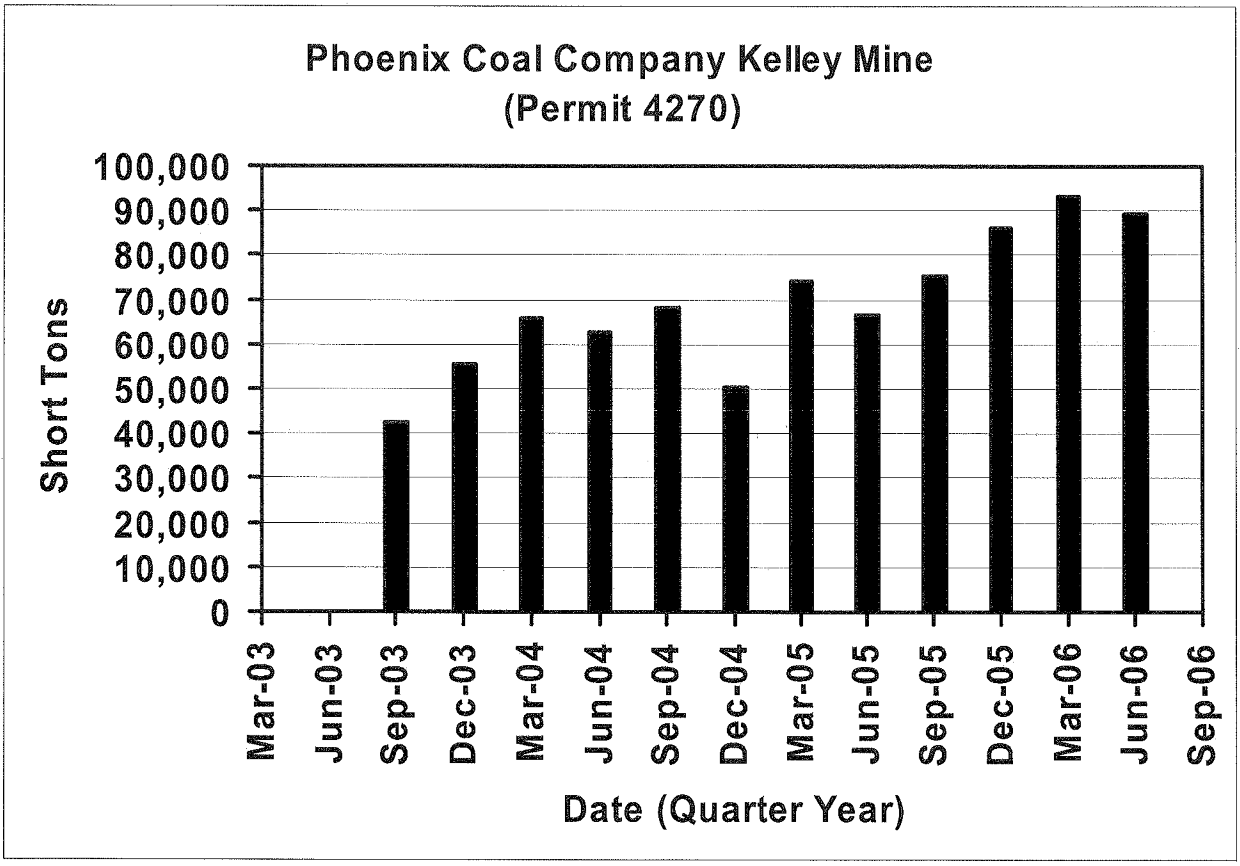
Measured section 29 (from Hemish, 1986).

Petrographic coal rank: high volatile A bituminous
[vitrinite reflectance (Rmax) = 0.85%].

Chemical analyses (as-received basis) of Croweburg coal:

Moisture	6.72%
Ash	5.26%
Volatile Matter	32.35% [36.75% dmmf]
Fixed Carbon	55.67% [63.25% dmmf]
B.T.U./LB	12,957 [13,747 moist, mmf; hvBb]
Sulfur	0.37%

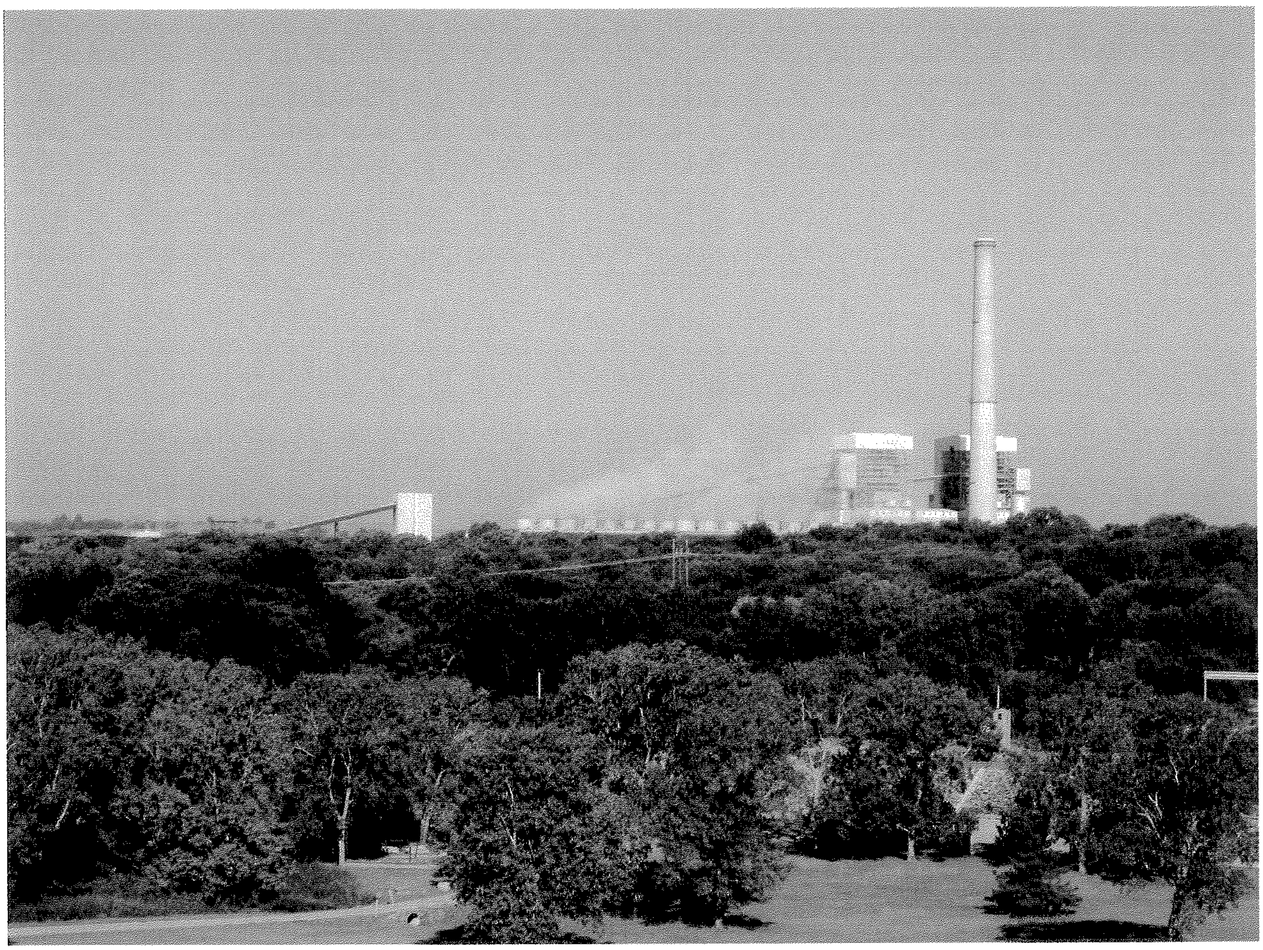
The Kelley mine opened in July 2003. Year 2005 production was 302,499 short tons (18.5% of Oklahoma coal production; total Oklahoma coal production in 2005 was 1,638,210 short tons from 9 mines). Cumulative coal production from the Kelley mine through June 2006 is 830,439 short tons.



Stop 3. Overlook and lunch stop at Oologah Lake

Location: NW¼ NW¼ SW¼ NE¼ Sec. 2, T.22N., R.15E., Rogers County, Oklahoma, north side of state highway 88. Oologah 7.5 minute quadrangle.

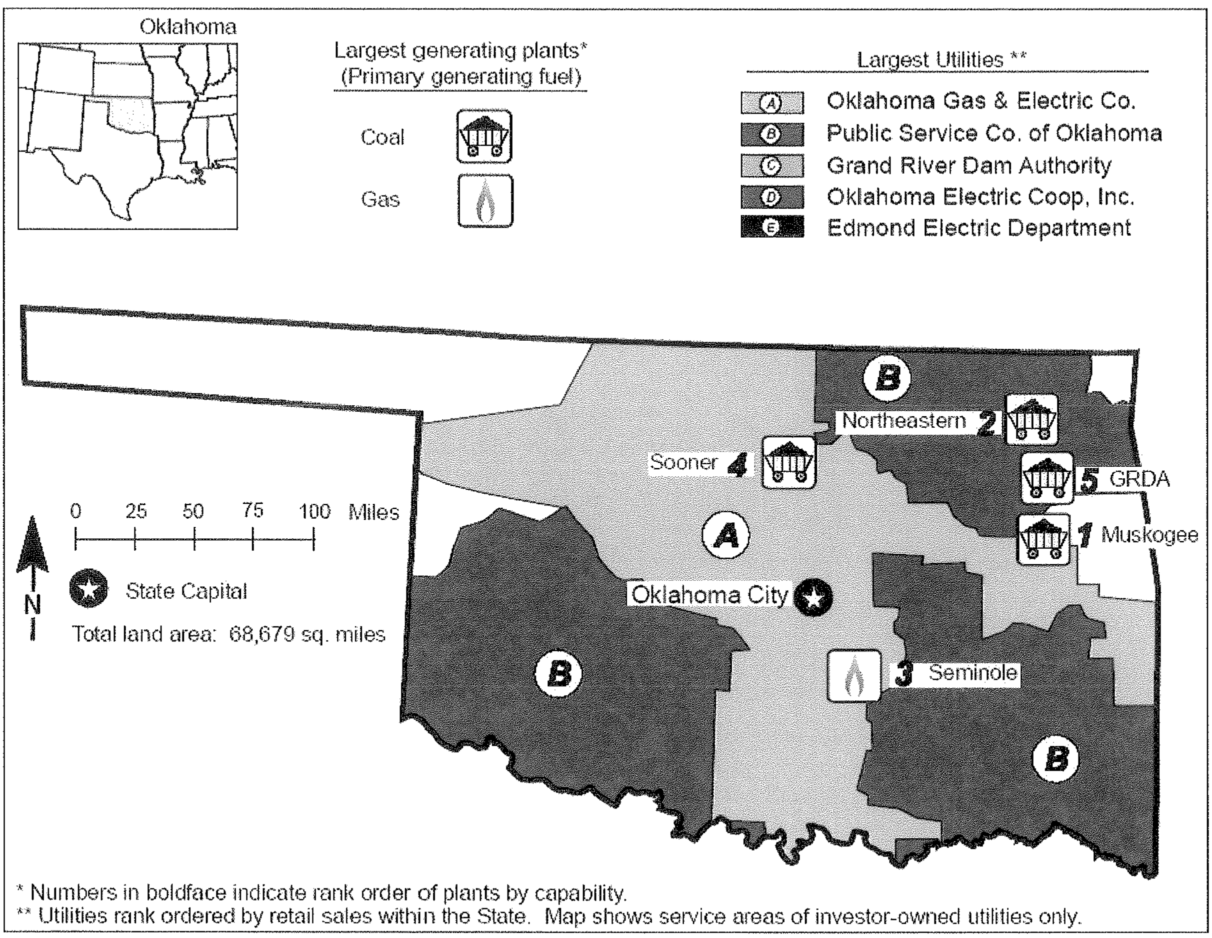
Introduction: The overlook at the south end of Oologah Lake (**Map 2**) provides a scenic view of the Oologah Dam and the Public Service Company of Oklahoma (PSO) Northeastern coal-fired utility electric power plant at Oologah (1.5 miles to the northwest). PSO is a subsidiary of American Electric Power Company, Inc.



PSO generates, purchases, markets, transmits and distributes electric power to approximately 500,000 retail customers in eastern and southwestern Oklahoma. In addition, it supplies electric power at wholesale to other utilities, municipalities and rural electric cooperatives.
(http://www.business.com/directory/energy_and_environment/electric_power_utilities/public_service_company_of_oklahoma/)

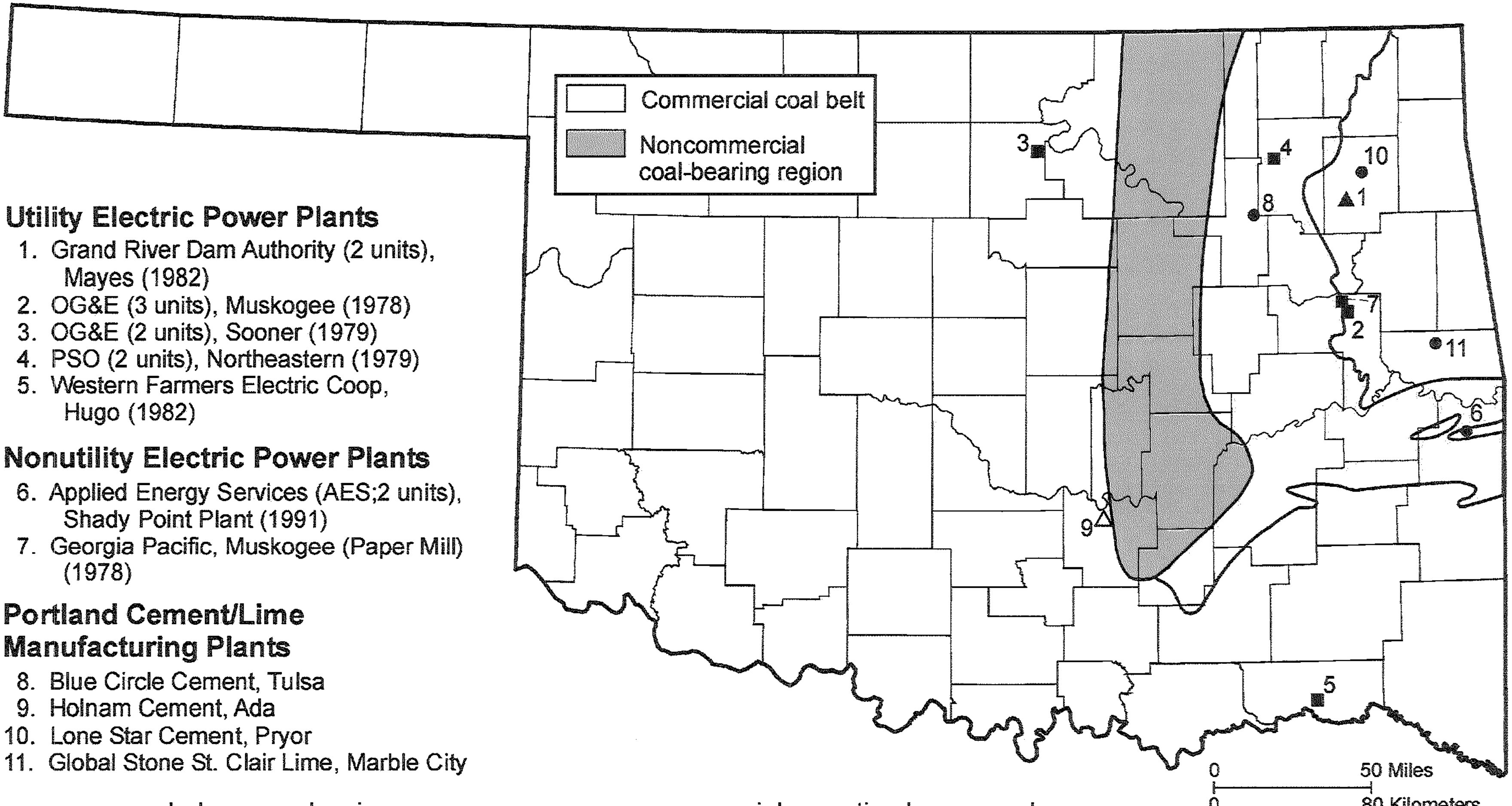
PSO Northeastern plant (Oologah) went online in 1961. Units 1 and 2 use natural gas as the primary energy source. Coal-fired units 3 and 4 were operational in 1979 and 1980 (EIA, 2002). Electric capacity from the coal units is 900 megawatts (MW) (441 MW from each unit). Net capability of the plant is 1,549 MW (EIA, 2006a). The plant consumes about 3.7 million tons of low-sulfur (0.27%) subbituminous coal per year. The plant stockpiles a 45-day supply of coal (about 550,000 short tons)(Hemish, 1999). The coal, which has 8,790 BTUs/LB, comes by unit train from Wyoming. A unit train consists of about 115 railroad cars and delivers about 12,000 tons of coal (each car has a capacity of about 100 tons).

Coal-fired power plants generated 56% of electricity in Oklahoma in 2004 (down from 68% in 1997)(EIA, 2006a).



Five coal-fired, public-utility electric power plants were placed on-line from 1978 to 1982 (see map on next page; Boyd and Cardott, 2001). In order to comply with strict sulfur emission requirements, Oklahoma became a net importer of coal in 1980 (importing 6.0 million short tons of coal; Späth and others, 1998, table 3.1). Oklahoma imported 19.4 million short tons of subbituminous coal from Wyoming to five utility electric power plants in 2004 (EIA, 2006b).

Coal Consumers in Oklahoma



Utility Electric Power Plants

1. Grand River Dam Authority (2 units), Mayes (1982)
2. OG&E (3 units), Muskogee (1978)
3. OG&E (2 units), Sooner (1979)
4. PSO (2 units), Northeastern (1979)
5. Western Farmers Electric Coop, Hugo (1982)

Nonutility Electric Power Plants

6. Applied Energy Services (AES;2 units), Shady Point Plant (1991)
7. Georgia Pacific, Muskogee (Paper Mill) (1978)

Portland Cement/Lime Manufacturing Plants

8. Blue Circle Cement, Tulsa
9. Holnam Cement, Ada
10. Lone Star Cement, Pryor
11. Global Stone St. Clair Lime, Marble City

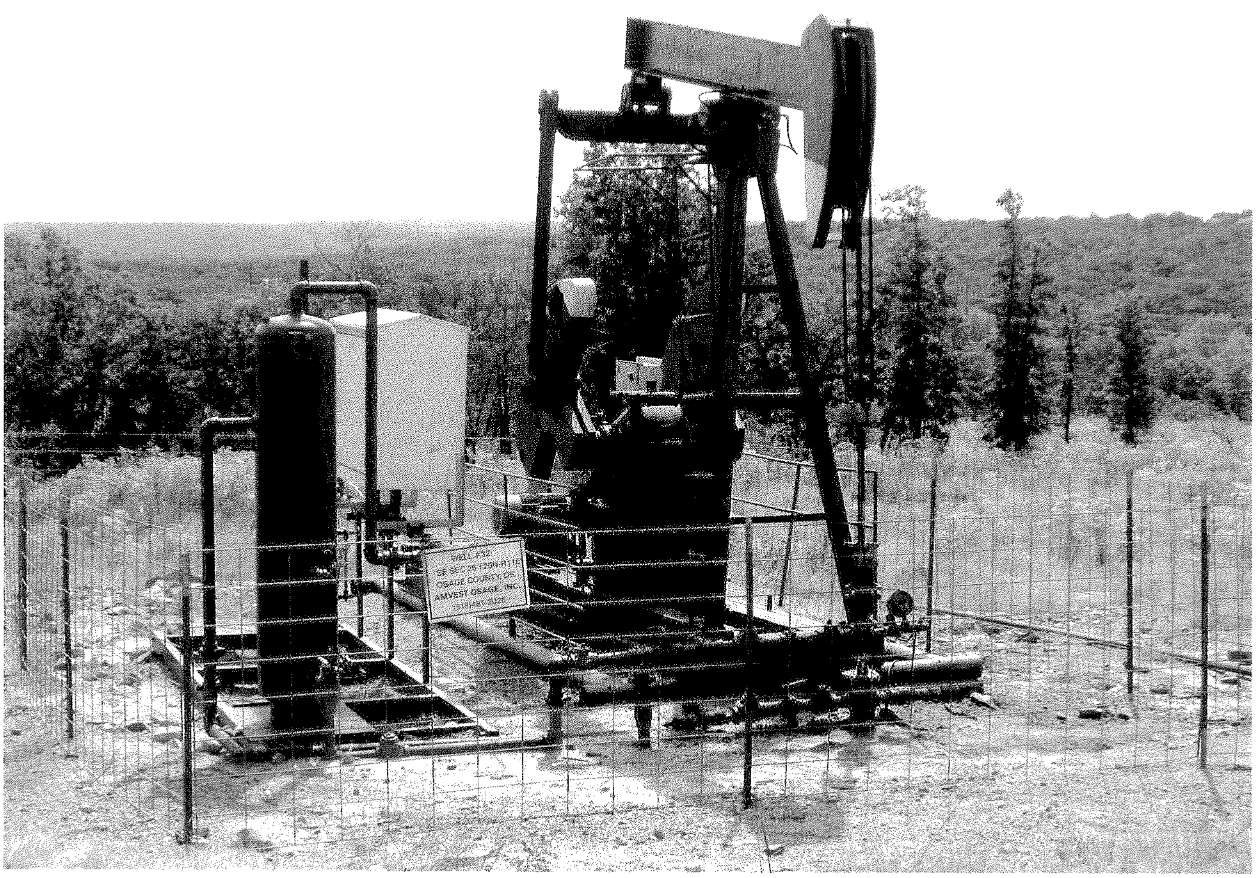
Index map showing company name, year commercial operation began, and location of major consumers in Oklahoma of Wyoming coal (■), Oklahoma coal (●), Wyoming/Oklahoma coal blend (▲), and coal source from other states (△).

Stop 4. Producing CBM well and Salt Water Disposal Well

Location: SE¼ NE¼ SE¼ Sec. 26, T.20N., R.11E., Osage County, Oklahoma.
Sand Springs 7.5 minute quadrangle.

Introduction: This site contains both the Amvest Osage, Inc. No. 32 Osage CBM well and the Amvest Osage, Inc. No. 101 Salt Water Disposal (SWD) well in the Sand Springs production area of southern Osage County, Oklahoma.

Amvest No. 32 Osage CBM well (API 35-113-41300)
Located 1,575 ft FSL and 600 ft FEL of SE¼, Section 26, T.20N., R.11E.
Latitude 36.177219; Longitude -96.093151
Completed May 5, 2001 with Initial Potential Gas Rate of 152 MCFD.
Rig: Thornton Drilling.
Surface Casing: 11in. hole, 7 in. at 323 ft – cemented to surface
Production Casing: 6 ¼ in. hole, 4 ½ in. at 2,122 ft – cemented to surface
Fracture Stimulated in 3 Stages – used a total of 27,000 pounds of sand
Rowe (1,950 ft)
Bluejacket coal (1,750 ft); Weir-Pittsburg and Tebo coals (1,650 ft)
Mineral coal (1,500 ft)
Date of First Production: June 21, 2002; Current Production: 45 MCFD & 15 BWPD
Cumulative Production: 256 MMCF.

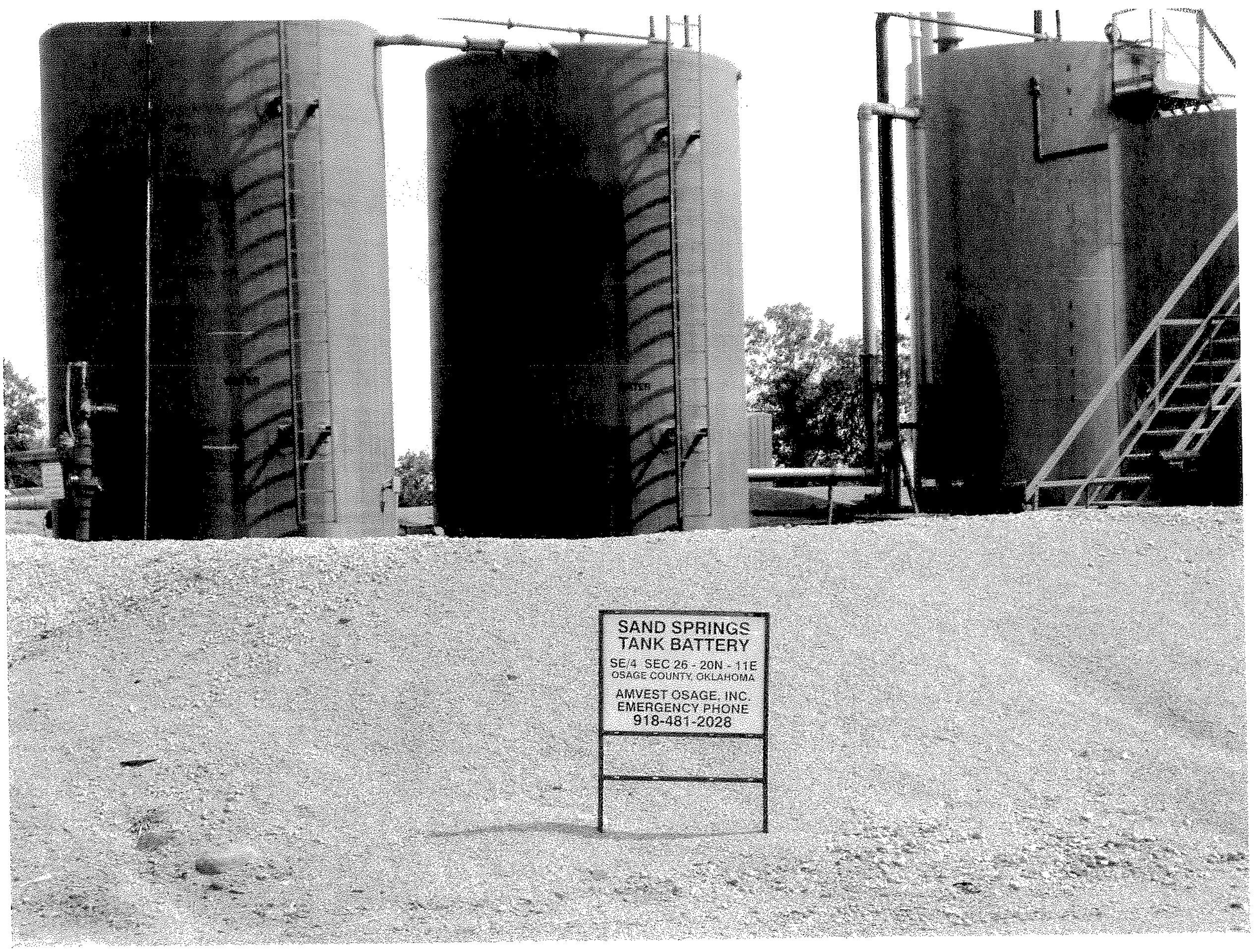


Amvest No. 32 Osage well

Amvest No. 101 Salt Water Disposal well
Located 1,925 ft FSL and 1,907 ft FWL of SE¼, Section 26, T.20N., R.11E.
Spud: June 15, 2001 Rig: Thornton Drilling

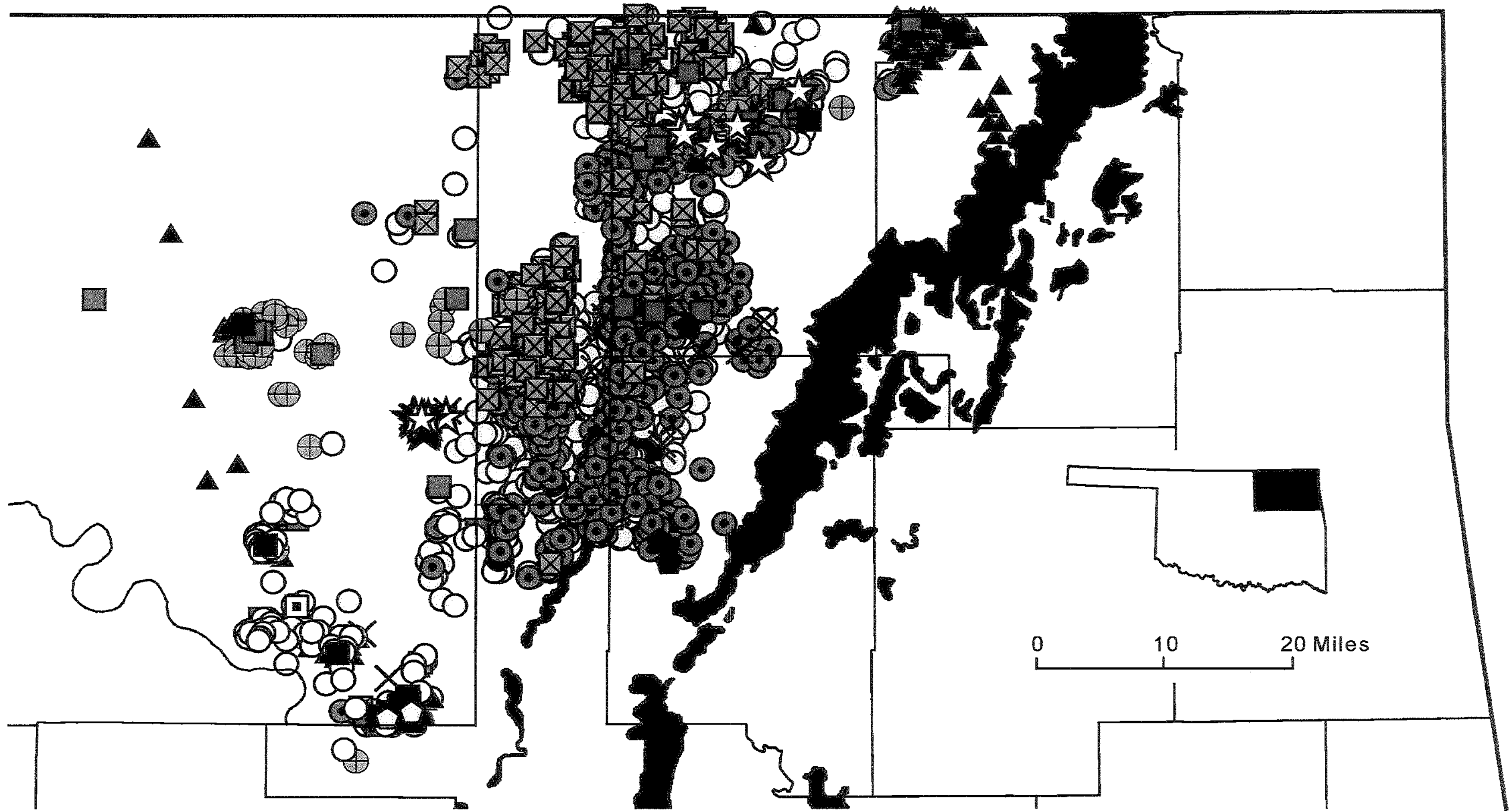
Surface Casing: 11 in. hole, 8 5/8 in. casing at 719 ft – cemented to surface
Long String: 7 7/8 in. hole to 2,950 ft, 5 ½ in. casing at 2,568 ft – cemented to surface

Completed with 3 ½ in. tubing and packer at 2,568 ft, after acidizing open hole interval with acid using a coiled tubing unit. Injecting into Arbuckle in the open hole interval, 2,568–2,950 ft (1,200–2,000 BWPD).



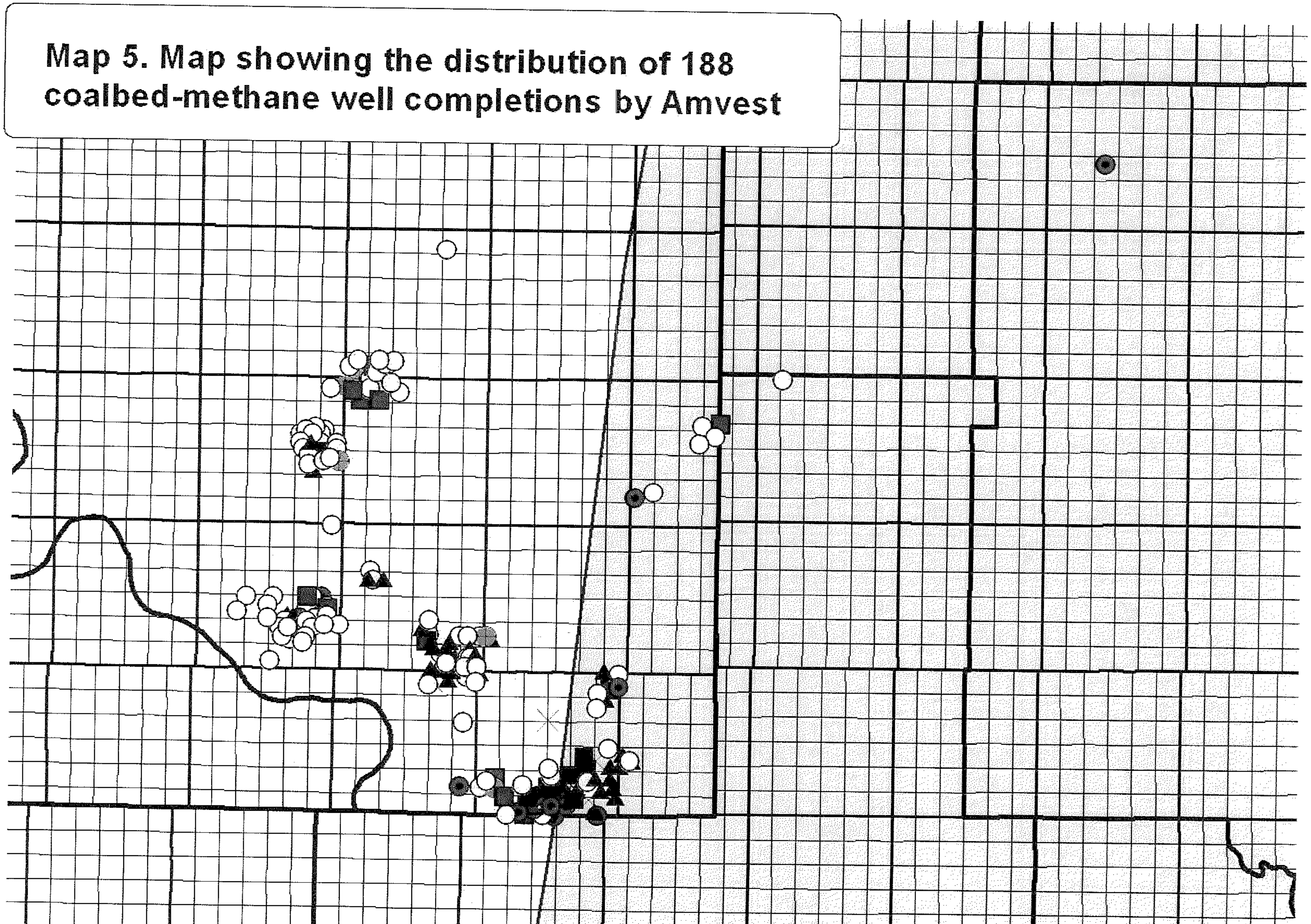
Amvest Osage, Inc. Sand Springs Tank Battery.

Amvest No. 101 Salt Water Disposal well.



Map 4. Map showing the distribution of coalbed-methane well completions and outcrop/subcrop of coal beds in a portion of the northeast Oklahoma shelf (modified from Friedman and Woods, 1982, plate 1).

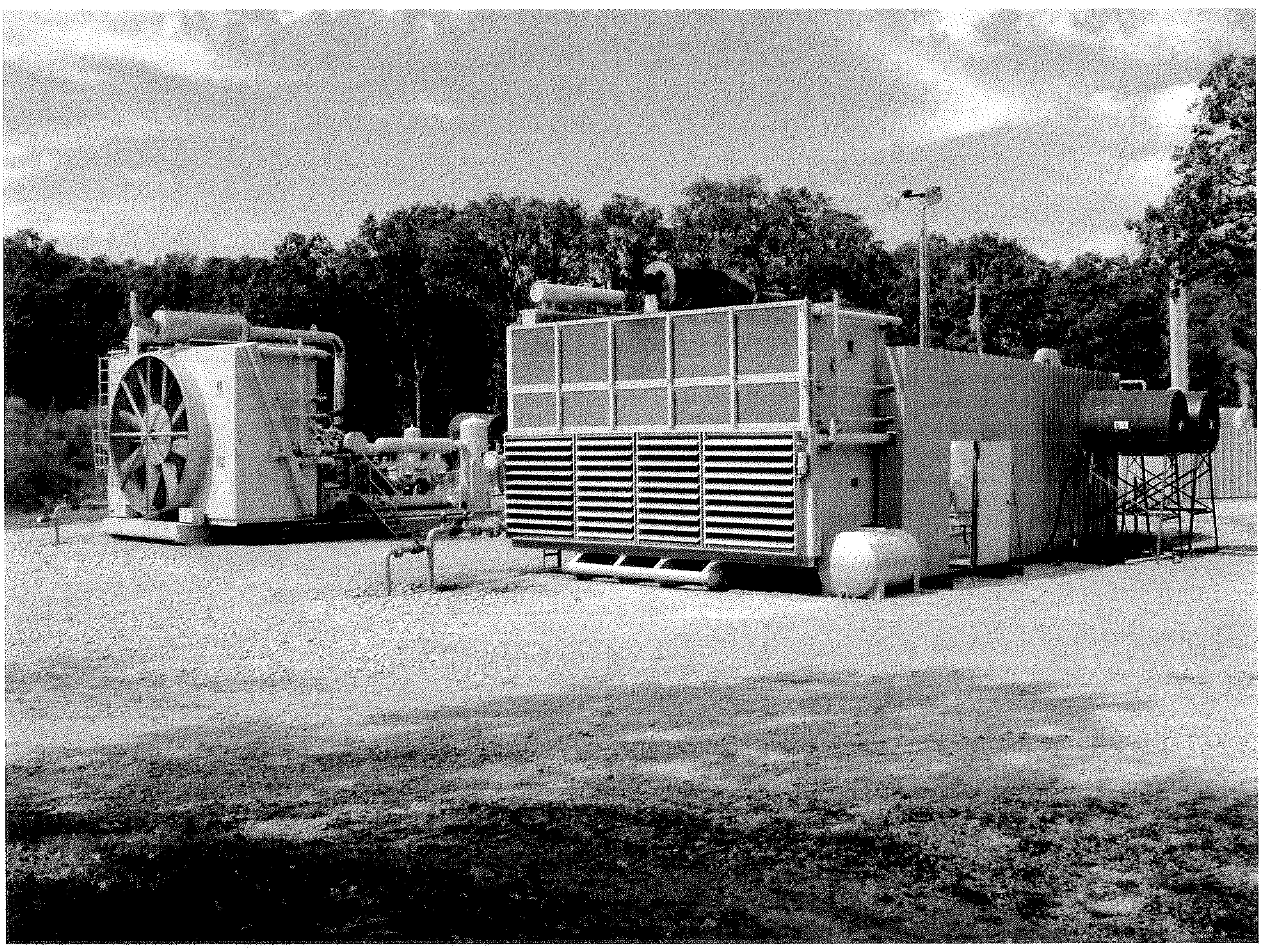
Map 5. Map showing the distribution of 188 coalbed-methane well completions by Amvest



Stop 5. Amvest Osage, Inc. Gilcrease Compressor Station

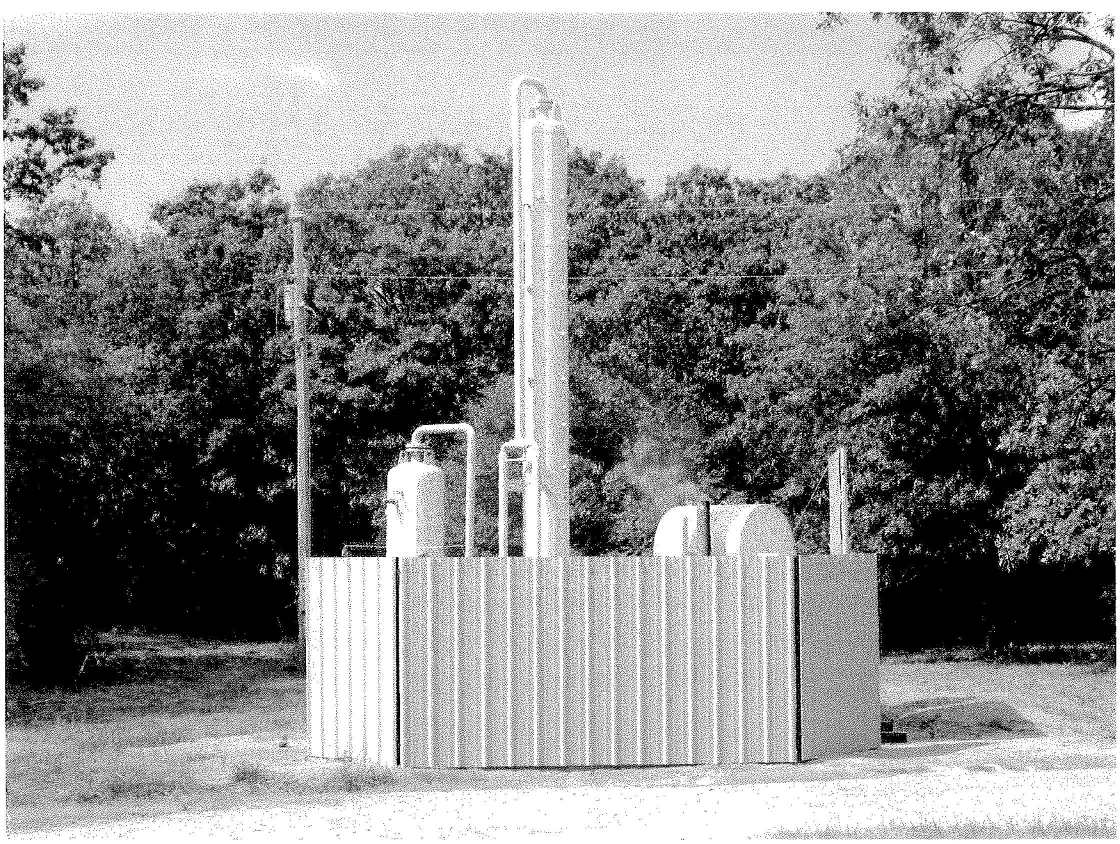
Location: Sec. 26, T.20N., R.11E., Osage County, Oklahoma.
Sand Springs 7.5 minute quadrangle.

Introduction: The Amvest Osage, Inc. Gilcrease Compressor Station was commissioned in January 2003. Three compressors total 3,625 HP: two units are 1,340 HP, one unit is 945 HP.
Current Sales: 10,500 to 11,000 MCFD (capacity of 13,000 MCFD)



Compressors used in 2004: 800 Brake Horse Power (BHP) compressor (on left) and 450 BHP compressor are leased from Hanover.

Inlet scrubber (on right) and inlet gas meter.



Dehydrator (removes moisture from gas prior to sales point)

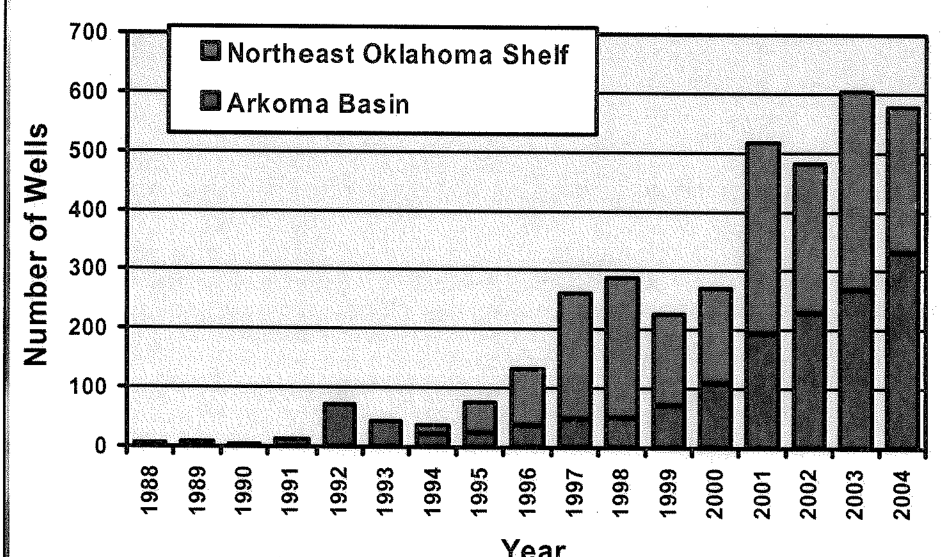
Oklahoma Coalbed-Methane Activity, 2006 Update

Brian J. Cardott

Oklahoma Geological Survey

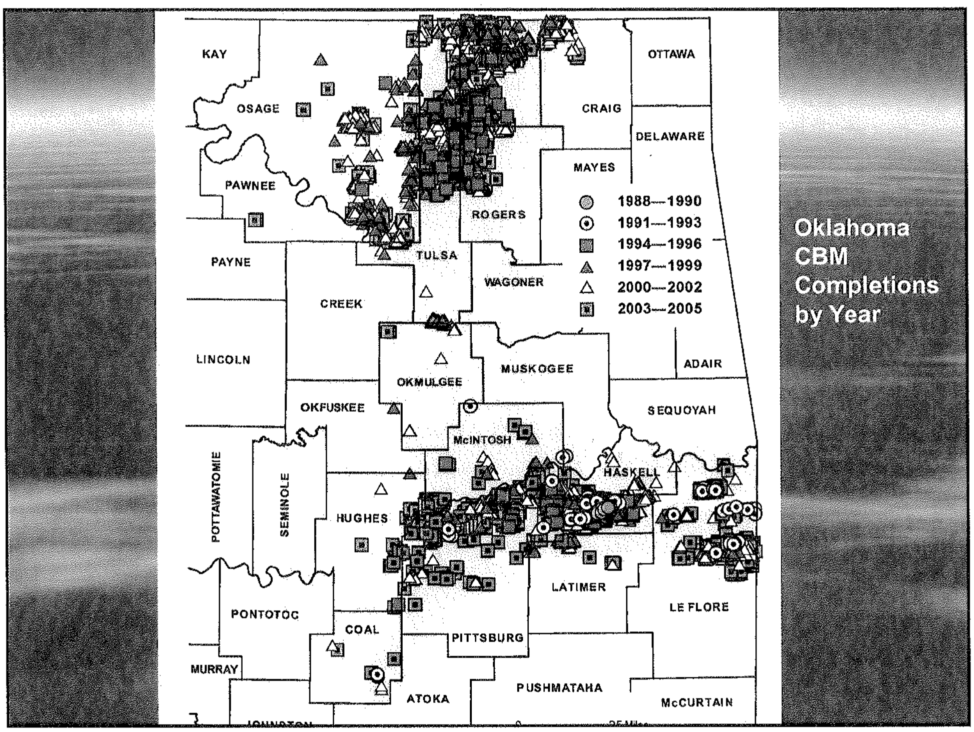
Presented at OGS conference on "Coalbed Methane and Gas Shales in the Southern Midcontinent" in Oklahoma City on March 21, 2006

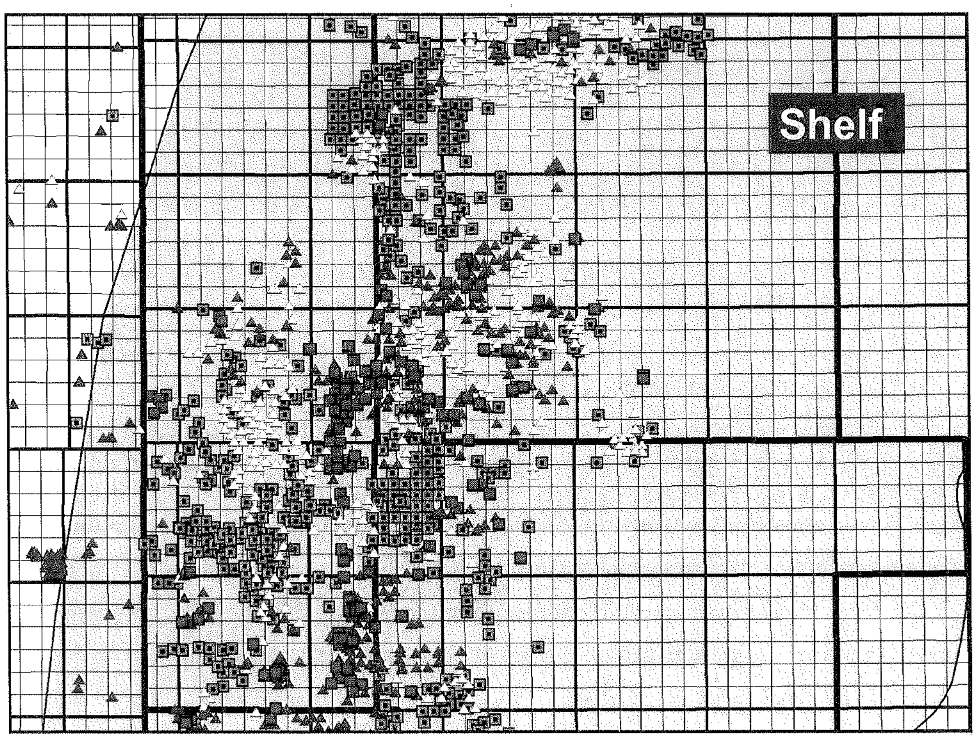
CBM Well Completions in Oklahoma

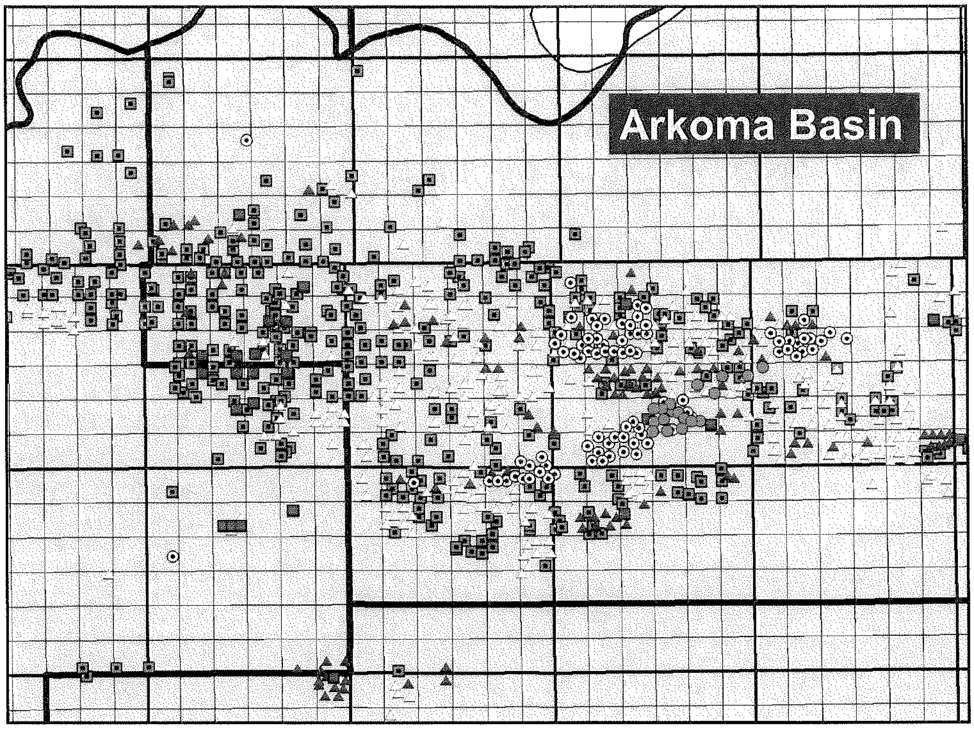


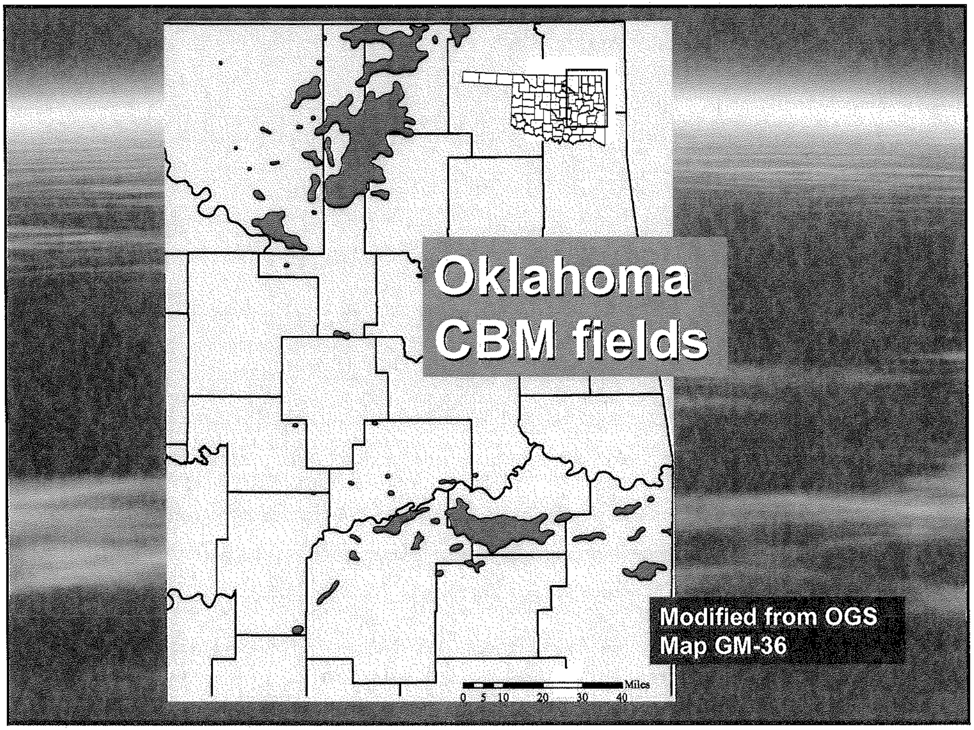
3,621 CBM Completions 1988-2004

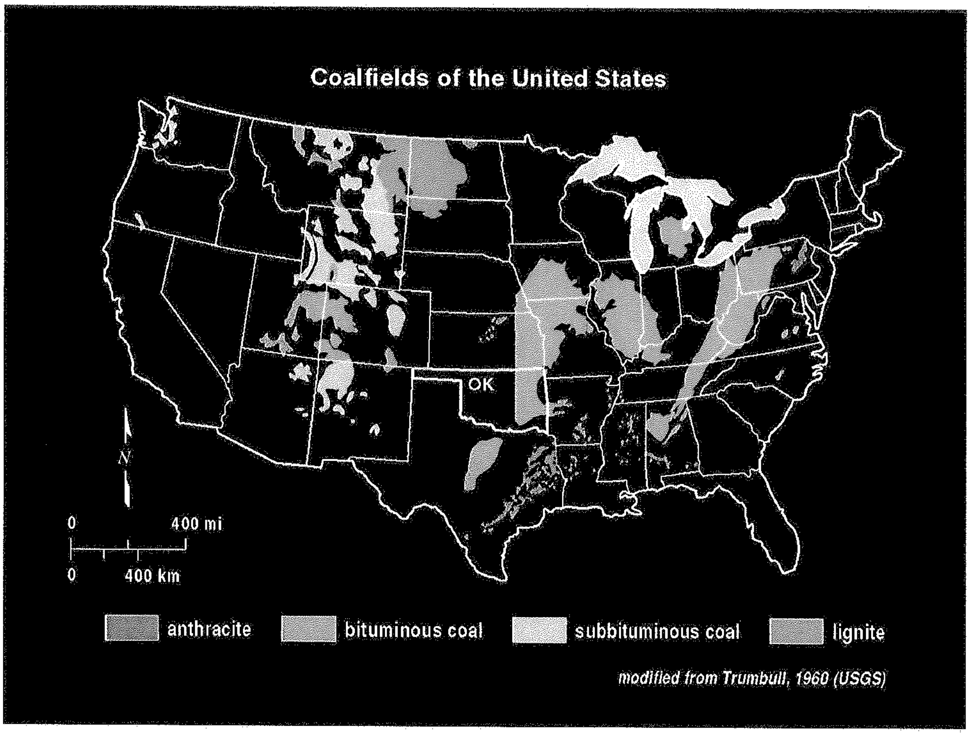
578 wells in 2004

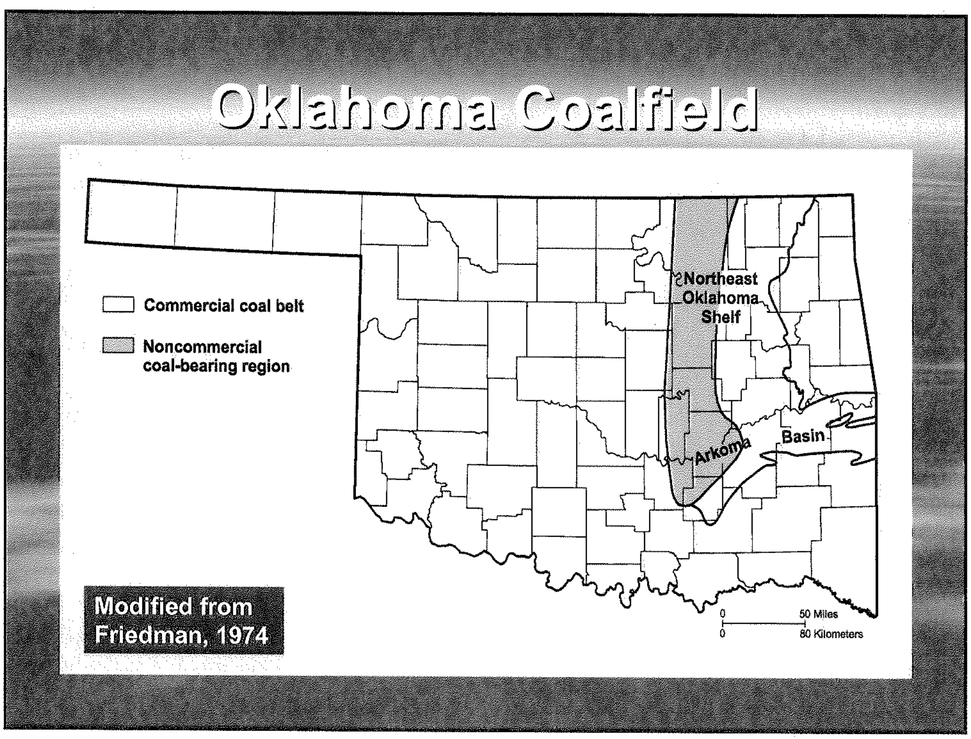

Oklahoma CBM Completions by Year
1988—1990
1991—1993
1994—1996
1997—1999
2000—2002
2003—2005
KAY
OSAGE
OTTAWA
CRAIG
DELAWARE
MAYES
PAWNEE
ROGERS
PAYNE
TULSA
WAGONER
CREEK
LINCOLN
OKMULGEE
MUSKOGEE
ADAIR
OKFUSKEE
SEQUOYAH
McINTOSH
HASKELL
POTTAWATOMIE
SEMINOLE
HUGHES
LATIMER
LE FLORE
PONTOTOC
COAL
PITTSBURG
MURRAY
PUSHMATAHA
ATOKA
McCURTAIN

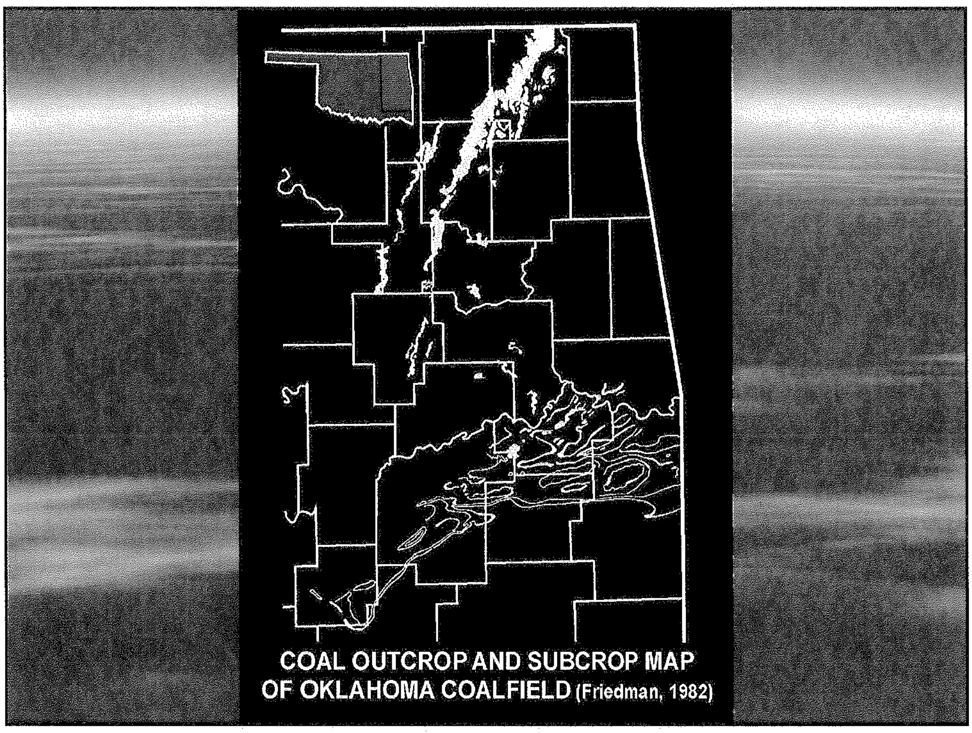

Shelf

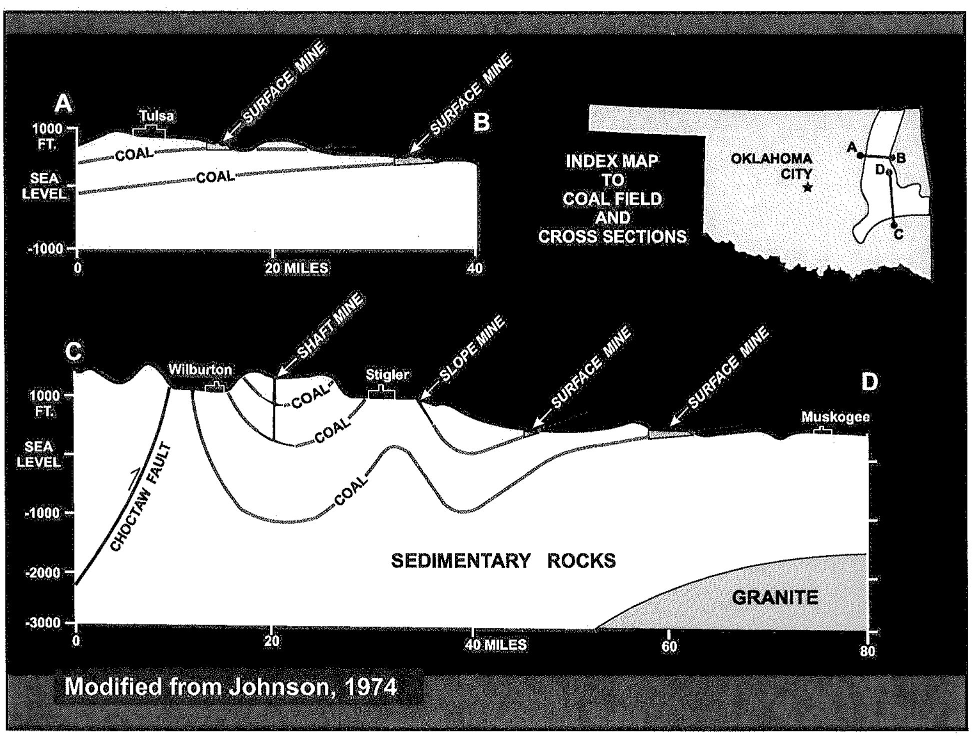

Arkoma Basin

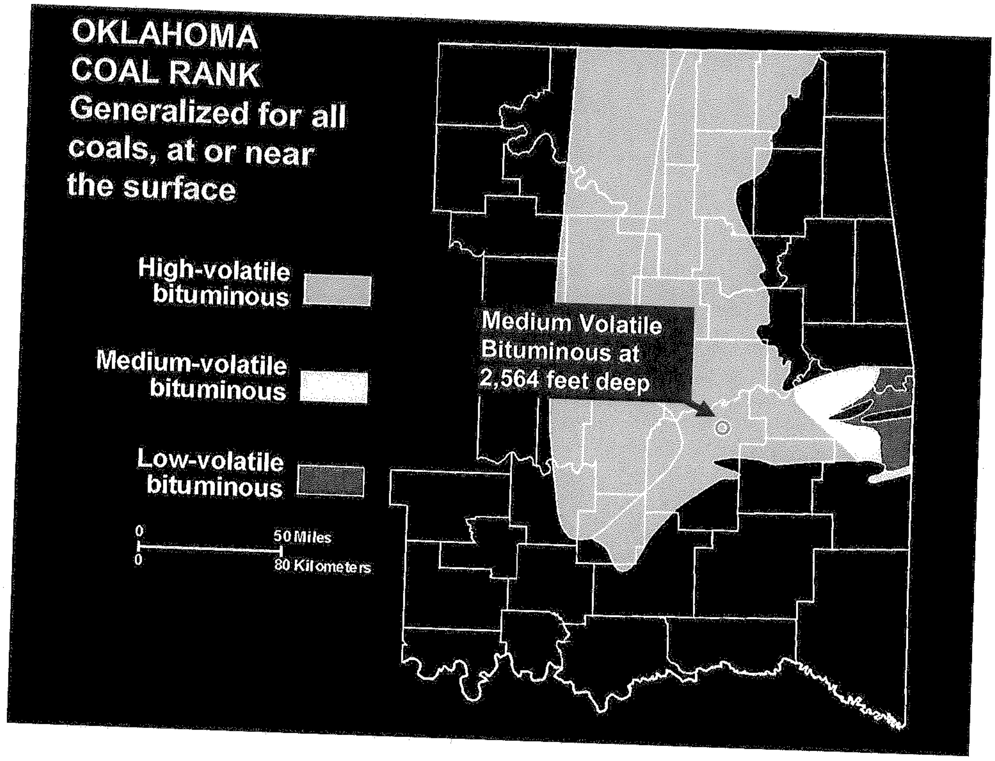

Oklahoma
CBM fields
Modified from OGS
Map GM-36
Miles
0 5 10 20 30 40

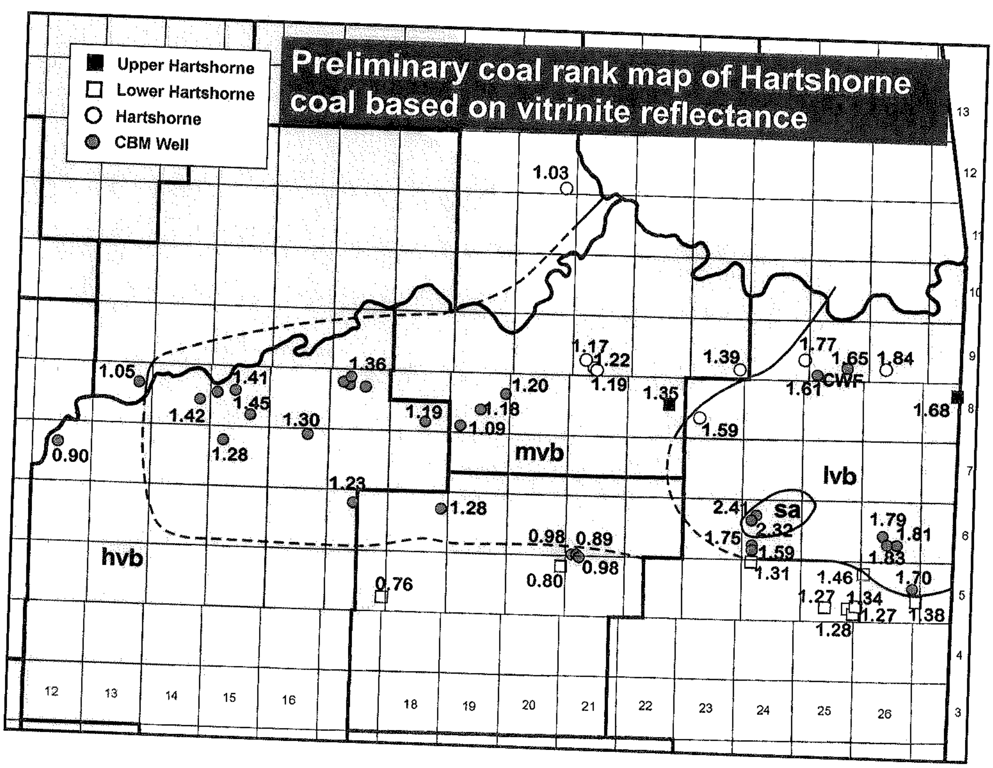

Coalfields of the United States
OK
N
0
400 mi
0
400 km
anthracite
bituminous coal
subbituminous coal
lignite
modified from Trumbull, 1960 (USGS)

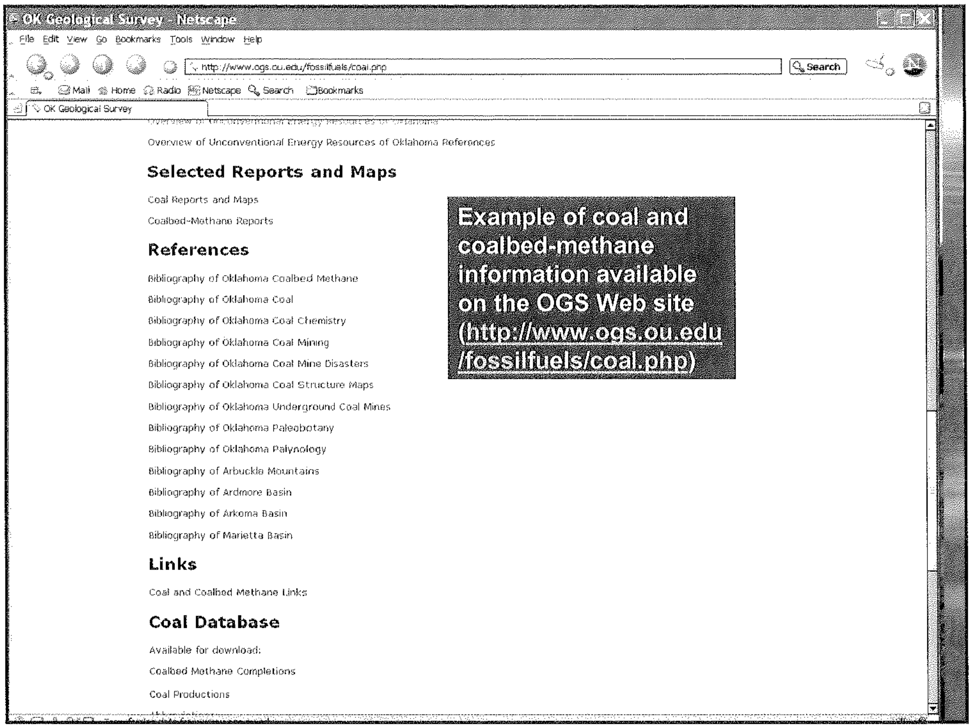

Oklahoma Coalfield
Commercial coal belt
Noncommercial coal-bearing region
Northeast Oklahoma Shelf
Arkoma
Basin
0
50 Miles
0
80 Kilometers
Modified from Friedman, 1974

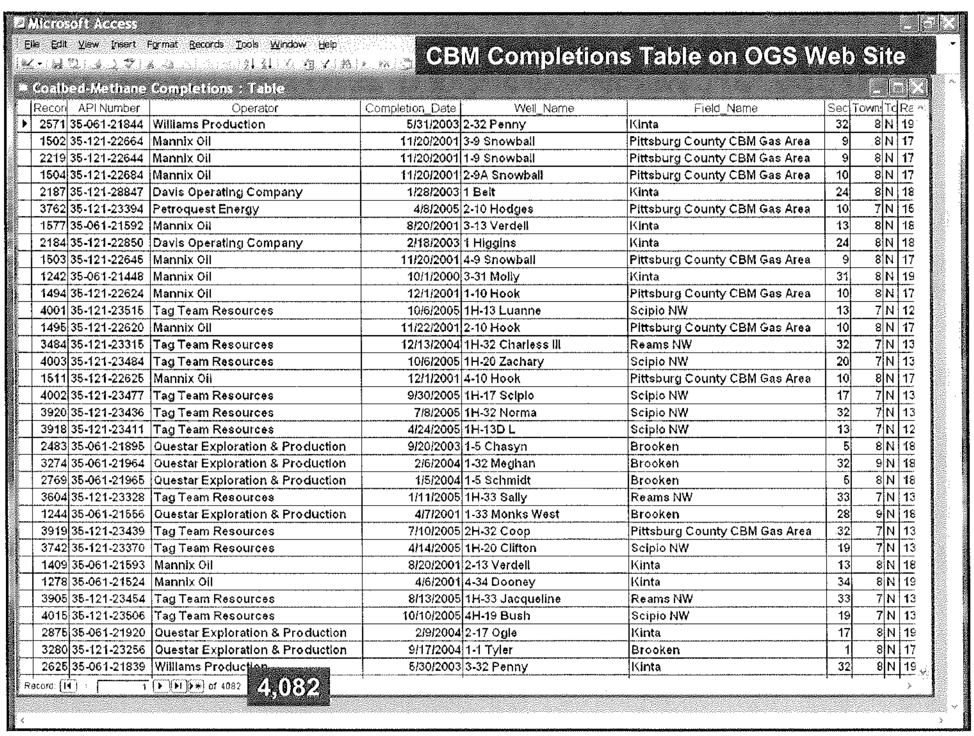

COAL OUTCROP AND SUBCROP MAP
OF OKLAHOMA COALFIELD (Friedman, 1982)


A
B
Tulsa
SURFACE MINE
SURFACE MINE
COAL
COAL
1000 FT.
SEA LEVEL
-1000
0
20 MILES
40
INDEX MAP TO COAL FIELD AND CROSS SECTIONS
OKLAHOMA CITY
A
B
D
C
C
D
Wilburton
SHAFT MINE
Stigler
SLOPE MINE
SURFACE MINE
SURFACE MINE
Muskogee
COAL
COAL
COAL
CHOCTAW FAULT
-2000
-3000
SEDIMENTARY ROCKS
GRANITE
20
40 MILES
60
80
Modified from Johnson, 1974

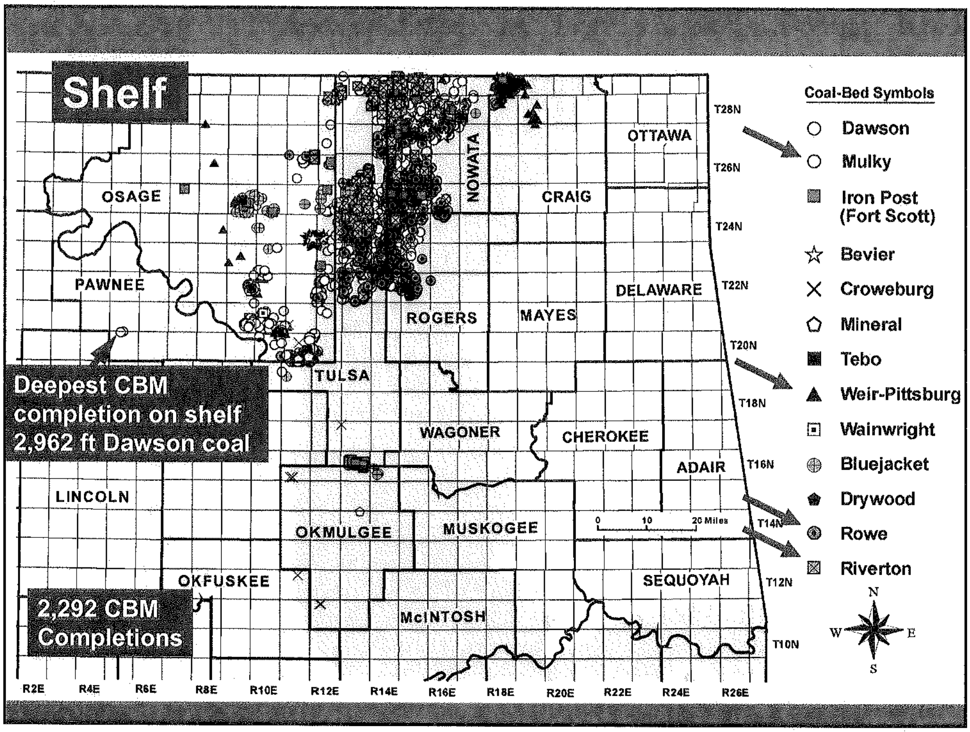

OKLAHOMA
COAL RANK
Generalized for all coals, at or near the surface
High-volatile bituminous
Medium-volatile bituminous
Low-volatile bituminous
0 50 Miles
0 80 Kilometers
Medium Volatile Bituminous at 2,564 feet deep

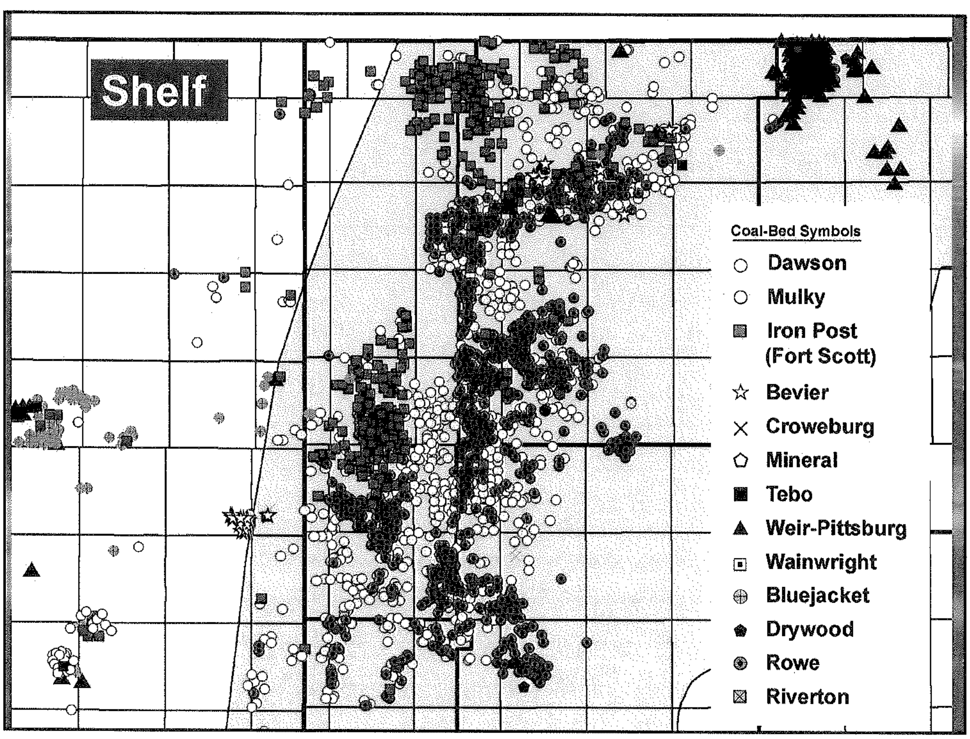

Upper Hartshorne
Lower Hartshorne
Hartshorne
CBM Well
Preliminary coal rank map of Hartshorne coal based on vitrinite reflectance
hvb
mvb
lvb
sa

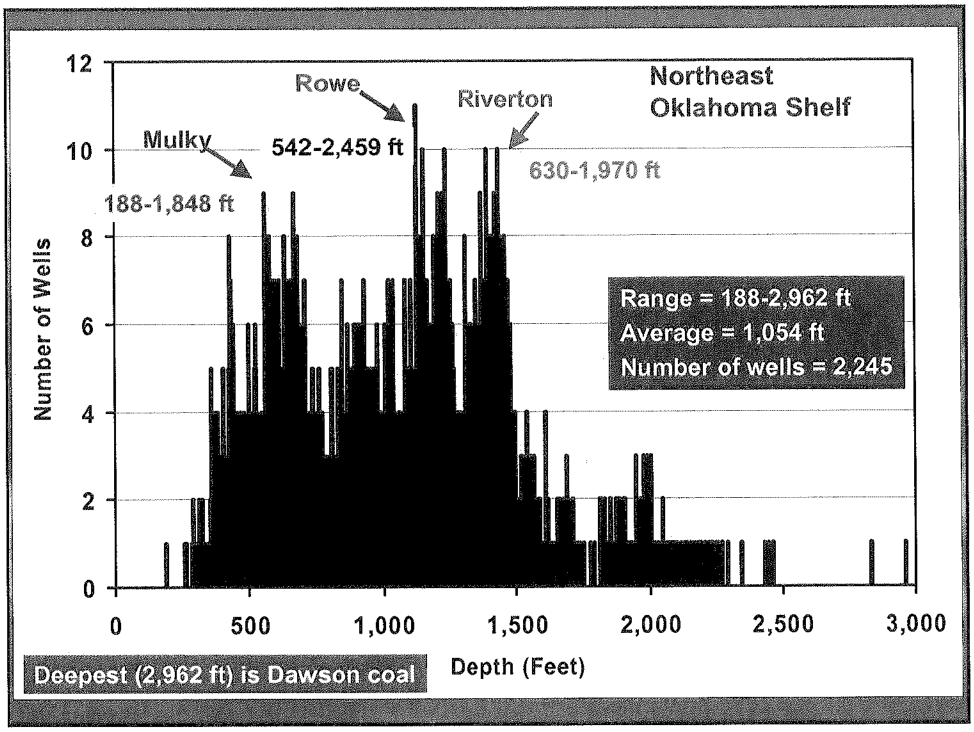


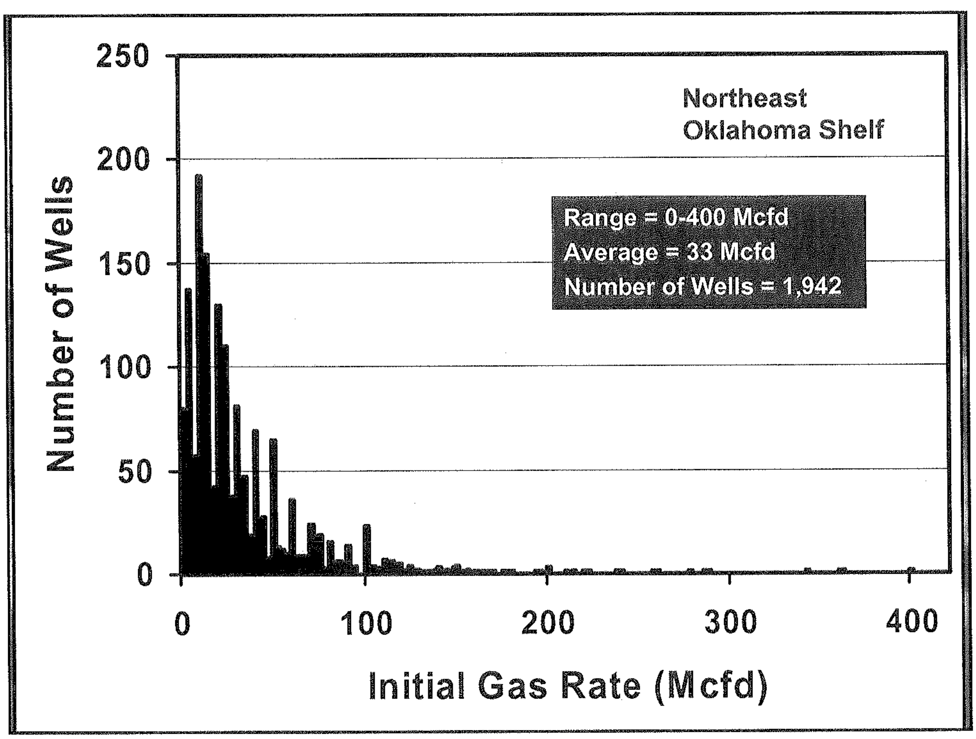


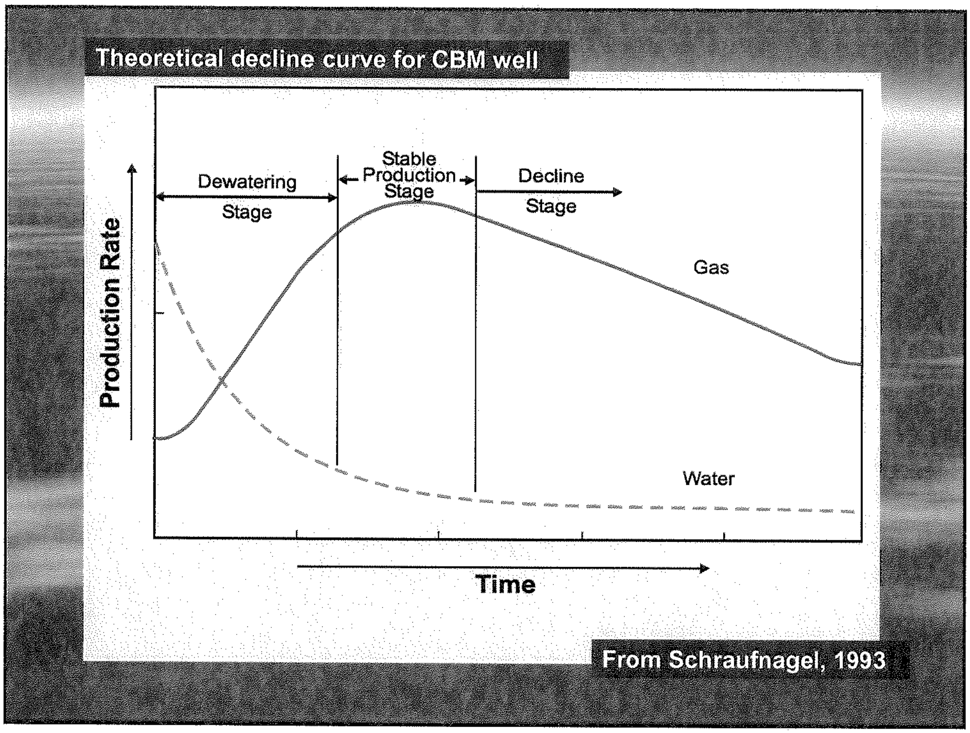
Recor	API Number	Operator	Completion_Date	Well_Name	Field_Name	Sec	Town	To
2571	35-061-21844	Williams Production	5/31/2003	2-32 Penny	Kinta	32	8	N
1502	35-121-22664	Mannix Oil	11/20/2001	3-9 Snowball	Pittsburg County CBM Gas Area	9	8	N
2219	35-121-22644	Mannix Oil	11/20/2001	1-9 Snowball	Pittsburg County CBM Gas Area	9	8	N
1504	35-121-22684	Mannix Oil	11/20/2001	2-9A Snowball	Pittsburg County CBM Gas Area	10	8	N
2187	35-121-28847	Davis Operating Company	1/28/2003	1 Belt	Kinta	24	8	N
3762	35-121-23394	Petroquest Energy	4/8/2005	2-10 Hodges	Pittsburg County CBM Gas Area	10	7	N
1577	35-061-21592	Mannix Oil	8/20/2001	3-13 Verdell	Kinta	13	8	N
2184	35-121-22850	Davis Operating Company	2/18/2003	1 Higgins	Kinta	24	8	N
1503	35-121-22645	Mannix Oil	11/20/2001	4-9 Snowball	Pittsburg County CBM Gas Area	9	8	N
1242	35-061-21448	Mannix Oil	10/1/2000	3-31 Molly	Kinta	31	8	N
1494	35-121-22624	Mannix Oil	12/1/2001	1-10 Hook	Pittsburg County CBM Gas Area	10	8	N
4001	35-121-23515	Tag Team Resources	10/6/2005	1H-13 Luanne	Scipio NW	13	7	N
1495	35-121-22620	Mannix Oil	11/22/2001	2-10 Hook	Pittsburg County CBM Gas Area	10	8	N
3484	35-121-23315	Tag Team Resources	12/13/2004	1H-32 Charless III	Reams NW	32	7	N
4003	35-121-23484	Tag Team Resources	10/6/2005	1H-20 Zachary	Scipio NW	20	7	N
1511	35-121-22625	Mannix Oil	12/1/2001	4-10 Hook	Pittsburg County CBM Gas Area	10	8	N
4002	35-121-23477	Tag Team Resources	9/30/2005	1H-17 Scipio	Scipio NW	17	7	N
3920	35-121-23436	Tag Team Resources	7/8/2005	1H-32 Norma	Scipio NW	32	7	N
3918	35-121-23411	Tag Team Resources	4/24/2005	1H-13D L	Scipio NW	13	7	N
2483	35-061-21895	Questar Exploration & Production	9/20/2003	1-5 Chasyn	Brooken	5	8	N
3274	35-061-21964	Questar Exploration & Production	2/6/2004	1-32 Meghan	Brooken	32	9	N
2769	35-061-21965	Questar Exploration & Production	1/5/2004	1-5 Schmidt	Brooken	5	8	N
3604	35-121-23328	Tag Team Resources	1/11/2005	1H-33 Sally	Reams NW	33	7	N
1244	35-061-21556	Questar Exploration & Production	4/7/2001	1-33 Monks West	Brooken	28	9	N
3919	35-121-23439	Tag Team Resources	7/10/2005	2H-32 Coop	Pittsburg County CBM Gas Area	32	7	N
3742	35-121-23370	Tag Team Resources	4/14/2005	1H-20 Clifton	Scipio NW	19	7	N
1409	35-061-21593	Mannix Oil	8/20/2001	2-13 Verdell	Kinta	13	8	N
1278	35-061-21524	Mannix Oil	4/6/2001	4-34 Dooney	Kinta	34	8	N
3905	35-121-23454	Tag Team Resources	8/13/2005	1H-33 Jacqueline	Reams NW	33	7	N
4015	35-121-23506	Tag Team Resources	10/10/2005	4H-19 Bush	Scipio NW	19	7	N
2875	35-061-21920	Questar Exploration & Production	2/9/2004	2-17 Ogle	Kinta	17	8	N
3280	35-121-23256	Questar Exploration & Production	9/17/2004	1-1 Tyler	Brooken	1	8	N
2625	35-061-21839	Williams Produc	5/30/2003	3-32 Penny	Kinta	32	8	N

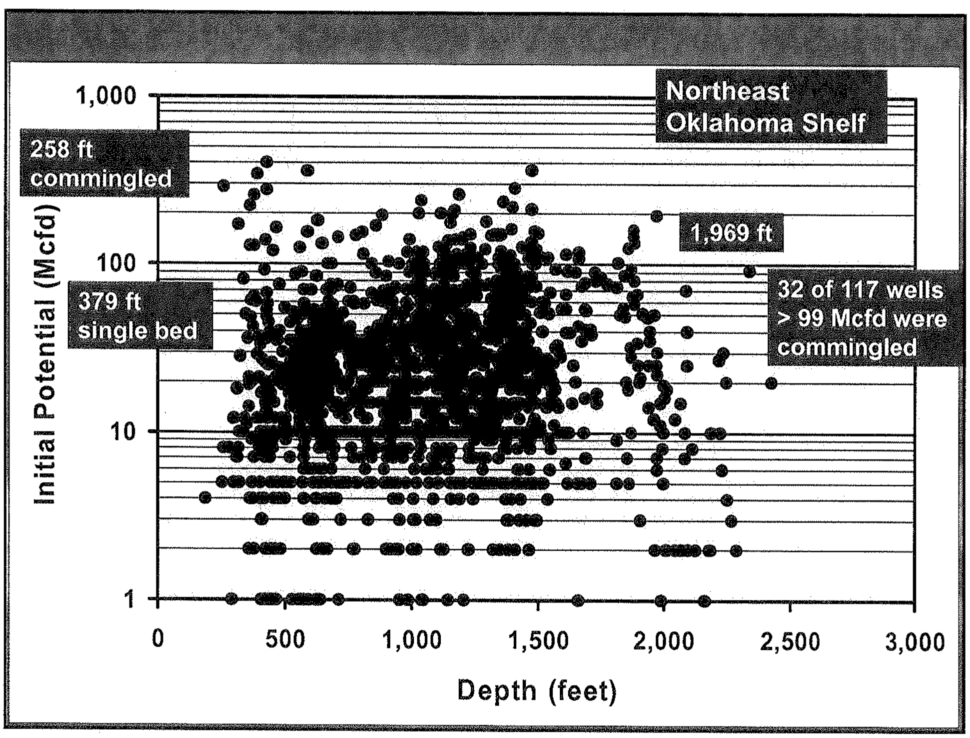

Shelf
OSAGE
PAWNEE
NOWATA
CRAIG
OTTAWA
DELAWARE
ROGERS
MAYES
TULSA
WAGONER
CHEROKEE
ADAIR
LINCOLN
OKMULGEE
MUSKOGEE
OKFUSKEE
McINTOSH
SEQUOYAH
Deepest CBM completion on shelf 2,962 ft Dawson coal
2,292 CBM Completions
T28N
T26N
T24N
T22N
T20N
T18N
T16N
T14N
T12N
T10N
R2E
R4E
R6E
R8E
R10E
R12E
R14E
R16E
R18E
R20E
R22E
R24E
R26E
Coal-Bed Symbols
Dawson
Mulky
Iron Post (Fort Scott)
Bevier
Croweburg
Mineral
Tebo
Weir-Pittsburg
Wainwright
Bluejacket
Drywood
Rowe
Riverton
N
W
E
S

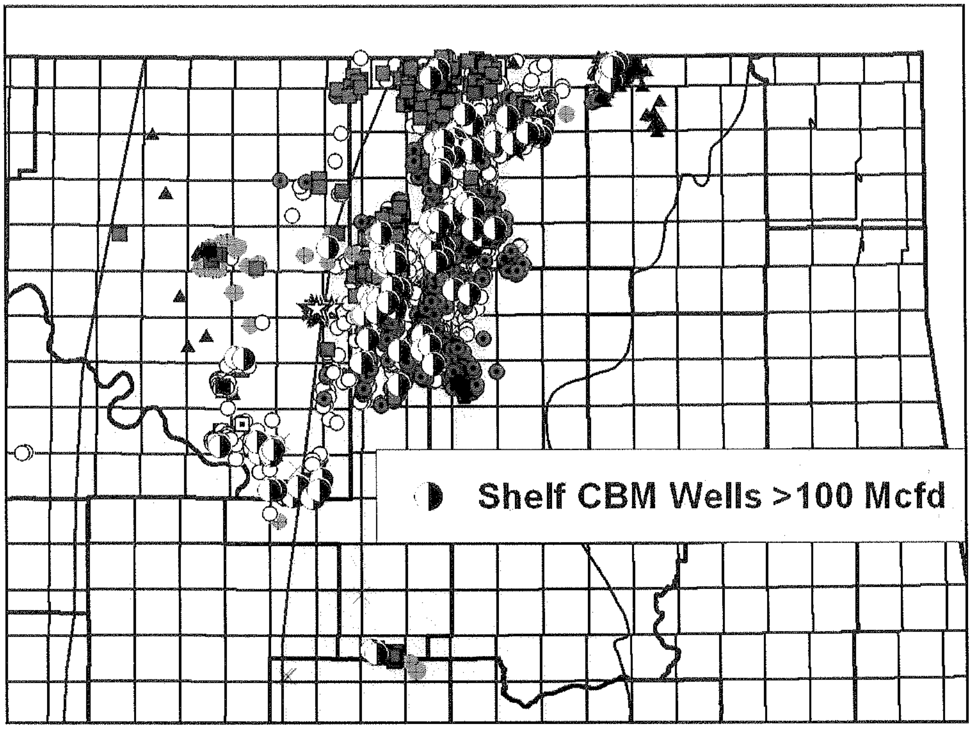

Shelf
Coal-Bed Symbols
Dawson
Mulky
Iron Post (Fort Scott)
Bevier
Croweburg
Mineral
Tebo
Weir-Pittsburg
Wainwright
Bluejacket
Drywood
Rowe
Riverton

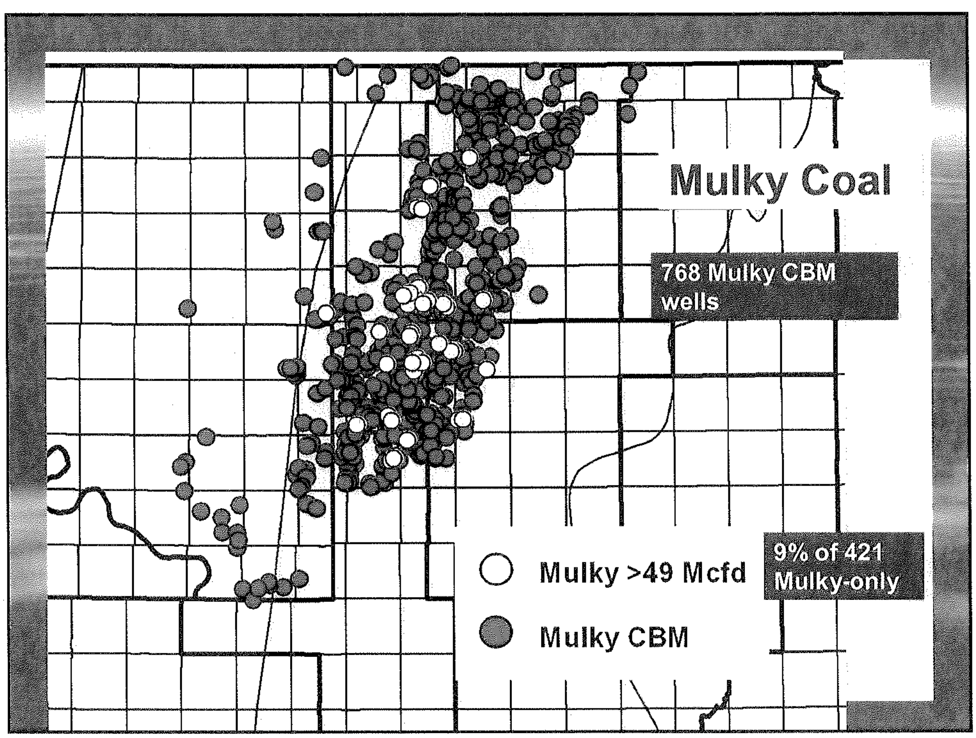

Northeast
Oklahoma Shelf
Rowe
542-2,459 ft
Riverton
630-1,970 ft
Mulky
188-1,848 ft
Range = 188-2,962 ft
Average = 1,054 ft
Number of wells = 2,245
Number of Wells
Depth (Feet)
Deepest (2,962 ft) is Dawson coal

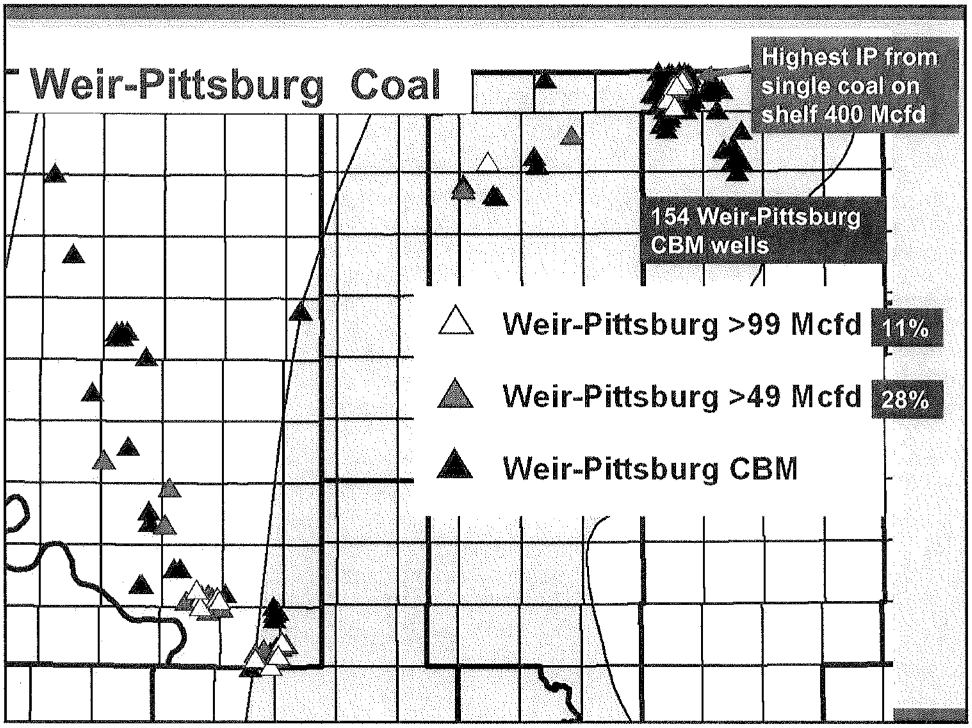

Northeast
Oklahoma Shelf
Range = 0-400 Mcfd
Average = 33 Mcfd
Number of Wells = 1,942
Number of Wells
Initial Gas Rate (Mcfd)

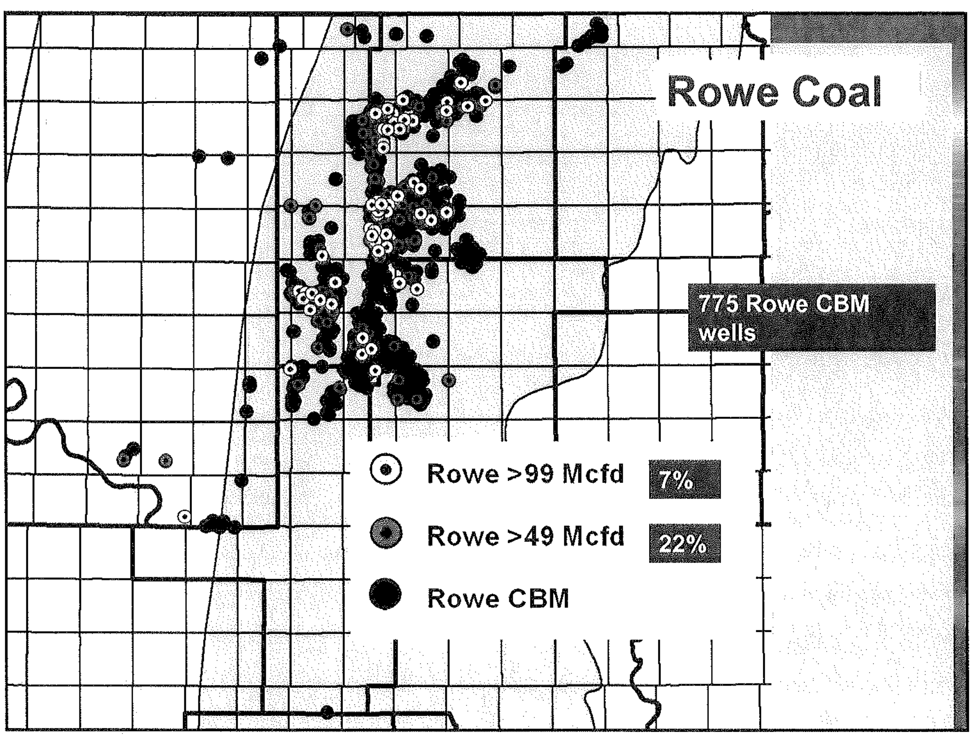

Theoretical decline curve for CBM well
Dewatering Stage
Stable Production Stage
Decline Stage
Production Rate
Gas
Water
Time
From Schraufnagel, 1993

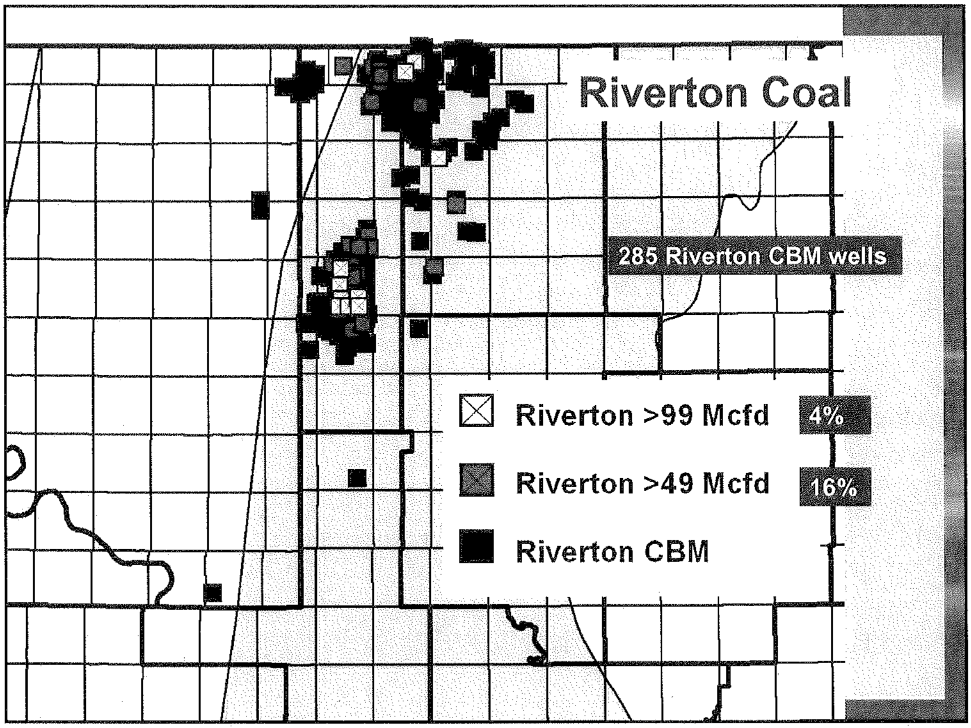

Northeast Oklahoma Shelf
258 ft commingled
379 ft single bed
1,969 ft
32 of 117 wells > 99 Mcfd were commingled
Initial Potential (Mcfd)
1,000
100
10
1
0
500
1,000
1,500
2,000
2,500
3,000
Depth (feet)

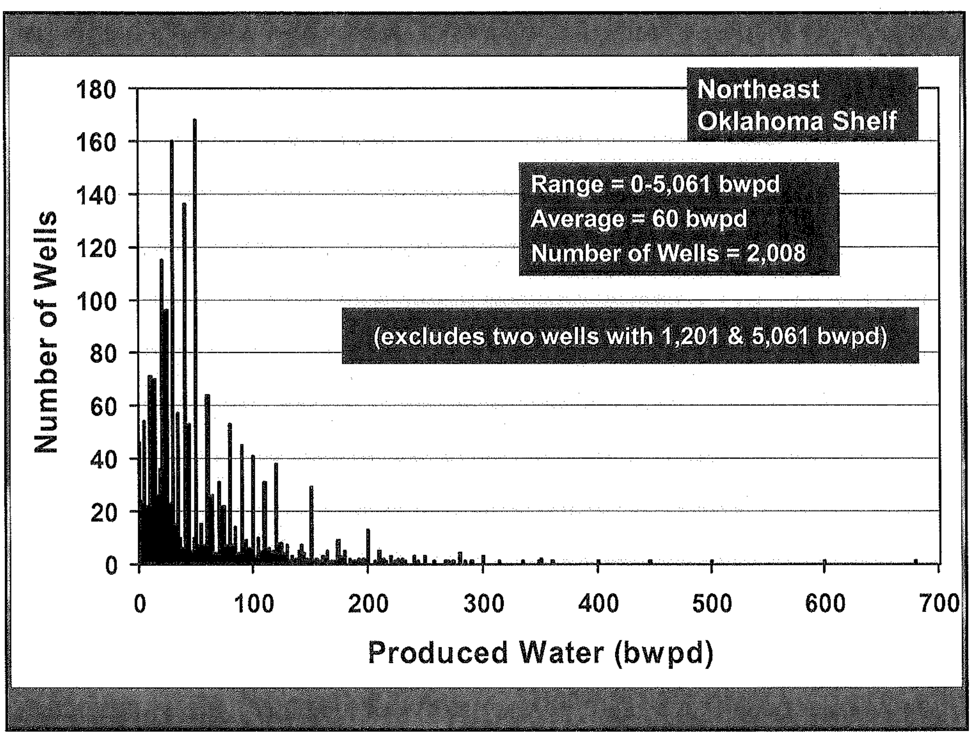

Shelf CBM Wells >100 Mcfd


Mulky Coal
768 Mulky CBM wells
Mulky >49 Mcfd
Mulky CBM
9% of 421 Mulky-only


Weir-Pittsburg Coal
Highest IP from single coal on shelf 400 Mcfd
154 Weir-Pittsburg CBM wells
Weir-Pittsburg >99 Mcfd
11%
Weir-Pittsburg >49 Mcfd
28%
Weir-Pittsburg CBM


Rowe Coal
775 Rowe CBM wells
Rowe >99 Mcfd
7%
Rowe >49 Mcfd
22%
Rowe CBM

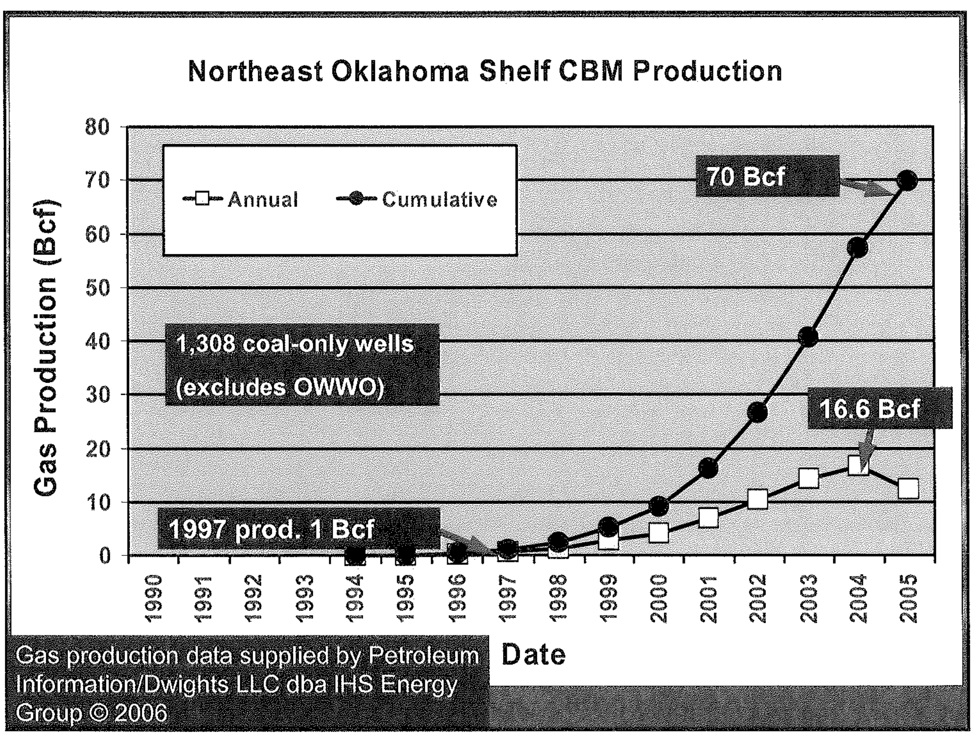

Riverton Coal
285 Riverton CBM wells
Riverton >99 Mcfd
4%
Riverton >49 Mcfd
16%
Riverton CBM

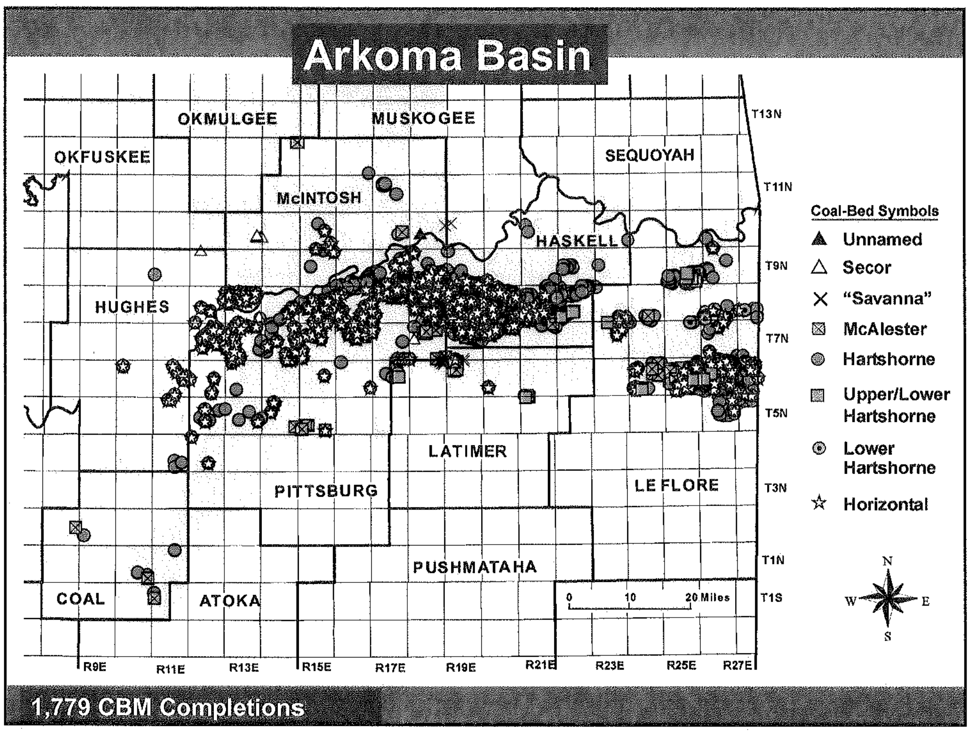

Northeast Oklahoma Shelf
Range = 0-5,061 bwpd
Average = 60 bwpd
Number of Wells = 2,008
(excludes two wells with 1,201 & 5,061 bwpd)
Number of Wells
0
20
40
60
80
100
120
140
160
180
0
100
200
300
400
500
600
700
Produced Water (bwpd)

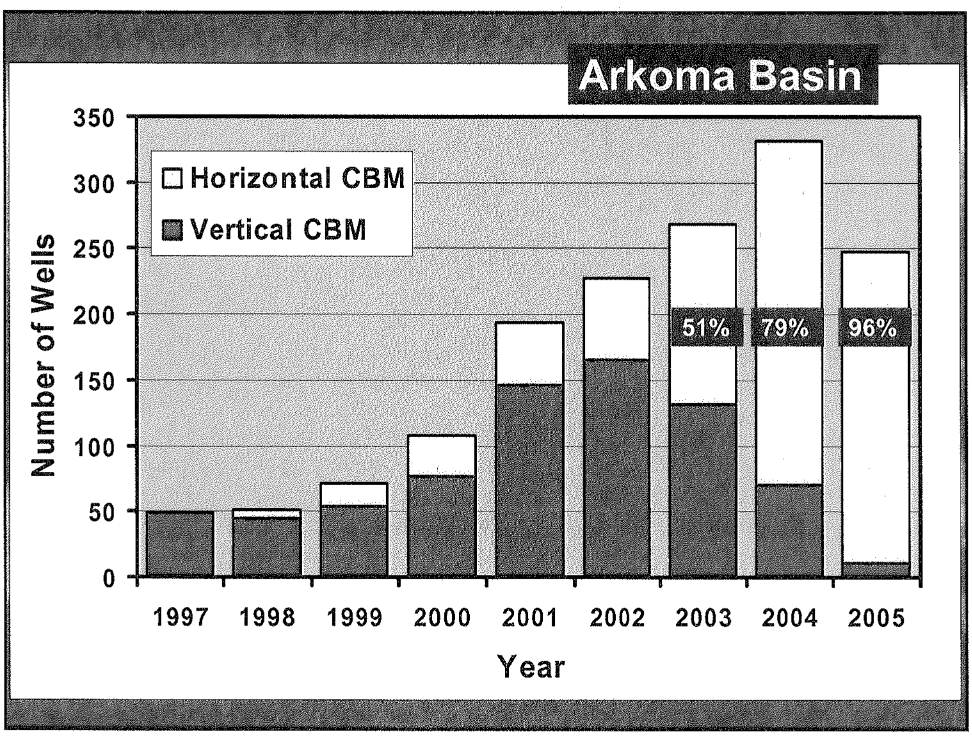
Water Quality

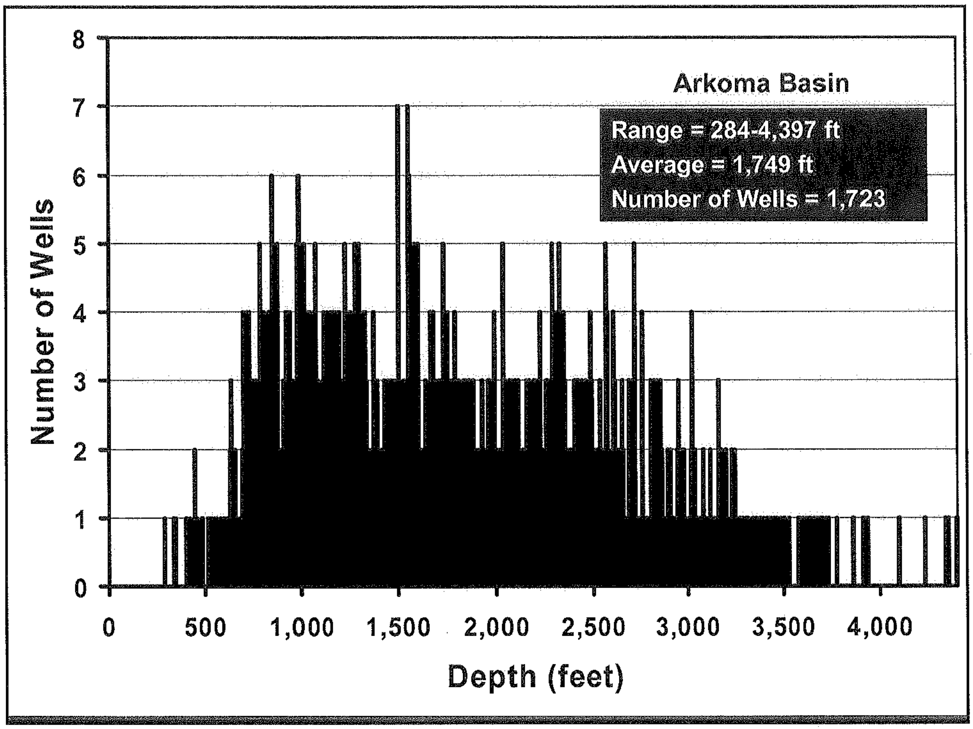
Water samples from the Mulky and Rowe coals in 4 wells in Nowata and Osage Counties had 86,200-152,900 mg/L Total Dissolved Solids (TDS)

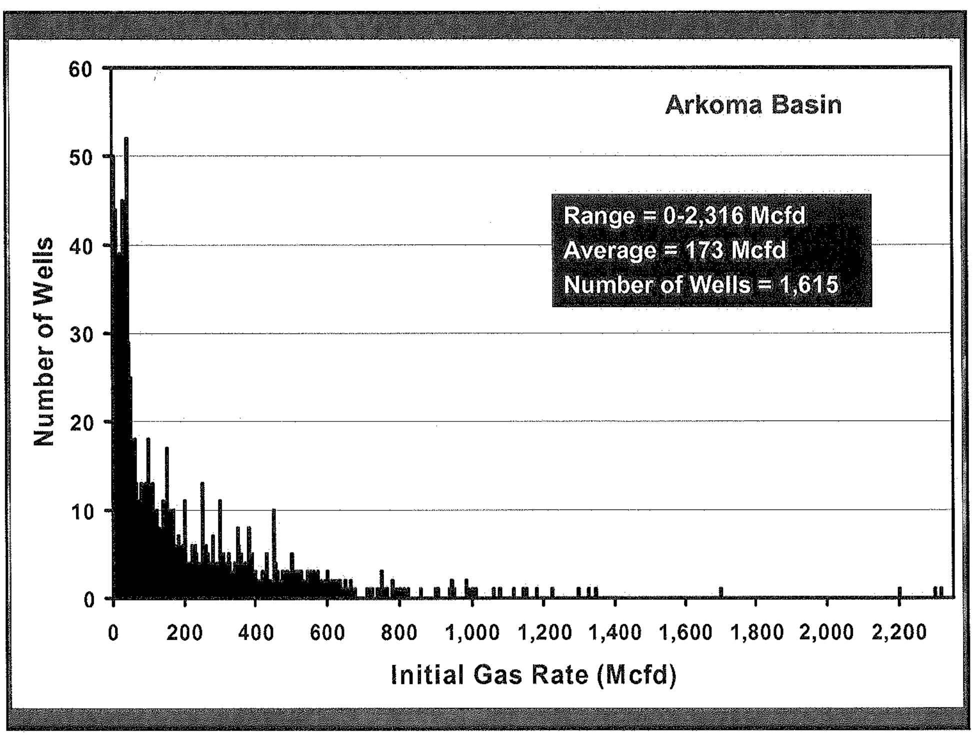
[Underground Sources of Drinking Water (USDW) contain <10,000 mg/L TDS; seawater is @35,000 mg/L TDS]

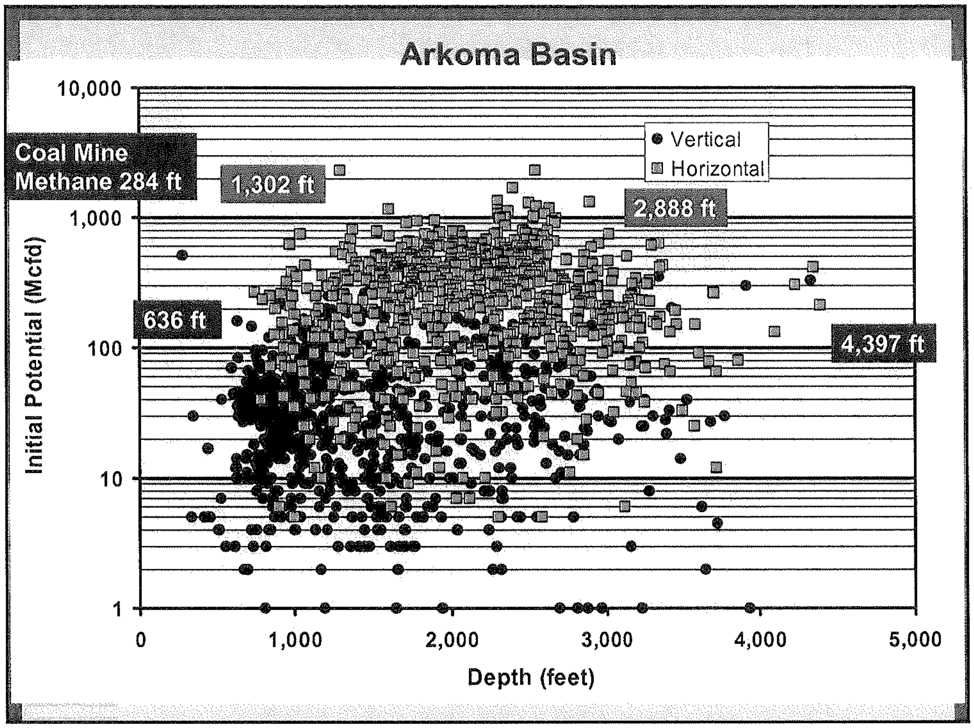


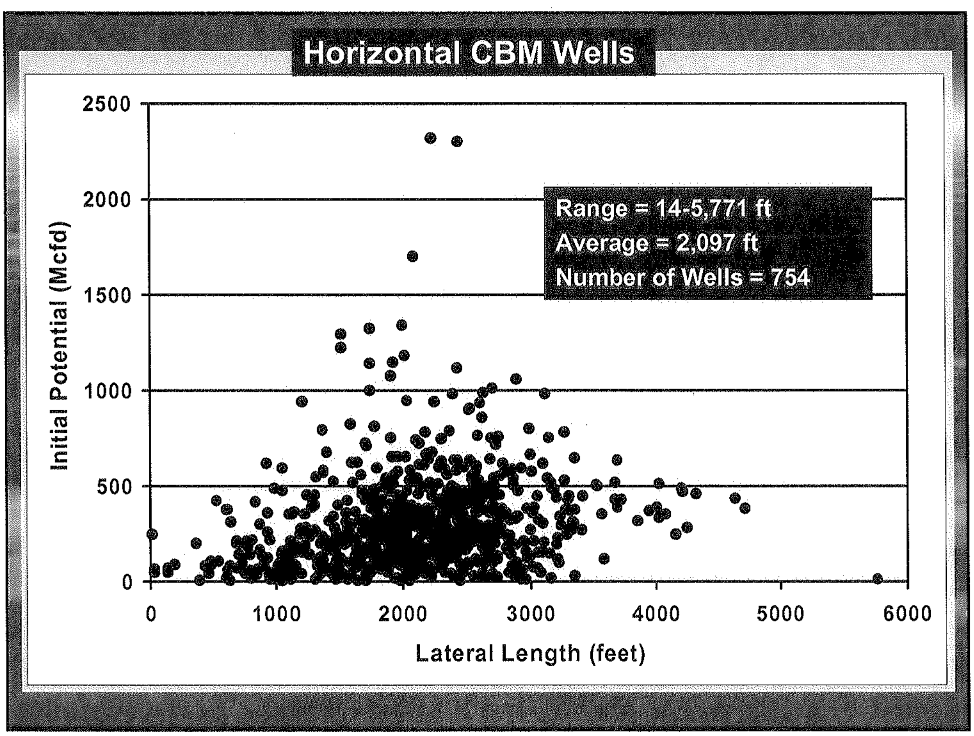

Arkoma Basin
OKMULGEE
MUSKOGEE
OKFUSKEE
SEQUOYAH
McINTOSH
HASKELL
HUGHES
LATIMER
PITTSBURG
LE FLORE
PUSHMATAHA
COAL
ATOKA
T13N
T11N
T9N
T7N
T5N
T3N
T1N
T1S
R9E
R11E
R13E
R15E
R17E
R19E
R21E
R23E
R25E
R27E
0 10 20 Miles
Coal-Bed Symbols
Unnamed
Secor
"Savanna"
McAlester
Hartshorne
Upper/Lower Hartshorne
Lower Hartshorne
Horizontal
N
W
E
S
1,779 CBM Completions

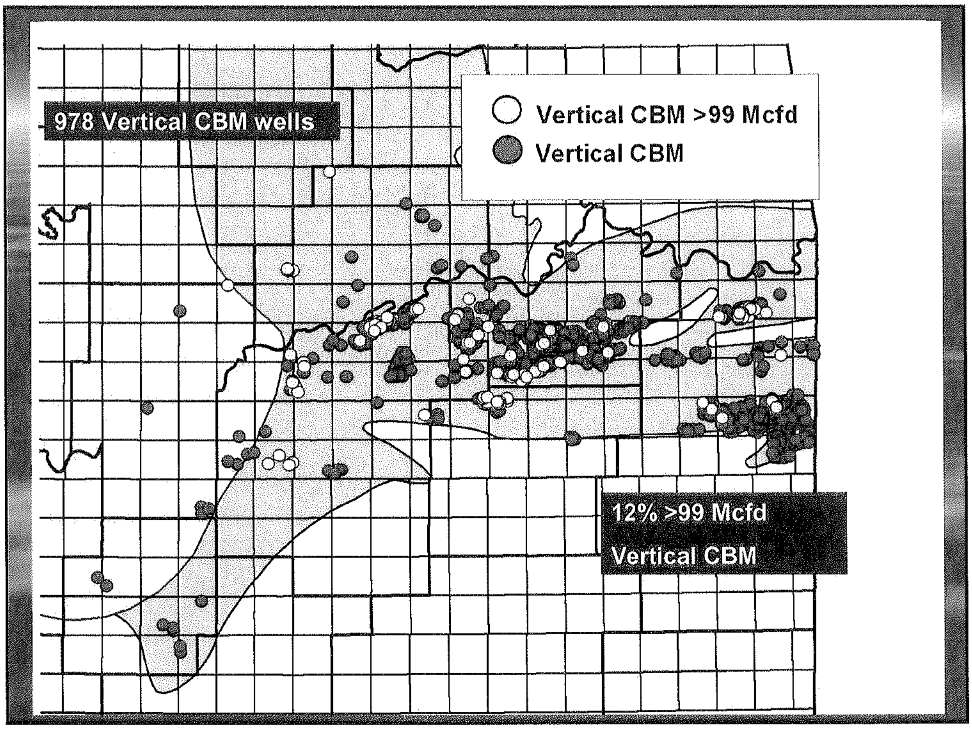

Arkoma Basin
Horizontal CBM
Vertical CBM
Number of Wells
350
300
250
200
150
100
50
0
51%
79%
96%
1997
1998
1999
2000
2001
2002
2003
2004
2005
Year

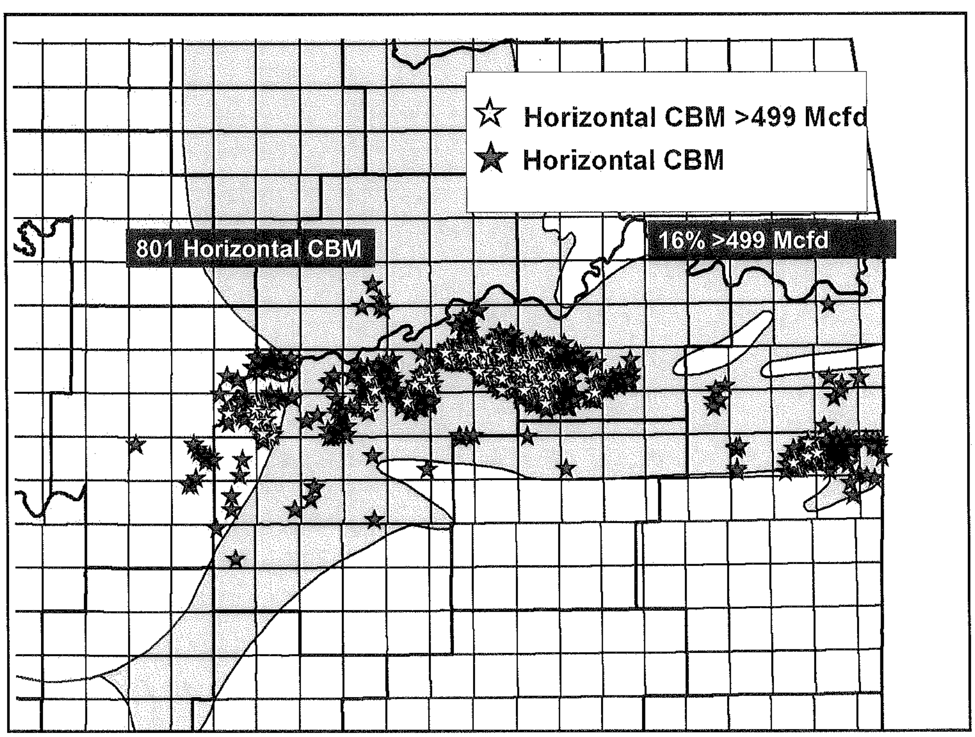

Arkoma Basin
Range = 284-4,397 ft
Average = 1,749 ft
Number of Wells = 1,723
Number of Wells
Depth (feet)
0
1
2
3
4
5
6
7
8
0
500
1,000
1,500
2,000
2,500
3,000
3,500
4,000

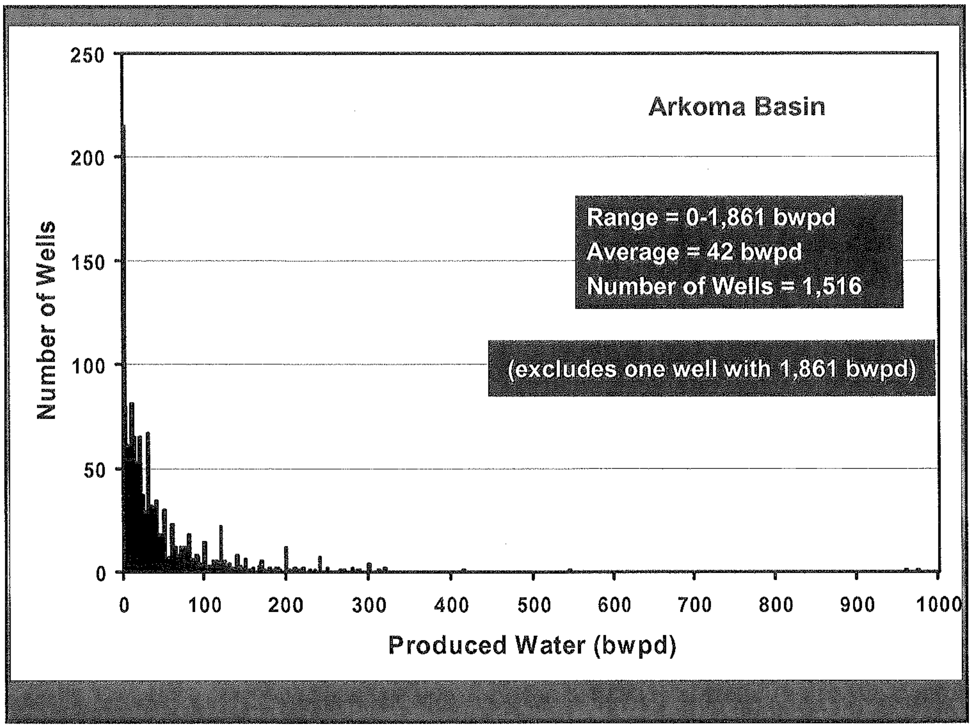

Arkoma Basin
Range = 0-2,316 Mcfd
Average = 173 Mcfd
Number of Wells = 1,615
Number of Wells
Initial Gas Rate (Mcfd)
0
10
20
30
40
50
60
0
200
400
600
800
1,000
1,200
1,400
1,600
1,800
2,000
2,200

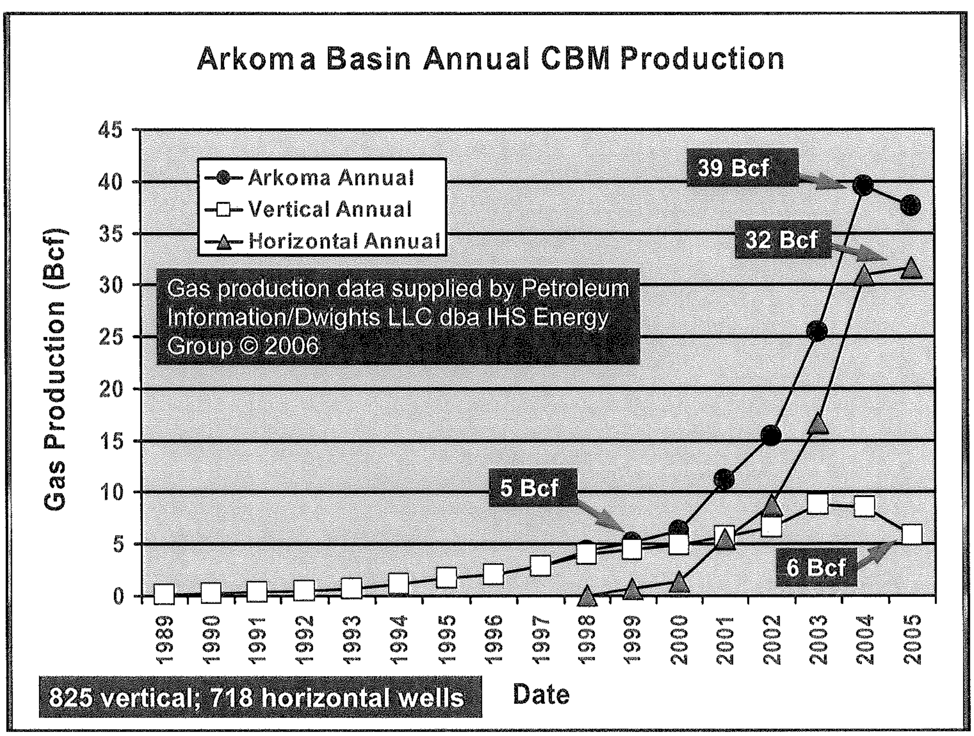

Arkoma Basin
10,000
1,000
100
10
1
Initial Potential (Mcfd)
0
1,000
2,000
3,000
4,000
5,000
Depth (feet)
Vertical
Horizontal
Coal Mine Methane 284 ft
1,302 ft
2,888 ft
636 ft
4,397 ft

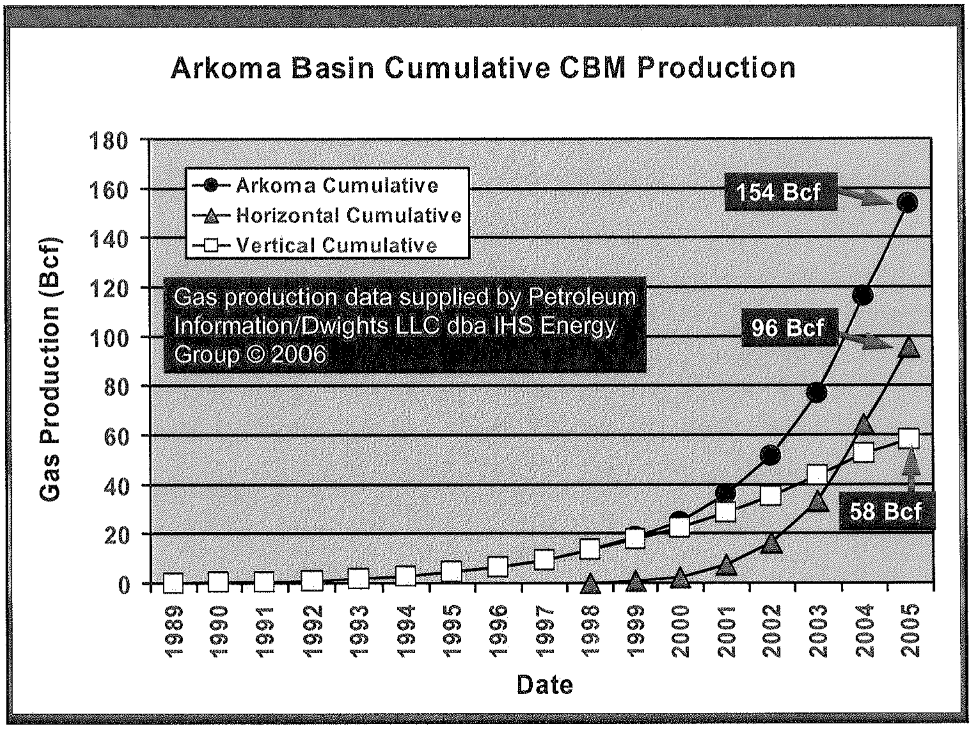

Horizontal CBM Wells
2500
2000
1500
1000
500
0
Initial Potential (Mcfd)
0
1000
2000
3000
4000
5000
6000
Lateral Length (feet)
Range = 14-5,771 ft
Average = 2,097 ft
Number of Wells = 754


978 Vertical CBM wells
Vertical CBM >99 Mcfd
Vertical CBM
12% >99 Mcfd
Vertical CBM


Horizontal CBM >499 Mcfd
Horizontal CBM
801 Horizontal CBM
16% >499 Mcfd


Arkoma Basin
Range = 0-1,861 bwpd
Average = 42 bwpd
Number of Wells = 1,516
(excludes one well with 1,861 bwpd)
Number of Wells
250
200
150
100
50
0
0 100 200 300 400 500 600 700 800 900 1000
Produced Water (bwpd)


Arkoma Basin Annual CBM Production
Arkoma Annual
Vertical Annual
Horizontal Annual
Gas production data supplied by Petroleum Information/Dwights LLC dba IHS Energy Group © 2006
39 Bcf
32 Bcf
5 Bcf
6 Bcf
Gas Production (Bcf)
45
40
35
30
25
20
15
10
5
0
1989 1990 1991 1992 1993 1994 1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005
825 vertical; 718 horizontal wells
Date


Arkoma Basin Cumulative CBM Production
Arkoma Cumulative
Horizontal Cumulative
Vertical Cumulative
Gas production data supplied by Petroleum Information/Dwights LLC dba IHS Energy Group © 2006
154 Bcf
96 Bcf
58 Bcf
Gas Production (Bcf)
180
160
140
120
100
80
60
40
20
0
1989
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
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2003
2004
2005
Date

KANSAS COAL AND COALBED METHANE—AN OVERVIEW*

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INTRODUCTION

Bituminous coal resources of Middle and Upper Pennsylvanian age are widespread in eastern Kansas and represent nearly all the coal resources in the state. These coal beds have been exploited for over 160 years with a total recorded production of approximately 300 million tons. Peak production for Kansas coal was during World War I (1918) with 7.3 million tons.

Exploration and development of natural gas from coal beds in areas of the central and western U.S. has increased interest in other coal areas, especially in eastern Kansas following the success of coalbed methane development in northeastern Oklahoma. Earlier developments of coalbed methane in southeast Kansas in the late 1980's and early 1990's -- mainly in Montgomery, Wilson, and Labette counties -- has shown the potential for developments in other portions of eastern Kansas. This resulted in the review of existing data and information by many companies and consultants resulting in extensive leasing in both the Cherokee basin of southeastern Kansas and the Forest City basin in east-central and northeastern Kansas.

Deep coal resources are recognized for 32 coal beds, and strippable coal resources have been determined for 17 coal beds. At present, six coals stratigraphically higher than the Cherokee Group also are included in the deep coal resource total. However, the deep bituminous coal resources -- primarily of the Cherokee Group -- appear to provide the best potential for present and future development of coalbed methane in Kansas. Important to the early coalbed methane development in southeast Kansas in the late 1980's and early 1990's was the Section 29 federal tax credits for development of this unconventional gas source. The recent interest has developed due to the increase in price of natural gas, a recognized Kansas petroleum industry infrastructure including major pipelines through eastern Kansas, primarily fee lands, and a coal resource that suggests potential development of that resource at an economic cost.

Gas content for coal cores obtained from a well from Montgomery County, in the middle of the developing coalbed methane area in southeastern Kansas, are shown in Figure 6 (from Newell and others, 2004). Deeper coals in the Cherokee Group, specifically the Weir-Pittsburg and Riverton coals, have gas contents (as received, not including residual gas) ranging from 150-250 scf/ton. Shallower coals generally have lesser gas content. To date, the maximum gas content recorded in southeastern Kansas from 250 desorption tests by the Kansas Geological Survey is 346 scf/ton for a Rowe coal at 1400 ft depth.

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*Modified from Brady, L. L., and Newell, K. D., 2004, Kansas coal and coalbed methane—an overview, in Overview of coal and coalbed methane in the Cherokee basin, northeast Oklahoma: Fieldtrip guidebook for the First Coalbed Methane Symposium, Tulsa, Oklahoma, November, 9, 2004, Oklahoma Geological Survey and Kansas Geological Survey, p. 97-116. (Available as Kansas Geological Survey Open-file report 2004-49).

DEEP COAL RESOURCES AND STRATIGRAPHIC POSITION OF COAL BEDS

When evaluating the deeper coal resources, informal terms and names were used to identify unnamed coals and certain key marker beds, especially in the Cherokee Group. Many of these coal names are formally recognized in Zeller (1968), and Baars and Maples (1998), but several of the coals and most of the "black shale" marker beds in the Cherokee Group are not listed. These terms evolved during usage in coal and stratigraphic studies at the Kansas Geological Survey as shown in Figure 1. Informal names used in Kansas for some coals do not correspond with the stratigraphic nomenclature of adjacent states, but most of the important coal beds do correlate and maintain the same coal names used in western Missouri and northeastern Oklahoma.

Stratigraphy of the deep coal beds, especially of the Cherokee Group, was determined and developed from mine and outcrop studies, especially those of Abernathy (1937), Pierce and Courtier, (1938), Howe (1956), and Harris (1984), all of whom helped establish the Kansas stratigraphy of the Cherokee Group in outcrop and shallow subsurface studies. These stratigraphic units and their relations were extended into the subsurface by various workers including Ebanks and others (1977), Livingston and Brady (1981), Harris (1984), Killen (1986), Staton (1987), Brady and Livingston (1989), Brenner (1989), Huffman (1991), and Walton (1996). Recent major studies of coal distribution and thickness in the deeper subsurface are by Lange (2003), Johnson (2004), and Brown (2005).

Deep coal resources in eastern Kansas determined in earlier studies (Brady and Livingston, 1989; Brady, 1990, 1997) using USGS coal resources criteria (Wood and others, 1983) amount to a conservative total of 53 billion tons of coal (Table 1) measured from 32 different coal beds using information from 600+ geophysical logs, numerous drillers logs from coal exploration wells, and continuous cores. Of this total, an estimated 45 billion tons of resources are from coals in the 14 to 28 inch thickness range; 6 billion tons in the 28-42 inch range; 1.9 billion tons in the 42-56 inch range; and 0.14 billion tons for coal resources exceeding 56 inches in thickness. Nearly all of these resources were determined for coal at depths less than 2500 ft, but based on recent drilling coals are known to be present in deeper parts of the eastern Kansas basins to depths of at least 3000 ft. Emphasis of the deep coal resources was on coal beds of the Cherokee Group because of the stratigraphic importance of the coal in this group in Kansas. However, six coal beds stratigraphically higher than the Cherokee Group are included in the deep coal resource total.

Most of the data points for the resource study are located in the Kansas portion of the Cherokee basin in southeastern Kansas and the area of the Bourbon arch (a low divide between the Forest City and Cherokee basins). A coal resource of 37 billions tons that was determined for this generalized Cherokee basin area and the resource is represented by 31 coal beds. Of these coals, 25 are in the Cherokee Group. A coal resource of 16 billion tons was determined for the Kansas portion of the Forest City basin. In the Forest City area, 27 coals are represented in the resource figure, and of these coals, 23 coals are part of the Cherokee Group or older Middle Pennsylvanian rocks. Due to the 3-mile limit on resource determination (Wood and others, 1983) and the limited amount of geophysical logs used in eastern Kansas for the coal resource analysis, a much larger coal quantity probably exists than is listed in the resource totals. Coal beds having the largest deep resources in Kansas include the Bevier, Riverton, Mineral, "Aw" (unnamed coal bed), and the Weir-Pittsburg coals. Recent studies by Lange (2003), Johnson (2004), Brown (2005), and on-going work at the Kansas Geological Survey, suggest that much larger coal resource totals exist in eastern Kansas. This is based mainly on new drilling in areas lacking drill data which has shown general continuity of the important coal beds.

Many of the highly radioactive "black shales" that commonly are present a few feet above a coal bed in a typical Kansas cycle give a high γ reading on the gamma-ray logs. The distinctive characteristics of these shales are important in the correlation of the different coal beds. These radioactive shales are used as stratigraphic markers and were found to have widespread occurrences (e.g., Ebanks and others, 1977; Livingston and Brady, 1981; Harris, 1984; Killen, 1986; Staton, 1987; and Huffman, 1991). Important marker beds with widespread readily identifiable signatures are the Anna Shale and Little Osage Shale in the Marmaton Group (overlies the Cherokee Group), and the Excello Shale, "V-shale marker", "Tebo marker", and the "Bjb marker". Other more local shales such as the "Mineral marker", "Scammon marker", and "Weir-Pittsburg marker" are important in limited areas—primarily in the Cherokee basin and southern Forest City basin.

COAL QUALITY

Kansas coal of Pennsylvanian age is all of apparent high-volatile bituminous rank. Nearly 90 percent of the coal mined in the past was of apparent high-volatile A bituminous rank, with most of this coal produced in southeastern Kansas in Crawford, Cherokee, and southern Bourbon counties. Large amounts of high-volatile B bituminous coal were produced in Leavenworth County (Bevier coal of the Cherokee Group produced from deep mines at depths of 700-750 ft). Proximate and ultimate analyses of Kansas coals are listed in numerous sources including: Young and Allen (1925) and Fieldner and others (1929, p. 30-37). Recent work that includes proximate and ultimate analyses and elemental analyses include: Swanson and others (1976), Tewalt and Finkelman (1990), Finkelman and others (1990), Bostic and others (1993), and Brady and Hatch (1997).

Vitrinite reflectance values for coals in eastern Kansas are presented along with other maturity indexes by Newell (1997, p. 23) in his paper on thermal history in Kansas. However, care must be taken in considering coal rank from the vitrinite measurements in Kansas because apparent coal rank determined from proximate and Btu values for the coals indicates a higher rank than is suggested by the vitrinite reflectance values. This suggests possible suppression of the vitrinite reflectance values.

Gas-content data for eastern Kansas is limited, but preliminary information indicates that the gas content (scf/ton) for most coals varies over short distances and even with separate samples for the same coal in a given well. Nevertheless, gas content generally decreases northward toward the Bourbon arch and eastward toward the outcrop. The northward decrease is likely due to an overall northward decreasing maturation in eastern Kansas, which is reflected in maturation measurements made on shale samples from oil and gas wells (see Newell, 1997; Hatch and Newell, 1999; Newell and others, 2002, 2004). The eastward decrease is likely due to lower confining pressure due to shallower overburden and possibly lesser maturity.

METHANE FROM COAL

Drilling and fracturing of the thicker coal beds or multiple coal beds at depth does produce large amounts of the gas from multiple coal beds in southeastern Kansas, and also east-central parts of the state. By August 2004, nearly 1800 wells were drilled for coalbed methane in eastern Kansas (Adkins-Heljeson and others, 2004), with an estimated 1000 coalbed methane producing wells in the state (generalized in Figure 2). By May 2006, about 3250 wells were drilled for coalbed methane. Most of these wells in eastern Kansas have been drilled since 2000, with about 700 wells per year being drilled since 2003 (Figure 3). Production is largely concentrated in a five-county area in southeastern Kansas, including Montgomery, Neosho, Wilson, Labette, and Chautauqua counties. Concomitant with this drilling effort, coalbed gas production in southeastern Kansas has markedly increased in the last decade, and is now approaching 17 bcf/year (Figure 4). The production rise is expected to continue for the next few years. Southeastern Kansas coalbed gas wells hit their peak gas production from 12 to 36 months after their initial production (Figure 5, from Newell and others, 2002, 2004). A long and gradual decline follows.

Several coalbed gas pilot projects have been initiated farther north in eastern Kansas on the Bourbon arch and Forest City basin, but the economic viability of these pilot projects especially in the Forest City basin is questioned. Similarly, westward expansion of production to the axis of the Cherokee basin is limited. Coal thickness, gas content, and dewatering behavior of the wells is largely unknown for this region. One outpost of commercial development, by Osborn Energy, is present just south of the Kansas City metropolitan area in southern Johnson/northern Miami counties. This area is on the broad, shallow southeastern flank of the Forest City basin.

Gas content for coal cores obtained from a well from Montgomery County, in the middle the developing coalbed methane area in southeastern Kansas, is shown in Figure 6 (from Newell and others, 2004). Deeper coals in the Cherokee Group, specifically the Weir-Pittsburg and Riverton coals, have gas contents (as received, not including residual gas) ranging from 150-250 scf/ton. Shallower coals generally have lesser gas content. To date, the maximum gas content recorded in southeastern Kansas from 250 desorption tests run by the Kansas Geological Survey is 346 scf/ton for a Rowe coal at 1400 ft depth.

Farther north on the flanks of the Forest City basin in Miami County, gas content for a well in Miami County is less than for the same coals buried almost as deep as they are in Montgomery County (Figure 7). Gas content data from Johnson (2004) shows that coals on the Bourbon arch and southeastern Forest City basin have gas contents (as received, not including residual gas) not exceeding 143 scf/ton.

The coals observable in the well in Montgomery County (Figure 6) are buried less deeply in a well 18 miles to the southeast in Labette County (Figure 8; from Newell and others, 2004) because the Labette County well is higher on the flank of the Cherokee basin and closer to the outcrop. Some of the coals in the well in Labette County have only half the gas content they have in the well in Montgomery County. The gas reserves in the coals in Labette County, based on this one well, are considerably less than the Montgomery County coals. However, the Iron Post coal at 382 ft (116 m) depth in the Labette County well has an unexpectedly high gas content (144 scf/ton), exceeding that of the deeper coals in the same well.

A microbial or mixed thermogenic-microbial origin for this Iron Post gas is suggested (Newell and others, 2004). Pennsylvanian coal-bearing units crop out at the surface in Cherokee County (the county immediately east of Labette County). Downdip movement of fresh water from the outcrop may augment biogenic production of coalbed gas in shallow coals along the eastern flank of the Cherokee and Forest City basins. A possible consequence to this model is that separate thermogenic and biogenic production fairways in the same coal may be present. The thermogenic fairway would be deeper in the basin where there is sufficient burial and confining pressure. The biogenic fairway would be updip and closer (and likely parallel) to the outcrop where basinal brines would be diluted by meteoric waters carried downdip from the outcrop. Coals with unusually high gas content for their relatively shallow depth in eastern Kansas could constitute tantalizing economic targets, but considerably more testing needs to be done to identify these types of production fairways.

SOUTHEAST KANSAS COAL AND ITS RELATIONS TO COALS OBSERVED AT FIELD TRIP STOPS

Coal beds observed on the Oklahoma field trip (Cardott and others, 2004) at the Phoenix Coal Company Alluwe Mine (Sec. 33-T.25N.-R.17E., Nowata Co., OK--Iron Post coal) and their Kelley Mine (Sec. 19-T.25N.-R.25N.-R.18E., Craig Co., OK--Croweburg coal) continue northward into Kansas. The Mulky coal (not observed at either mine) is commonly located just below the "black" Excello Shale (also observed at the Alluwe Mine) and also continues northward into Kansas. Distribution and thickness of these three coals in southeast Kansas are shown in Figures 9, 10, and 11, as mapped by Lange (2003).

Gas from coals produced at the Amvest Osage Inc. #32 well (Sec 26-T.20N.-R.11E., Osage Co., OK) include the Rowe, Bluejacket, Weir-Pittsburg, Tebo, and Mineral coals. Lange (2003) mapped the distribution and thickness of the Weir-Pittsburg, Tebo, and Mineral coals as shown in figures 12 through 14. Of those five coals in the Amvest well, the Weir-Pittsburg is the most important coal in Kansas and represents a significant portion of the southeast Kansas coalbed methane production. Also shown is the Riverton coal (Fig. 15) mapped by Lange (2003), another important widespread coal for coalbed gas production throughout southeastern Kansas and other areas of the state.

SUMMARY

Kansas has a coal resource base that exceeds 50 billion tons that is widespread in the eastern one-fourth of the state. That resource base is determined primarily from evaluation of 600+ geophysical wells, and also driller's logs for coal exploration, and limited continuous cores. Therefore, a large amount of coal present is not included in those resource figures. New isopach mapping of key coal beds is underway at the Kansas Geological Survey. Most of the coal resource lies at a depth of less than 2500 ft.

Estimated coalbed in-place gas resource of the Bourbon arch region in east-central Kansas is 2.1 tcf (Johnson, 2004). Coals in the Cherokee basin in southeastern Kansas, in general, are thicker, more extensive, and have higher gas content. An assessment of the Cherokee basin coalbed gas resource by Lange (2003) places this resource base at 6.6 tcf. Brown (2005) estimated the coalbed in-place gas resource of the Forest City basin to be 2.2 tcf, but gas-content data are very sparse for this estimate.

Based on coal chemistry, the rank of the coals is high volatile bituminous, with the coal ranging generally from high-volatile A bituminous in southeastern Kansas to high-volatile B and C bituminous in the central and northern areas of eastern Kansas. Because of the cyclic nature of coals and associated rock units in the Pennsylvanian rock column, especially in the Cherokee Group, multiple coal beds (up to 14 coals) could be encountered in a given well drilled through the Pennsylvanian section. The main problem to solve is locating coals with sufficient thickness to provide the quantities of gas needed for economic development. Most of the individual Kansas coal beds making up the resource are less than 28 inches thick, but in some places coal beds exceed five feet in thickness. Early desorption in southeastern Kansas shows some coals having values up to 343 cubic feet of gas/ton of coal. Many gas pipeline networks are in place, and Kansas has recognized disposal zones for the formation waters. With all of the given factors considered, Kansas represents an important area for present and future coalbed methane exploration and development.

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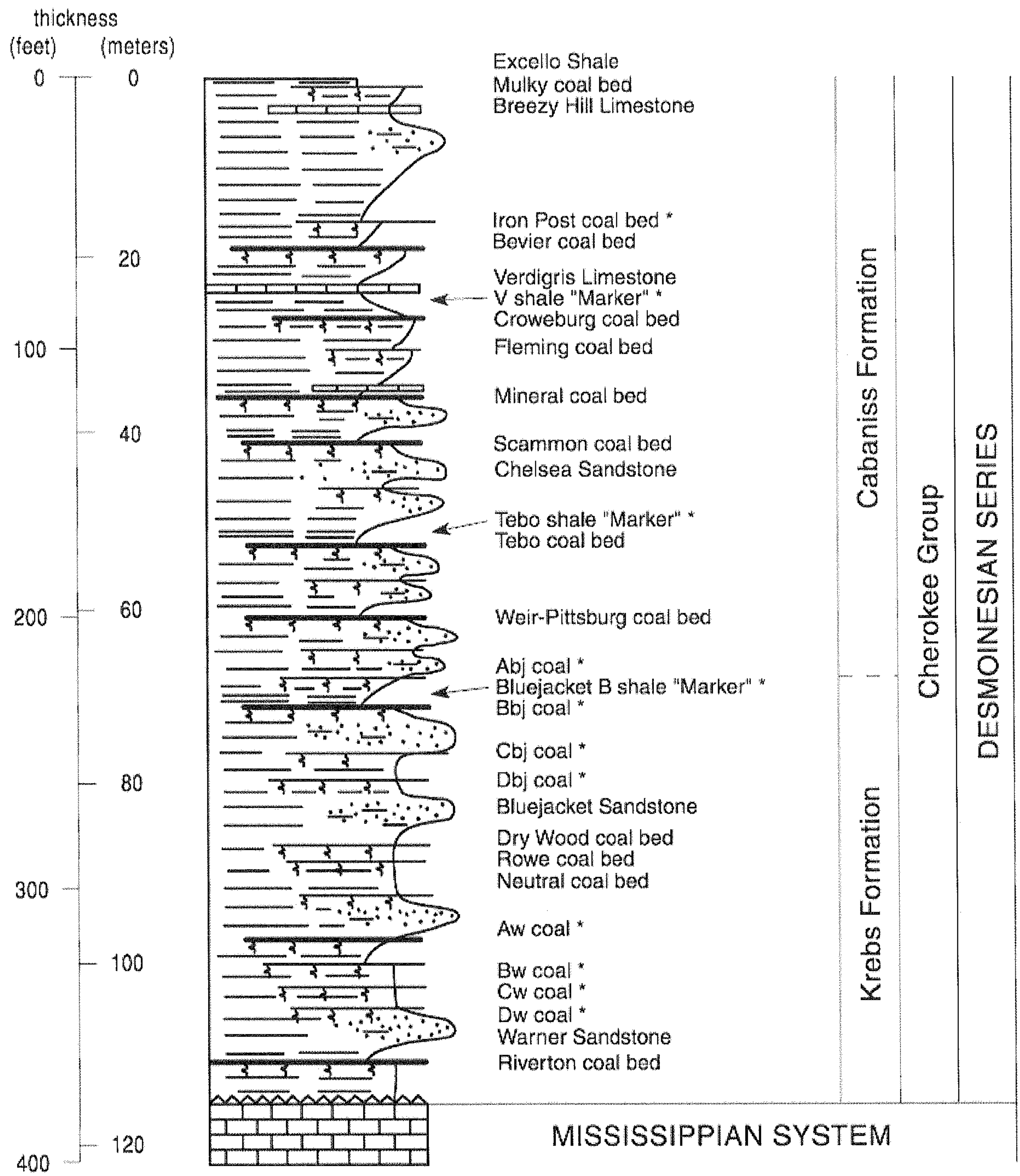

* Coal bed names that are used for correlation purposes, but are not formal or informal names recognized in Kansas.

Figure 1. Composite section of the Cherokee Group in southeastern Kansas showing relations of marker beds and coal beds. Modified from Harris, 1984, p. 30.

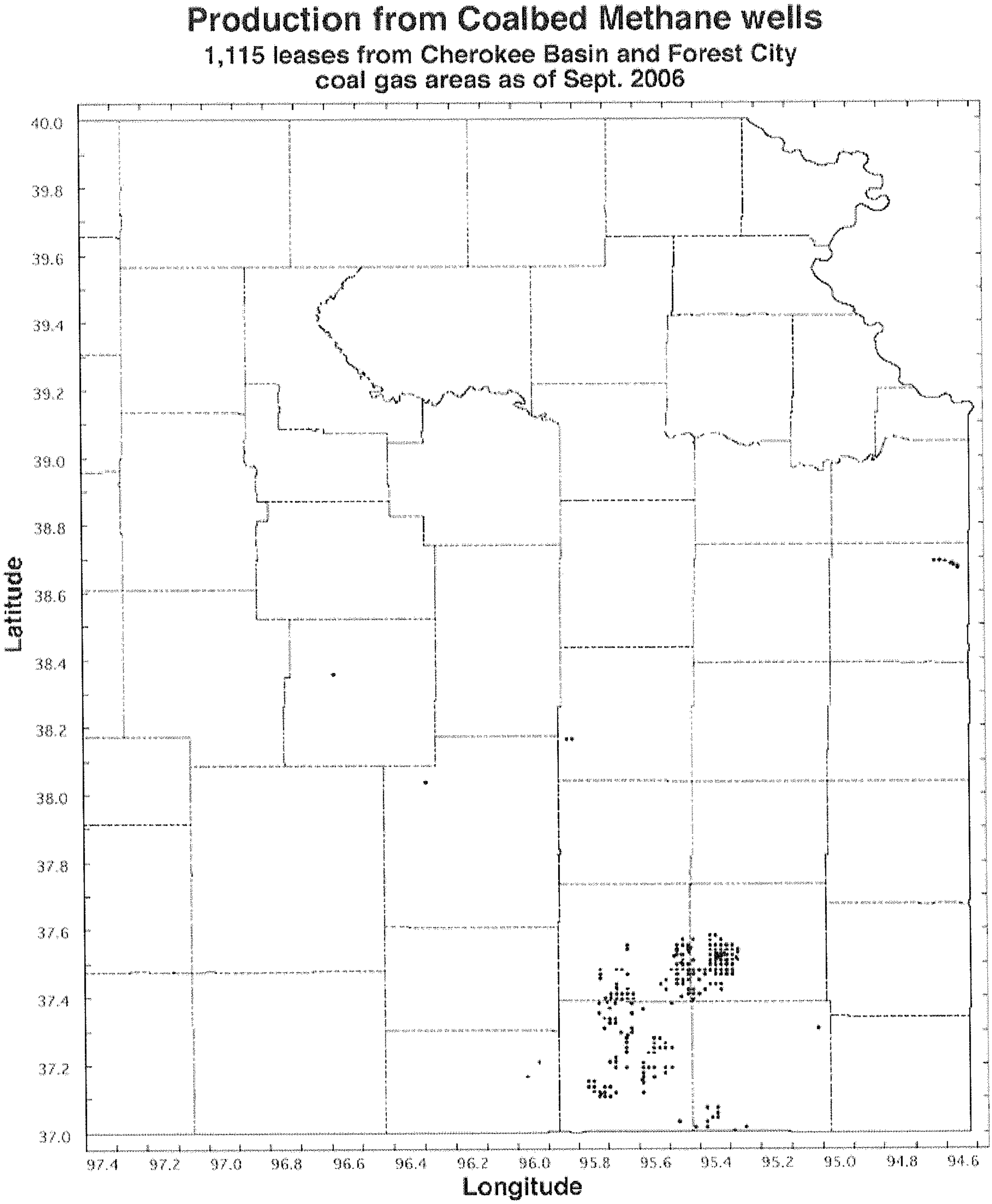

Figure 2. General location of coalbed methane production leases in eastern Kansas. A total of total of 1115 leases are entered in the database through September, 2006. Information from Adkins-Heljeson and others (2004).

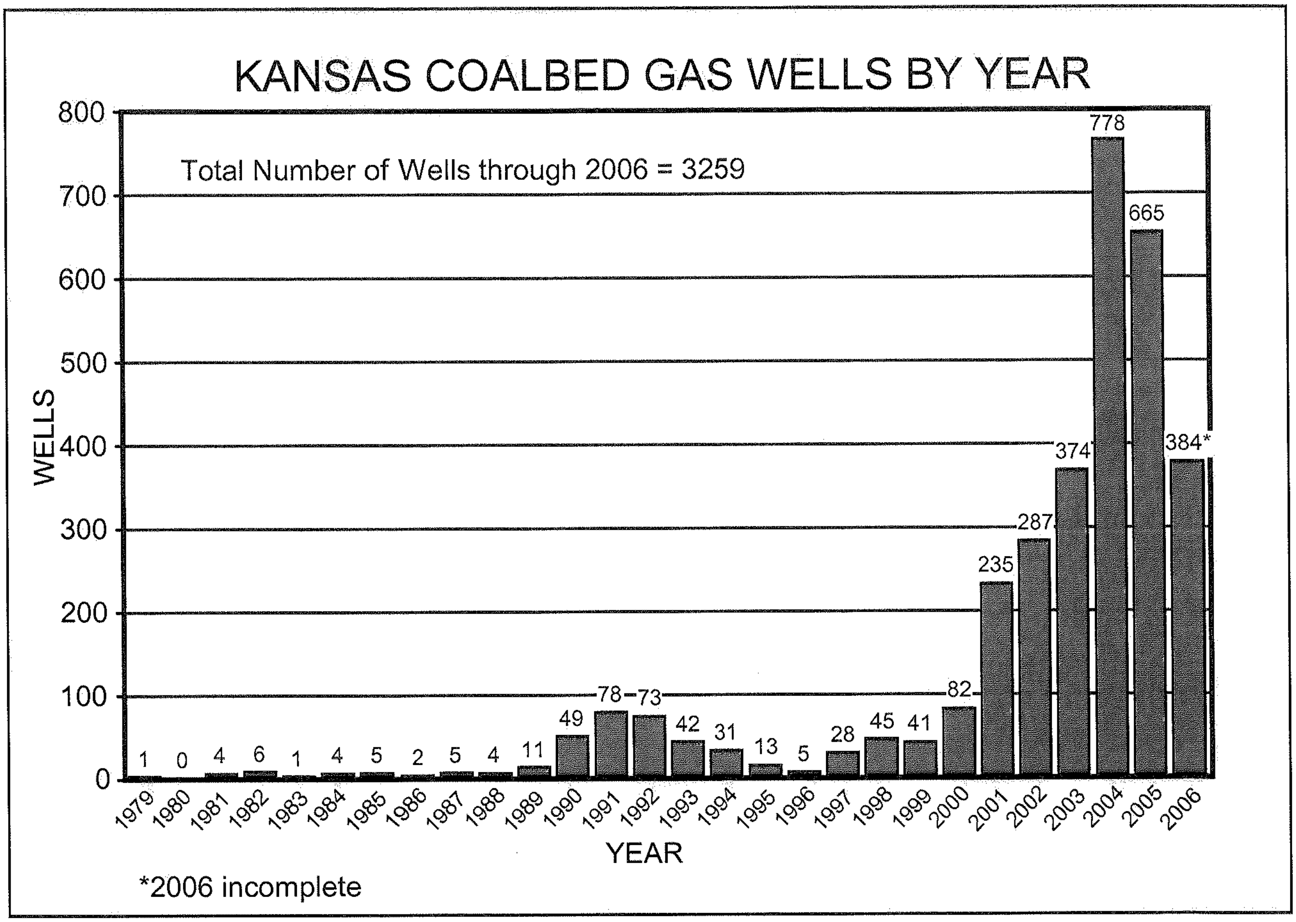

Figure 3. Annual tally of coalbed gas wells drilled in Kansas. The small surge in drilling in the 1990s is due to the influence of temporary federal tax credits for unconventional gas wells. The latest surge in drilling is largely price driven, in combination with available excess capacity in pipelines crossing the state.

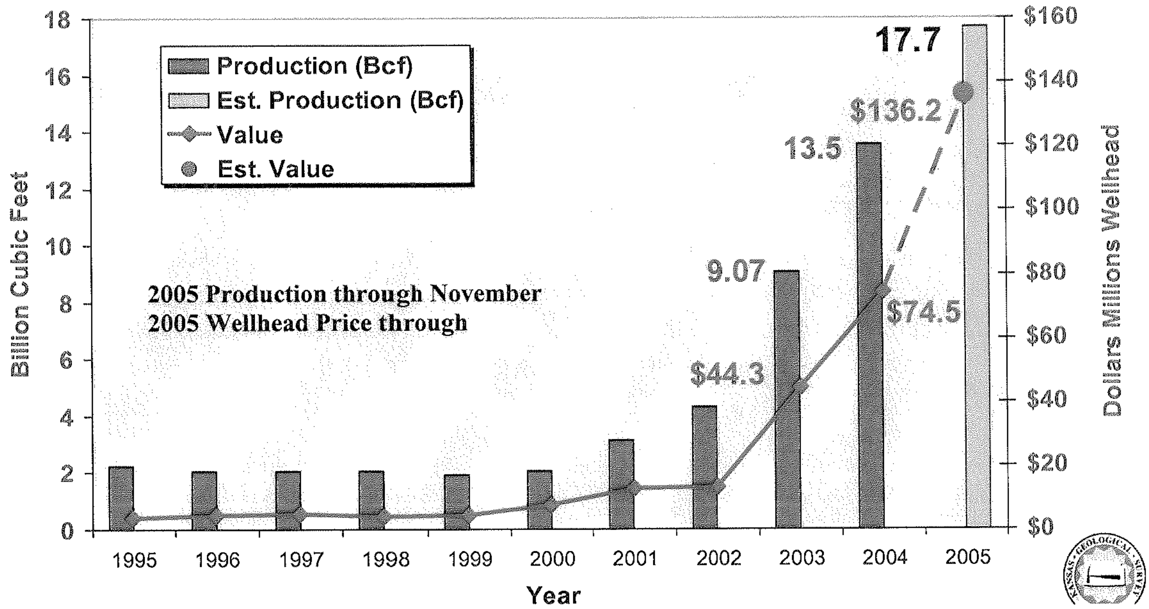

Figure 4. The surge in drilling for coalbed gas wells has been quickly followed by an increase in gas production in southeastern Kansas. Most of this new production is from Labette, Montgomery, Neosho, and Wilson counties.

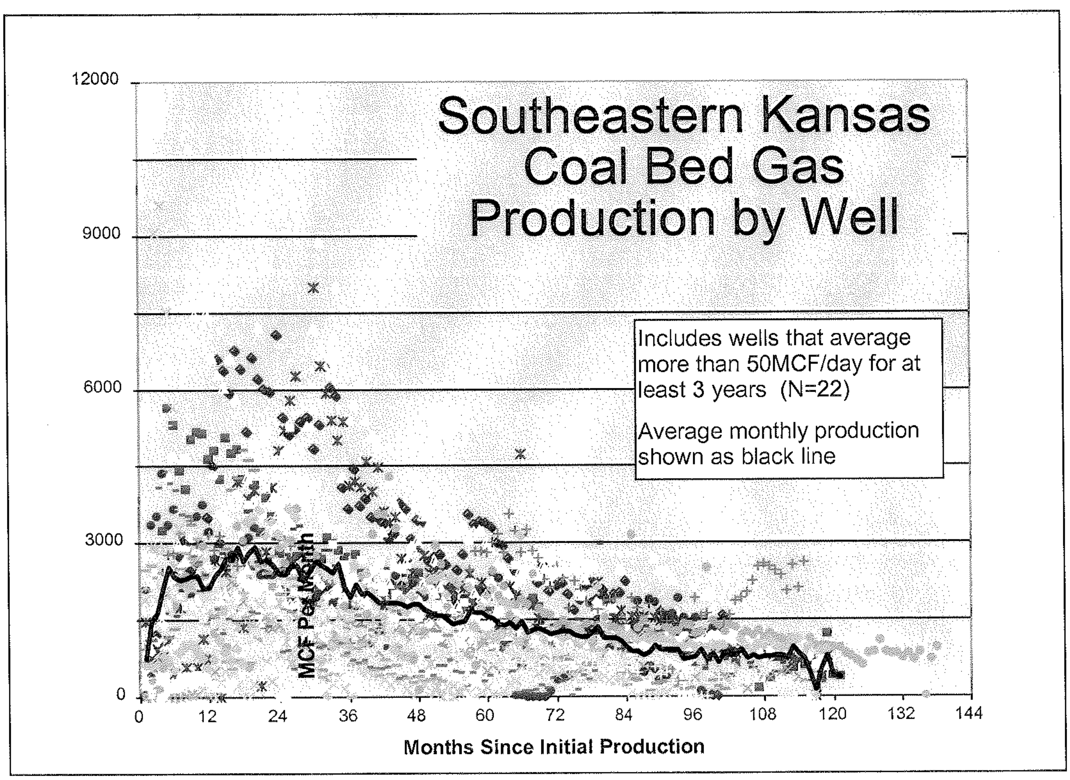

Figure 5. Production is reported in Kansas by lease name, customarily with the monthly production and number of wells producing from the lease. In order to gain an understanding of individual coalbed-well production characteristics, only single-well leases were used for this diagram. Production appears to peak about two years after initial production is reported, then a long period of decline follows (from Newell and others, 2002).

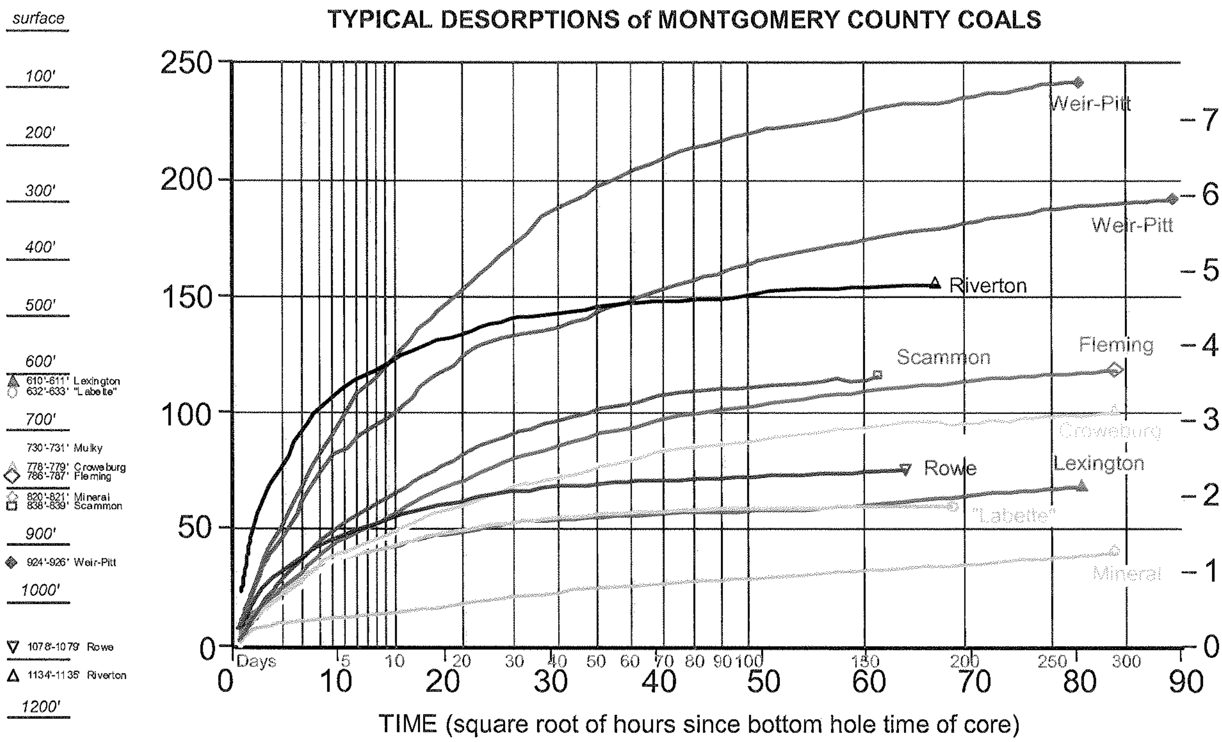

Figure 6. Desorption diagram for coals from a well in central Montgomery County, KS. Deeper coals (Weir-Pittsburg, Riverton) have the greatest gas content. Gas content is on an as-received basis, and does not include residual gas.

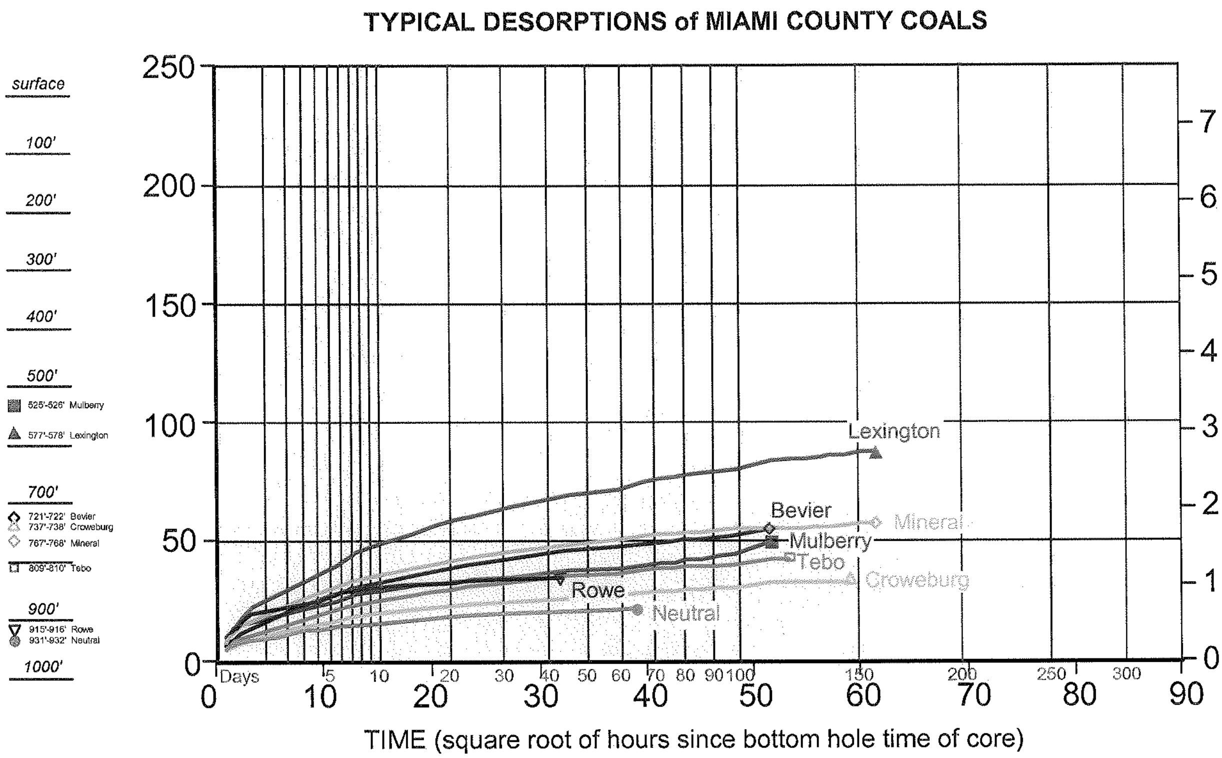

Figure 7. Desorption diagram for coals from a well in northern Miami County, KS. Less gas content is recorded for this locality (on the southeastern flank of the Bourbon arch) than farther south in the Cherokee basin. Gas content is on an as-received basis, and does not include residual gas.

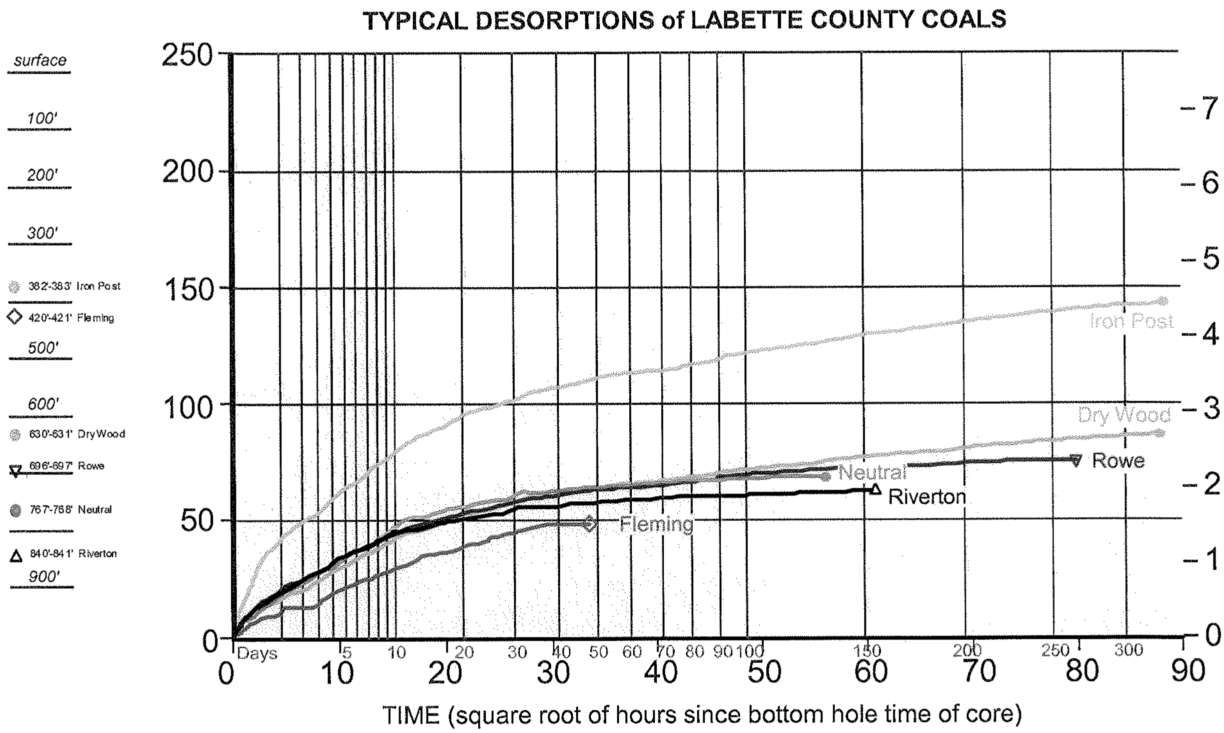

Figure 8. Desorption diagram for coals from a well in southern Labette County, KS. Shallower burial probably decreases the gas content of the coals at this locality (just 15 miles [25 km] southeast of the Montgomery County well). Nevertheless, the Iron Post coal at 380-ft depth has substantial gas content compared to deeper coals. Gas content is on an as-received basis, and does not include residual gas.

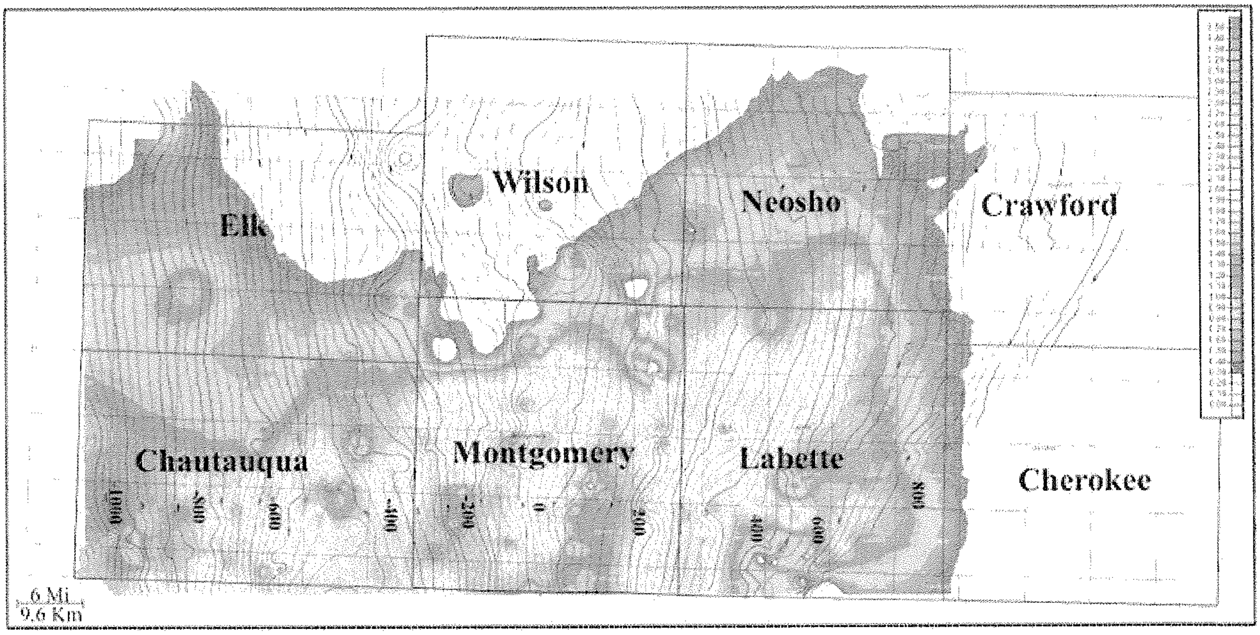

Figure 9. Isopach of Iron Post coal overlain with contours of the top of the Iron Post coal structure (isopach-color interval: 0.1 ft; structure CI: 25 ft). Modified from Lange, 2003, p. 104.

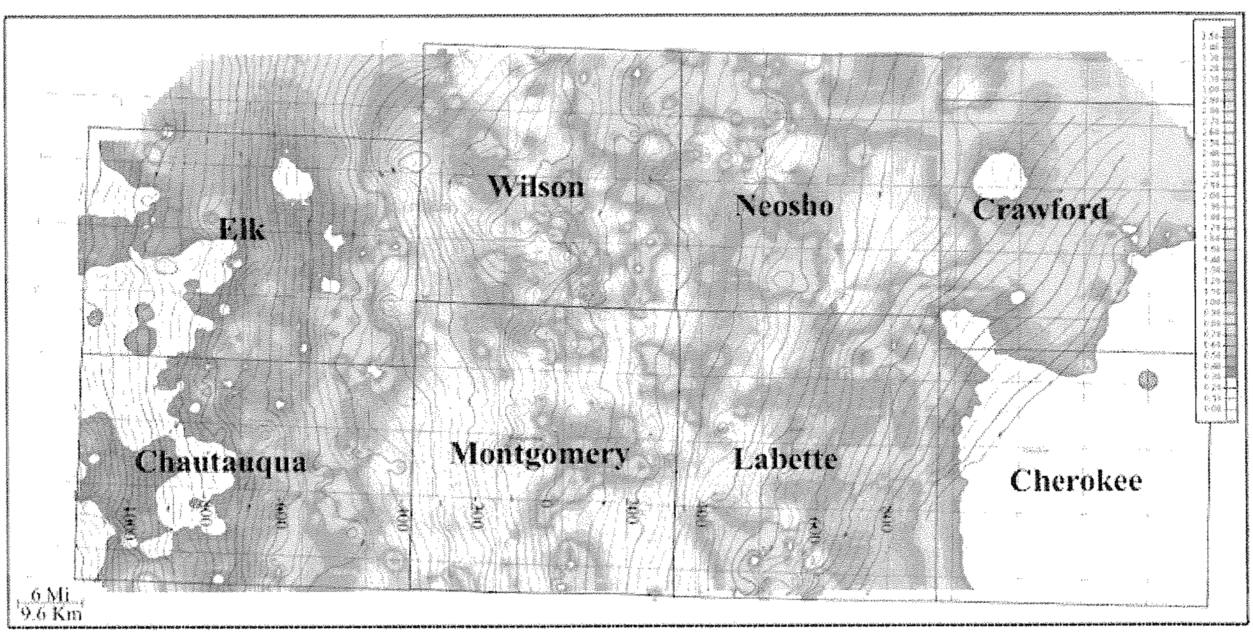

Figure 10. Isopach of Croweburg coal overlain with contours of the bottom of the Croweburg coal structure (isopach-color interval: 0.1 ft; structure CI: 25 ft). Modified from Lange, 2003, p. 97.

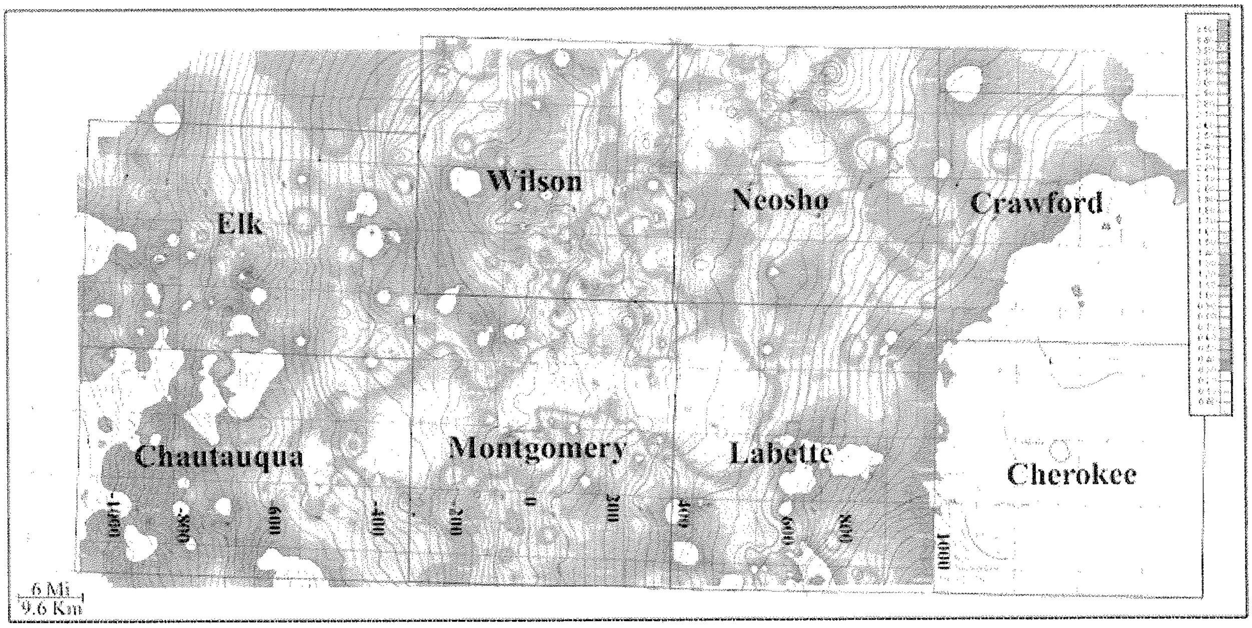

Figure 11. Isopach of Mulky coal overlain with contours of the top of the Breezy Hill Limestone structure (isopach-color interval: 0.1 ft; structure CI: 25 ft). Modified from Lange, 2003, p. 106.

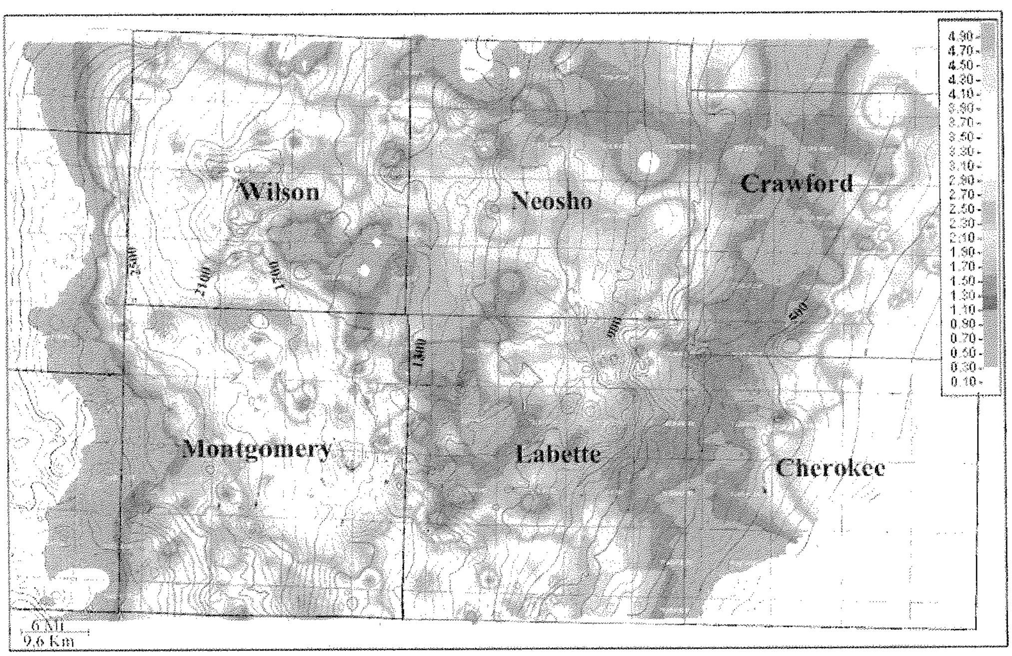

Figure 12. Isopach of Weir-Pittsburg coal overlain with contours of the top of the Mississippi limestone structure (isopach-color interval: 0.1 ft; structure CI: 25 ft). Modified from Lange, 2003, p. 82.

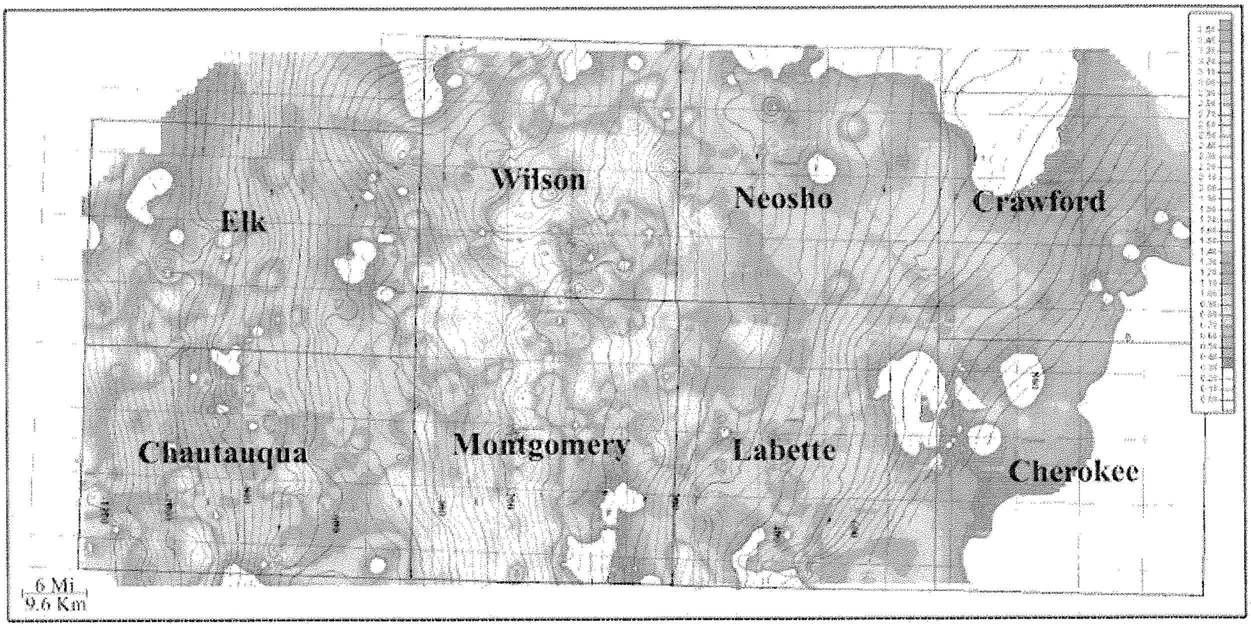

Figure 13. Isopach of Tebo coal overlain with contours of the bottom of the Tebo coal structure (isopach-color interval: 0.1 ft; structure CI: 25 ft). Modified from Lange, 2003, p. 86.

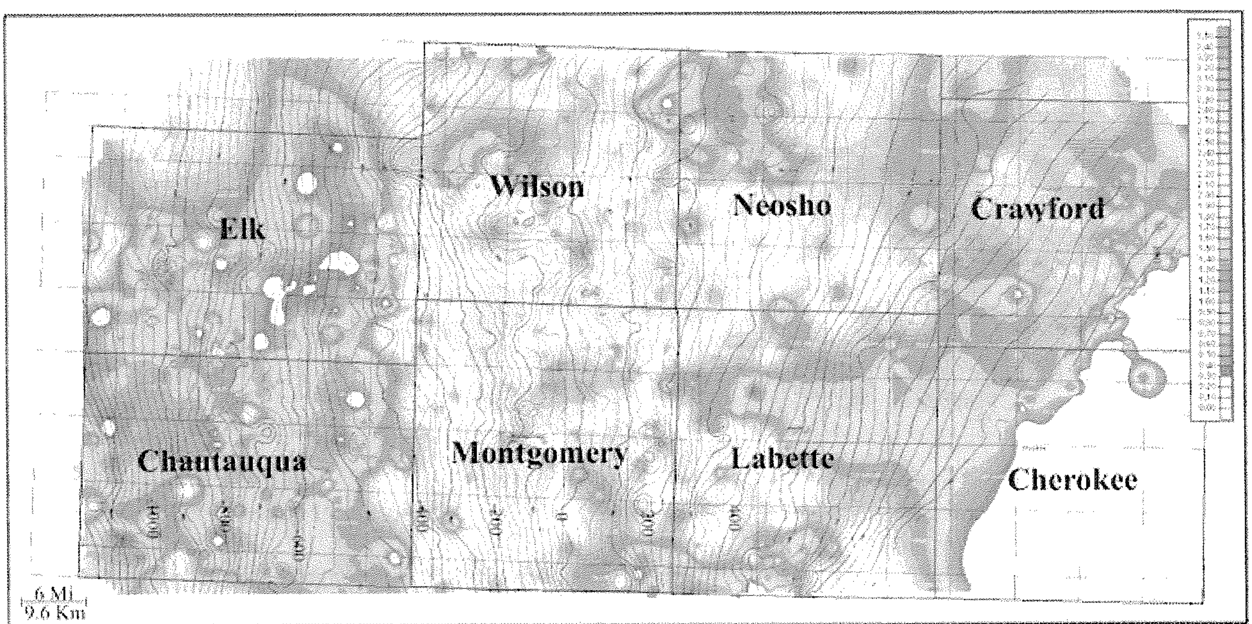

Figure 14. Isopach of Mineral coal overlain with contours of the top of the Mississippian limestone structure (isopach-color interval: 0.1 ft; structure CI: 25 ft). Modified from Lange, 2003, p. 92

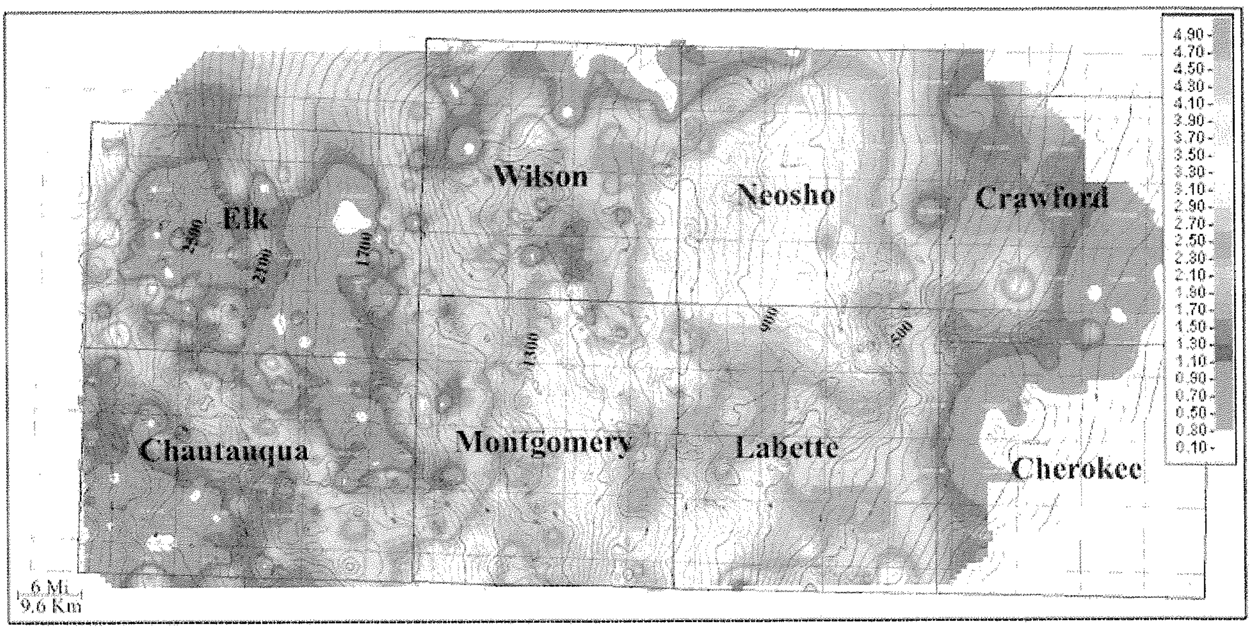

Figure 15. Isopach of Riverton coal overlain with contours of the top of the Mississippian limestone structure (isopach-color interval: 0.1 ft; structure CI: 25 ft). Modified from Lange, 2003, p. 76.

Table 1. Preliminary summary of deep coal resources and reliability category in Kansas **

Geologic Group	Coal Bed	Tonnages (million short tons) by Reliability Category Measured	Indicated	Inferred	Total	Total (MT)
Douglas	Williamsburg	1	6	109	116	(105)
Kansas City	Thayer	3	20	282	305	277
Pleasanton	* "Dawson"	4	33	473	510	463
Marmaton	Mulberry	11	83	1,158	1,252	1,136
"	* "Labette B"	19	120	1,381	1,520	1,379
"	* "Labette C"	2	17	249	268	243
Cherokee	Mulky	5	31	413	449	407
"	* "Iron Post"	13	82	771	866	786
"	* Unnamed	6	42	433	481	436
"	Bevier	90	561	5,477	6,12	5,559
"	Croweburg	20	141	1,613	1,774	1,609
"	Fleming	13	74	615	702	637
"	Mineral	87	540	4,975	5,602	5,082
"	Scammon	20	148	1,752	1,920	1,742
"	* "Scammon B"	2	18	158	178	161
"	Tebo	16	117	1,576	1,709	1,550
"	* "Tebo B"	1	6	99	106	96
"	Weir-Pittsburg	73	364	2,616	3,053	2,770
"	* "Weir-Pittsburg B"	5	44	719	768	697
"	* "Abj"	13	91	1,170	1,274	1,156
"	* "Bbj"	3	23	298	324	294
"	Dry Wood	4	31	413	448	406
"	Rowe	35	258	3,135	3,428	3,110
"	Neutral	3	26	420	449	407
"	* "Neutral B"	0	2	23	25	23
"	* "Aw"	49	381	4,579	5,009	4,544
"	* "Bw"	15	109	1,330	1,454	1,319
"	* "Cw"	29	228	2,862	3,119	2,830
"	* "Dw"	15	114	1,446	1,575	1,429
"	* Unnamed	2	17	175	194	176
"	Riverton	88	654	7,225	7,967	7,228
"	*Unnamed	5	40	516	561	509
Totals	(short tons)	652	4,421	48,461	53,534	
	(metric tons)	(591)	(4,011)	(43,964)	(48,566)	

* Coal bed names that are used for correlation purposes, but are not formal or informal names recognized in Zeller (1968).

** Modified from Brady, 1990, p.120.

Table 1. Preliminary summary of deep coal resources and reliability category in Kansas**

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