1st Midcontinent Coalbed Methane Symposium

Field Trip

Overview of Coal and Coalbed Methane in the Cherokee Basin, Northeast Oklahoma

Oklahoma Geological Survey 1908

November 9, 2004

Leaders: Brian J. Cardott,
Lawrence L. Brady, and
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Kansas Geological Survey University of Kansas

KANSAS GEOLOGICAL SURVEY
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Road Log and Geological Guide

The field trip begins at the Crowne Plaza Hotel (2nd St. at Boulder, Tulsa).

Distance in miles

Cumulative	Interval	
0.0	0.0	Depart Crowne Plaza Hotel driving east on 2nd St. (**Map 1**)
0.7	0.7	Merge with Interstate 244 East.
10.0	9.3	Merge with Interstate 44 East.
14.0	4.0	Enter ramp to Will Rogers Turnpike.
18.0	4.0	Bridge over Kerr-McClellan Navigation System.
27.1	9.1	Leave turnpike at Exit 255 (Claremore).
27.9	0.8	Turn left on State Route 20 W.
29.3	1.4	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.
47.8	12.5	Turn left on State Route 28 W in Chelsea, Oklahoma.
50.6	2.8	Cross outcrop of Croweburg coal at base of hill.
52.6	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).
54.3	1.7	Abandoned surface coal mine in Croweburg coal on east (right) side of road.
55.0	0.7	Abandoned coal mining equipment on east side of road.
55.2	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).
56.2	1.0	Turn left on rural road 28 (at Alluwe Baptist Church in New Alluwe).
56.7	0.5	Phoenix Coal Company Alluwe coal mine active pit is on south side of road.
57.2	0.5	Turn left at stop sign.
57.5	0.3	**STOP 1**: Phoenix Coal Company Alluwe coal mine (see **Maps 2 and 3**). Exit mine and drive north on rural road.
57.8	0.3	Turn right (east) at stop sign.
58.8	1.0	Turn left (north) on State Route 28 W.
59.2	0.4	Road crosses Panther Creek.
59.8	0.6	Turn right (east) on rural road 27.
60.0	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).
61.6	1.6	Reclaimed surface coal mine in Croweburg coal on right.

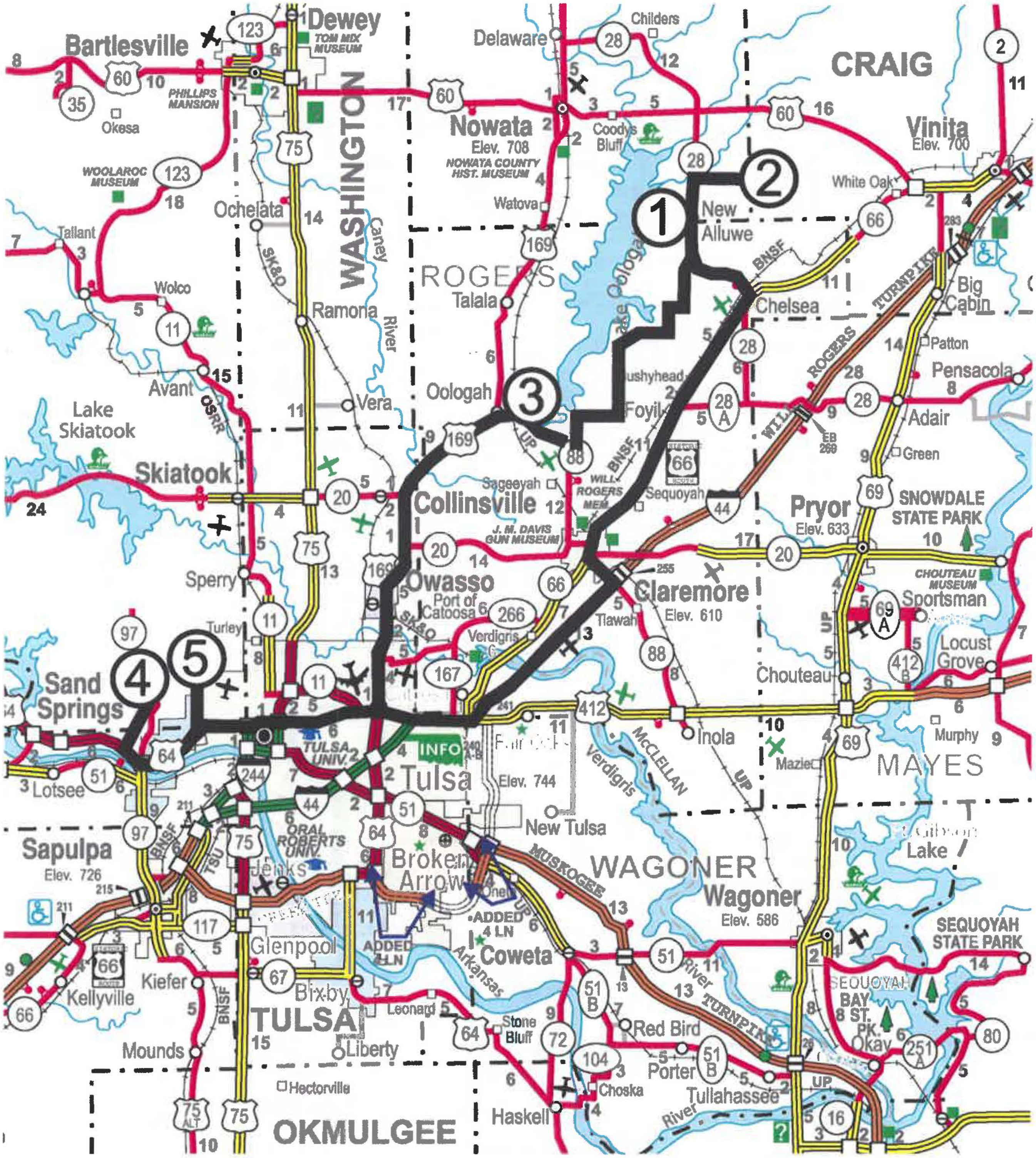
63.4	1.8	**STOP 2**: Phoenix Coal Company Kelley coal mine. Active surface coal-mine reclamation in Croweburg coal on right. Exit mine and drive west on rural road 27.
63.8	0.4	Reclaimed surface coal mine in Croweburg coal on right showing water-filled last cut.
67.1	3.3	Turn left (south) on State Route 28 E.
71.4	4.3	At fork in road, stay to the right on rural road NS 422.
71.9	0.5	Abandoned surface mine in Croweburg coal on left (east).
72.1	0.2	Turn right (west) at stop sign on rural road EW 32.
73.1	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).
76.2	3.1	Turn right (west) at stop sign on rural road E 350. Sign indicates direction to Oklahoma's first oil well.
78.4	2.2	Unreclaimed surface mine (spoil piles) in Croweburg coal on left.
79.4	1.0	Turn left (south) at stop sign on rural route NS 418.
80.3	0.9	Abandoned surface mine in Iron Post coal on both sides of road.
83.4	3.1	Abandoned surface mine in Croweburg coal on right (west).
83.9	0.5	Turn right (west) at stop sign on rural road EW 40.
85.9	2.0	View of Round Mound on left (south).
86.9	1.0	Turn left (south) at stop sign on rural route NS 415.
88.9	2.0	Turn right (west) on rural route EW 42.

89.9	1.0	Turn right (north) at stop sign on State Route 88.
90.7	0.8	Cross over Lake Oologah spillway.
92.6	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.
92.7	0.1	Turn right (west) on State Route 88.
93.6	0.9	Optional lunch stop at Hawthorn Bluff shelter on right.
95.3	1.7	View of PSO power plant on left.

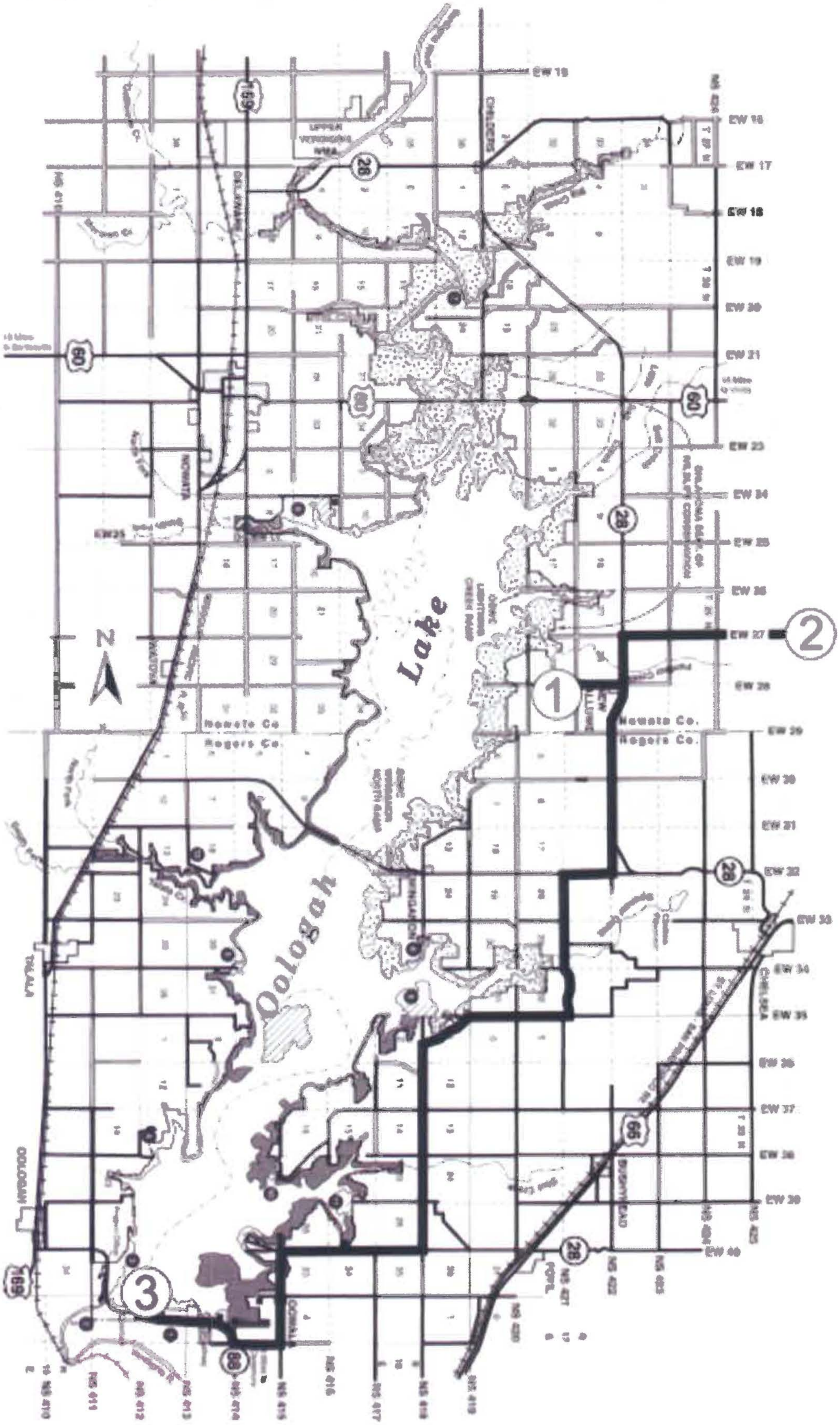
View of unit train with subbituminous coal from Wyoming for PSO power plant.

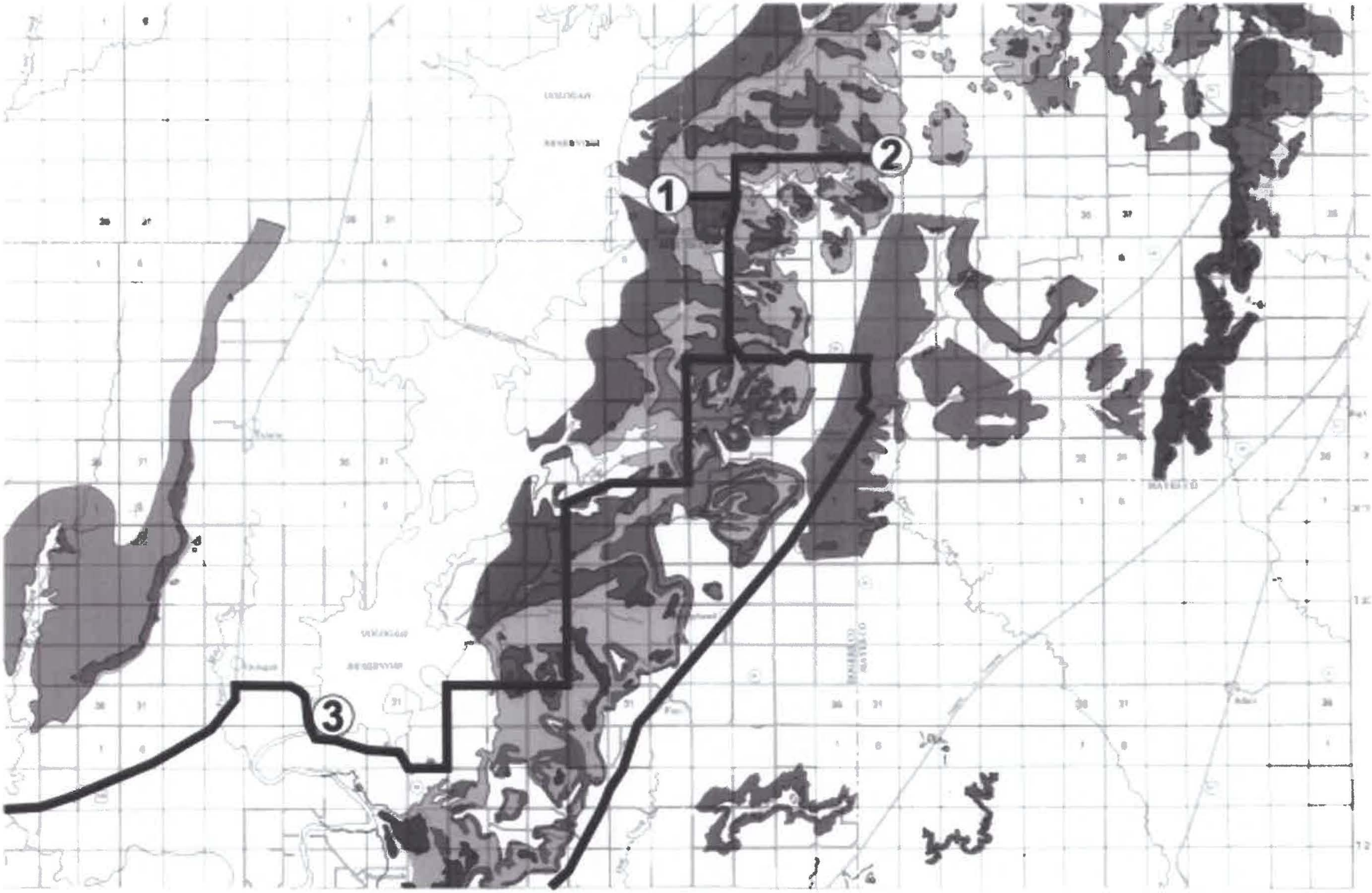
96.3	1.0	Turn left (south) at traffic light on U.S. Route 169 South.
116.1	19.8	Exit (right) on Interstate 244 West/U.S. Route 412 West.
124.2	8.1	Exit (left) on U.S. Route 412 West/U.S. Route 64 West.
132.3	8.1	Exit (right) on 129th West Avenue (State Route 97T).
135.7	3.4	Intersection with State Route 97 South (on right).
135.9	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.
139.5	3.6	Turn left (east) on U.S. Route 64 East.
143.5	4.0	Exit (right) on 65th W Avenue.
143.8	0.3	Turn left (north) on 65th W Ave.
144.1	0.3	At fork in road, stay to the right on Edison Street.
144.9	0.8	Turn left (north) on 57th W.
147.0	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.
149.1	2.1	Turn right (west) on Edison at stop sign.
149.7	0.6	At fork in road, stay left on 65th W Ave.
150.2	0.5	Turn left (east) on U.S. Route 64 East/U.S. Route 412 East.
153.8	3.6	Turn right (south) on Interstate 244 West.
154.2	0.4	Exit (right) on 2nd Street Downtown.
155.0	0.8	Crowne Plaza 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.

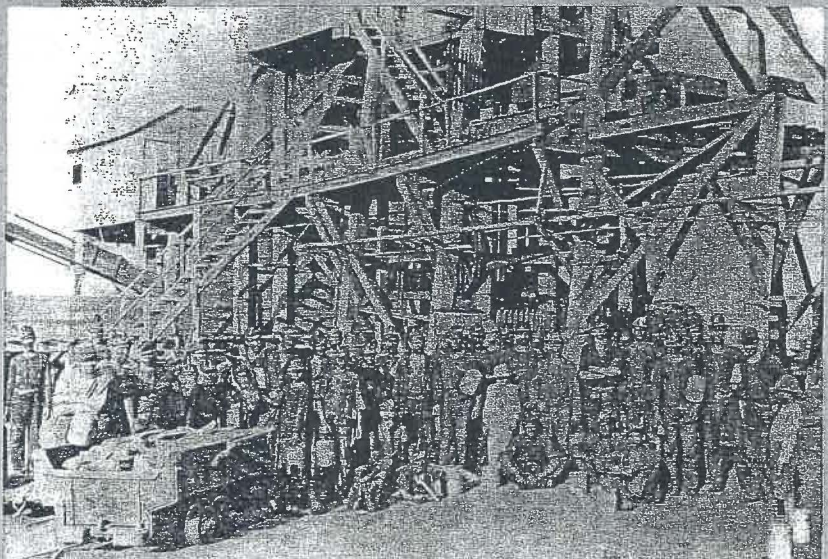
Even at that time, wages paid for mining coal were "the subject of an almost constant dispute between the employer and the employee" (Ashburner, 1890, p. 135). Wages were based primarily on the market price received for the product of the mine. If the employer did not meet wage demands—and mines could 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).

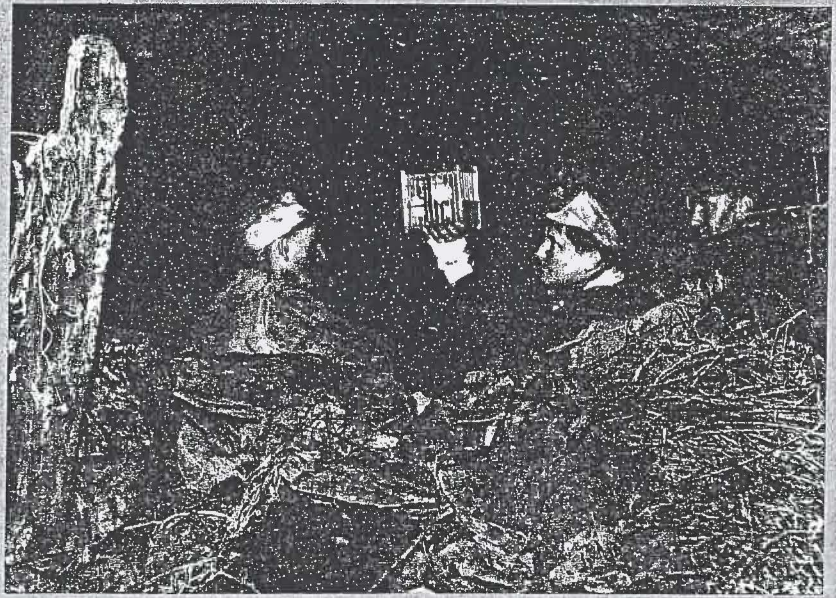
As a result of the completion of the four new railroad lines in the late 1880s, and of the increased market for coal, coal production in Oklahoma had reached a million tons per year by 1891. By 1903, production from 117 mines throughout the coal field exceeded 3.5 million tons per year (Trumbull, 1957,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

2

Introduction to coal geology of Oklahoma

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Cardott, B.J., 2002, Introduction to coal geology of Oklahoma, *in* Fourth annual Oklahoma coalbed-methane workshop: Oklahoma Geological Survey, Open-File Report 9-2002, p. 34-55.

Introduction to Coal Geology of Oklahoma

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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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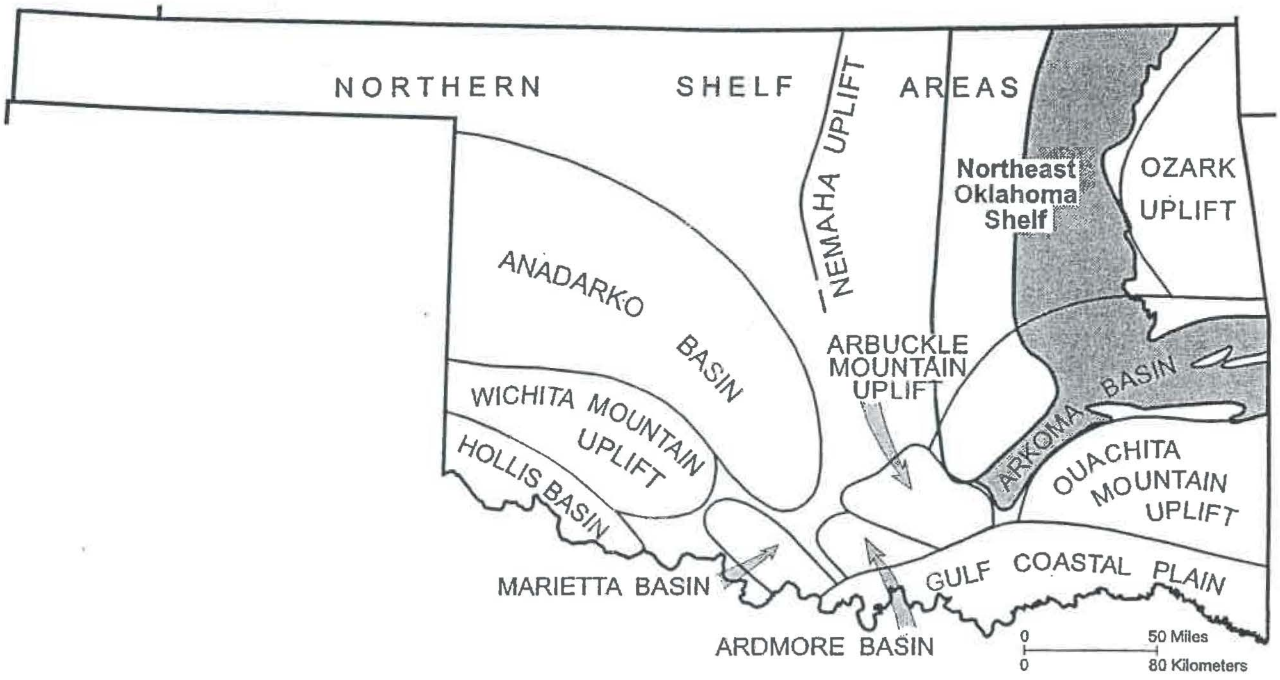


Figure 1. Map of Oklahoma coalfield (modified from Friedman, 1974) in relation to the major geologic provinces of Oklahoma (modified from Johnson and Cardott, 1992).

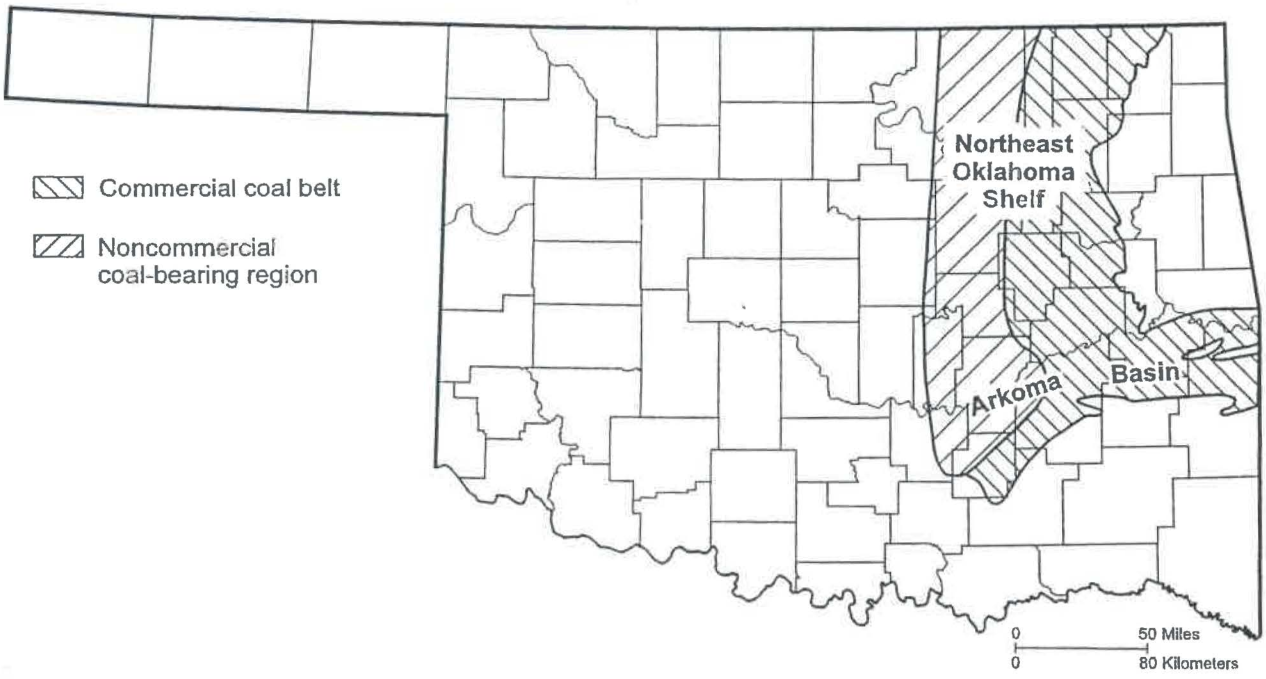


Figure 2. Map of Oklahoma coalfield. Modified from Friedman (1974).

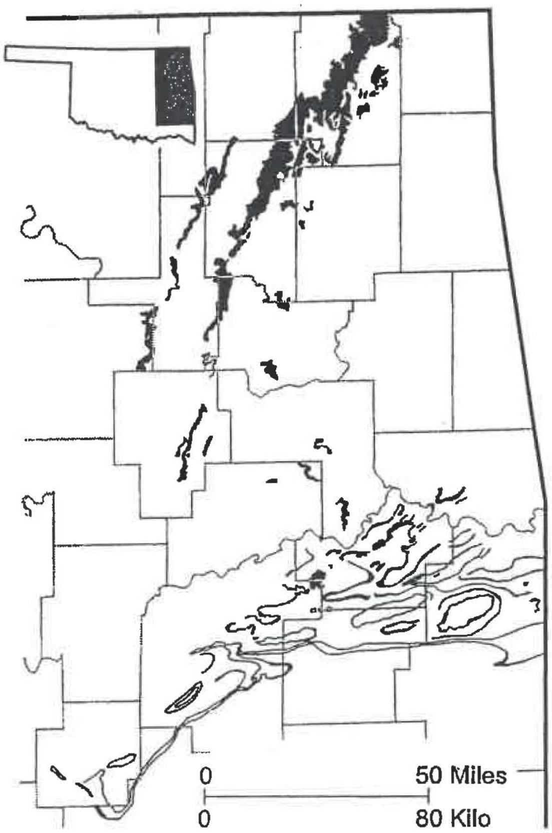


Figure 3. Map showing potentially strippable coal beds in eastern Oklahoma (modified from Friedman, 1982b).

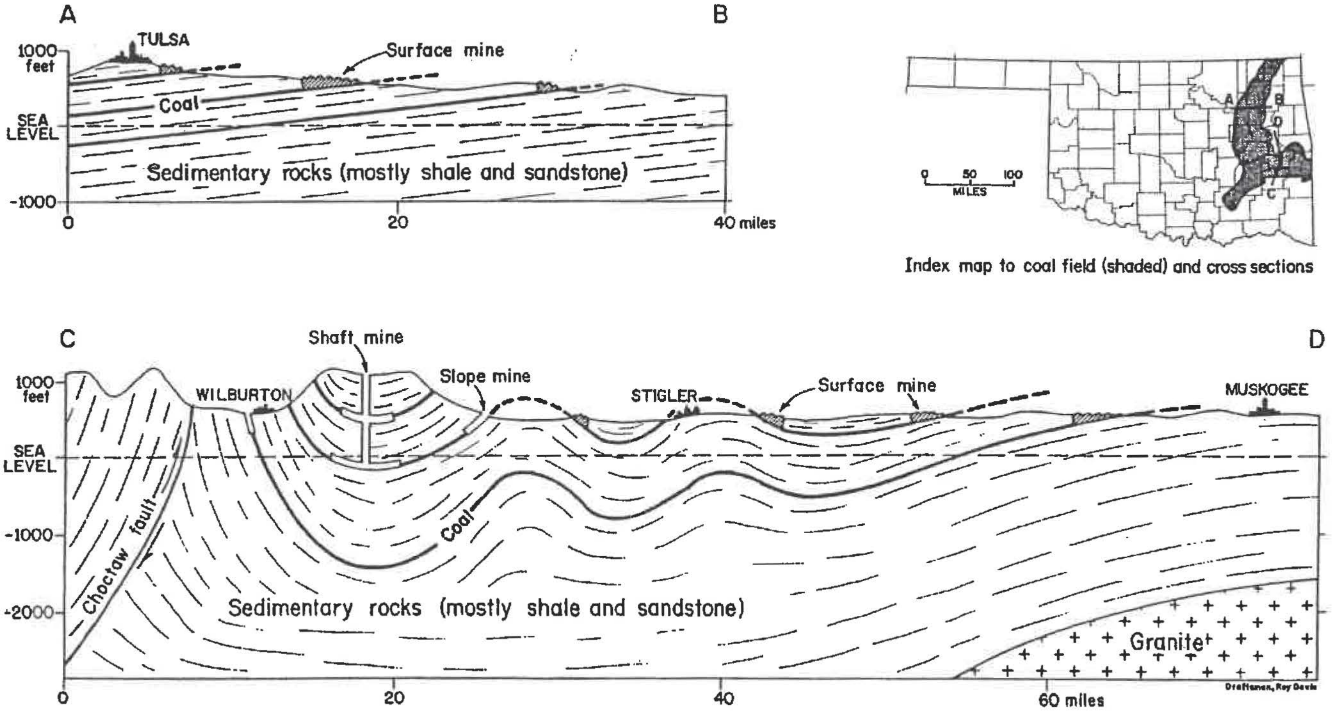
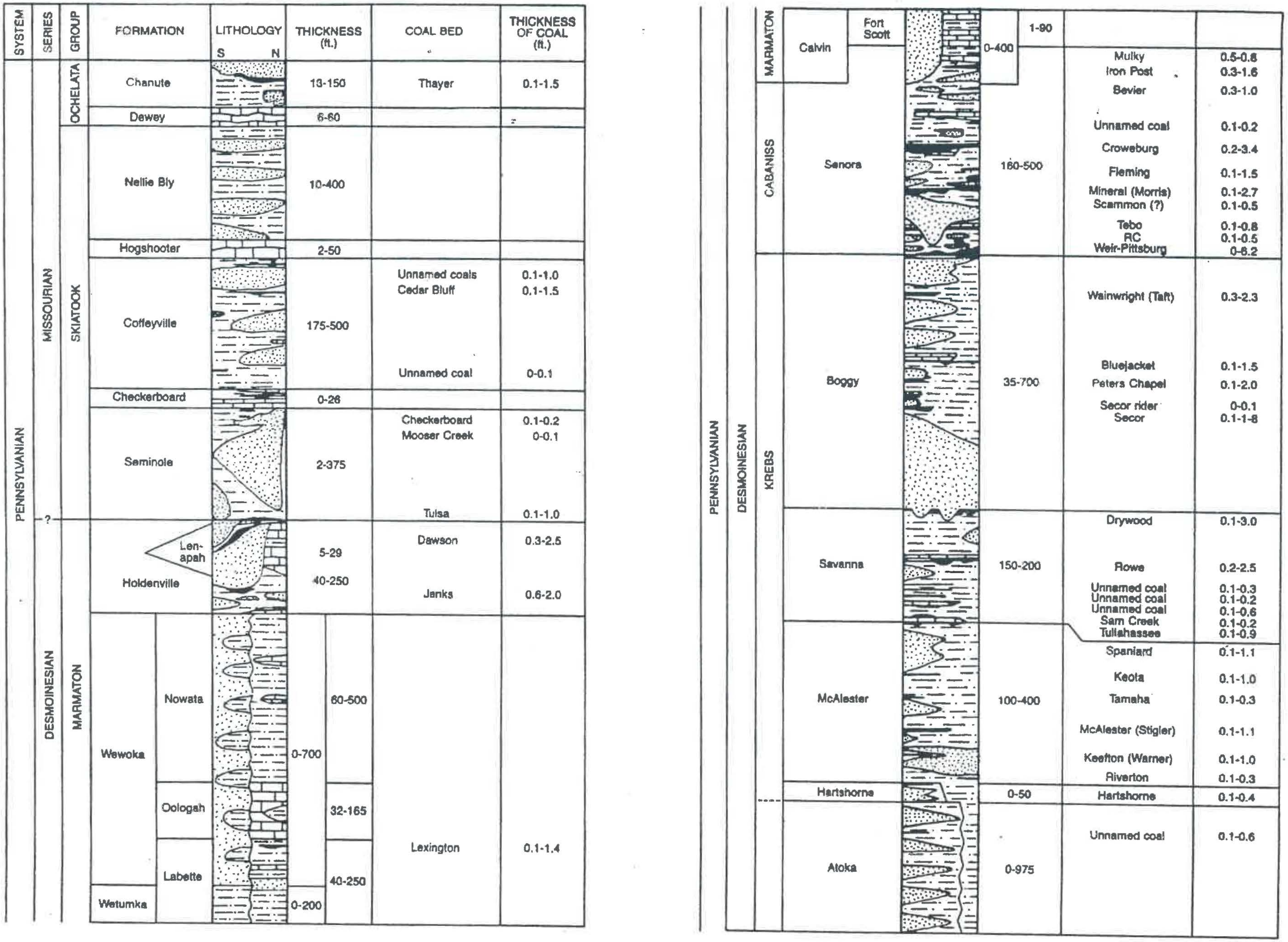


Figure 4. Schematic sections showing geologic structure and types of mines in the Oklahoma coalfield (from Johnson, 1974).



SYSTEM	SERIES	GROUP	FORMATION	THICKNESS (ft.)	COAL BED	THICKNESS OF COAL (ft.)
PENNSYLVANIAN	MISSOURIAN	OCHELATA	Chanute	13-150	Thayer	0.1-1.5
			Dewey	6-60		
		SKIATOOK	Nellie Bly	10-400		
			Hogshooter	2-50		
			Coffeyville	175-500	Unnamed coals Cedar Bluff Unnamed coal	0.1-1.0 0.1-1.5 0-0.1
			Checkerboard	0-26		
			Seminole	2-375	Checkerboard Mooser Creek Tulsa	0.1-0.2 0-0.1 0.1-1.0
	? DESMOINESIAN	MARMATON	Lenapah	5-29	Dawson	0.3-2.5
			Holdenville	40-250	Jenks	0.6-2.0
			Wewoka (0-700): Nowata	60-500		
			Wewoka: Oologah	32-165		
			Wewoka: Labette	40-250	Lexington	0.1-1.4
			Wetumka	0-200		

SYSTEM	SERIES	GROUP	FORMATION	THICKNESS (ft.)	COAL BED	THICKNESS OF COAL (ft.)
PENNSYLVANIAN	DESMOINESIAN	MARMATON	Calvin	0-400		
			Fort Scott	1-90		
		CABANISS	Senora	160-500	Mulky Iron Post Bevier Unnamed coal Croweburg Fleming Mineral (Morris) Scammon (?) Tebo RC Weir-Pittsburg	0.5-0.8 0.3-1.6 0.3-1.0 0.1-0.2 0.2-3.4 0.1-1.5 0.1-2.7 0.1-0.5 0.1-0.8 0.1-0.5 0-6.2
		KREBS	Boggy	35-700	Wainwright (Taft) Bluejacket Peters Chapel Secor rider Secor	0.3-2.3 0.1-1.5 0.1-2.0 0-0.1 0.1-1.8
			Savanna	150-200	Drywood Rowe Unnamed coal Unnamed coal Unnamed coal Sam Creek Tullahassee	0.1-3.0 0.2-2.5 0.1-0.3 0.1-0.2 0.1-0.6 0.1-0.2 0.1-0.9
			McAlester	100-400	Spaniard Keota Tamaha McAlester (Stigler) Keefton (Warner) Riverton	0.1-1.1 0.1-1.0 0.1-0.3 0.1-1.1 0.1-1.0 0.1-0.3
			Hartshorne	0-50	Hartshorne	0.1-0.4
			Atoka	0-975	Unnamed coal	0.1-0.6

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

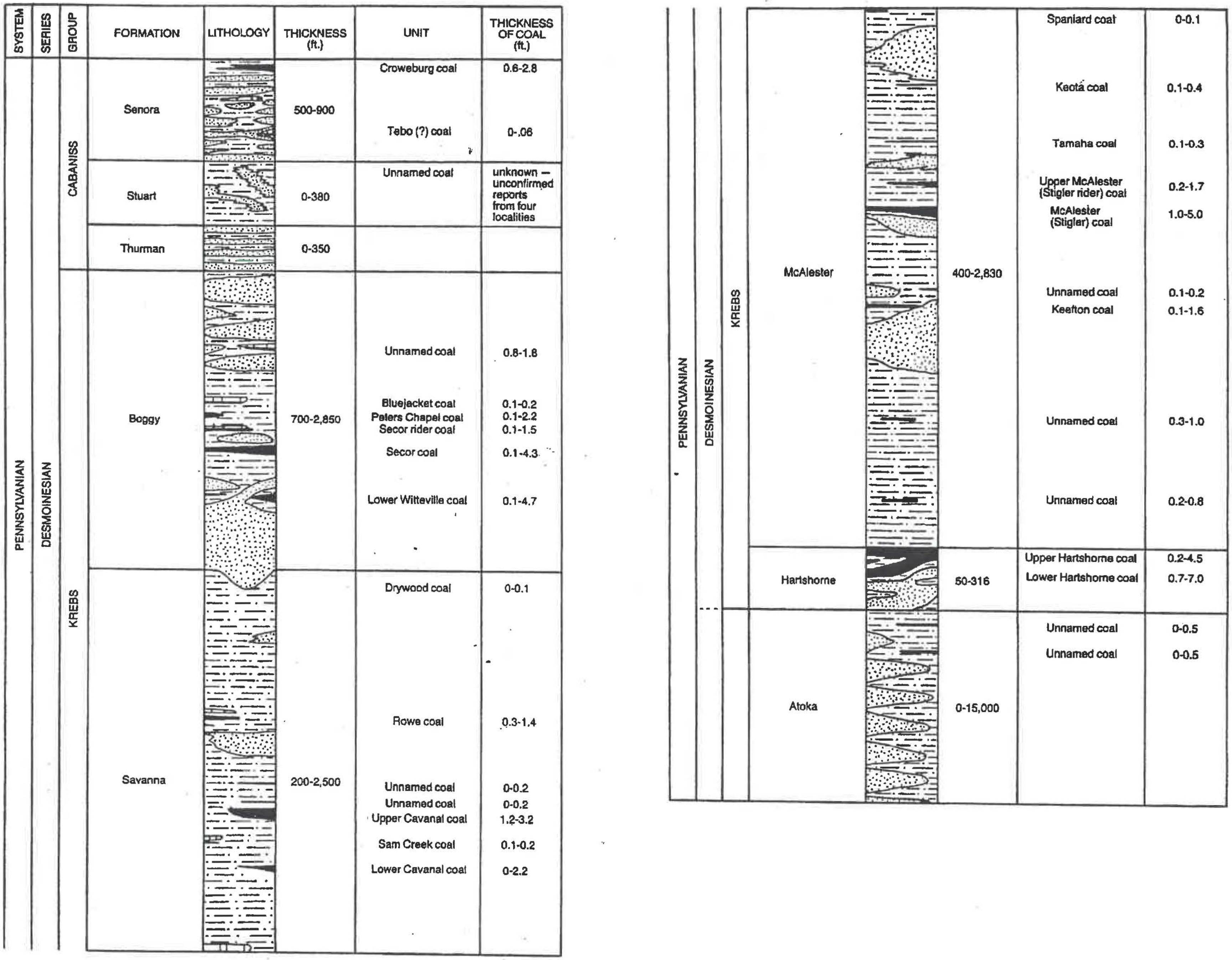


Figure 6. Generalized stratigraphy of coal-bearing strata of the Arkoma basin (from Hemish, 1988).

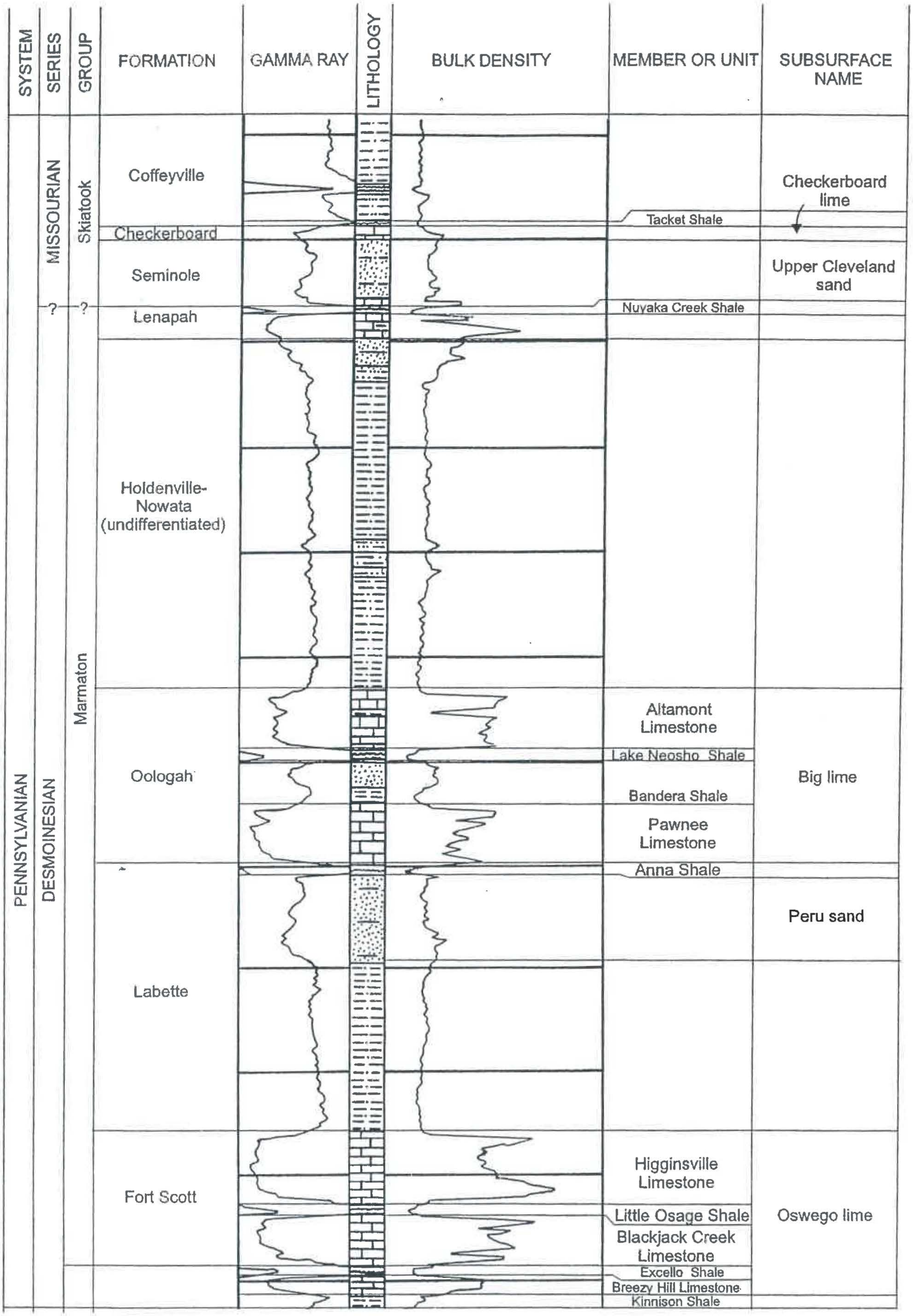
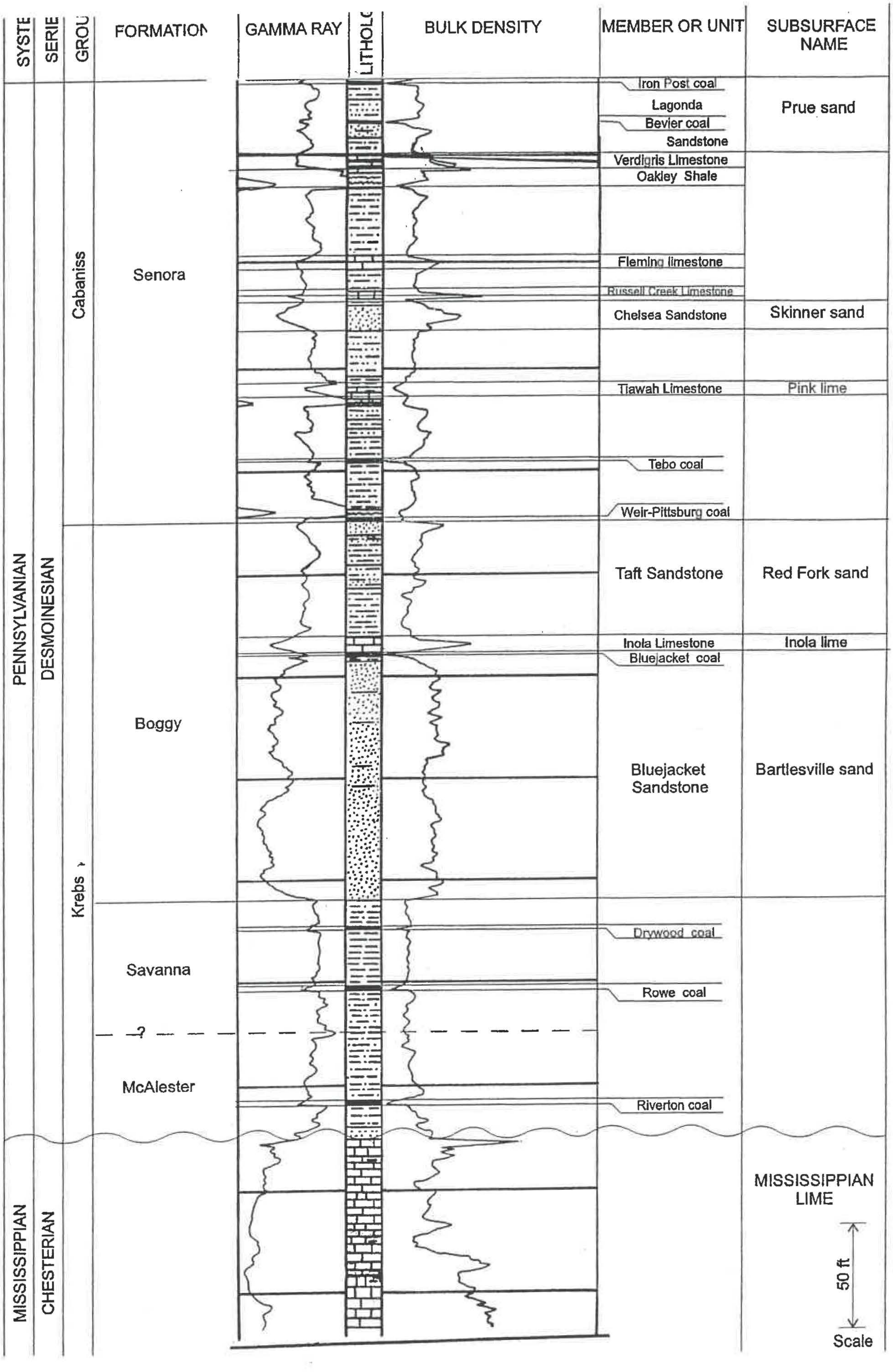


Figure 7. Type log for northern part of northeast Oklahoma shelf (from Hemish, 2002, fig. 18).


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

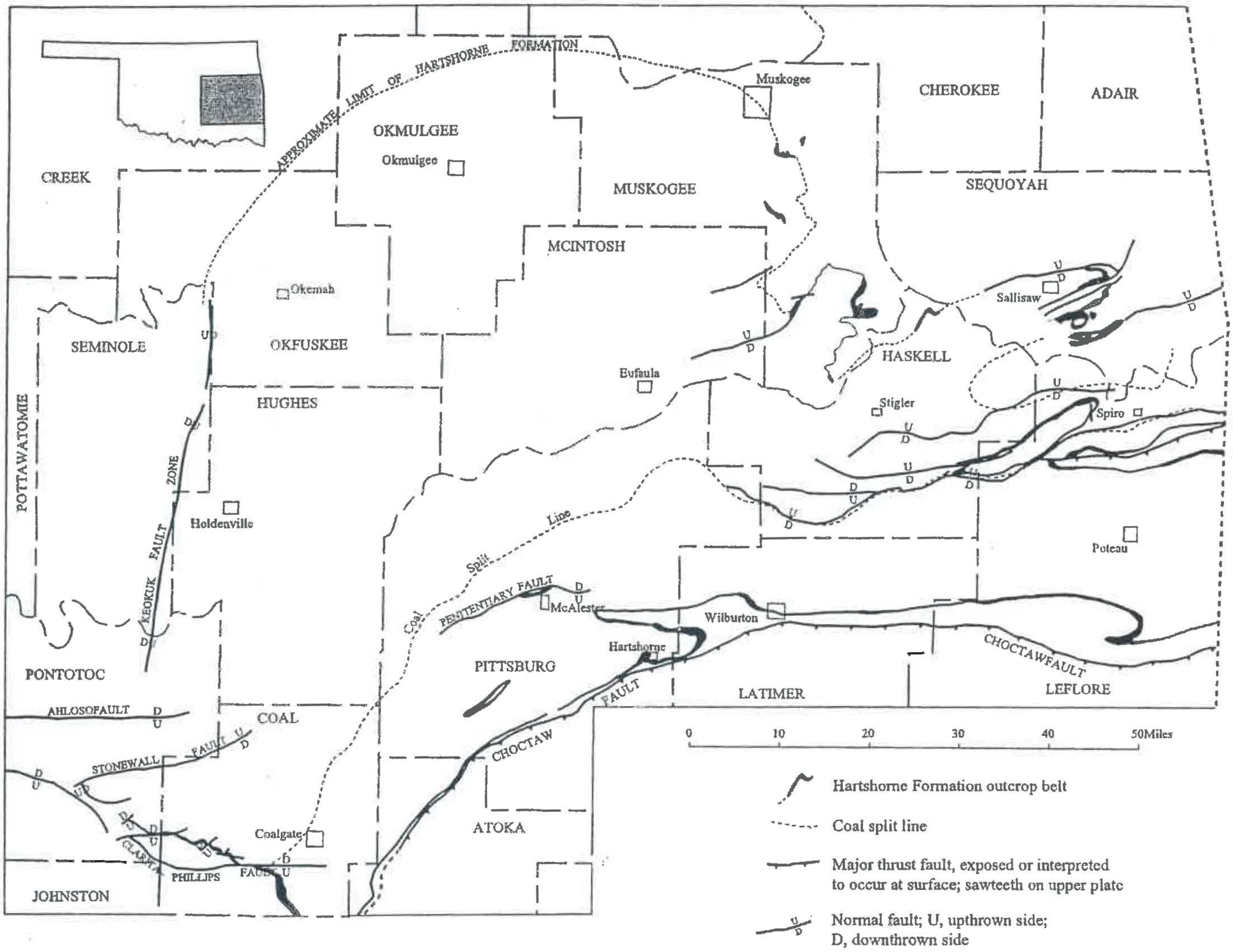


Figure 8. Distribution of the Hartshorne coal in the Arkoma basin, showing the coal split line (from Cardott, 2002a)

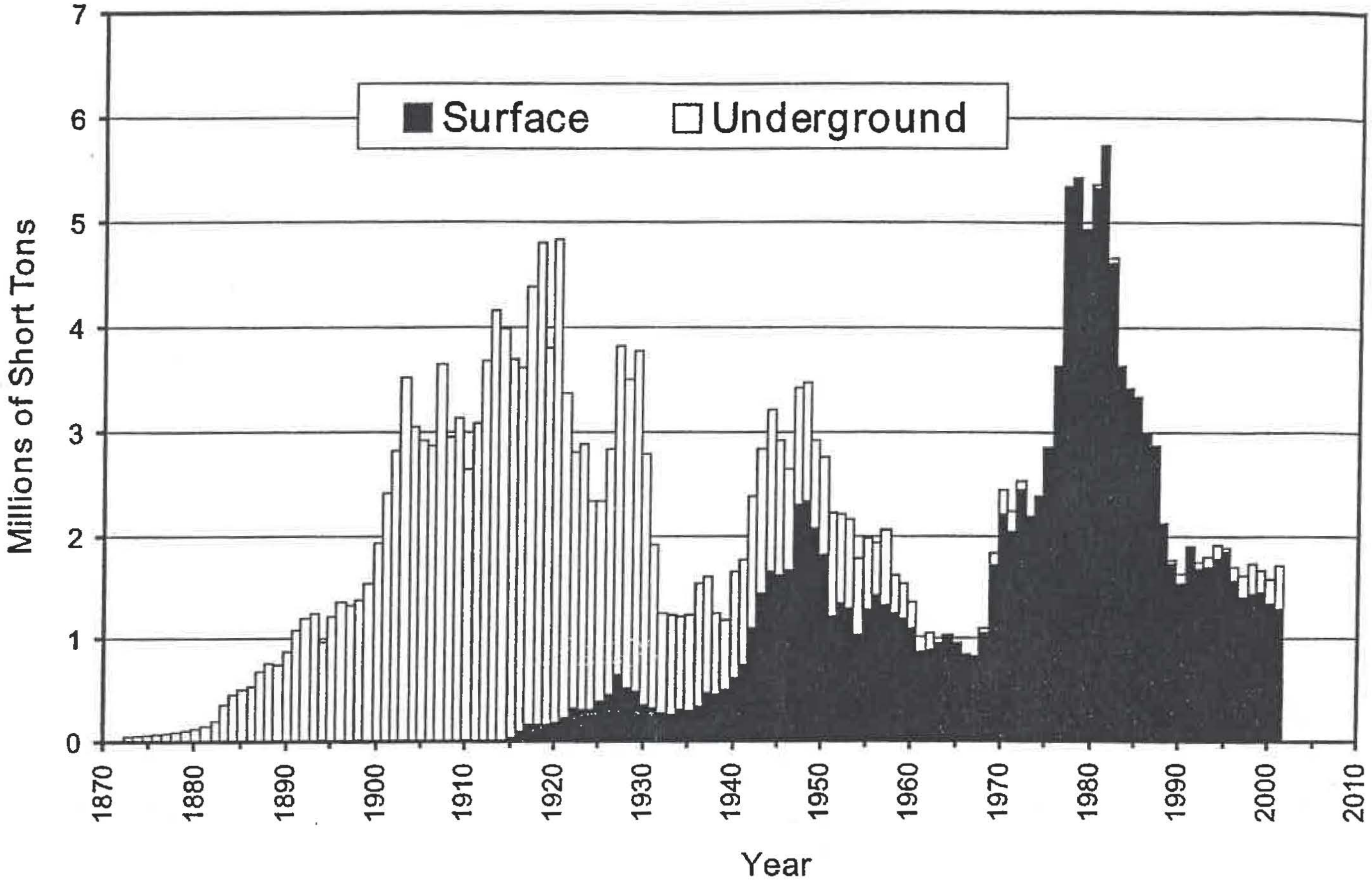


Figure 9. Coal production in Oklahoma, 1873-2001
(from Federal and State data).

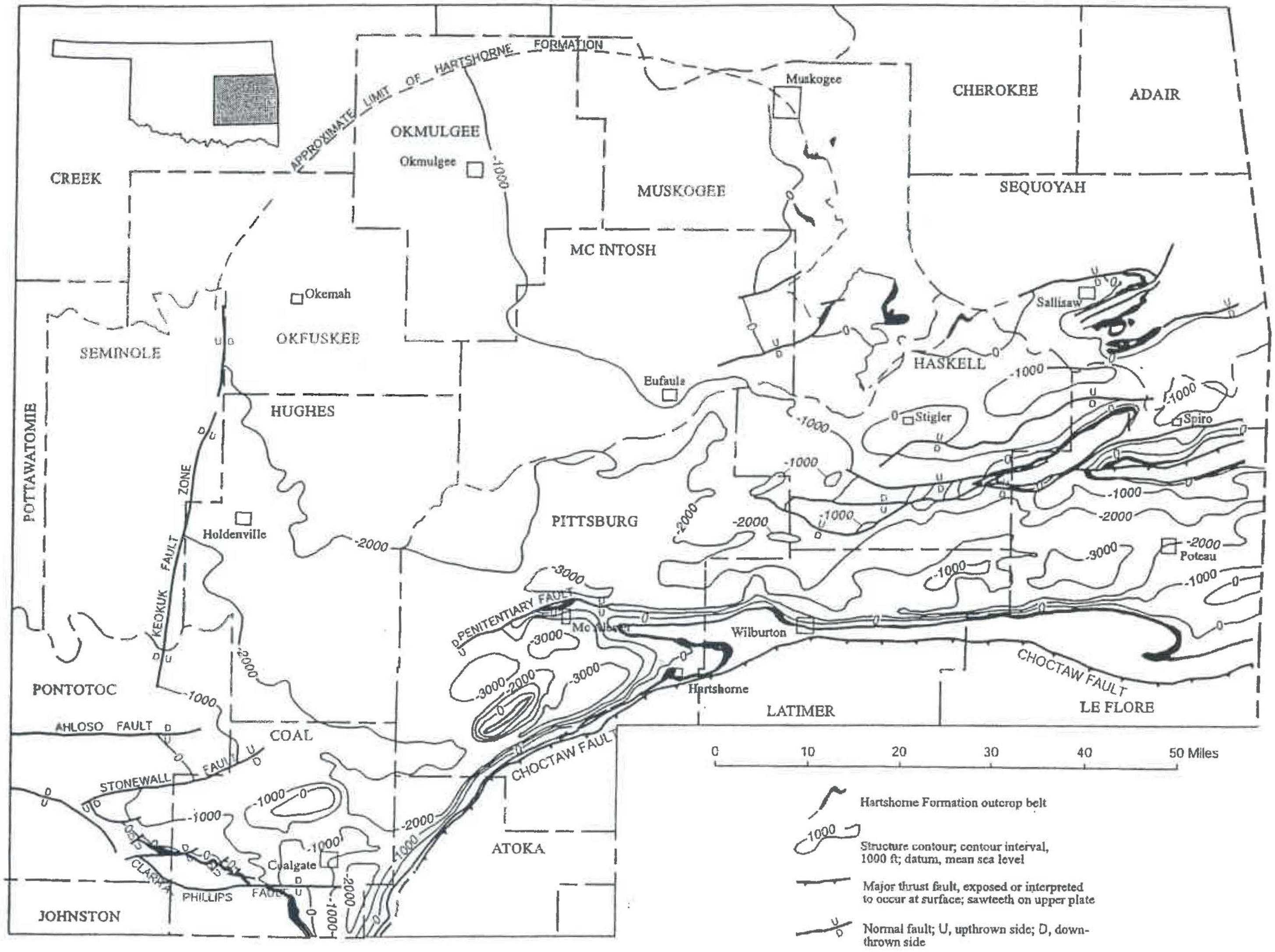


Figure 10. Regional structure on the top of the Hartshorne Formation (from Cardott, 2002a).

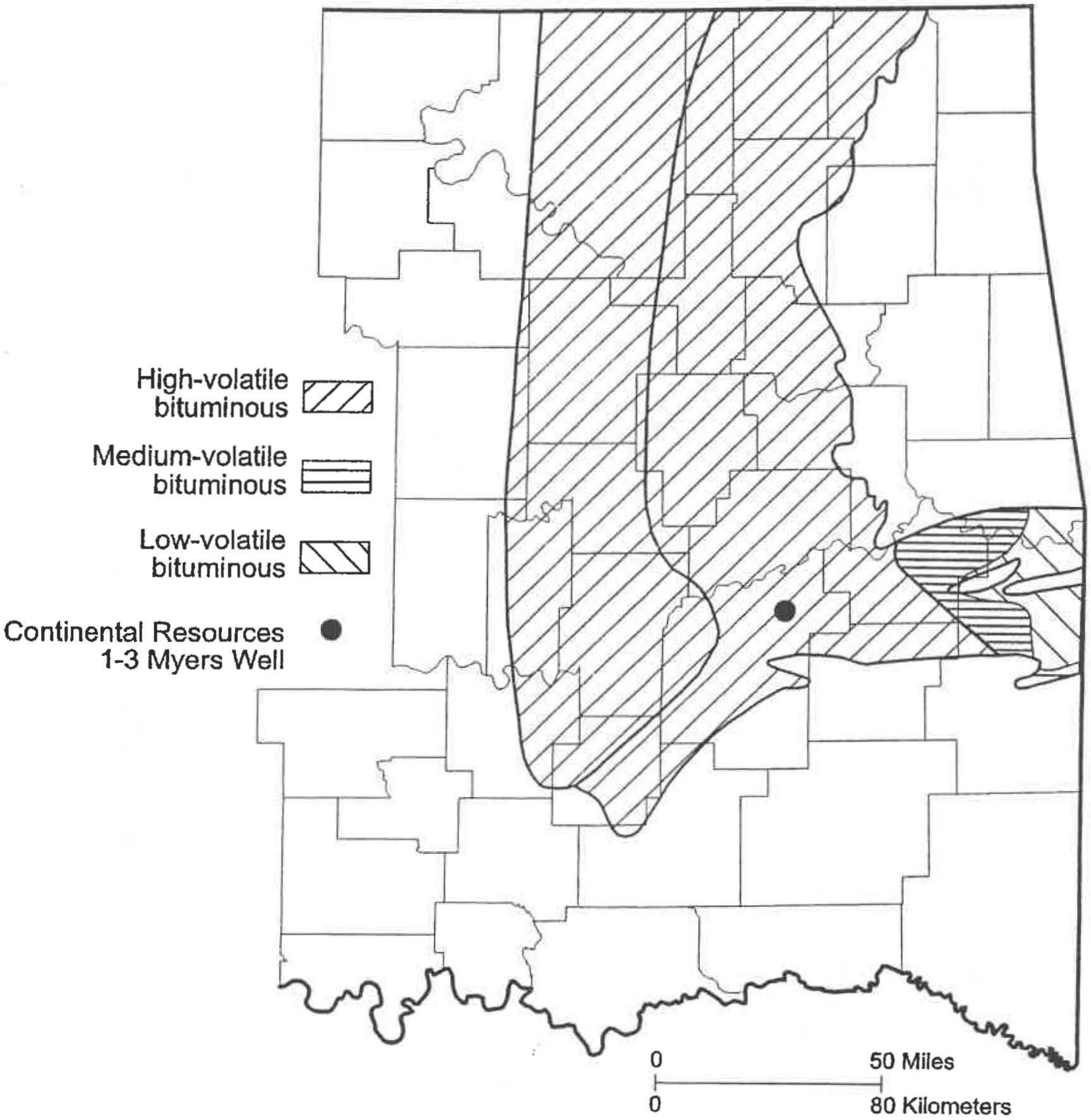


Figure 11. Generalized rank of all coal beds at or near the surface in the Oklahoma coalfield. Modified from Friedman (1974) and Andrews and others (1998).

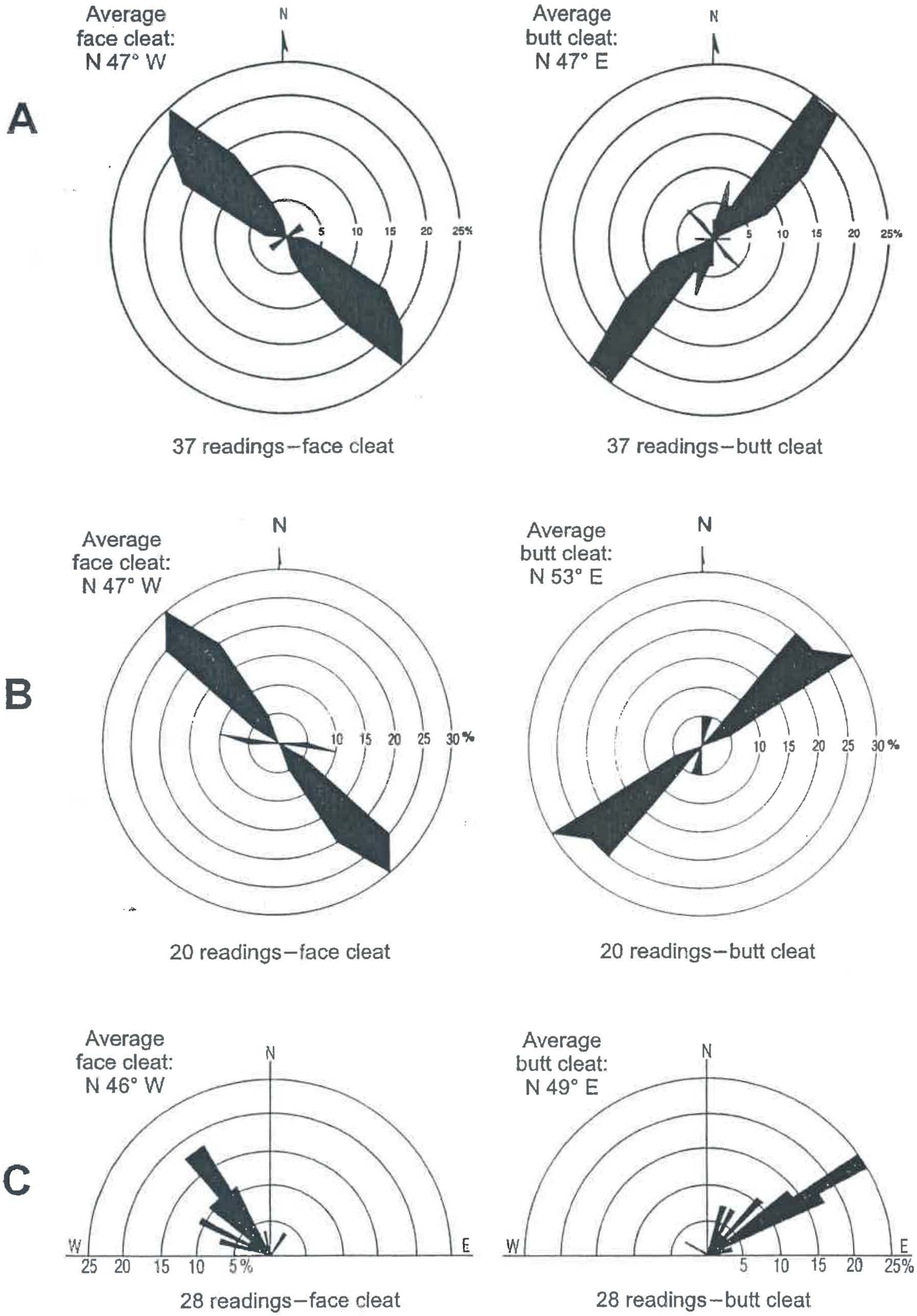


Figure 12. Rose diagrams of cleat orientations in coal beds (from Hemish, 2002). A. Craig and Nowata Counties. B. Rogers and Mayes Counties. C. Tulsa and Wagoner Counties.

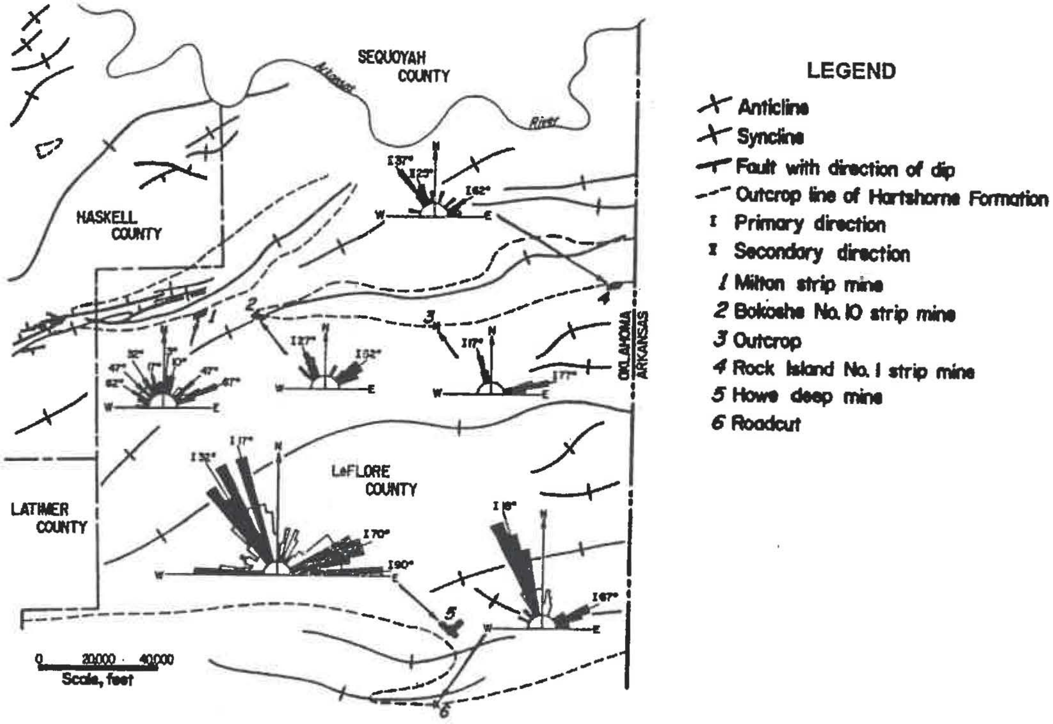


Figure 13. Coal cleat orientations of the Hartshorne coal, Le Flore County, Oklahoma (from Iannacchione and Puglio, 1979a).

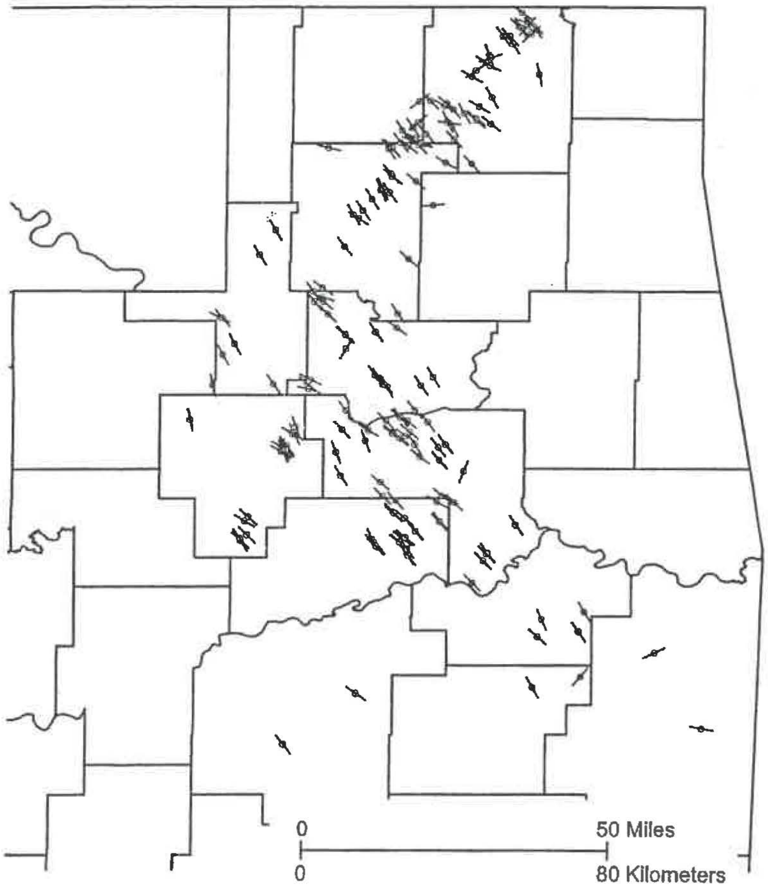


Figure 14. Map of face-cleat orientations in the Oklahoma coalfield from data in Hemish (1986, 1989, 1990a, 1994, 1998a, 1998b) and Friedman (unpublished).

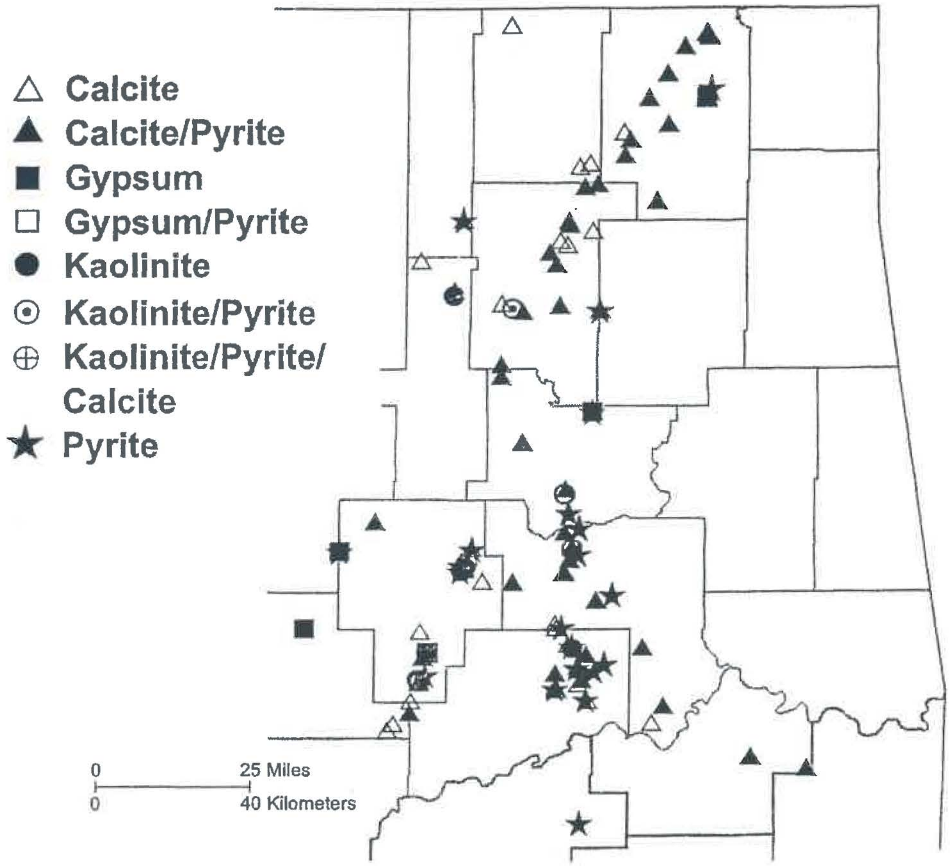


Figure 15. Map showing the distribution of cleat-filling minerals in northeast Oklahoma coal beds from data in Hemish (1986, 1988, 1989, 1990a, 1990b, 1994, 1997, 1998a, 1998b) and Friedman (unpublished).

Stop 1. Phoenix Coal Company Alluwe Mine

Location: NE¼ NW¼ Sec. 33, T.25N., R.17E., Nowata County, Oklahoma.
Winganon and Chelsea 7.5 minute quadrangles.

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 and overburden, and collect coal samples.

Coal crushing facility.

Coal is shipped by truck.

View of highwall, looking northeast.

View of Iron Post coal, Kinnison shale, and Breezy Hill Limestone (~12 ft highwall), looking southeast.

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

~17 in. thick, dip ~2° NW.

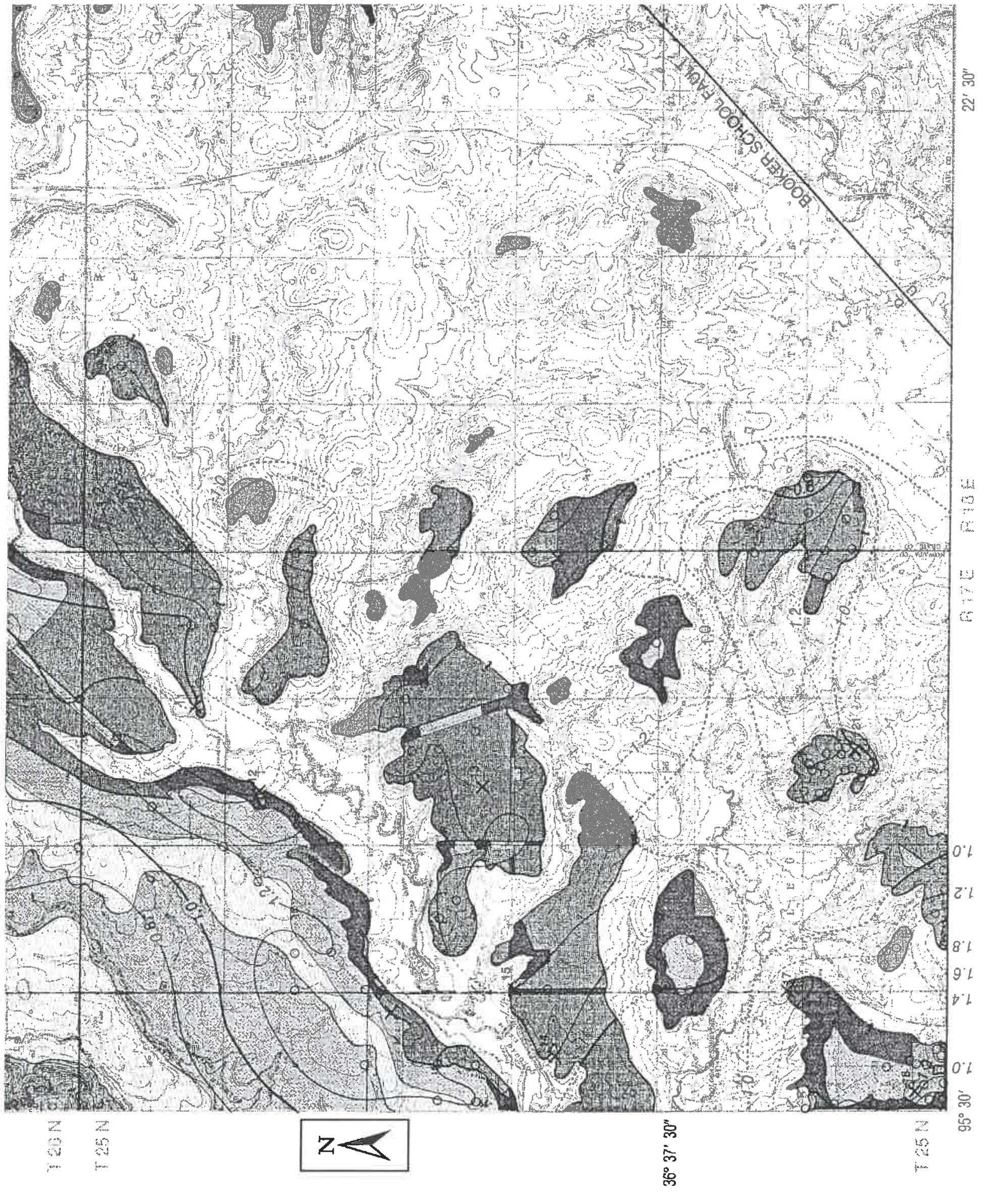
Face cleat N26°W, 0.5 in. spacing; calcite and pyrite filling cleat.

Overburden: 12-25 ft (Kinnison shale above coal;
Breezy Hill limestone above shale)

Petrographic coal rank: high volatile B bituminous
[vitrinite reflectance (Rmax) = 0.58%].

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).

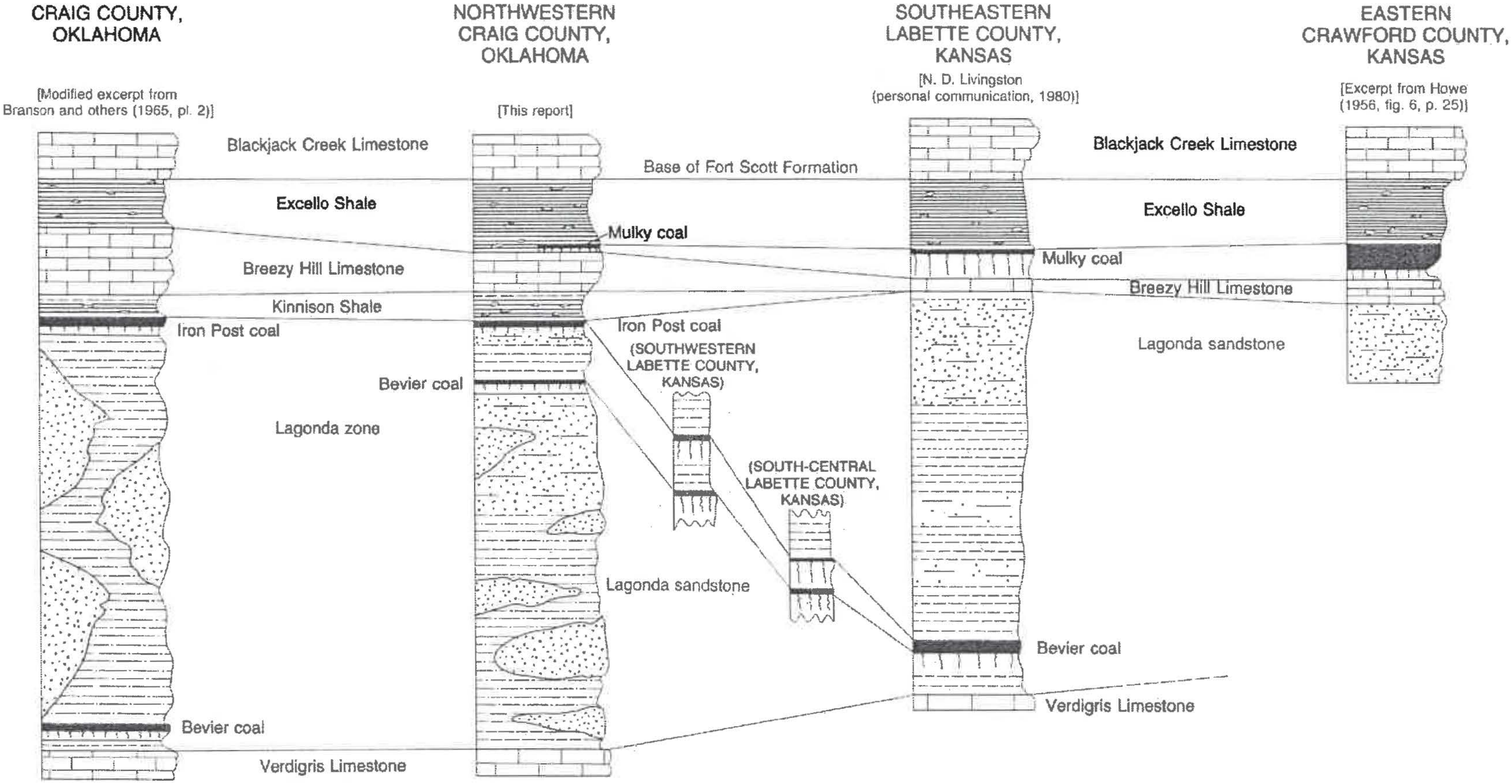
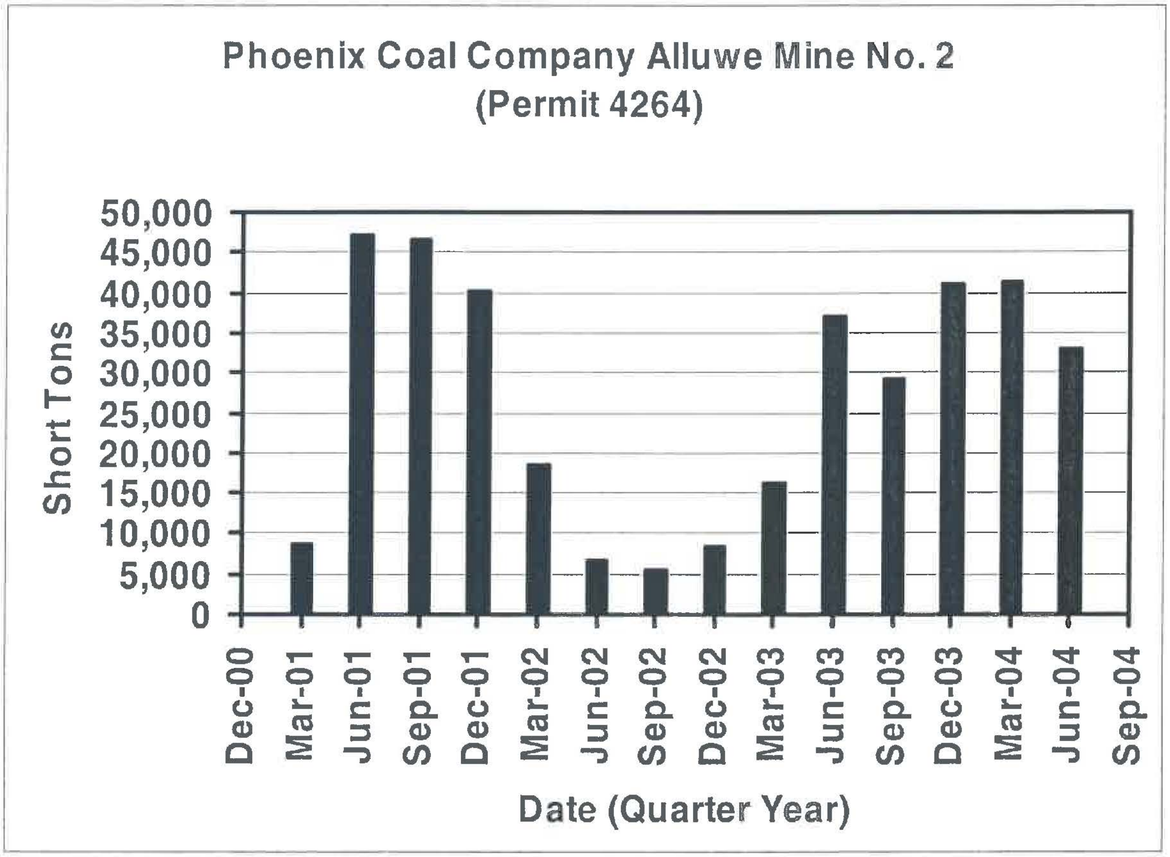


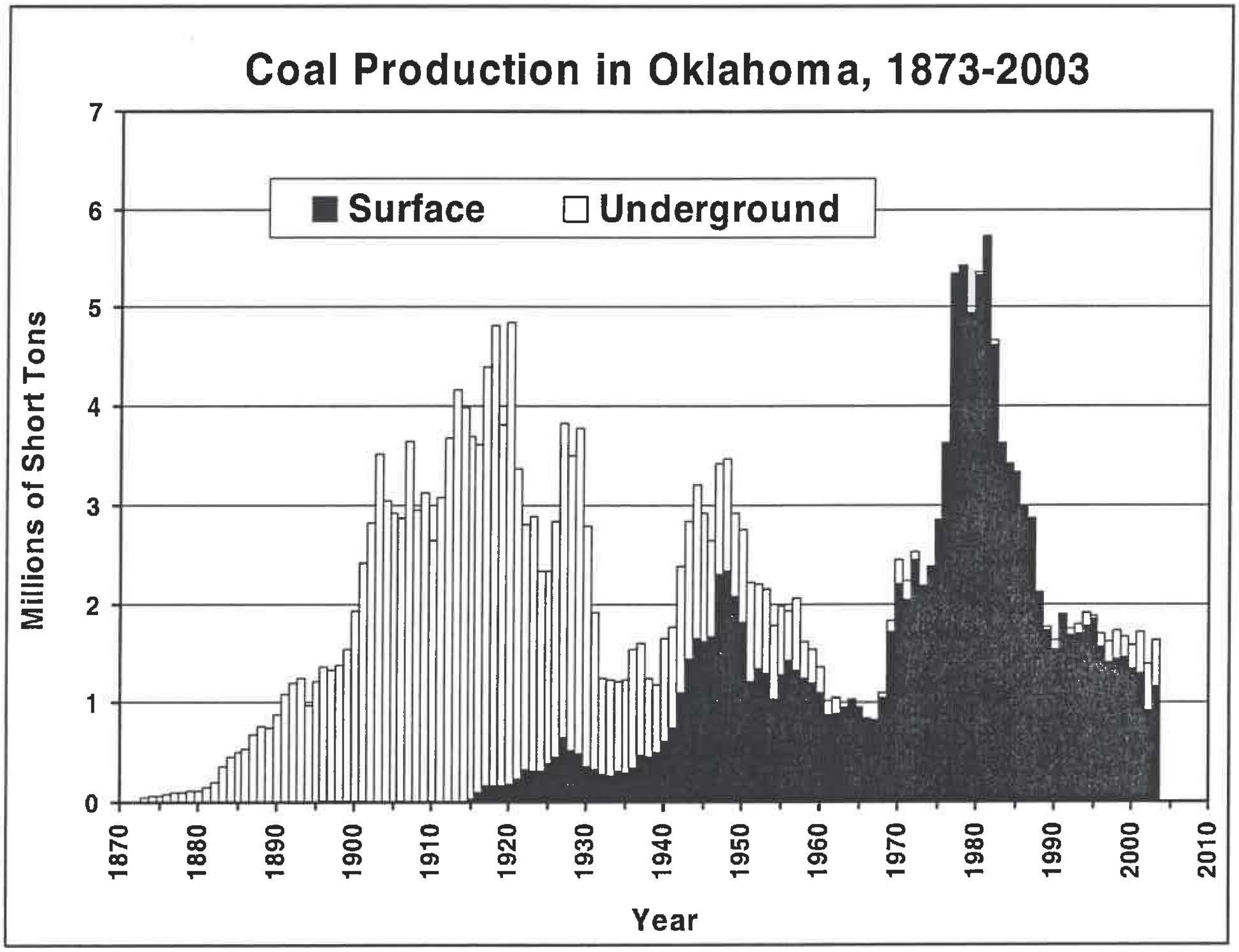
Figure 13. Stratigraphic positions of the Bevier coal, the Iron Post coal, and the Mulky coal, and correlation of beds in northwestern Craig County, Oklahoma, southern Labette County, Kansas, and eastern Crawford County, Kansas. The stratigraphic interpretation of Branson and others (1965) contrasts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

The Alluwe mine opened in March 2001. Year 2003 production was 123,558 short tons (7.6% of Oklahoma coal production; total Oklahoma coal production in 2003 was 1,631,073 short tons from 11 mines).



From 1873–2003, 284,347,034 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 and food-grade carbon dioxide to Tyson Foods. 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 per hour (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) M.	V.M.	F.C.	Ash	SULFUR (percent)	Btu
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

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

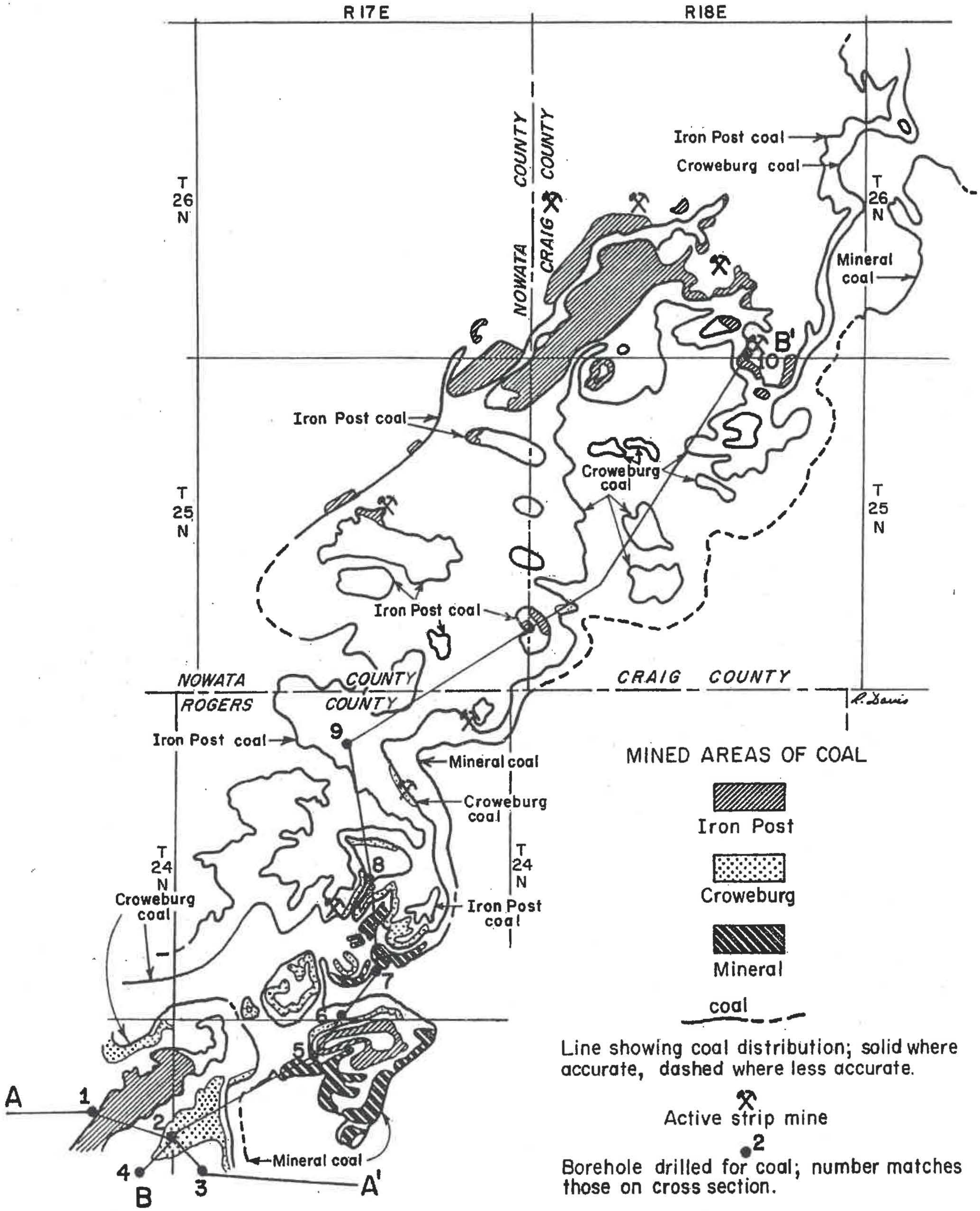

Fig. 1. Map showing distribution and surface-mined areas of principal coals in parts of Craig, Nowata, and Rogers Counties, northeastern Oklahoma. (Lines A-A' and B-B' indicate cross sections shown on Figs. 3 and 4.)

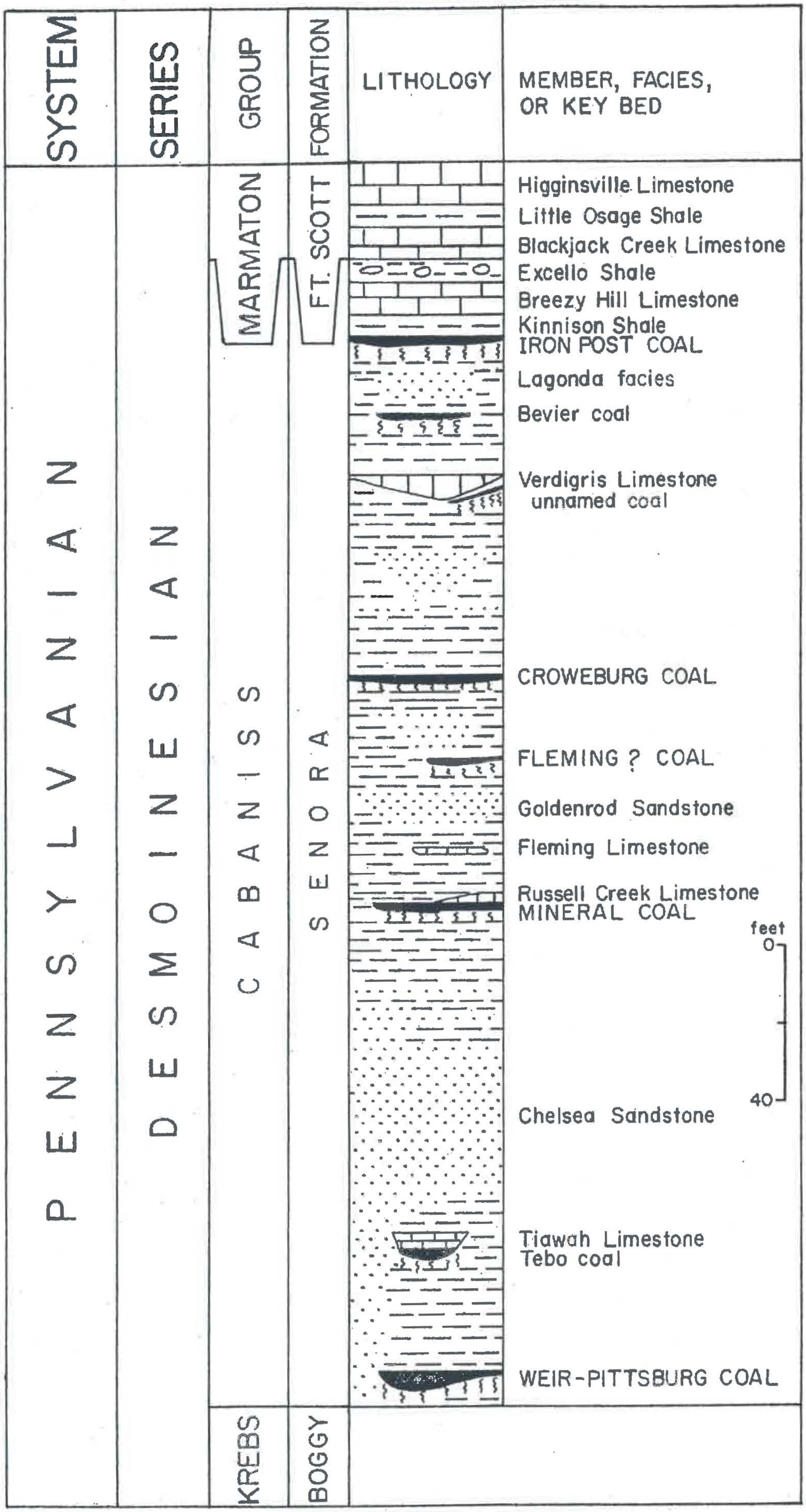

Fig. 2. Generalized geologic column showing the Senora and Ft. Scott Formations in the map area.

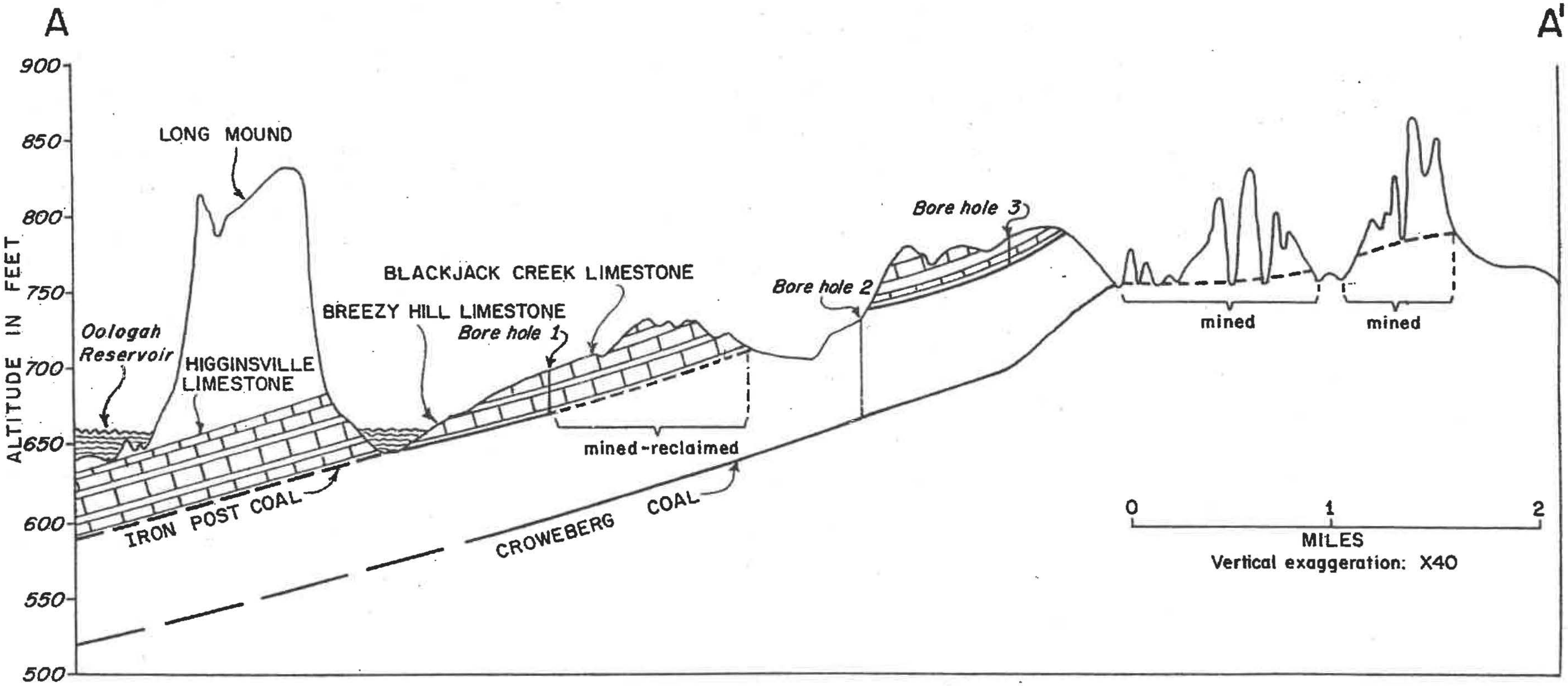

Fig. 3. Cross section along line A-A' (see Fig. 1) showing stratigraphic relationship of the Croweburg and Iron Post Coals and the Breezy Hill and Ft. Scott Limestones.

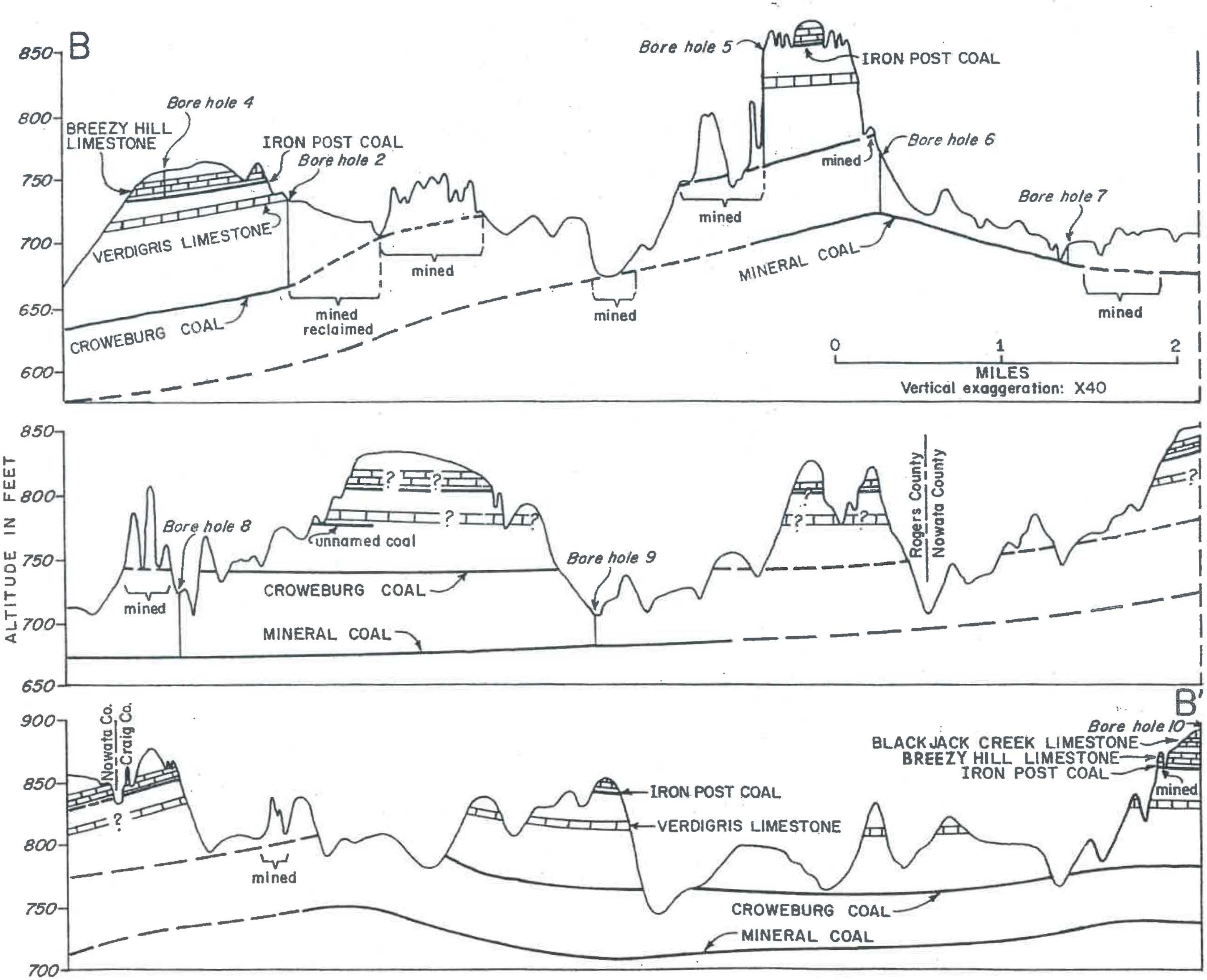

Fig. 4. Cross section B-B' showing stratigraphic relationship of the principal coals and limestones in the map.

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Stop 2. Phoenix Coal Company Kelley Mine

Location: SW_ SE_ 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 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 70 ft highwall.

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

~16.5 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

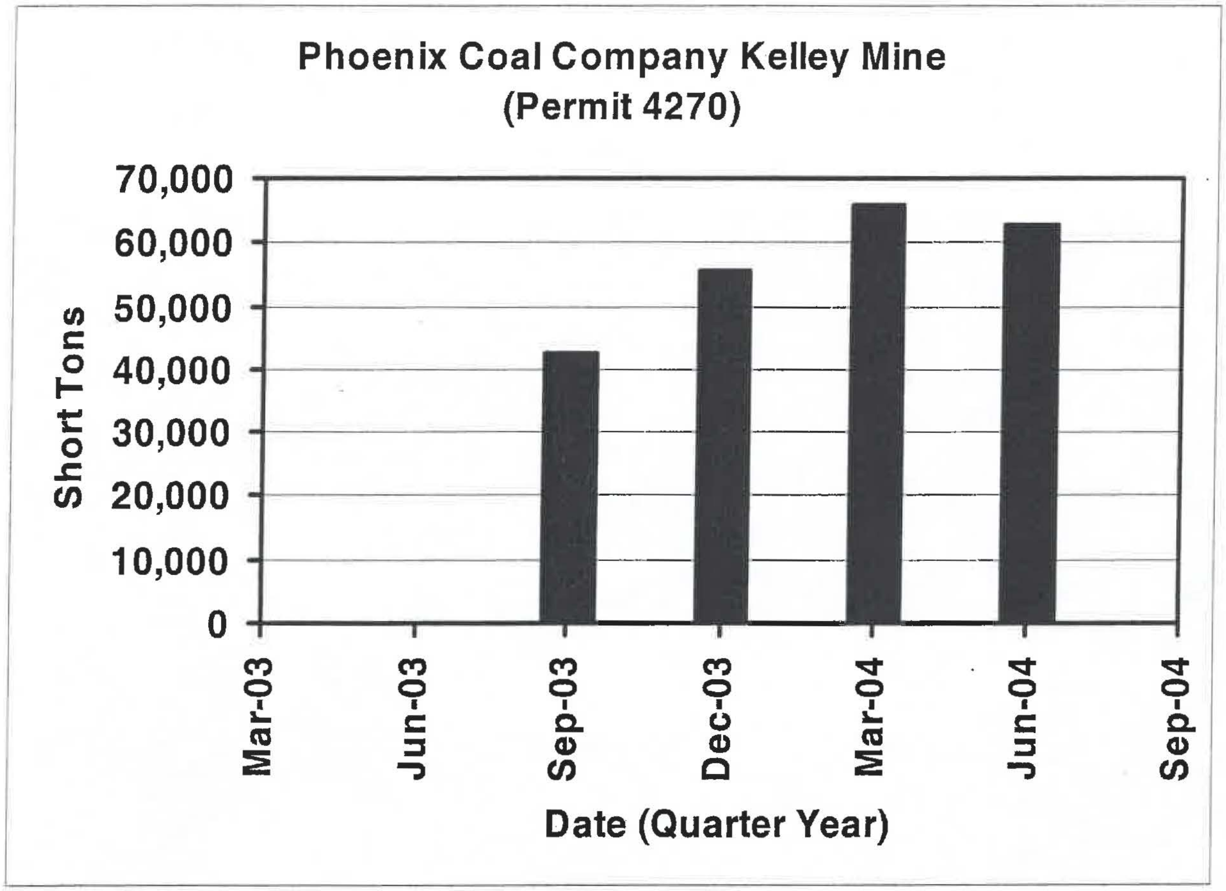
Measured section 29 (from Hemish, 1986).

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 2003 production was 98,020 short tons (6.0% of Oklahoma coal production; total Oklahoma coal production in 2003 was 1,631,073 short tons from 11 mines).



Stop 3. Overlook and lunch stop at Oologah Lake

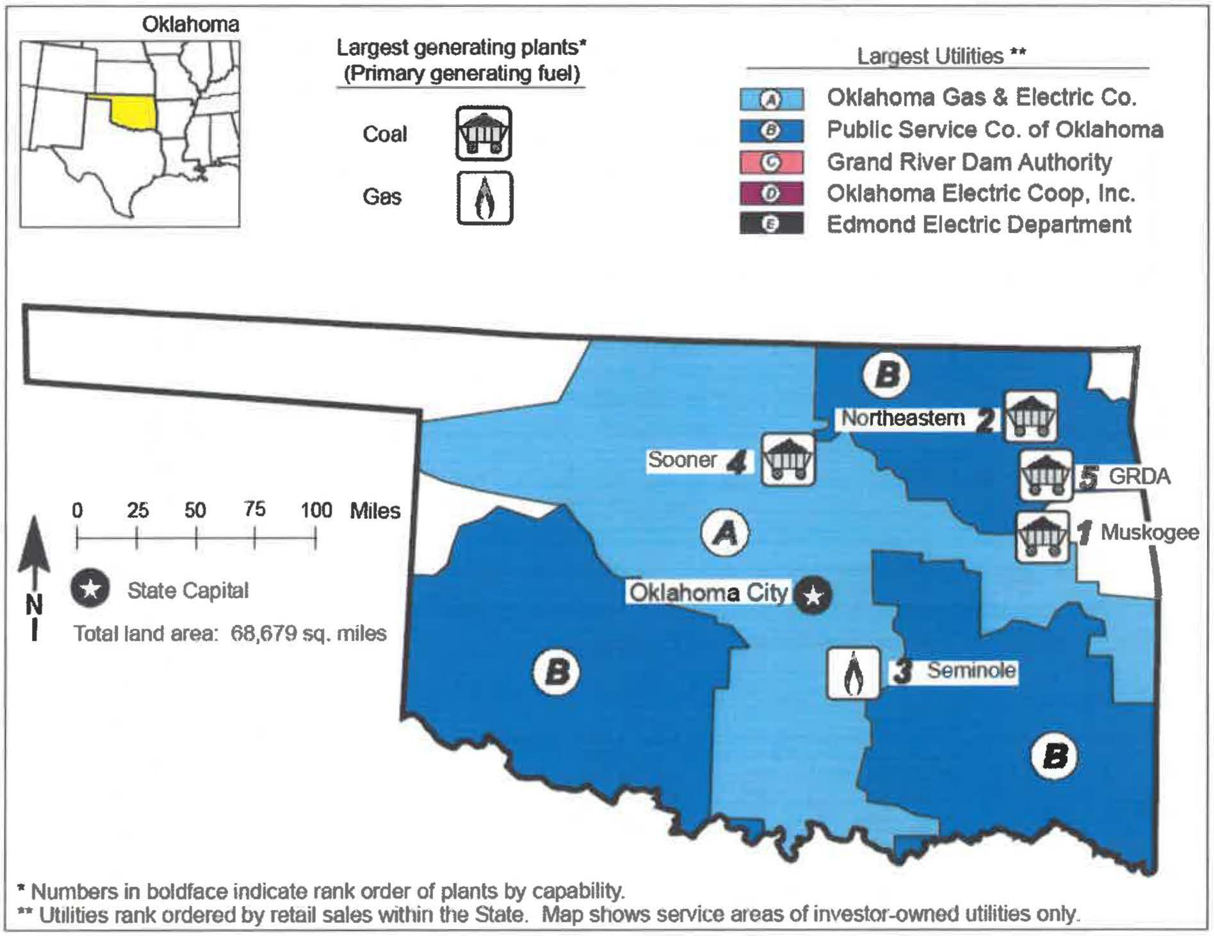
Location: NW_ NW_ SW_ NE_ Sec. 2, T.22N., R.15E., Rogers County, Oklahoma, north side of state highway 88. Oologah 7.5 minute quadrangle.

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.

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) per hour (441 MW from each unit). Net capability of the plant is 1,549 MW (EIA, 2004a). 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 61% of electricity in Oklahoma in 2002 (down from 68% in 1997)(EIA, 2004a).

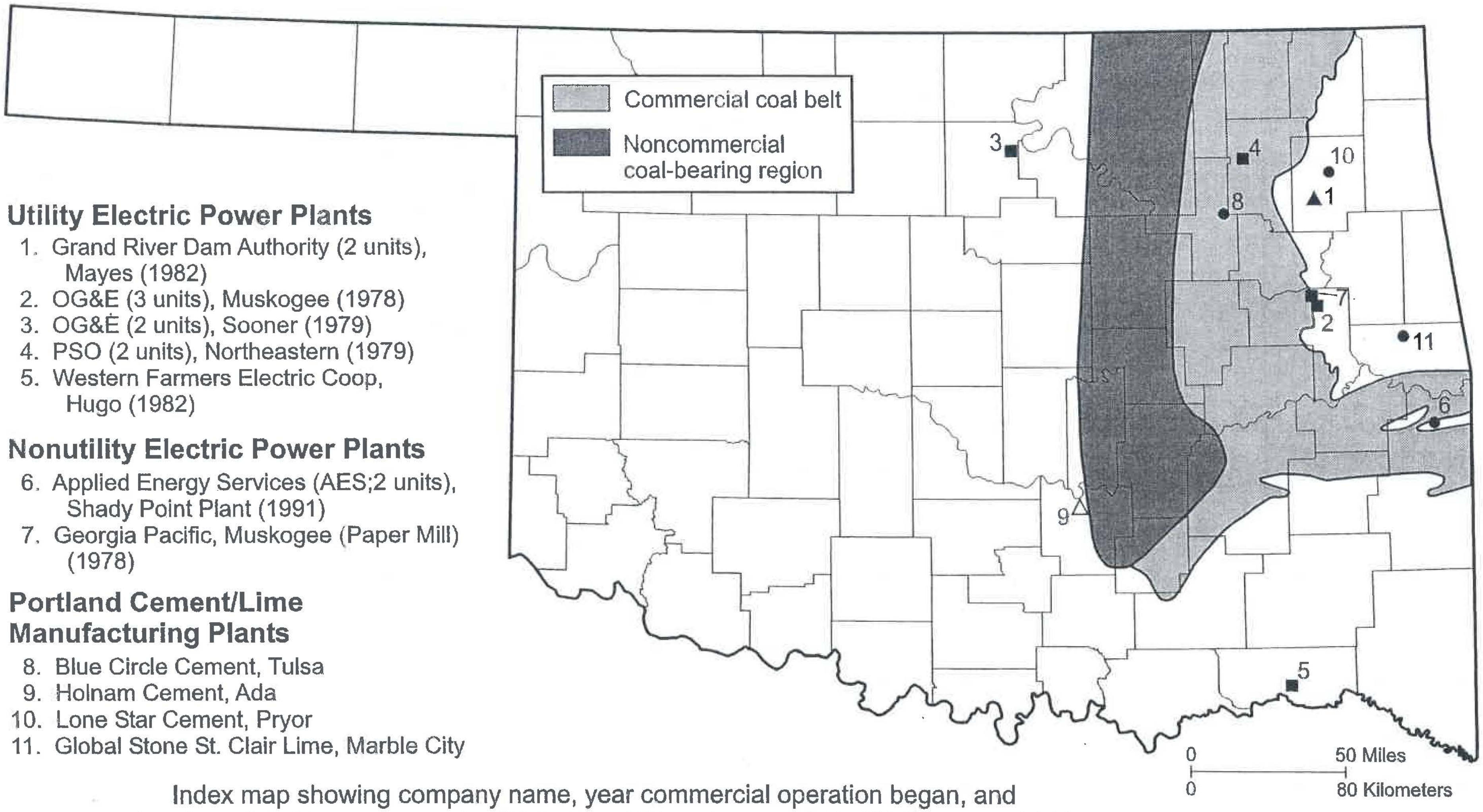


* Numbers in boldface indicate rank order of plants by capability.

** Utilities rank ordered by retail sales within the State. Map shows service areas of investor-owned utilities only.

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 20.7 million short tons of subbituminous coal from Wyoming to five utility electric power plants in 2002 (EIA, 2004b).

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

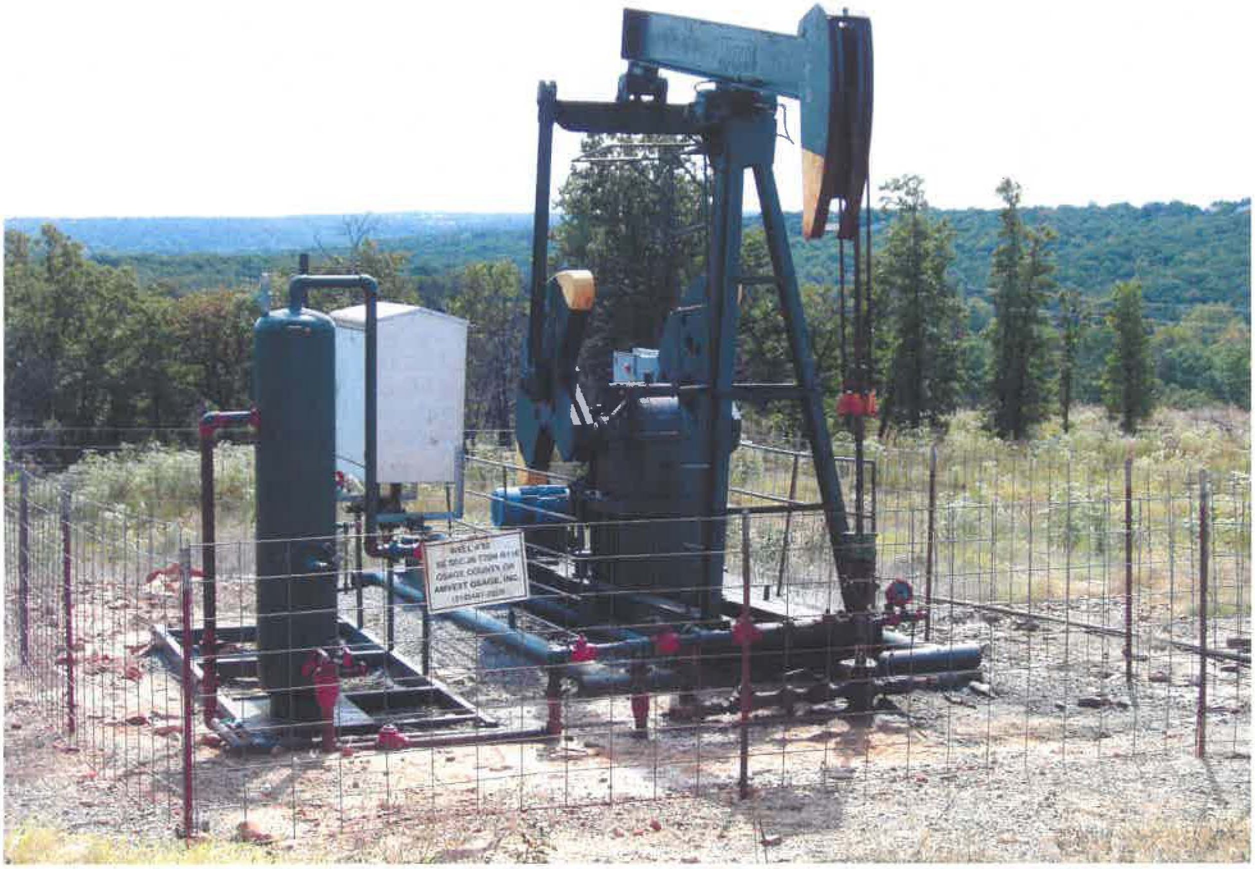
Index map showing company name, year commercial operation began, and location of major consumers in Oklahoma of Wyoming coal (■), Oklahoma coal (●), Wyoming/Oklahoma coal blend (▲), and coal source from other states (△).

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: 180 MCFD & 40 BWPD



Amvest No. 32 Osage well

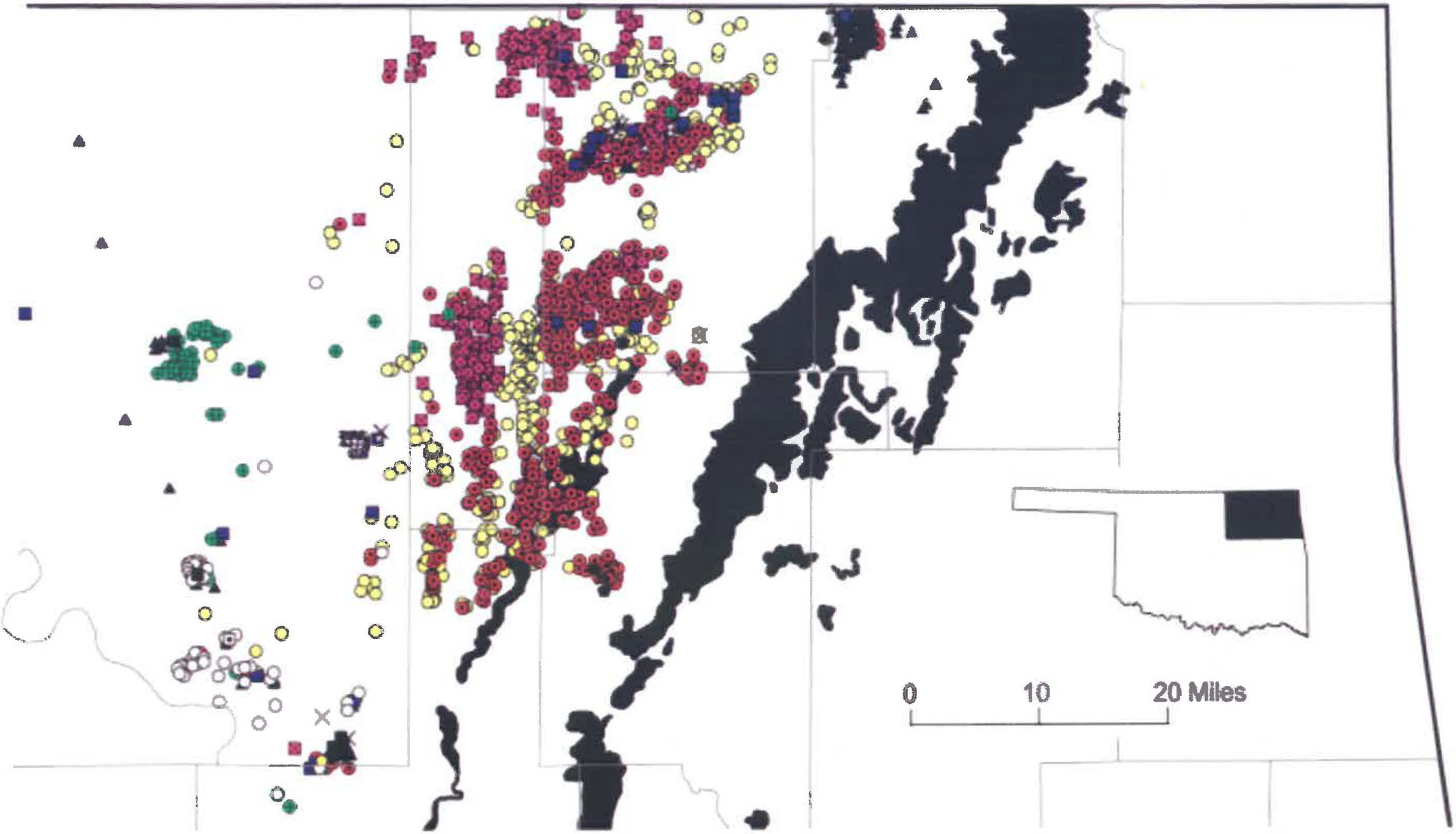
Amvest No. 101 Salt Water Disposal well
Located 1,925 ft FSL and 1,907 ft FWL of SE¼, Section 26, T.20N., R.11E.
Spud: June 15, 2001 Rig: Thornton Drilling

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).

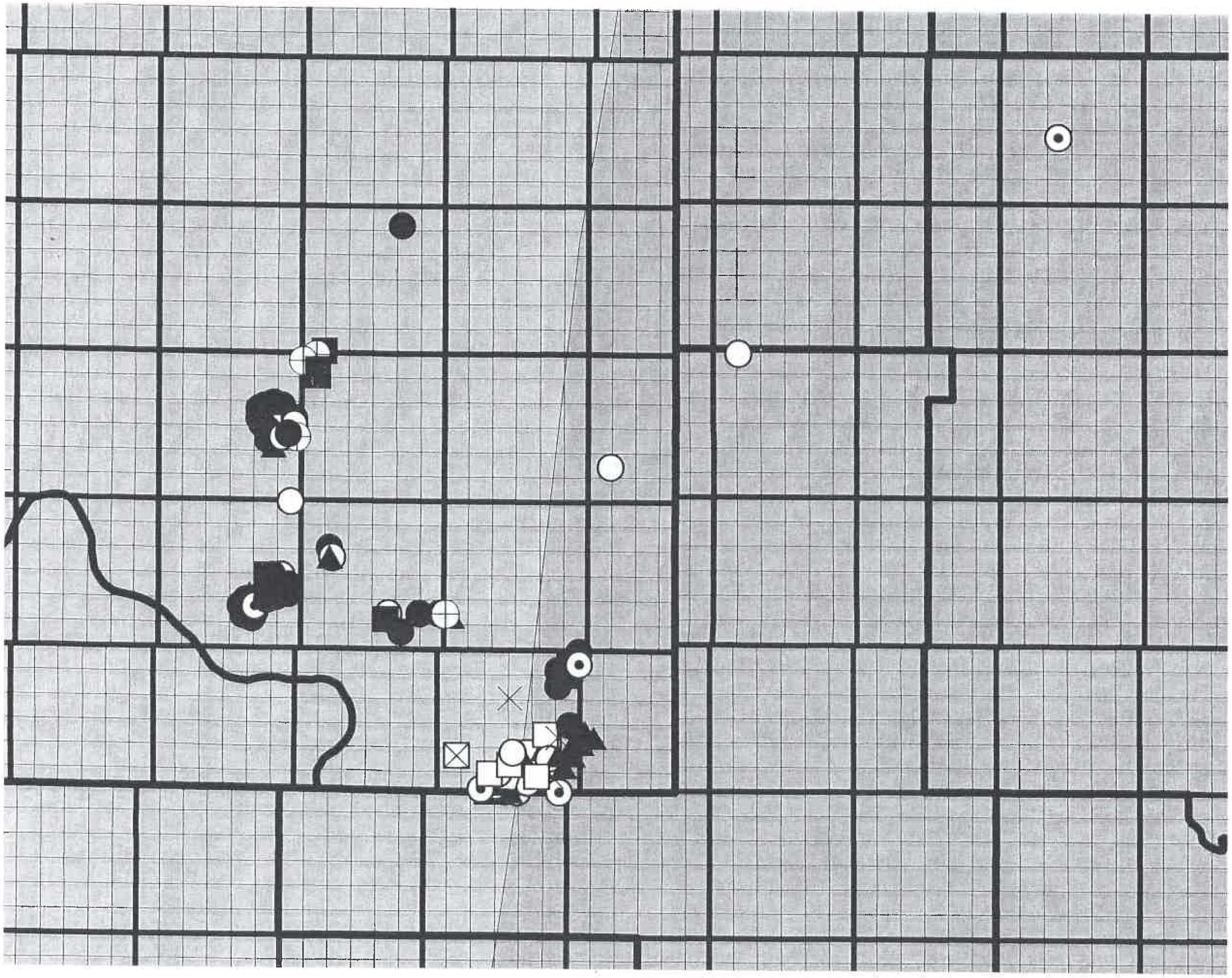
Amvest Osage, Inc. Sand Springs Tank Battery.

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 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.
Total Sales: 5,500 to 6,000 MCFD

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)

Coalbed-Methane Activity in Oklahoma, 2004 Update

Brian J. Cardott
Oklahoma Geological Survey
Norman, Oklahoma

ABSTRACT.— Nearly 2,900 wells in the Oklahoma coalfield have been drilled exclusively for coalbed methane (CBM) since 1988, in part for the Federal Section 29 tax credit and in part due to higher prices for natural gas. A database of CBM completions tabulates 1,725 completions in the northeast Oklahoma shelf and 1,171 completions in the Arkoma Basin. Operators presently target thirteen coal objectives in the shelf and five in the basin. The primary CBM objectives, all Desmoinesian (Middle Pennsylvanian) in age, are the Mulky (547 wells) and Rowe (601 wells) coals in the shelf and the Hartshorne coals (1,125 wells) in the basin.

In general, coals in Arkoma Basin CBM wells are deeper and thicker than those in the northeast Oklahoma shelf and have higher initial gas rates and lower initial produced-water rates. Many horizontal CBM wells have been drilled in the Arkoma Basin since 1998, the more successful wells following improvements in completion techniques. Much is known about the coal geology of the Oklahoma coalfield (e.g., number of coals, age, depth, thickness, rank, quality). The present emphasis is on finding permeable sweet spots and matching coal characteristics to optimum completion techniques.

INTRODUCTION

Mine explosions from gas and dust caused more than 500 deaths in 19 major coal-mining disasters in Indian Territory and Oklahoma from 1885 to 1945 (Oklahoma Department of Mines, 2003). Gas explosions in underground coal mines and safety studies of underground coal mines by the U.S. Bureau of Mines (Deul and Kim, 1988) have demonstrated that Oklahoma coals contain large amounts of methane. Applied research by the U.S. Bureau of Mines, U.S. Department of Energy, and Oklahoma Geological Survey, advances in coalbed methane (CBM) completion technology (especially through studies of coals in the Black Warrior and San Juan Basins by the Gas Research Institute), Federal non-conventional fuel tax credit (Section 29 of the IRS Code; see Sanderson and Berggren (1998) for details), and high natural gas prices (>$3/MCF since 2000) all promoted interest in development of the Oklahoma CBM industry.

The CBM play in Oklahoma began in 1988 with the first completions in the Arkoma Basin (**Figs. 1, 2**). Bear Productions reported initial-potential (IP) gas rates of 41 to 45 thousand cubic feet of gas per day (MCFD) per well from seven wells in the Hartshorne coal at depths ranging from 611 to 716 ft in the Kinta gas field (sec. 27, T.8N., R.20E., Indian Meridian) in Haskell County. Bear Productions was the only CBM operator in Oklahoma from 1988–1990. Following a peak of 73 completions in 1992 (at the end of the first phase of the Section 29 tax credit for new CBM wells drilled from 1980 through 1992), activity declined for several years before rising to 247 completions reported in the basin in 2003 (stimulated by high gas prices). CBM completions in the northeast Oklahoma shelf began in 1994 with 15 wells. Numerous CBM completions in the shelf were recompletions and were eligible for the second phase of the Section 29 tax credit (recompletion to qualifying coal beds in conventional wells drilled from 1980 through 1992; gas must be produced and sold by December 31, 2002). Shelf completions totaled 235 and 304 in 1998 and 2001, respectively. More CBM wells per year have been drilled in the shelf than in the basin since 1995. Through December 2003, 2,896 CBM completions have been reported in Oklahoma — 1,171 in the Arkoma Basin and 1,725 in the northeast Oklahoma shelf.

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, 1929; Friedman, 2002). The coalfield is divided into the northeast Oklahoma shelf and the Arkoma Basin (Friedman, 1974; **Fig. 3**). CBM completions are in both the commercial coal belt and noncommercial coal-bearing region. Cardott (2002) summarized the coal geology of Oklahoma. The remainder of this report will discuss the CBM activity of the northeast Oklahoma shelf and the Arkoma Basin.

SOURCE OF DATA

The following discussion of Oklahoma CBM activity is based on information reported to the Oklahoma Corporation Commission and Osage Indian Agency. The names of coal beds are as reported by the operator. For the most part, coal names assigned by operators have not been verified with electric logs and may not conform to usage accepted by the Oklahoma Geological Survey. Since not all the wells are reported as CBM wells, some interpretation or verification with the operator was necessary. Dual completions in sandstone and coal beds, including perforations of more than one coal bed, were made in some wells. Therefore, not all the wells are exclusively CBM completions. Dual completions were included only if gas rates were reported for the coal beds.

This summary is incomplete inasmuch as some wells were not known to be CBM wells or were not reported as such at the time of this compilation. This evaluation is based on reported CBM completions, which may or may not have been connected to a gas pipeline. Likewise, some completions may have produced gas but have since been plugged.

The Coalbed-Methane Completions table of the Oklahoma Coal Database was used to summarize data in this report. Each record (well completion) in the table lists operator, well name, API number, completion date, location (county, gas field, township-range-section, latitude-longitude), coal bed, production depth interval, initial gas potential and water rates, pressure information, and comments. Incomplete copies of Oklahoma Corporation Commission Form 1002A limited the data summaries for coal depth, initial gas potential, and produced water in this report. The database is available for viewing at or purchase from the Oklahoma Geological Survey. A searchable version of the Coalbed-Methane Completions table is accessible on the Internet through a link on the OGS web site (http://ogs.ou.edu/).

COALBED METHANE ACTIVITY

Northeast Oklahoma Shelf

There have been 1,725 CBM well completions reported in the shelf by 70 operators through December 2003. Completions are in Craig, Nowata, Okfuskee, Okmulgee, Osage, Pawnee, Rogers, Tulsa, and Washington Counties (**Fig. 4**). About 29% of the wells are recompletions of older conventional gas and oil wells and coalbed methane wells. In ascending order (by coal as uppermost bed with number of completions in parentheses), the methane-producing coals include the Riverton (215) (McAlester Formation), Rowe (601) and Drywood (3) (Savanna Formation), and Bluejacket (59) and Wainwright (1) (Boggy Formation) in the Krebs Group; Weir-Pittsburg (113), Tebo (8), Mineral (1), Croweburg (37), Bevier (23), Iron Post (59), and Mulky (547) (Senora Formation) in the Cabaniss Group; and Dawson (51) (Holdenville Formation) in the Marmaton Group of Desmoinesian age (**Fig. 5**). There were 7 CBM wells for which the coal name was not reported.

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 coal beds. Two type logs were designated in the northern and southern parts of the study area. Persistent marker beds were identified to correlate the coal beds.

The nomenclature of coal-bearing strata and coal beds in Kansas and Oklahoma 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; the Drywood coal of Missouri and Dry Wood coal of Kansas are equivalent to the Spaniard coal of Oklahoma (Hemish, 1990).

The Mulky coal is one of the most important CBM reservoirs in the northeast Oklahoma shelf. 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."

Figure 6 shows the depth range of CBM completions in 1,565 wells in the shelf. Coal beds were perforated at depths-to-top of coal of 256 to 2,459 ft, for an average depth of 1,046 ft. Although two to seven coal beds were perforated in 383 completions, only the shallowest coal depth was used in Figure 6. Three modes are apparent in Figure 6. The shallower mode represents mostly the Mulky coal (547 wells; includes commingled wells with the Mulky as the shallowest perforated coal) completed over a depth range of 256 to 1,733 ft; 358 wells were completed in only the Mulky coal.

The second mode represents mostly the Rowe coal (1,123 wells), completed over a depth range of 542 to 2,459 ft. The deepest coal completion (2,459 ft) in the shelf is in the Rowe coal in Osage County (Amvest West, 99 Drummond II well, sec. 23, T. 21 N., R. 9 E.).

The third mode represents mostly the Riverton coal (204 wells), completed over a depth range of 630 to 1,970 ft.

Initial-potential (IP) gas rates range from a trace to 359 MCFD and average 31 MCFD from 1,391 wells (**Fig. 7**). However, IP rates do not demonstrate the full potential of a CBM well because they reflect only the first of the three stages of a typical CBM production-decline curve: dewatering, stable production, and decline (see Schraufnagel, 1993, fig. 2). **Figure 8** shows the relationship of depth and IP gas rate for CBM wells in the shelf. Single-coal-completion wells with the shallowest coals (256 to 377 ft) had IP rates of 1 to 50 MCFD. Eighty-four CBM wells (including 27 wells with multiple coal completions) with the highest IP rates (>100 MCFD) were from depths of 258 to 1,661 ft. The single-coal-completion well with the highest IP rate (278 MCFD) in the shelf is the STP Incorporated 2-29 Kirkpatrick well (sec. 29, T. 29 N., R. 18 E.; Craig Co.) in the Weir-Pittsburg coal at a depth of 433 ft. The maps in **Figures 9 to 12** highlight the Mulky, Weir-Pittsburg, Rowe, and Riverton CBM wells, respectively (including commingled wells), that exhibit generally higher IP rates—73 (15%) of 498 Mulky wells with initial gas rates of 50 to 359 MCFD, 21 (19%) of 109 Weir-Pittsburg wells with initial gas rates of 50 to 278 MCFD (8 Weir-Pittsburg wells had IP >100 MCFD), 118 (22%) of 534 Rowe wells with initial gas rates of 50 to 260 MCFD (36 Rowe wells had IP >100 MCFD), and 46 (24%) of 194 Riverton wells with initial gas rates of 50 to 150 MCFD (11 Riverton wells had IP >100 MCFD). IP was not reported for coals in some wells.

Initial water rates in the shelf range from 0 to 5,061 barrels of water per day (BWPD) and average 68 BWPD from 1,408 wells (**Fig. 13**). Most of the water is believed to be formation water and not water from fracture stimulation. Because of generally poor water quality, these wells require disposal wells for the produced water. With the assistance of Cynthia Rice (U.S. Geological Survey), water samples were collected from the Mulky and Rowe coals in 4 CBM wells in Nowata and Osage Counties in 2002. The water samples had 86,200 to 152,900 mg/L Total Dissolved Solids. In general, water volumes are not metered; therefore, the volume of disposed water and the effect of water production on gas rate are unknown.

Monthly gas production by well is reported on Form 1004/1005 (Measured Volume Report) by the Oklahoma Corporation Commission Oil & Gas Conservation Division. The information is available from the Oklahoma Corporation Commission web site (see "Oil and Gas Web Applications" at http://www.occ.state.ok.us/). Gas content and gas composition data are unpublished for coals in the northeast Oklahoma shelf.

API numbers for 1,725 CBM wells in the shelf were imported into the IHS Energy Group Production database for the Southern Mid-Continent. A subtotal of 1,420 wells (82%) had production data. Selecting coal-only wells reduced the subset to 837 wells (excluding numerous recompletions). **Figure 14** summarizes gas production by year for wells in the shelf from 1994 to 2003. CBM production from wells in the shelf was 12.6 billion cubic feet of gas (BCF) in 2003. Cumulative gas production in the shelf is 36.8 BCF from 1994 to 2003.

Arkoma Basin

Figure 15 shows the locations of 1,171 CBM completions in the basin reported by 73 operators through December 2003. Completions are in Coal, Haskell, Hughes, Latimer, Le Flore, McIntosh, Muskogee, and Pittsburg Counties. In ascending order, the methane-producing coals include the Hartshorne (undivided), Lower Hartshorne, and Upper Hartshorne (Hartshorne Formation), McAlester and "Savanna" (interpreted to be the McAlester coal, McAlester Formation; a 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 (**Fig. 16**). Most (1,125) of the CBM completions in the Arkoma Basin are in Hartshorne coals.

Figure 17 shows the depth range of CBM completions in the basin. Coals were perforated at depths-to-top of coal of 284 to 4,397 ft, for an average of 1,529 ft in 1,058 wells. The three deepest completions (4,233 to 4,397 ft vertical depth) were horizontal CBM wells in the Hartshorne coal in Le Flore County (T. 6 N., R. 24 E.). Although two to three coals were perforated in 29 completions, only the shallowest coal depth was used in Figure 17.

IP gas rates range from a trace to 2,316 MCFD (average 136 MCFD) from 943 wells (**Fig. 18**). Most (638 completions) wells produced 10 to 160 MCFD. The highest IP rates (> 330 MCFD) were reported from 130 horizontal CBM wells in the Hartshorne coal. Based on 1,117 completions with depth and initial potential pairs, **Figure 19** shows no relationship between IP gas rate and depth in the Arkoma Basin (depth of horizontal wells is based on vertical depth-to-top of coal). Low gas rates (<50 MCFD) span the entire depth range. The shallowest (284 ft) well is a coal-mine-methane well. The Cohort Energy 1-32 Greenwood well (sec. 32, T. 9 N., R. 26 E.; Le Flore Co.) was drilled to the Hartshorne coal into a sealed part of the Georges Colliers Inc. Pollyanna No. 8 underground coal mine and had an initial potential of 512 MCFD of low methane-content gas. The 336 wells (30% of 1,117) with the highest gas rates (>99 MCFD) are from depths of 636 to 4,397 ft. Twelve horizontal CBM wells (T. 8 N., R. 17 to 19 E.) had an IP >1,000 MCFD at a vertical depth of 1,302 to 2,632 ft. Theoretically, gas content increases with increasing rank, depth, and reservoir pressure (Kim, 1977; Scott and others, 1995; Rice, 1996). However, gas production depends on many variables, including gas content, coal thickness, water volume, cleat mineralogy, permeability, porosity, and stimulation method.

The first horizontal CBM well in Oklahoma was completed by Bear Productions in August 1998. By the end of December 2003, 287 horizontal CBM wells (25% of 1,171 completions) had been drilled in Haskell, Le Flore, McIntosh, and Pittsburg Counties by 18 operators (**Fig. 20**). IP gas rates were 5 to 2,316 MCFD (average of 358 MCFD) at true vertical depths-to-top of coal of 752 to 4,397 ft in 280 horizontal CBM wells. Sixty-four (22% of 287) horizontal CBM wells in Haskell and Pittsburg Counties had initial potential gas rates >500 MCFD (Fig. 20). Higher gas rates are possible in a horizontal well than in a single-bed vertical well by drilling at a high angle (perpendicular to oblique) to the face cleat to drain a larger area (Diamond and others, 1988). Horizontal CBM wells can drain as much as seven times the area of a vertical CBM well, depending on the lateral length (Stayton, 2002). Vertical CBM wells exhibit an elliptical drainage pattern, elongated parallel to the face cleat, as a result of the directional (anisotropic) permeability of the cleat (Diamond and others, 1988, fig. 4.1). Horizontal CBM wells extend the elliptical drainage pattern along the length of the lateral.

Horizontal CBM wells are completed openhole. The lateral distance within the coal for 260 horizontal CBM wells ranged from 439 to 4,034 ft, with an average of 1,854 ft. **Figure 21** shows that, in general, higher initial gas rates are related to longer horizontal lateral lengths. The highest gas rates (IP >1,000 MCFD) in wells with lateral lengths of 1,500 to 2,500 ft are related to a high permeability region (as noted above) and successful completion techniques, whereas lower gas rates (IP <500 MCFD) in wells with any lateral length are related to low permeability regions and completion complications, especially due to encountered faults.

Figure 22 shows a map of Hartshorne vertical CBM wells that have the highest initial potential gas rates—73 (10%) of 741 Hartshorne (including Upper and Lower Hartshorne) vertical CBM wells with initial gas rates of 100 to 512 MCFD.

Andrews and others (1998) summarized published information on gas resources, gas content, gas composition, and cleating in Hartshorne coals. Measured gas contents range from 70 to 560 cf/ton in high-volatile to low-volatile bituminous coal cores from depths of 175 to 3,651 ft in the Arkoma Basin.

Initial produced-water rates range from 0 to 1,861 BWPD (average 30 BWPD) from 890 wells (**Fig. 23**). Most (529) CBM completions produced less than 20 BWPD. An undisclosed amount of initial water production is frac water introduced during fracture stimulation. Most Arkoma Basin CBM well completions are situated on the flanks of anticlines (**Fig. 24**) and tend to produce relatively little water. Most operators do not test or meter water production; therefore, water quality and quantity produced during the life of the well are unknown.

API numbers for 1,171 CBM wells in the basin were imported into the IHS Energy Group Production database for the Southern Mid-Continent. A subtotal of 1,071 wells (91%) had production data. Selecting gas-only (excluding dry) wells reduced the subset to 972 wells. **Figure 25** summarizes gas production by year for wells in the basin from 1989 to 2003. CBM production from 661 vertical wells was 9.1 BCF in 2003. CBM production from 257 horizontal wells was 16.6 BCF in 2003. Cumulative gas production in the basin is 79.2 BCF from 1989 to 2003, 46.1 BCF from 704 vertical wells and 33.1 BCF from 274 horizontal wells.

CONCLUSIONS

The Oklahoma CBM play began in the Arkoma Basin in 1988. The play then expanded to the northeast Oklahoma shelf in 1994. Through December 2003, 2,896 CBM completions were reported in Oklahoma — 1,171 in the Arkoma Basin and 1,725 in the northeast Oklahoma shelf. The primary objectives are Hartshorne coals in the basin and the Mulky and Rowe coals in the shelf. Twenty-two percent (383 of 1,725) of the CBM completions in the shelf were multiple-coal completions with two to seven coal beds, while most of the CBM completions in the basin were single-coal completions.

Coal completion depths range from 256 to 2,459 ft and average 1,046 ft in 1,565 wells in the shelf, and 284 to 4,397 ft, averaging 1,529 ft in 1,058 wells in the basin.

Initial-potential gas rates range from a trace to 359 MCFD (average 31 MCFD) from 1,391 wells in the shelf, and a trace to 2,316 MCFD (average 136 MCFD) from 943 wells in the basin. The maximum initial gas rate was reported in the Hartshorne coal at a true vertical depth of 1,302 ft from a horizontal well in Haskell County.

Produced-water rates range from 0 to 5,061 BWPD (average 68 BWPD) from 1,408 wells in the shelf, and 0 to 1,861 BWPD (average 30 BWPD) from 890 wells in the basin.

From 1994 to 2003, 837 CBM wells in the shelf produced 36.8 BCF gas. From 1989 to 2003, 972 CBM wells in the basin produced 79.2 BCF gas, 46.1 BCF from 704 vertical CBM wells and 33.1 BCF from 274 horizontal wells.

Low initial gas rates and minimal initial increase in gas production during dewatering are often attributed to formation damage caused by well stimulation, including the generation of coal fines that plug permeability. Present industry emphasis is on matching the completion techniques to the specific coal.

Future development of CBM in Oklahoma is promising, especially if natural gas prices remain high. Applications of horizontal drilling and established completion practices have demonstrated the potential for CBM in the Midcontinent USA.

ACKNOWLEDGMENTS

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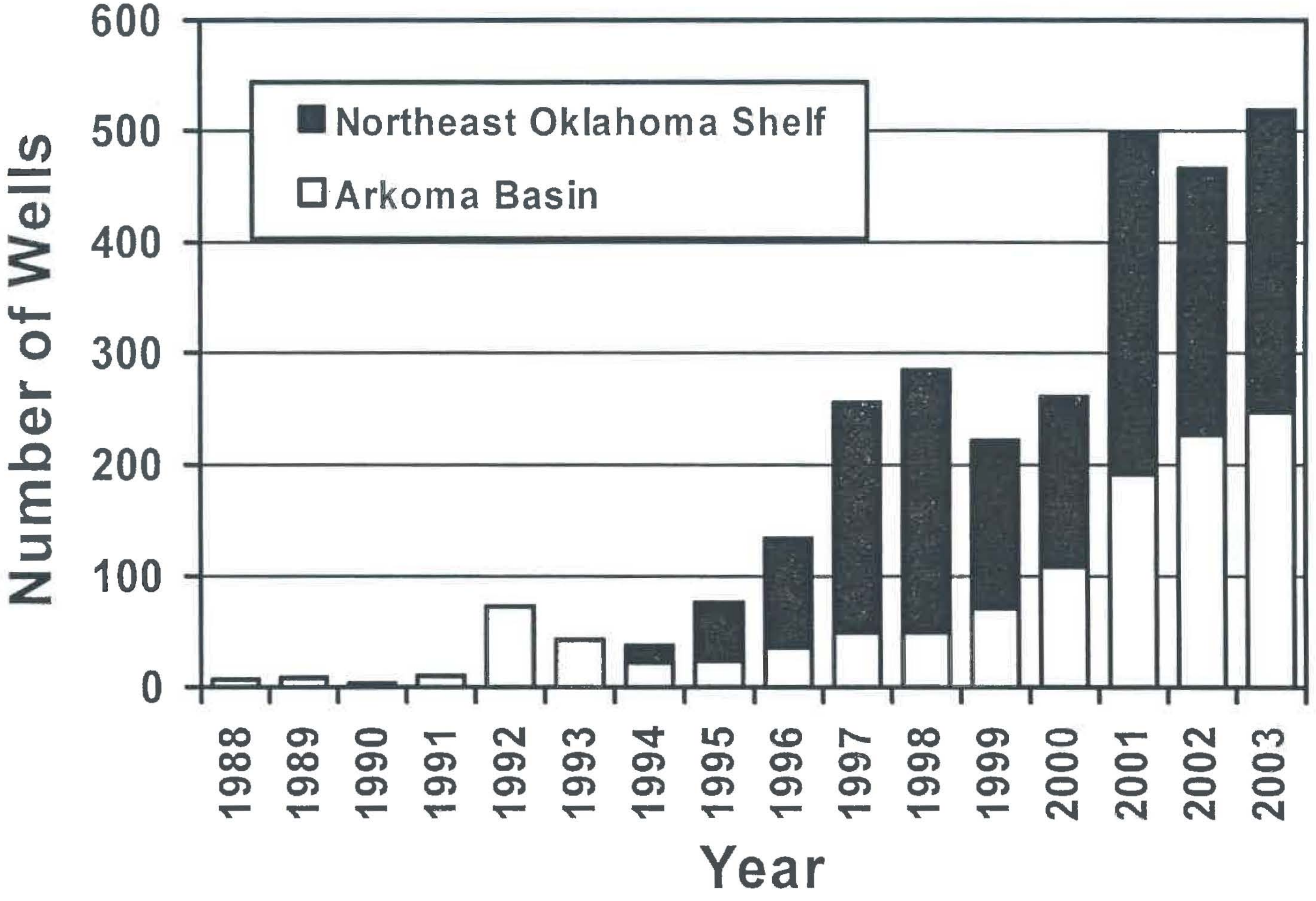
Figure 1. Histogram showing numbers of Oklahoma coalbed-methane well completions, 1988 to 2003.



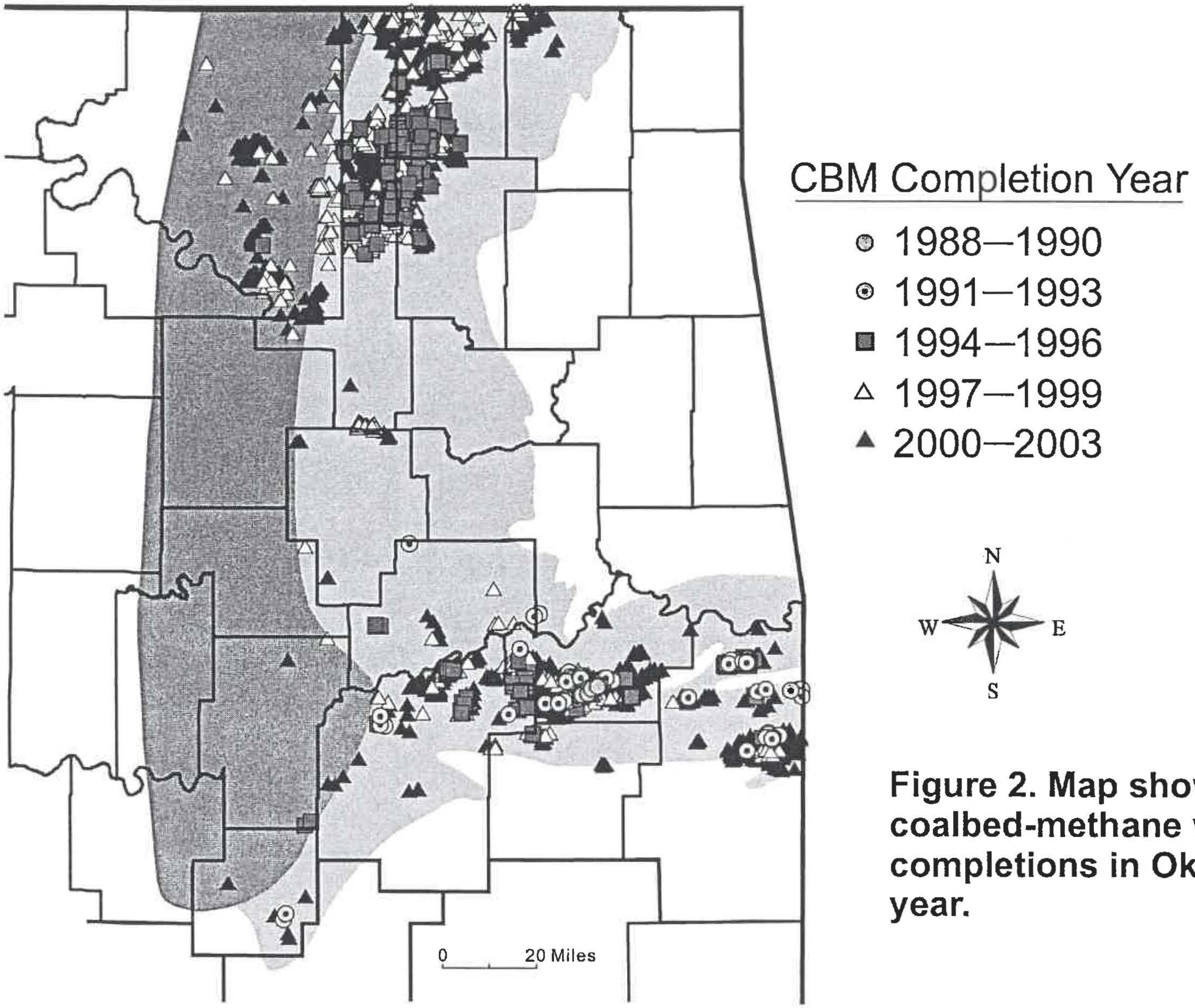


Figure 2. Map showing coalbed-methane well completions in Oklahoma by year.

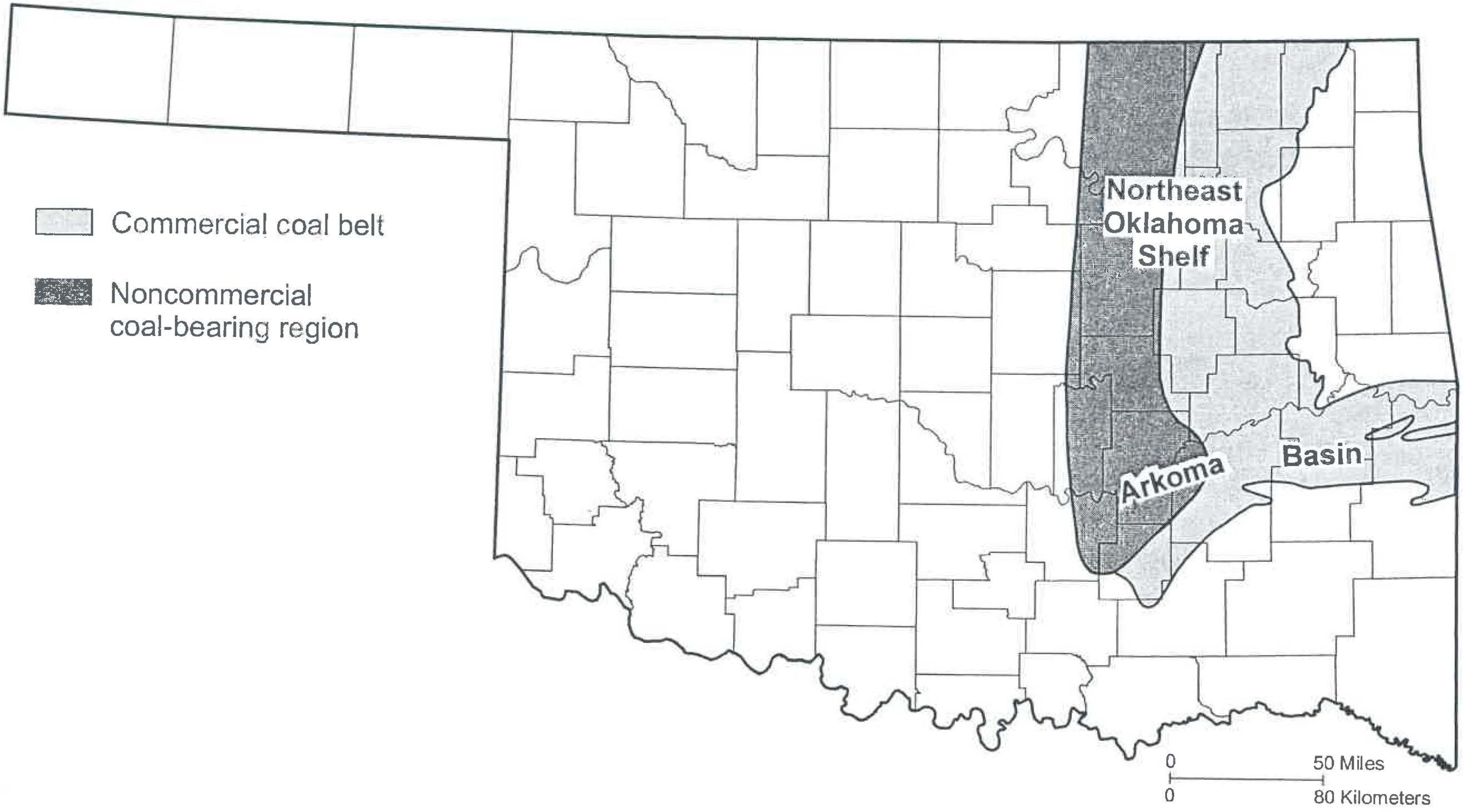


Figure 3. Map of Oklahoma coalfield (modified from Friedman, 1974).

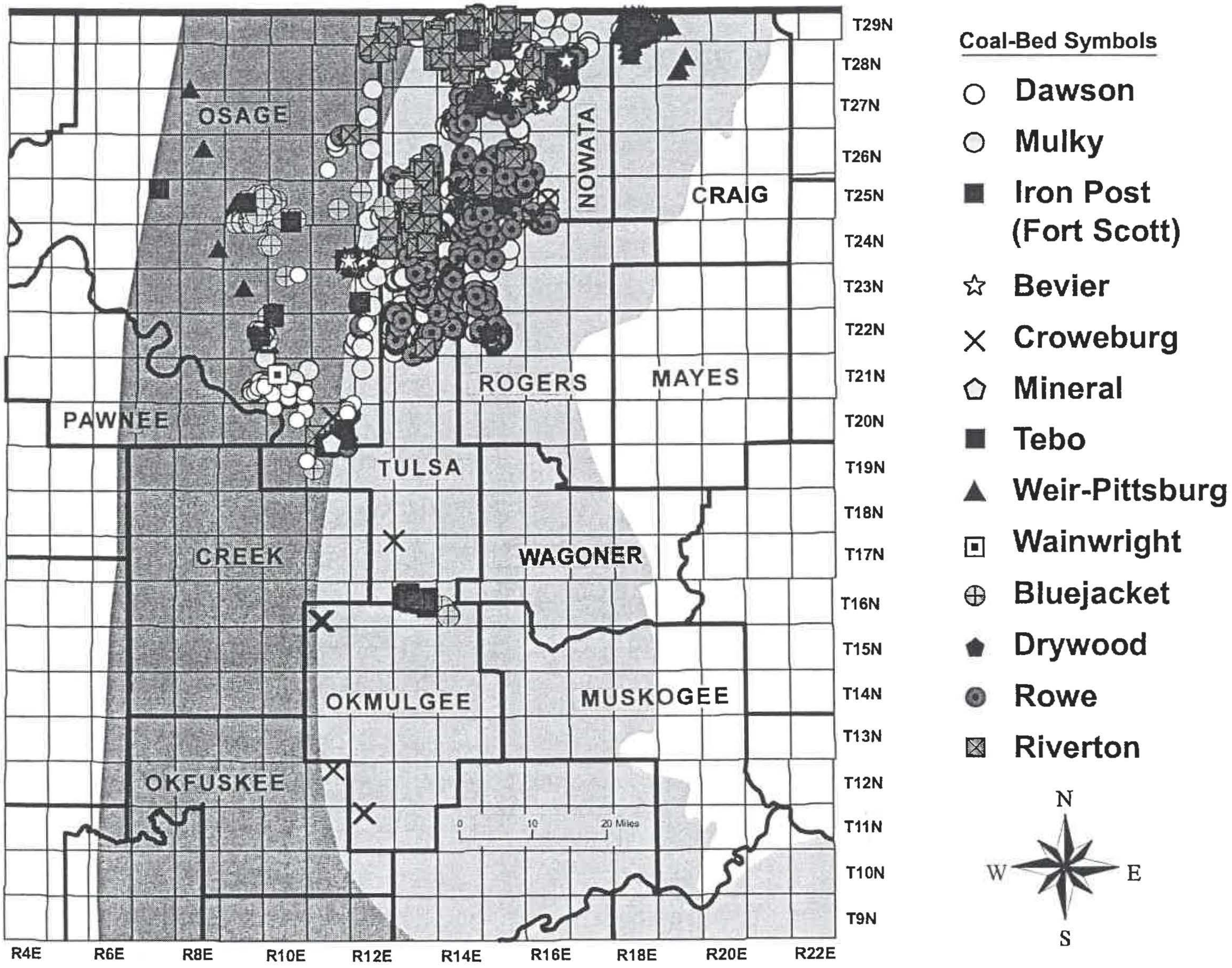


Figure 4. Distribution of CBM well completions by coal bed in the northeast Oklahoma shelf.

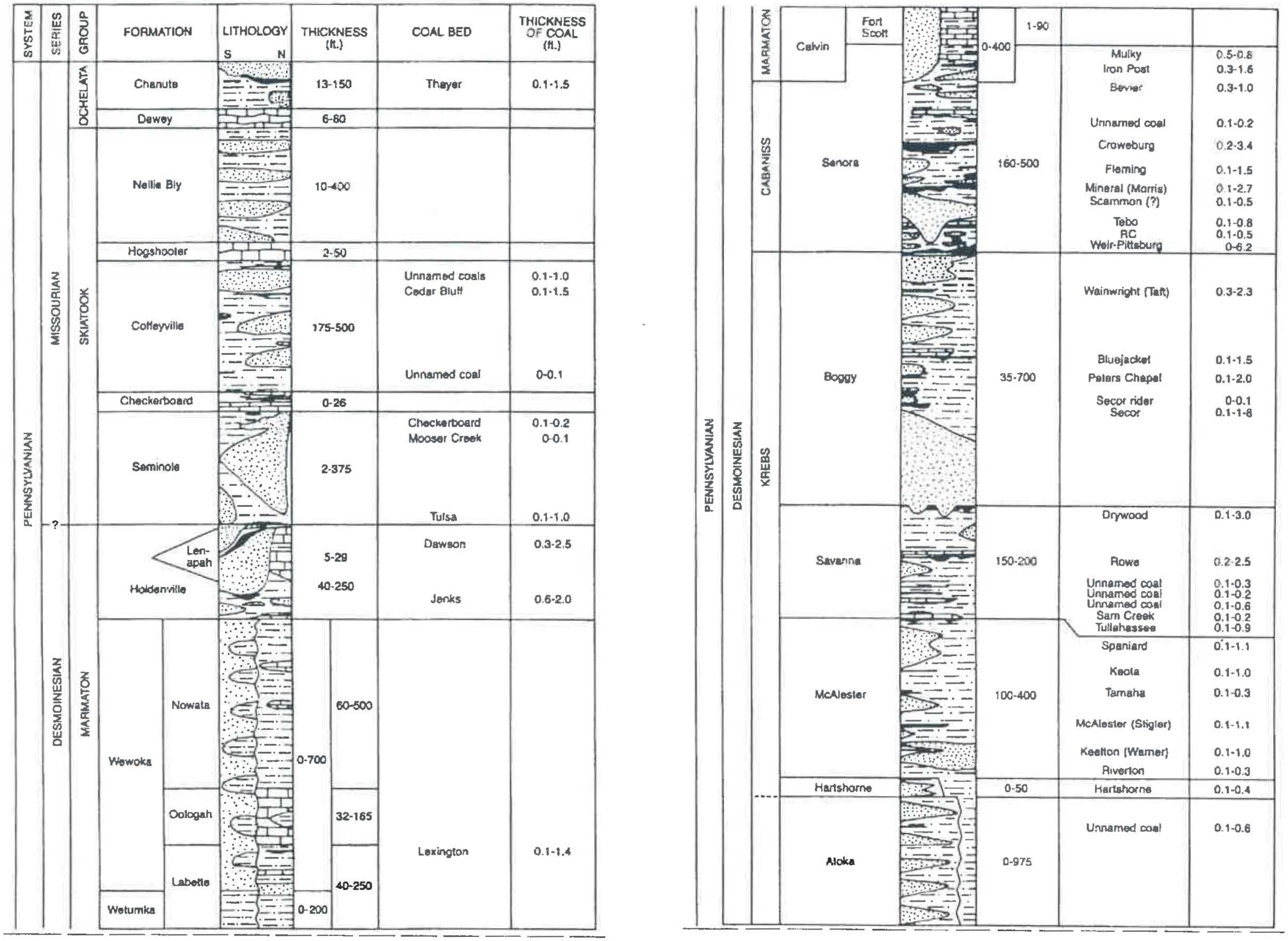


Figure 5. Generalized stratigraphy of coal-bearing strata of the northeast Oklahoma shelf (from Hemish, 1988).

Figure 6. Histogram of coalbed-methane well completion depths in the northeast Oklahoma shelf.

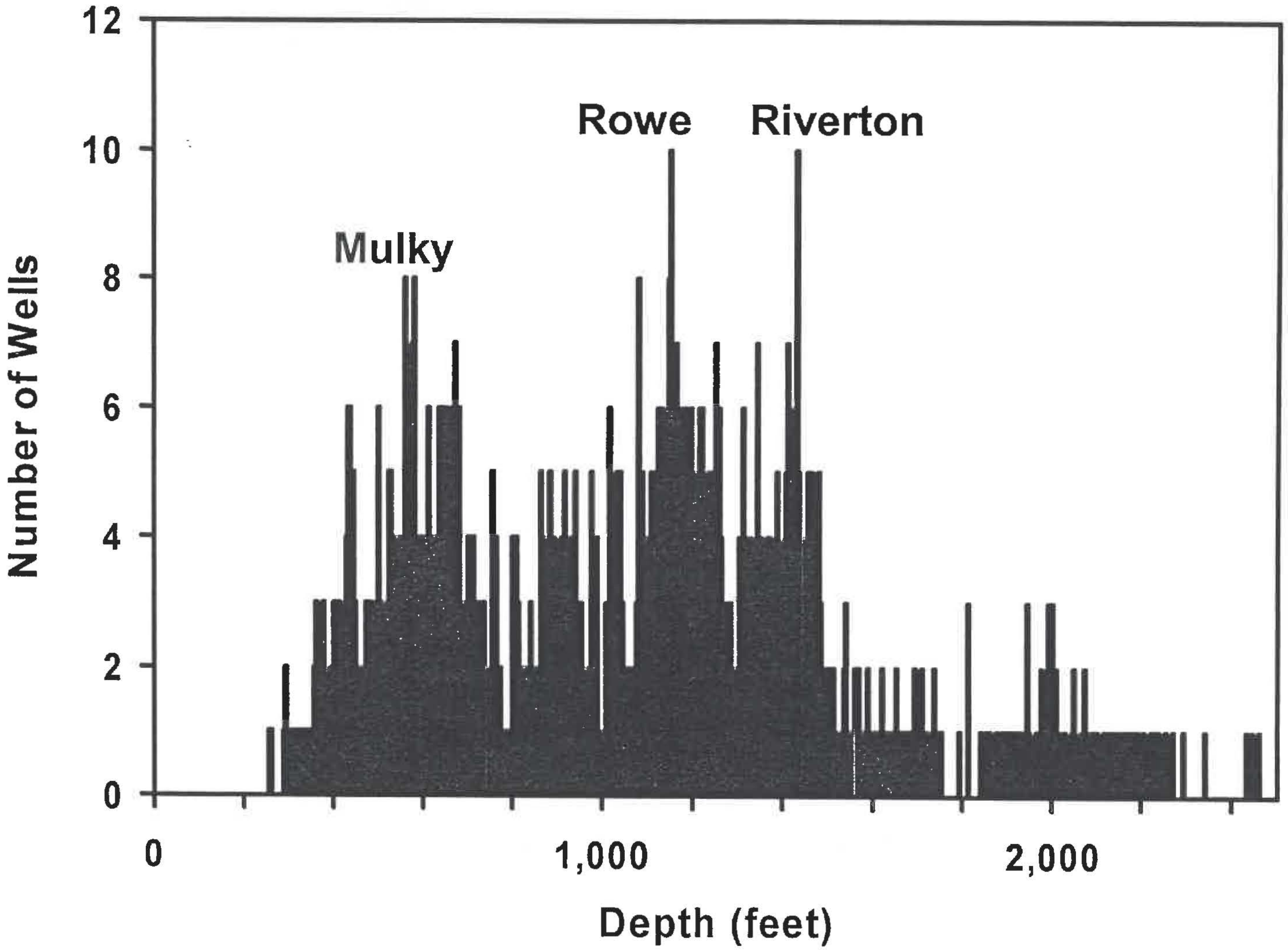


Figure 7. Histogram of initial-potential-gas rates (in thousand cubic feet of gas per day – MCFD) in coalbed-methane well completions in the northeast Oklahoma shelf.

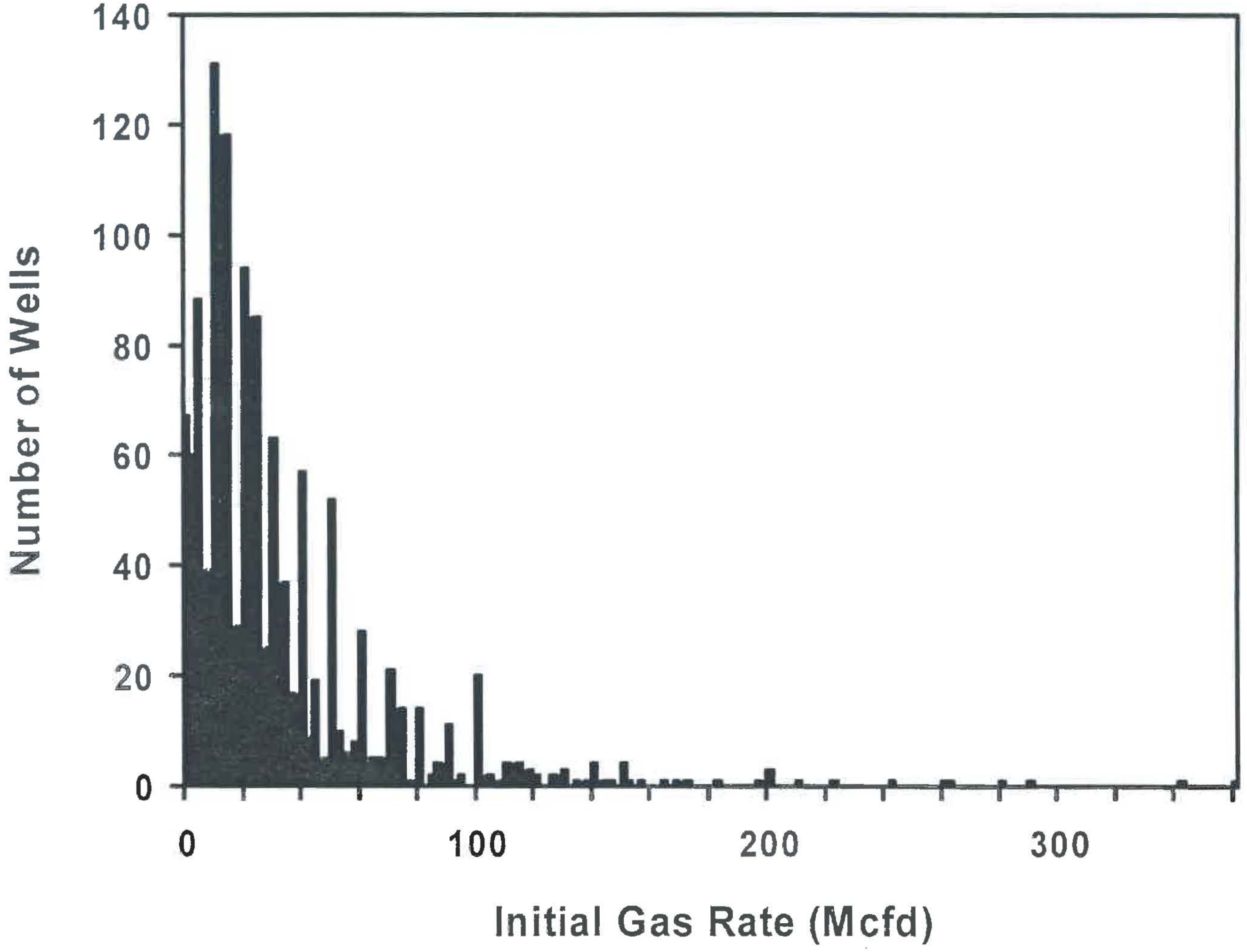
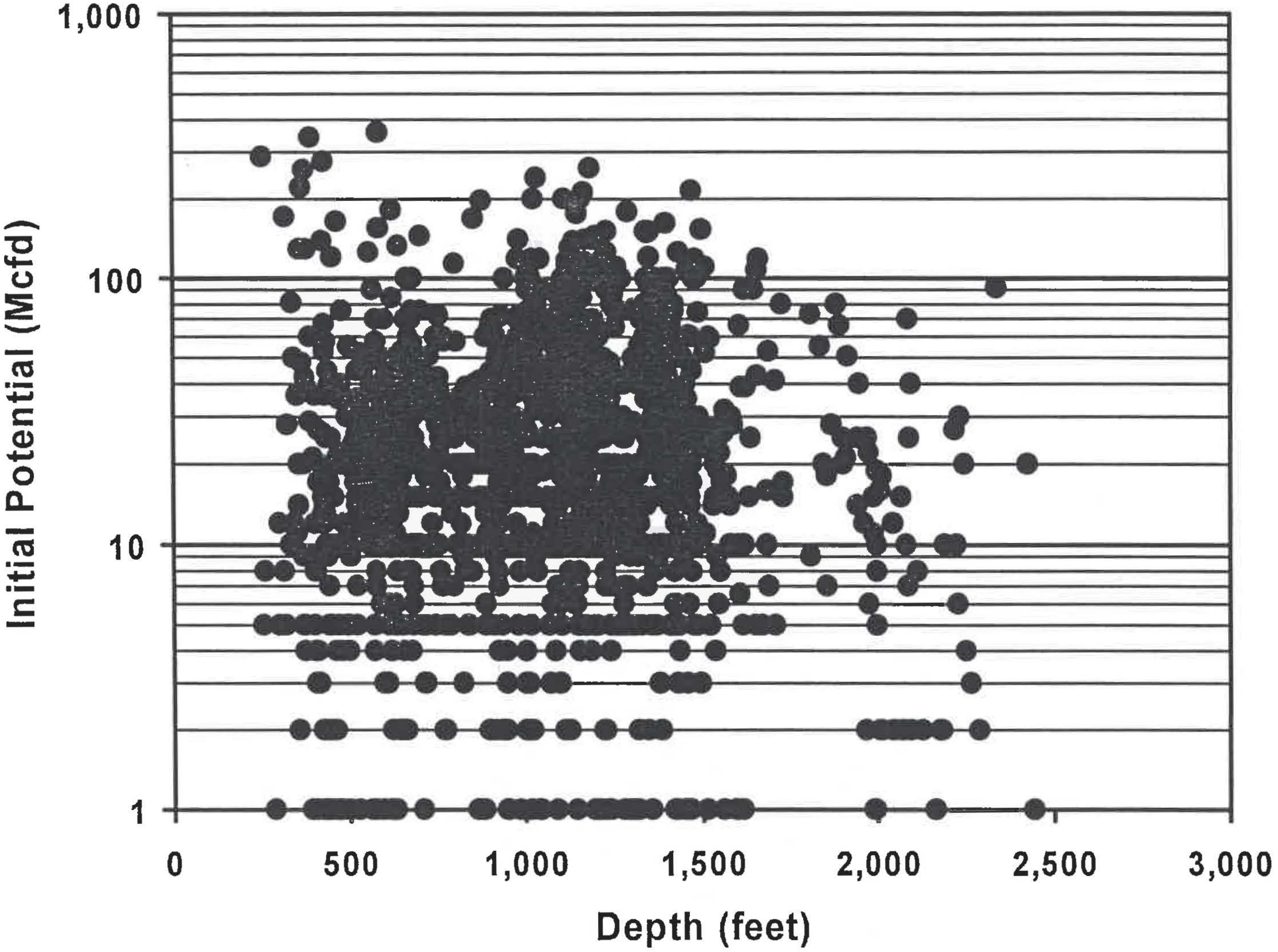


Figure 8. Scatter plot of initial-potential-gas rate and depth to top of coal in the northeast Oklahoma shelf.



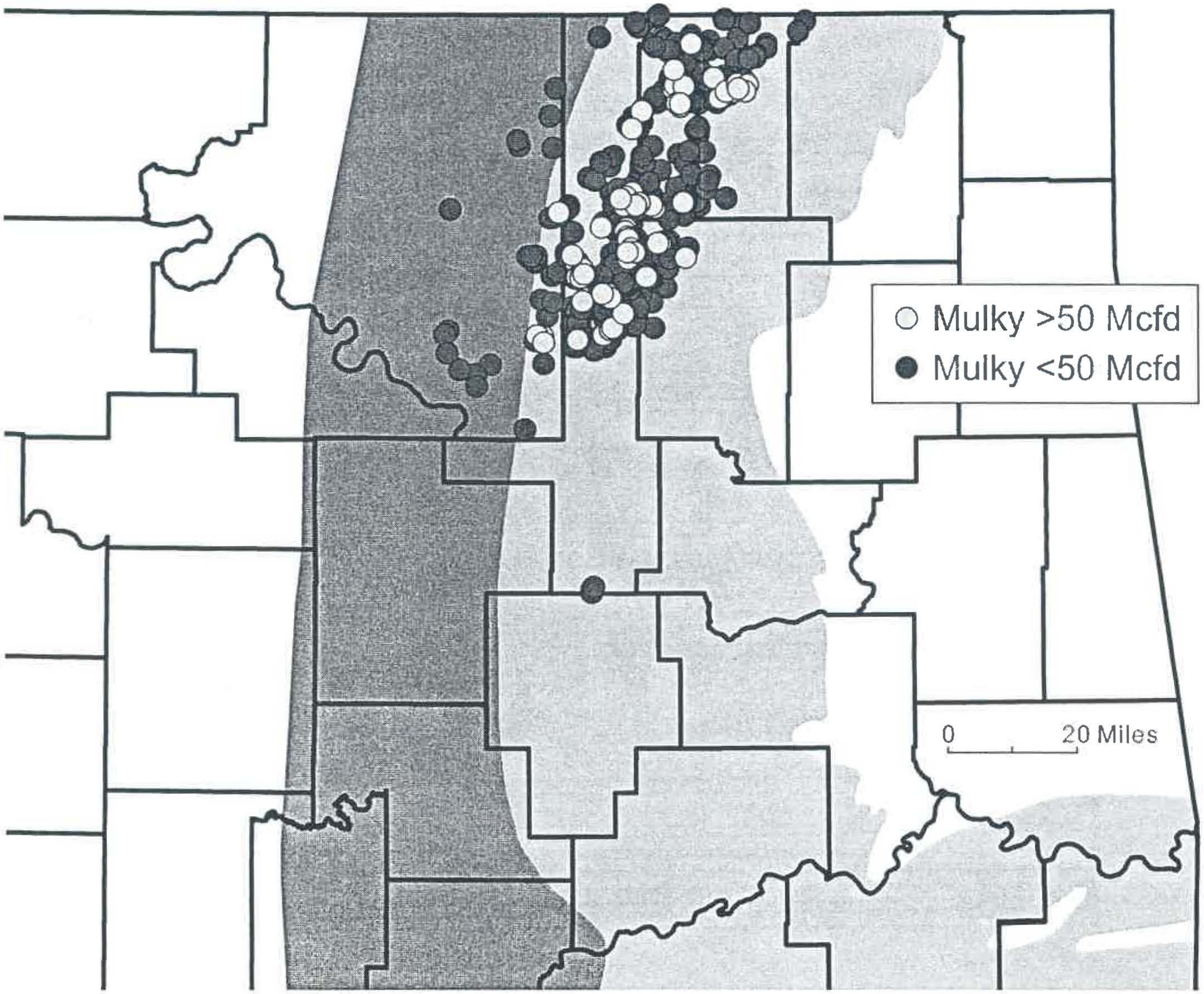


Figure 9. Distribution of well completions in the Mulky coal in the northeast Oklahoma shelf, showing wells with relatively high IP gas rates.

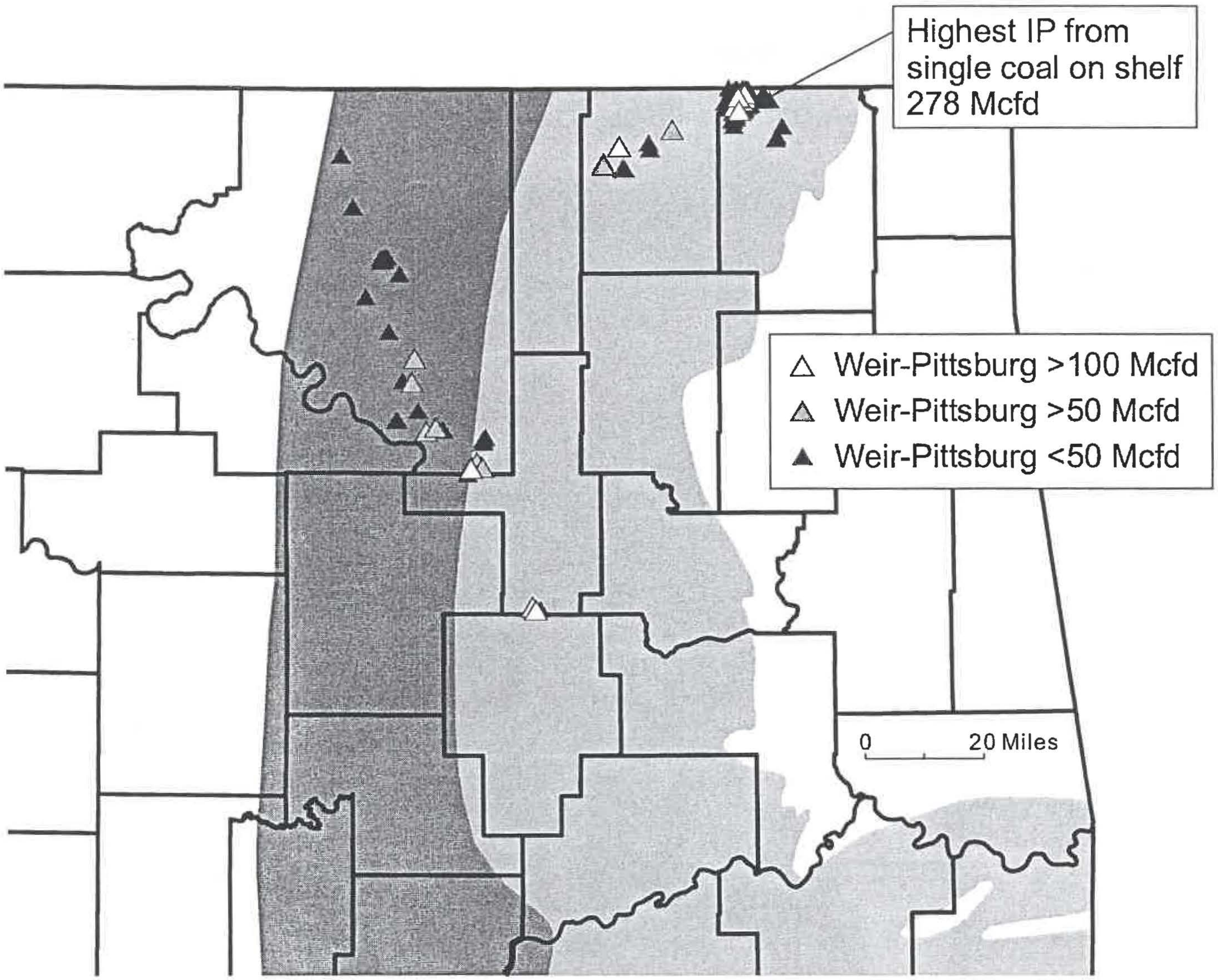


Figure 10. Distribution of well completions in the Weir-Pittsburg coal in the northeast Oklahoma shelf, showing wells with relatively high IP gas rates.

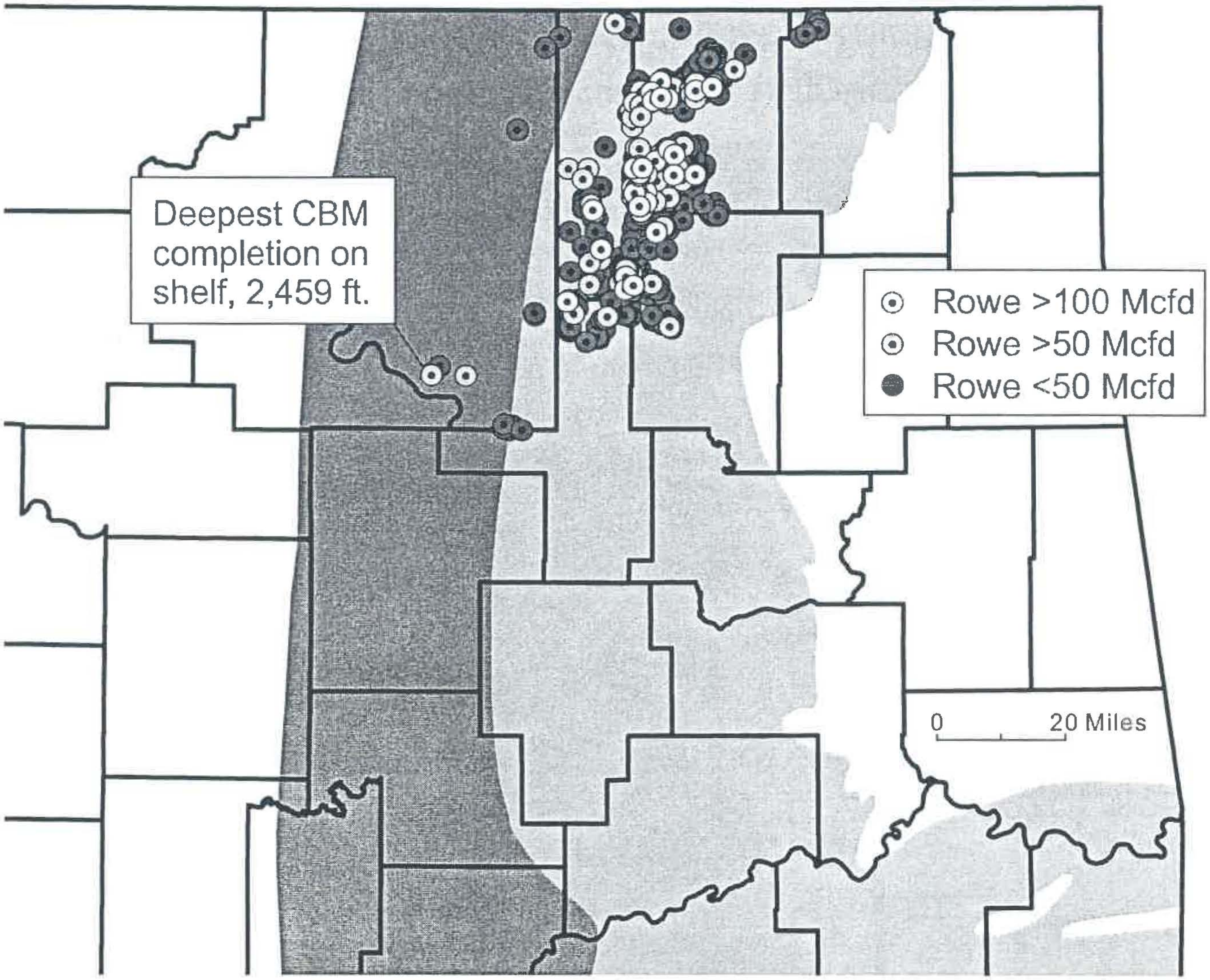


Figure 11. Distribution of well completions in the Rowe coal in the northeast Oklahoma shelf, showing wells with relatively high IP gas rates.

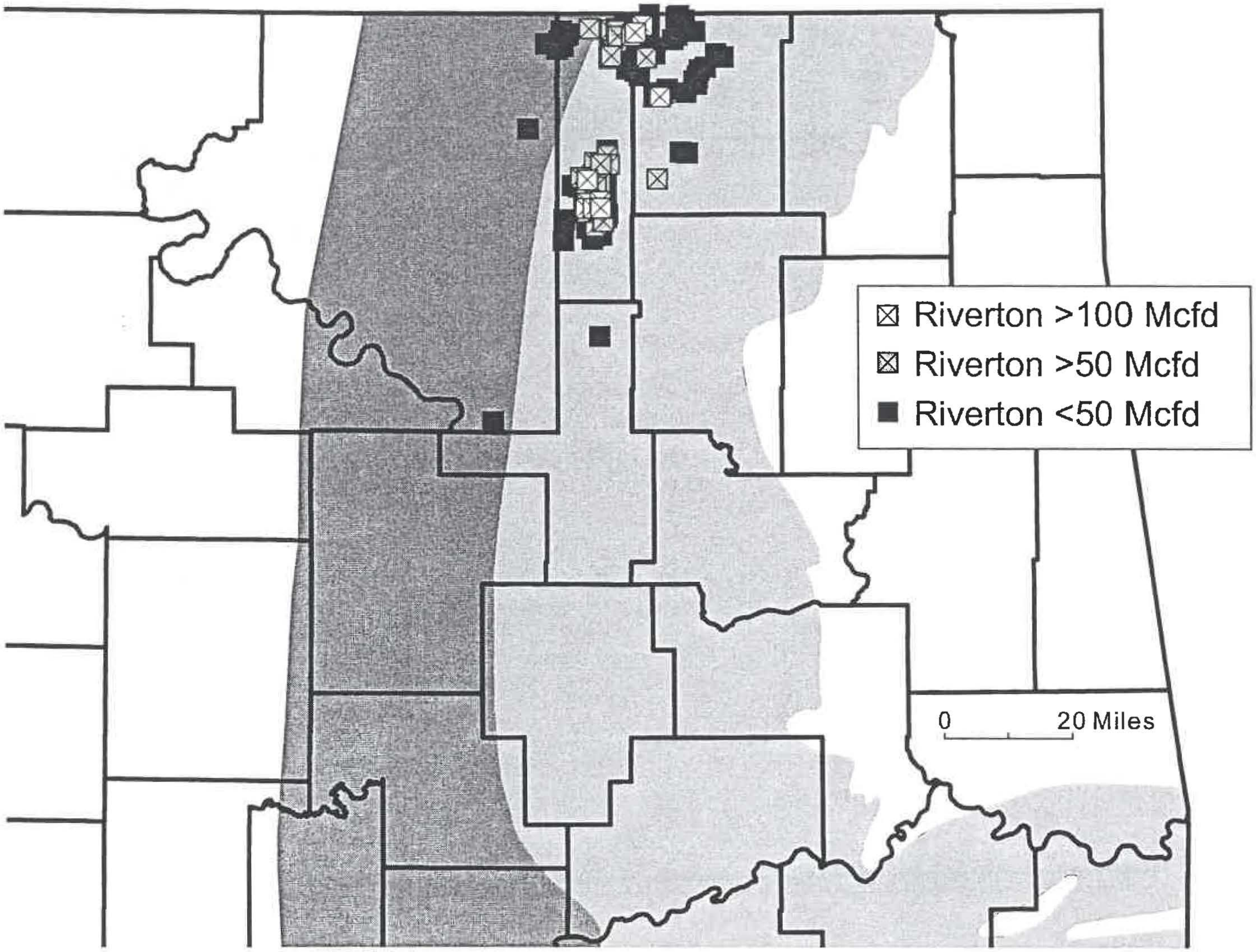


Figure 12. Distribution of well completions in the Riverton coal in the northeast Oklahoma shelf, showing wells with relatively high IP gas rates.

Figure 13. Histogram of initial water production rates from coalbed-methane wells in the northeast Oklahoma shelf (excluding two wells with 1,201 and 5,061 BWPD).

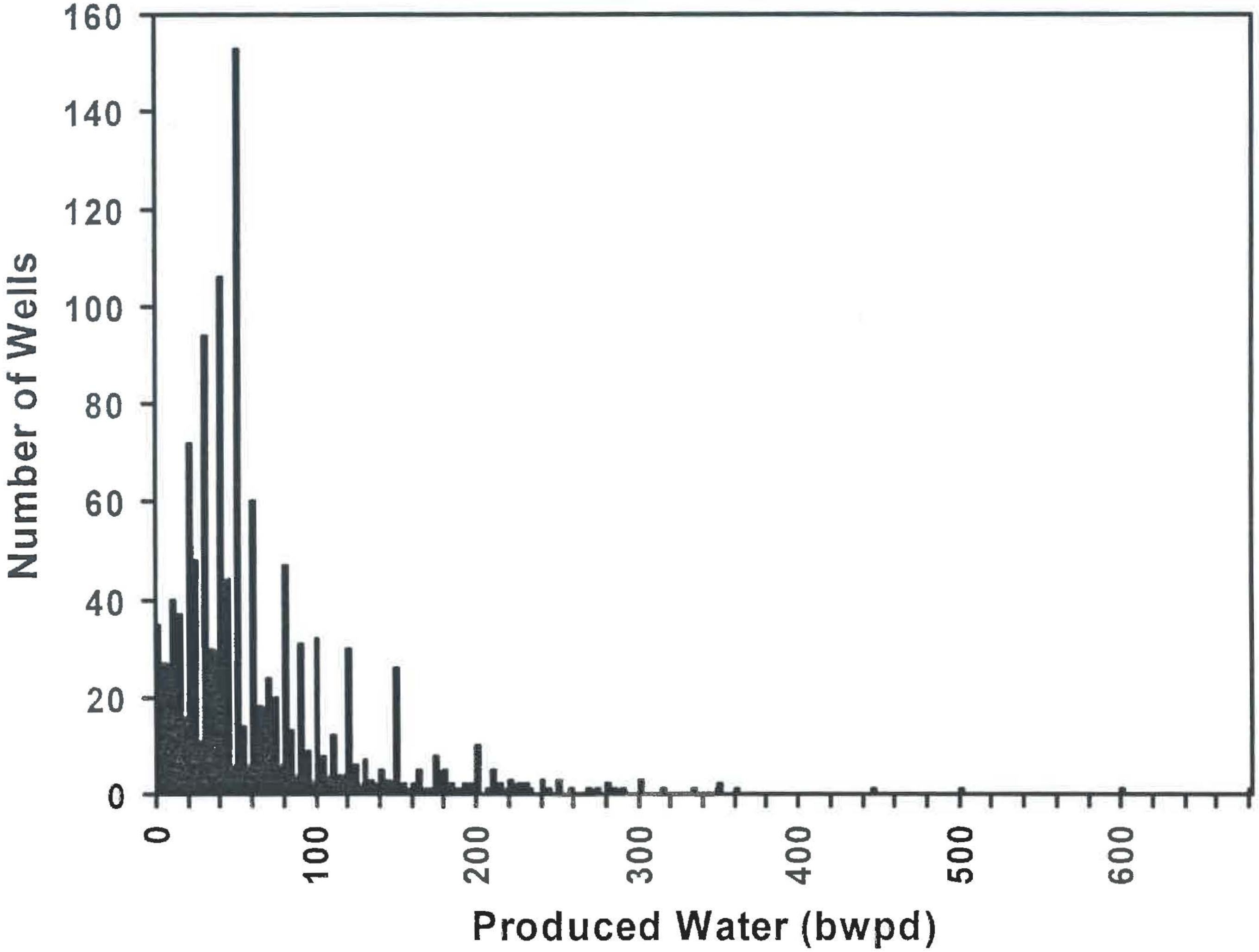
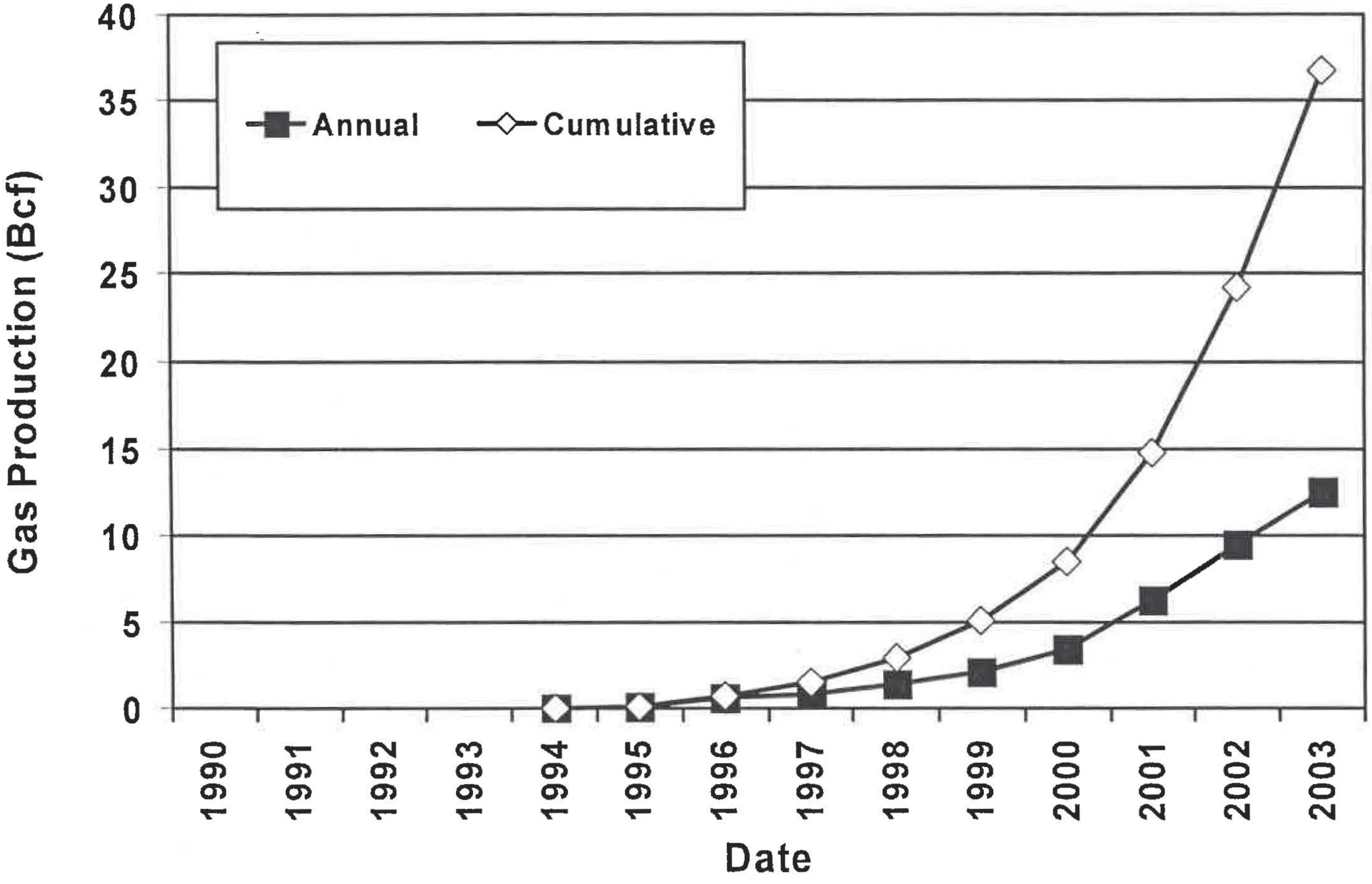


Figure 14. Graph showing annual and cumulative gas production for coalbed-methane wells in the northeast Oklahoma shelf, 1994 to 2003 (gas production data supplied by Petroleum Information/Dwights LLC dba IHS Energy Group, © 2004).



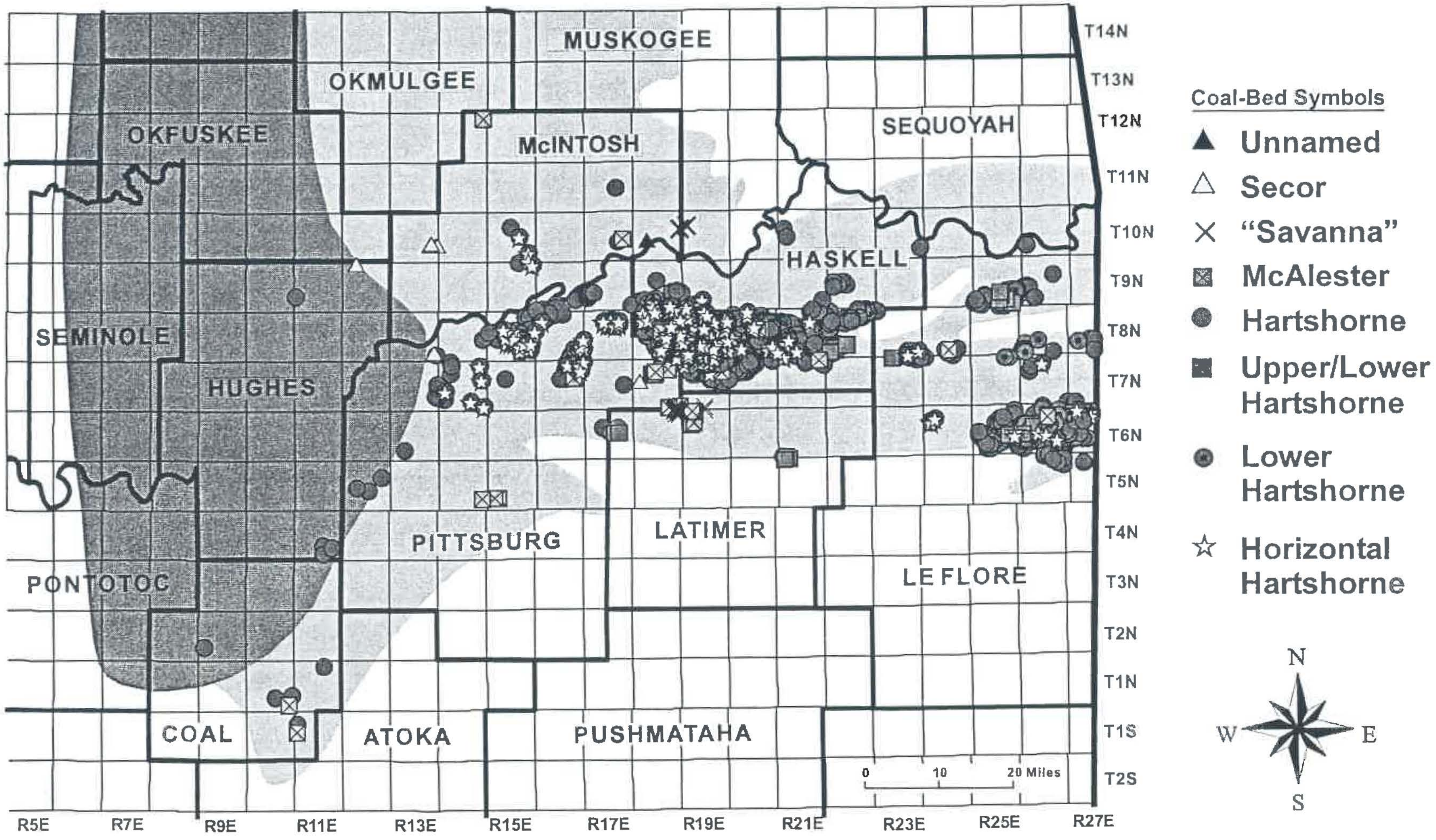
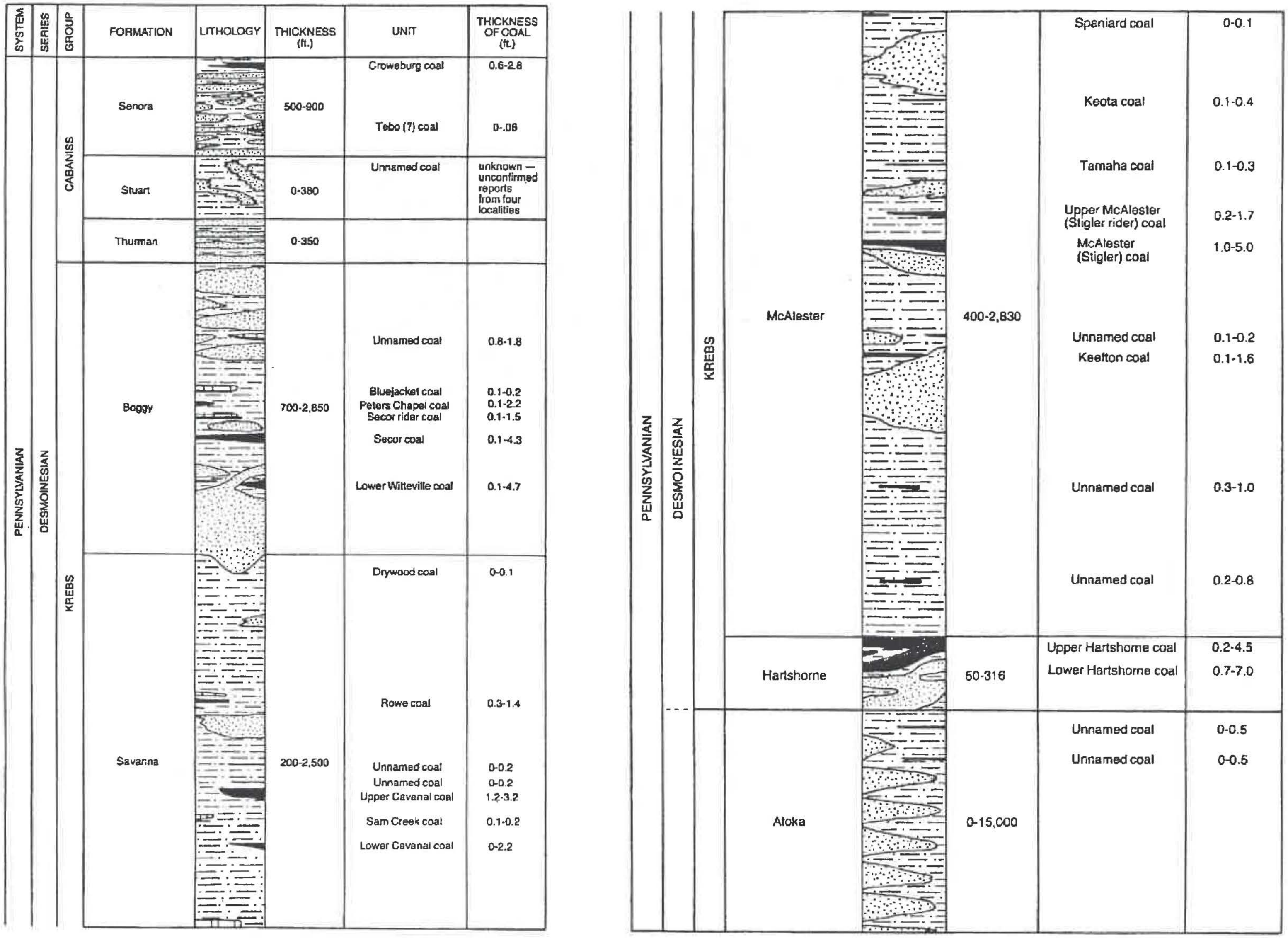


Figure 15. Distribution of coalbed-methane well completions by coal bed in the Arkoma Basin.



SYSTEM	SERIES	GROUP	FORMATION	LITHOLOGY	THICKNESS (ft.)	UNIT	THICKNESS OF COAL (ft.)
PENNSYLVANIAN	DESMOINESIAN	CABANISS	Senora		500-900	Croweburg coal	0.6-2.8
						Tebo (?) coal	0-.06
			Stuart		0-380	Unnamed coal	unknown — unconfirmed reports from four localities
			Thurman		0-350		
		KREBS	Boggy		700-2,850	Unnamed coal	0.8-1.8
						Bluejacket coal	0.1-0.2
						Peters Chapel coal	0.1-2.2
						Secor rider coal	0.1-1.5
						Secor coal	0.1-4.3
						Lower Witteville coal	0.1-4.7
			Savanna		200-2,500	Drywood coal	0-0.1
						Rowe coal	0.3-1.4
						Unnamed coal	0-0.2
						Unnamed coal	0-0.2
						Upper Cavanal coal	1.2-3.2
						Sam Creek coal	0.1-0.2
						Lower Cavanal coal	0-2.2
			McAlester		400-2,830	Spaniard coal	0-0.1
						Keota coal	0.1-0.4
						Tamaha coal	0.1-0.3
						Upper McAlester (Stigler rider) coal	0.2-1.7
						McAlester (Stigler) coal	1.0-5.0
						Unnamed coal	0.1-0.2
						Keefton coal	0.1-1.6
						Unnamed coal	0.3-1.0
						Unnamed coal	0.2-0.8
			Hartshorne		50-316	Upper Hartshorne coal	0.2-4.5
						Lower Hartshorne coal	0.7-7.0
			Atoka		0-15,000	Unnamed coal	0-0.5
						Unnamed coal	0-0.5

Figure 16. Generalized stratigraphy of coal-bearing strata of the Arkoma Basin (from Hemish, 1988).

Figure 17. Histogram of coalbed-methane well completion depths in the Arkoma Basin.

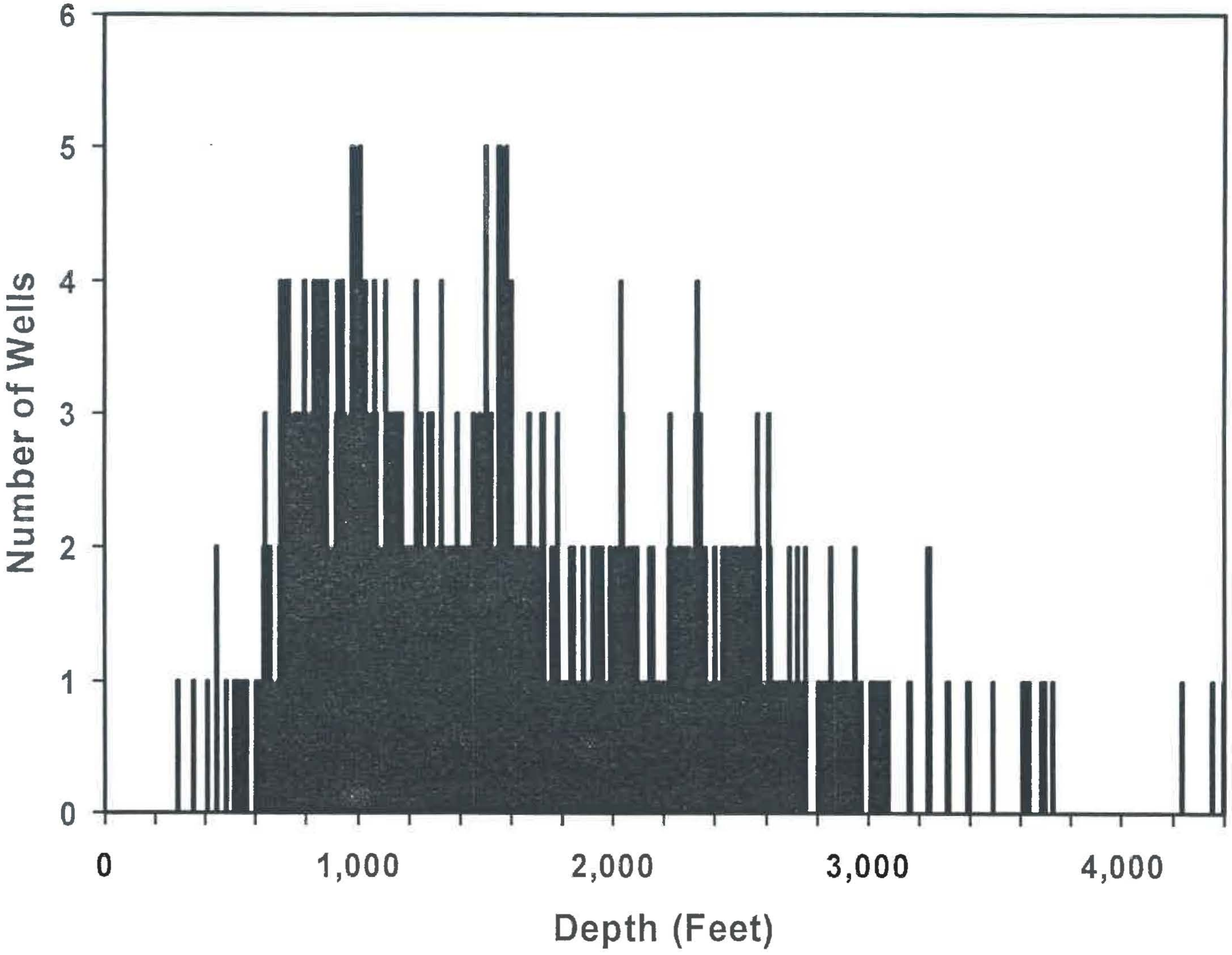


Figure 18. Histogram of initial-potential-gas rates in coalbed-methane well completions in the Arkoma Basin.

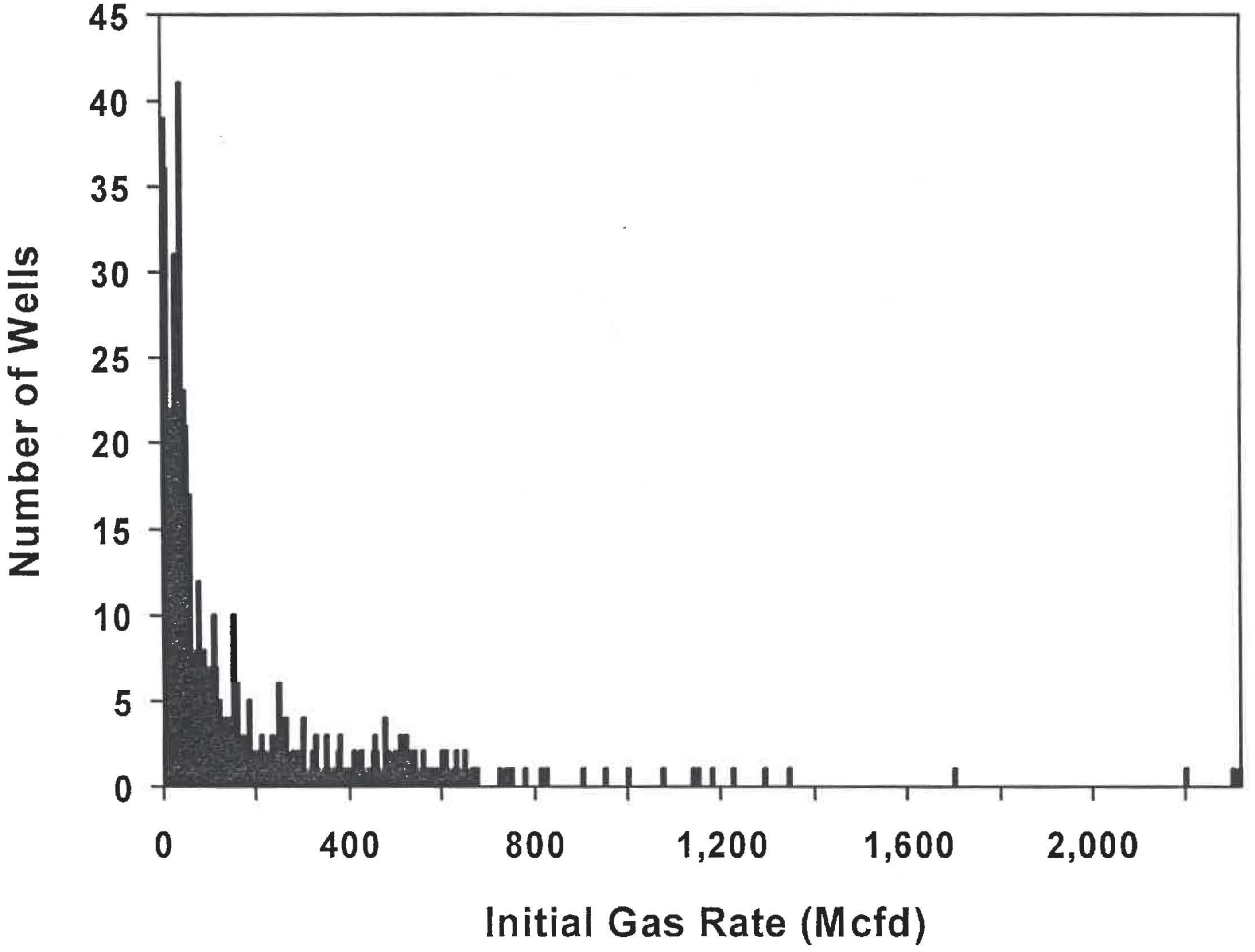
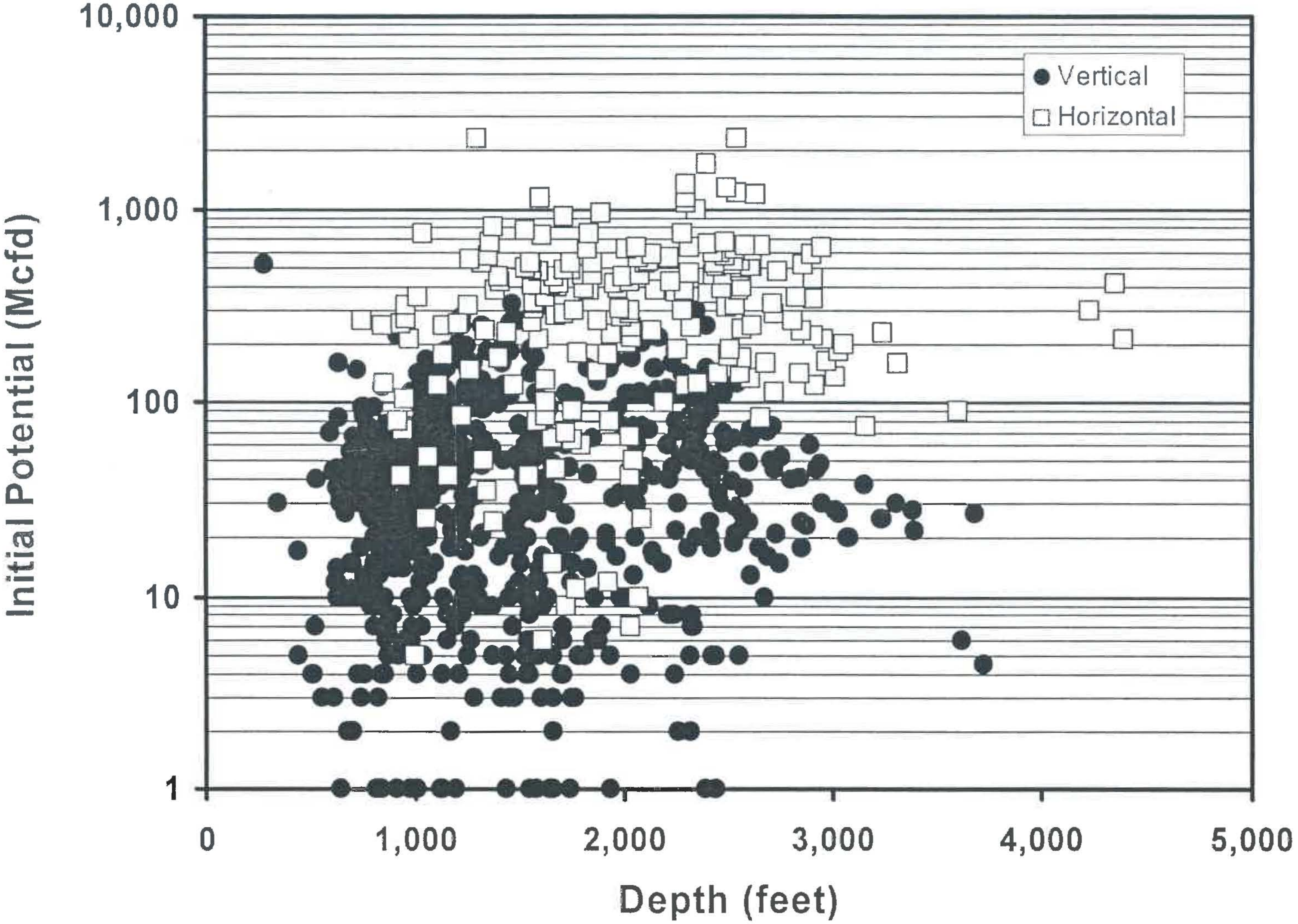


Figure 19. Scatter plot of initial-potential-gas rate and depth to top of coal in the Arkoma Basin.



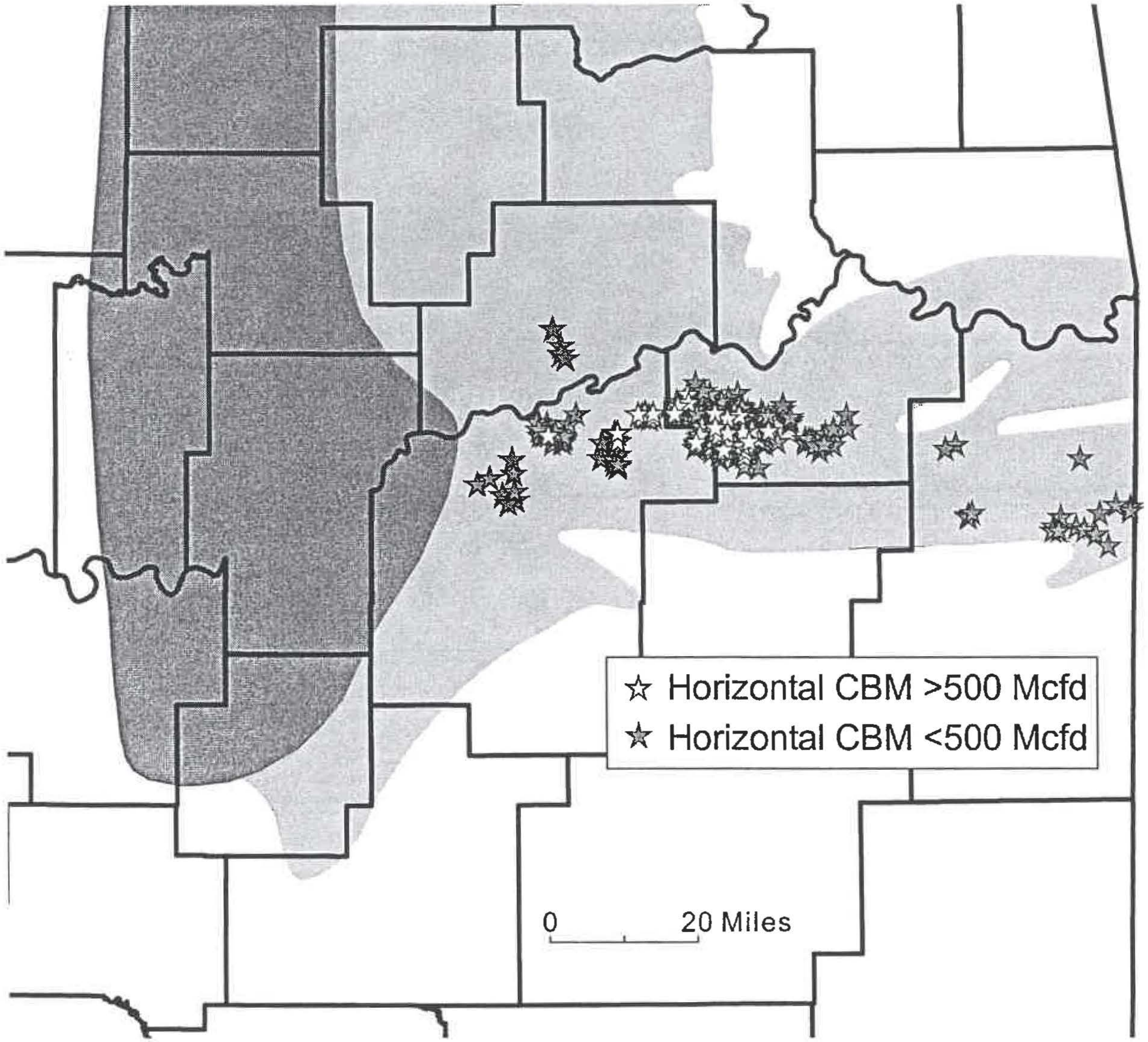
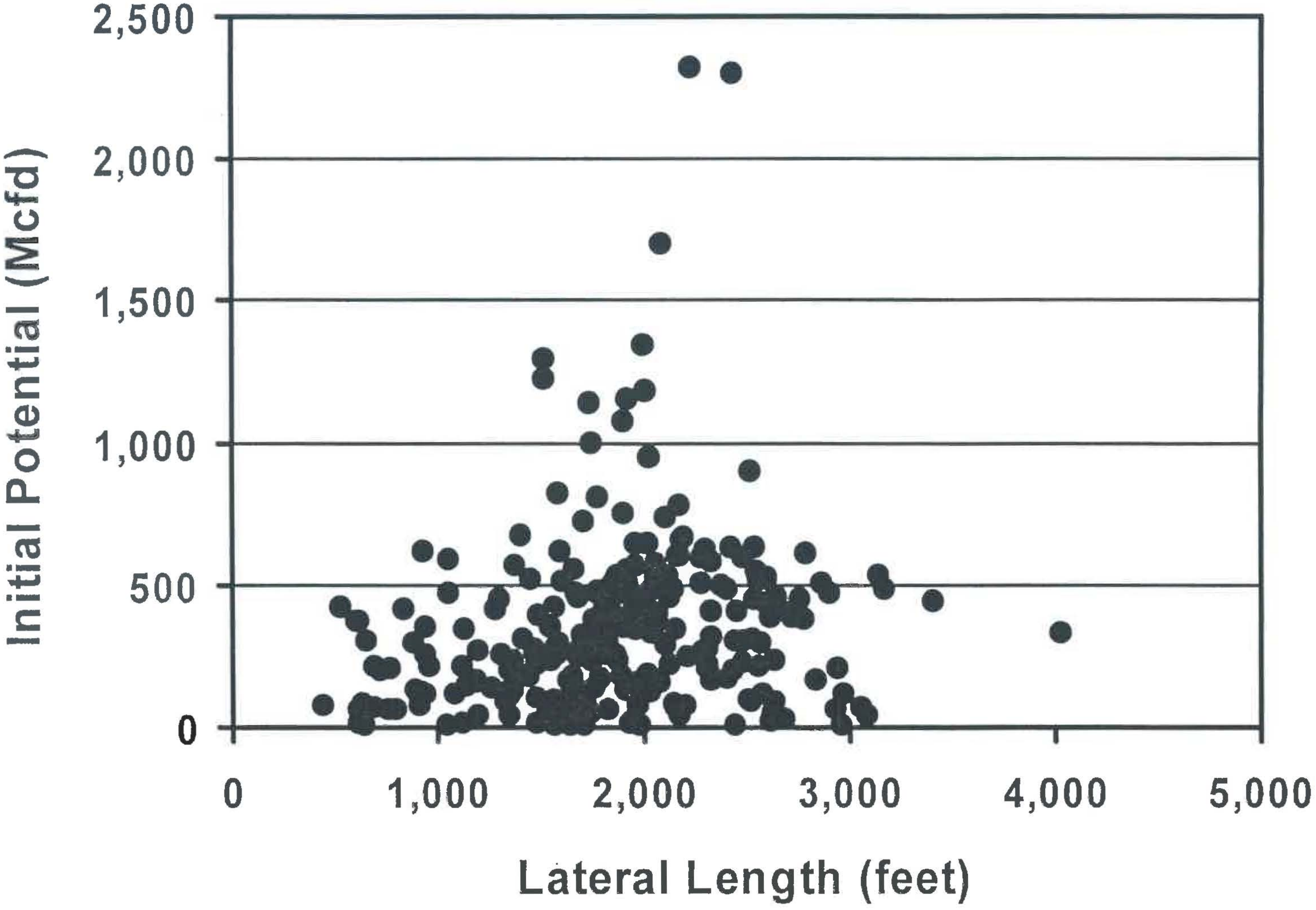


Figure 20. Distribution of horizontal coalbed-methane well completions in the Arkoma Basin, showing wells with relatively high IP gas rates.

Figure 21. Scatter plot of initial-potential-gas rate and horizontal lateral length in the Arkoma Basin.



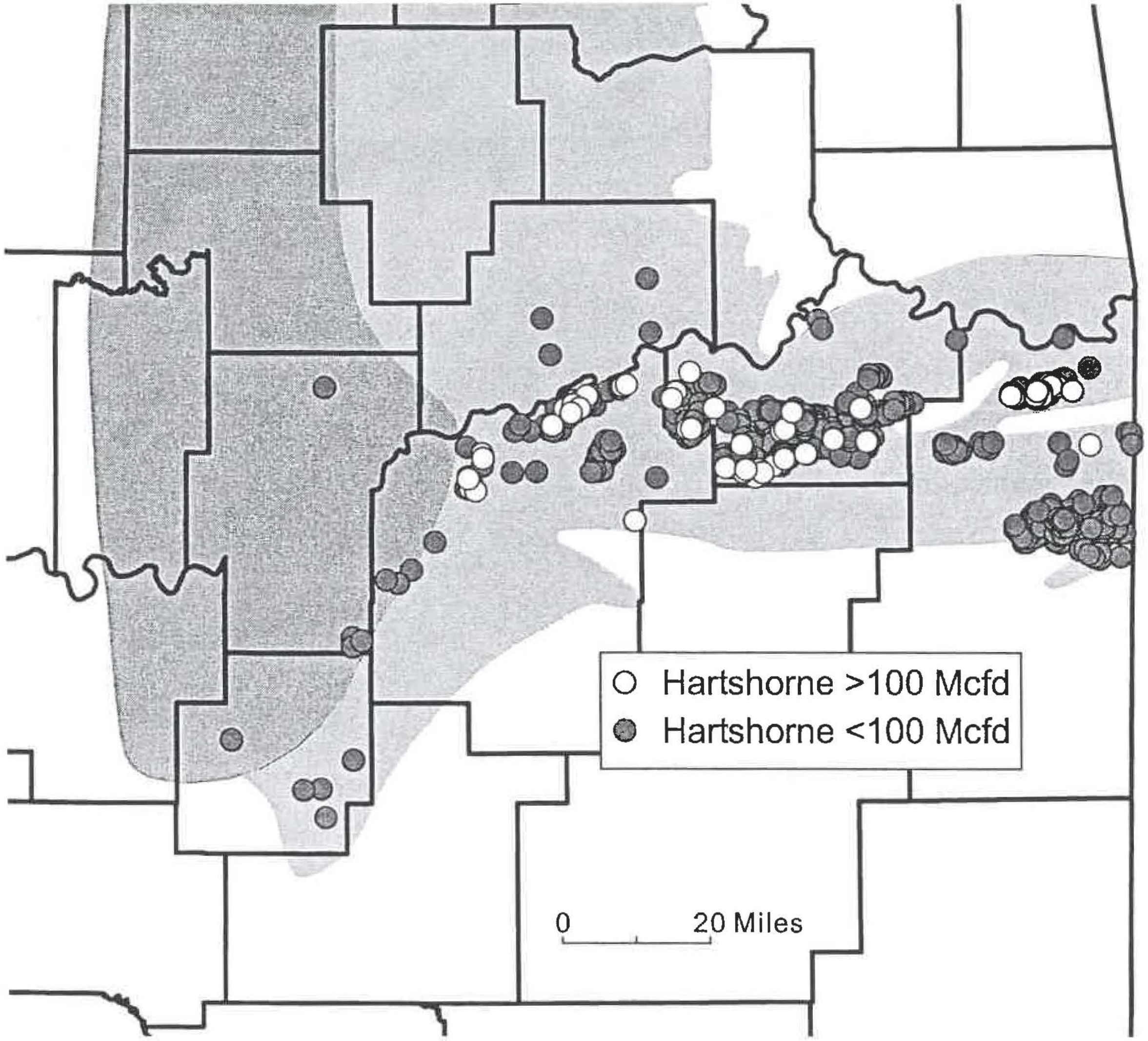
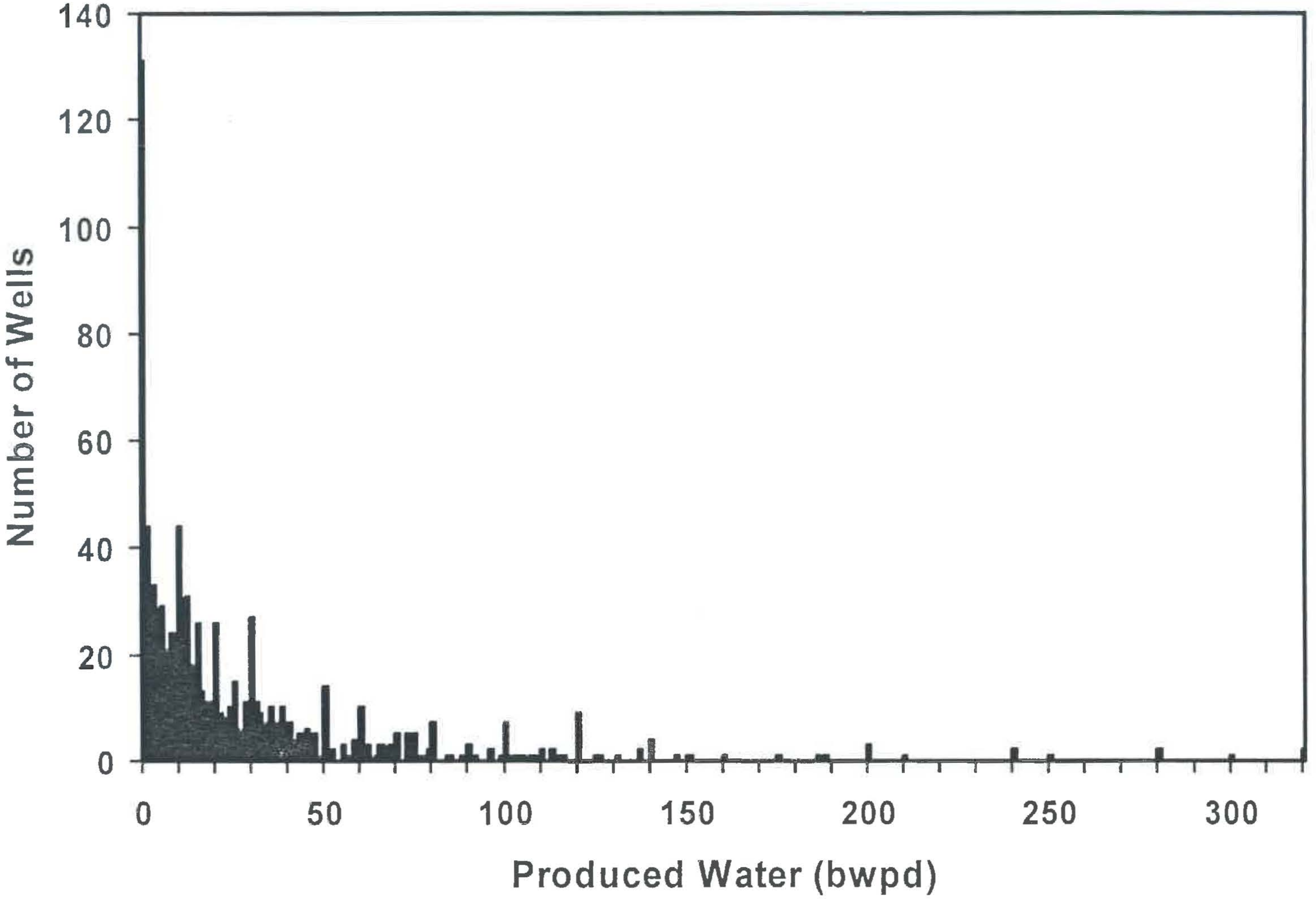


Figure 22. Distribution of well completions in the Hartshorne coal (excluding horizontal CBM wells) in the Arkoma Basin, showing wells with relatively high IP gas rates.

Figure 23. Histogram of initial water production rates from coalbed-methane wells in the Arkoma Basin (excluding one well with 1,861 BWPD).



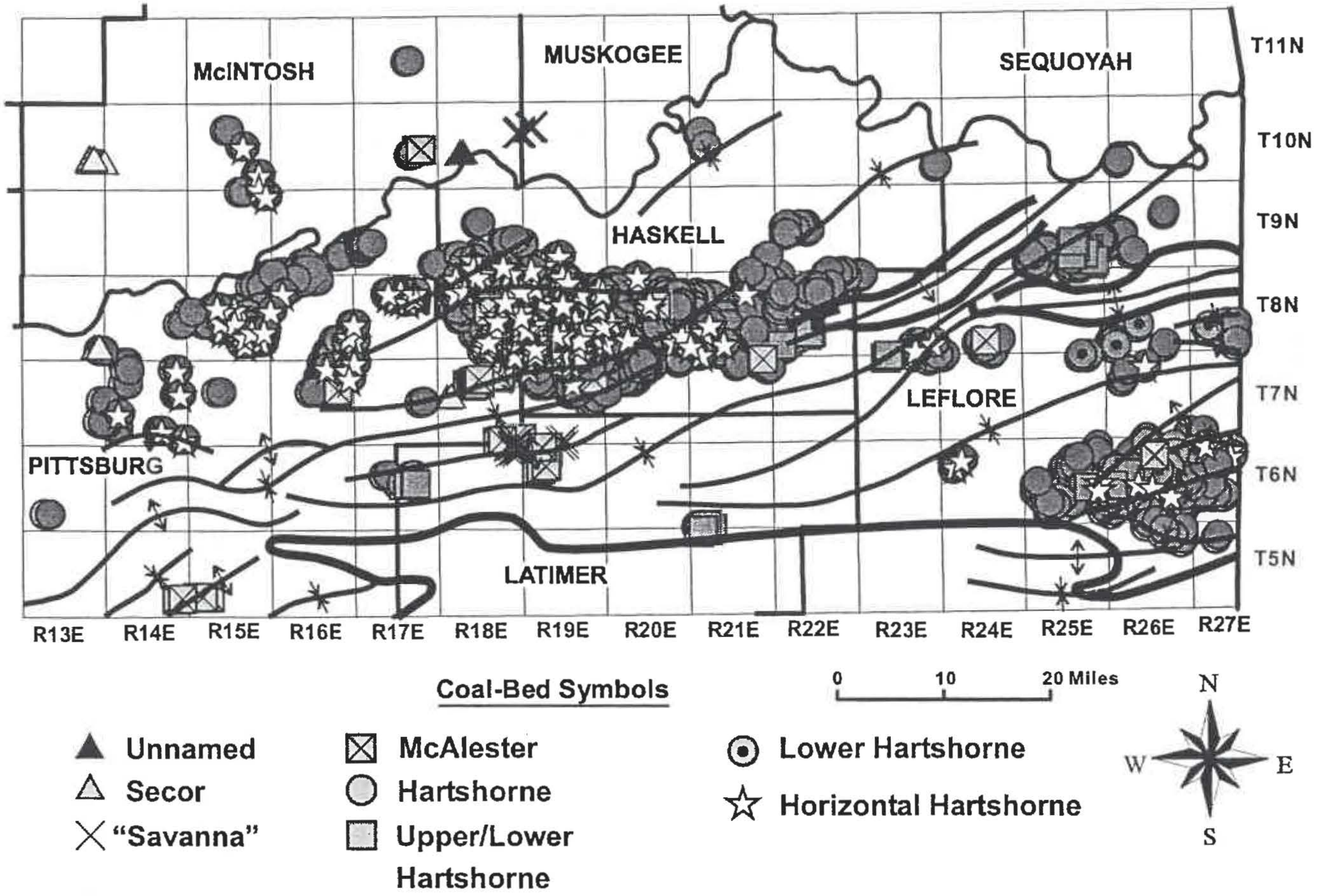
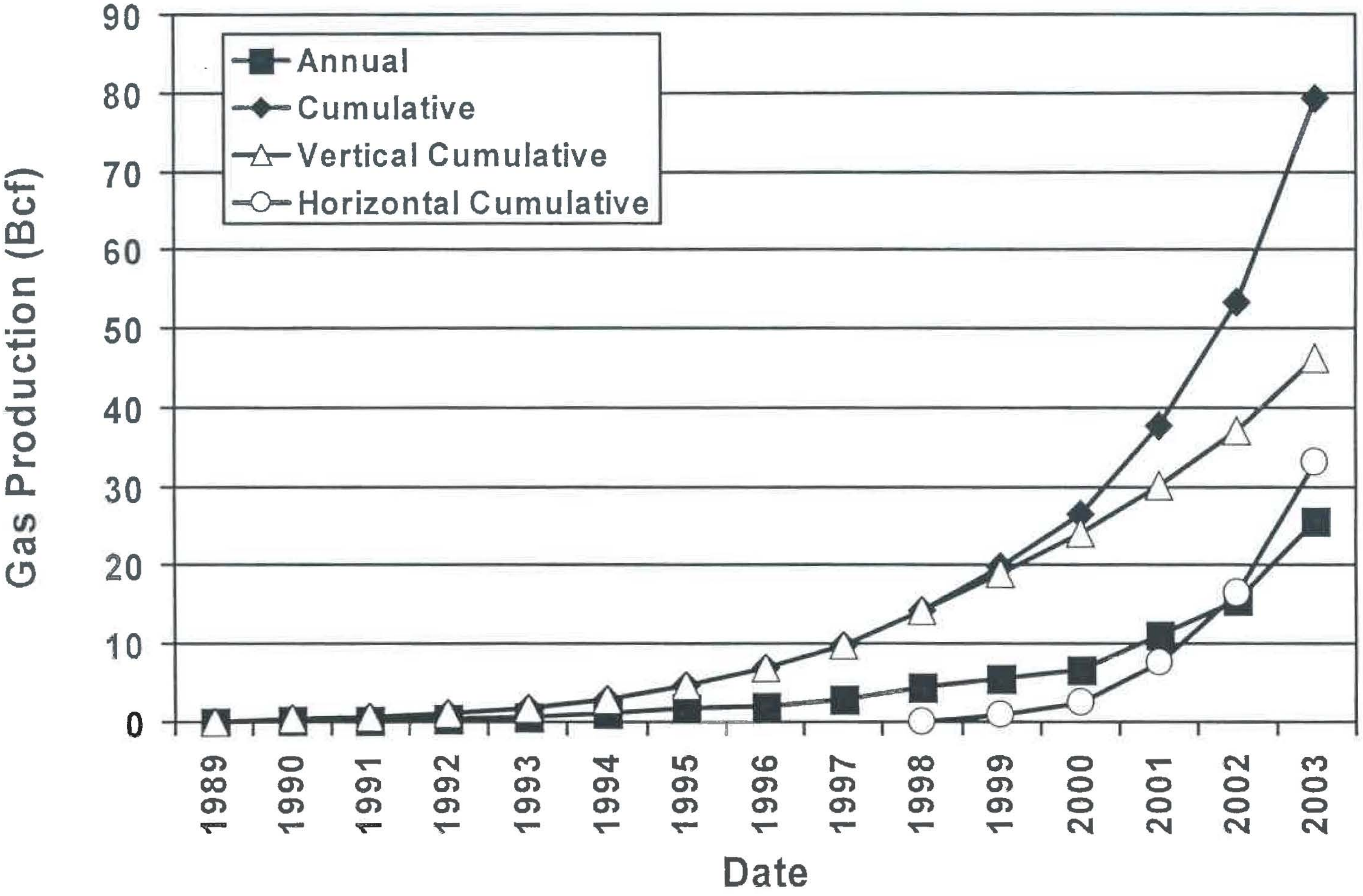


Figure 24. Major surface fold axes, Hartshorne coal outcrop (heavy line), and coalbed-methane well completions in the Arkoma Basin, Oklahoma. Structure modified from Arbenz (1956, 1989), Berry and Trumbly (1968), and Suneson (1998).

Figure 25. Graph showing annual and cumulative gas production for coalbed-methane wells in the Arkoma Basin, 1989 to 2003 (gas production data supplied by Petroleum Information/Dwights LLC dba IHS Energy Group, © 2004).



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 such as the Warrior basin in Alabama, San Juan basin in Colorado and New Mexico, Raton basin in Colorado, and the Powder River basin in Wyoming and Montana have 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 resulted in extensive leasing in both the Cherokee basin of southeast Kansas and the Forest City basin in east-central and northeast Kansas.

Deep coal resources are recognized for 32 coal beds, and strippable coal resources have been determined for 17 coal beds. At the present time, 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 90'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 ran by the Kansas Geological Survey is 346 scf/ton for a Rowe coal at 1400 ft depth.

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 have 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 northeast 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 established 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) and Johnson (2004).

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 determine for coal at depths less than 2500 feet, but based on recent drilling coals are know to be present in deeper parts of the eastern Kansas basins to depths of at least 3000 feet. 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 southeast 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 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) and Johnson (2004), and on-going work at the Kansas Geological Survey suggests that much larger coal resource totals probably exist in eastern Kansas. This is based mainly on new drilling in areas of earlier lacking drill data has shown general continuity of the principal 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 County. 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 feet). 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 is 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 sparse, 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, generally there is a decrease in gas content northward toward the Bourbon arch and eastward toward the outcrop. The northward increase 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 southeast Kansas, and also east-central parts of the state. By August 2004, there were nearly 1800 wells 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). Most of these wells in eastern Kansas have been drilled since 2000, with the number of wells per year continuing at a rapid pace (Figure 3; from Newell and others, 2004). 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 10 bcf/year (Figure 4; from Newell and others, 2004). 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 has yet to be determined. Similarly, westward expansion of production westward to the axis of the Cherokee and Forest City basins has yet to happen. 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, 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 ran 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 in the well in Montgomery County are buried less deeply in Labette County (the county immediately east), for Labette County is higher on the flank of the Cherokee basin and closer to the outcrop (Figure 8; from Newell and others, 2004). Some of these coals have only half the gas content they have in Montgomery County 15 miles to the west. The gas contents 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 need to be done to identify these types of production fairways.

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

Coal beds observed on the field trip at the Phoenix Coal Company Alluwe Mine (Iron Post coal) and their Kelley Mine (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) 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 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)—which is 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 that is not included in those resource figures. New isopach mapping of key coal beds is presently underway at the Kansas Geological Survey. Most of the coal resource lies at a depth of less than 2500 feet.

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.

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 economical 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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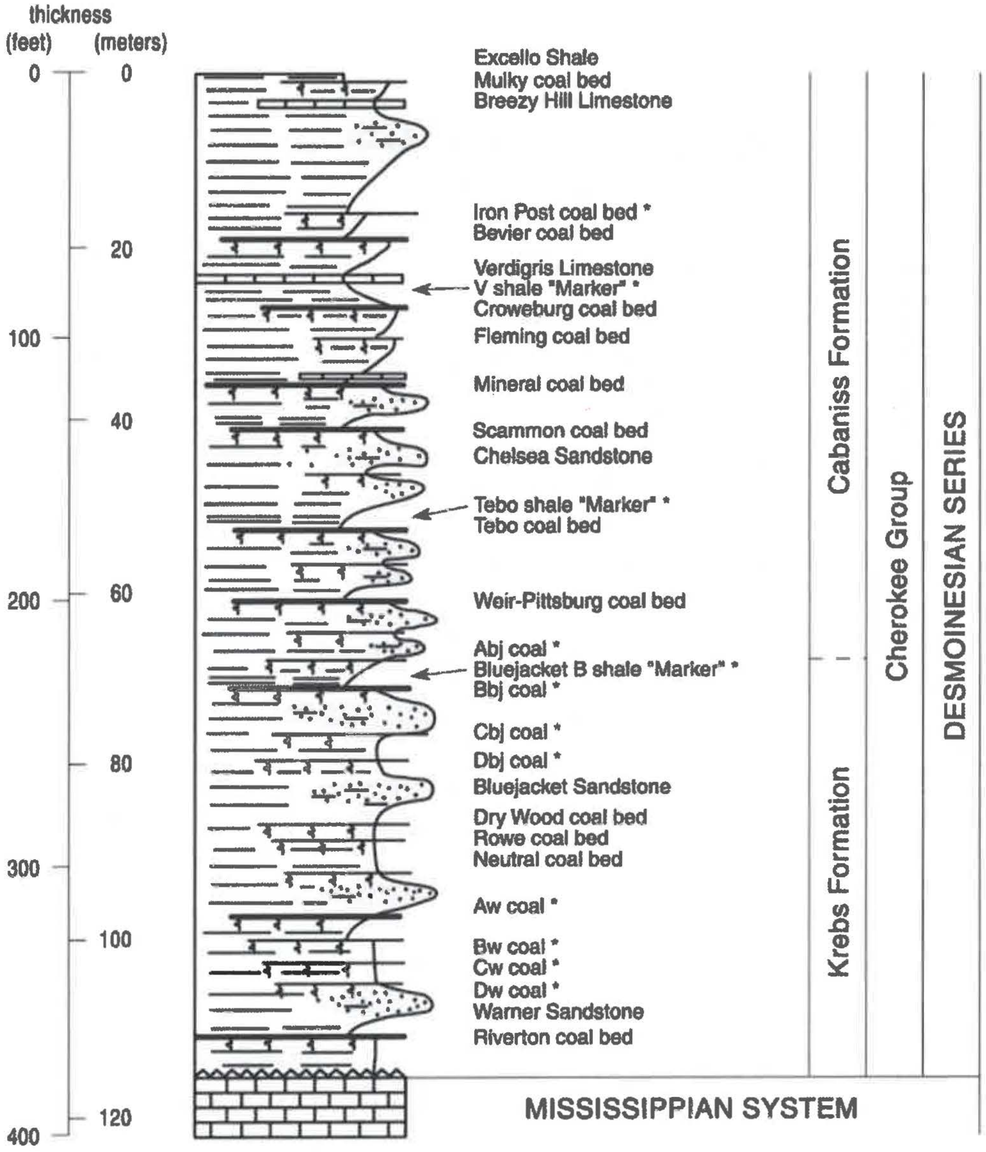

* Coal bed names that are used for correlation purposes, but are not formal or informal names recognized in Kansas.

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

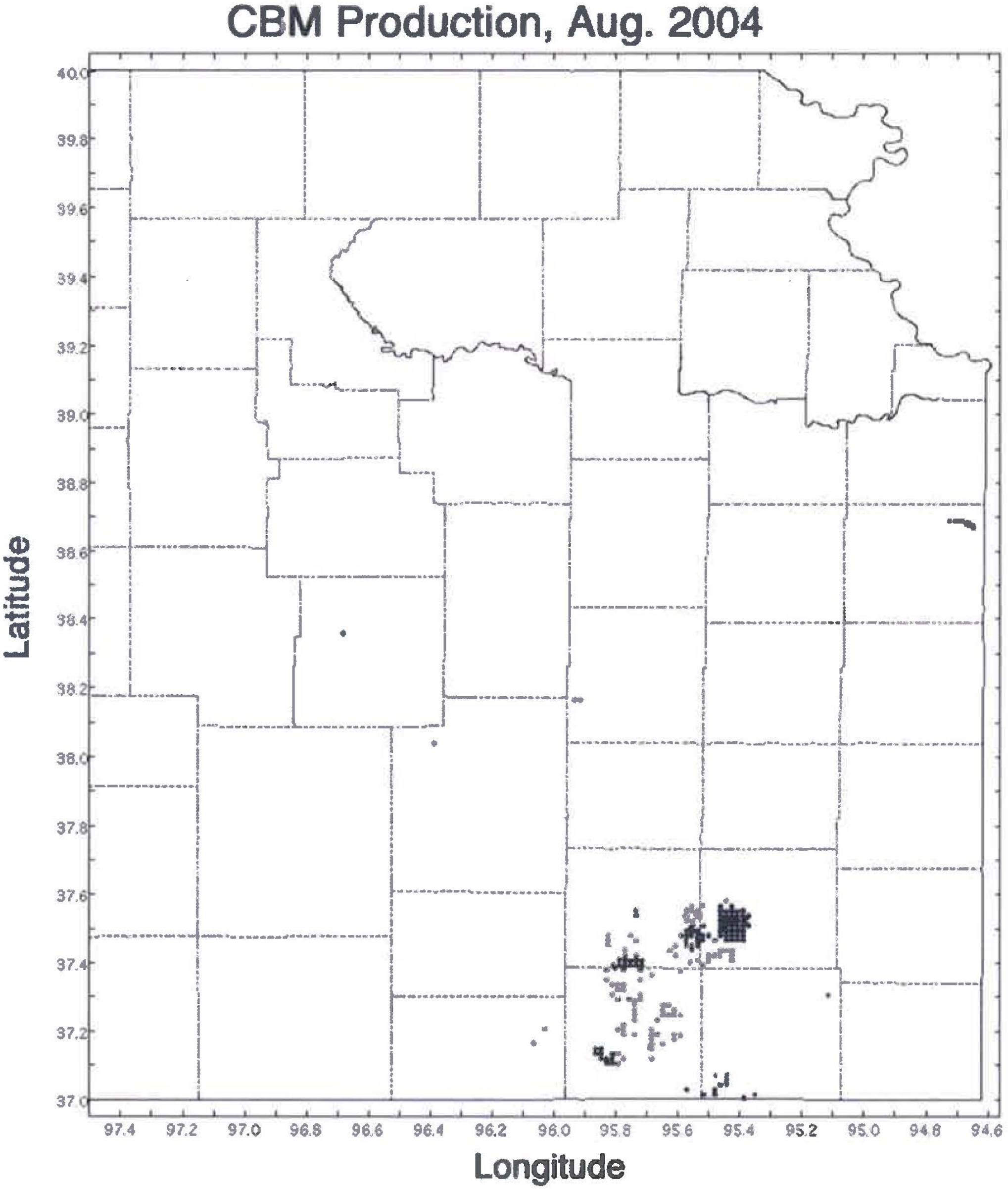

Figure 2. General location of coalbed methane production leases in eastern Kansas. A total of total of 847 leases are entered in the database through July 31, 2004. Modified from Adkins-Heljeson (2004).

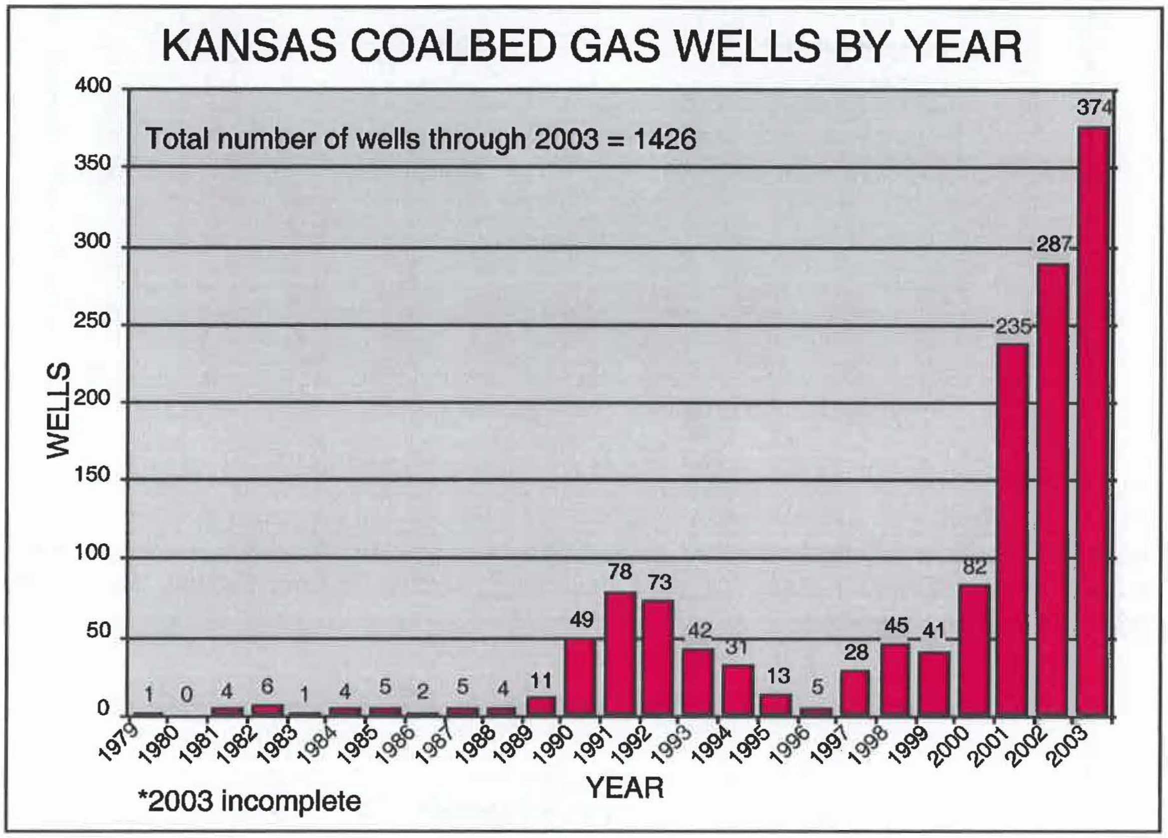

Figure 3. Annual tally of coalbed gas wells drilled in Kansas. The small surge in drilling in the 1990s is due to the influence of temporary federal tax credits for unconventional gas wells. The latest surge in drilling is largely price driven, in combination with available excess capacity in pipelines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

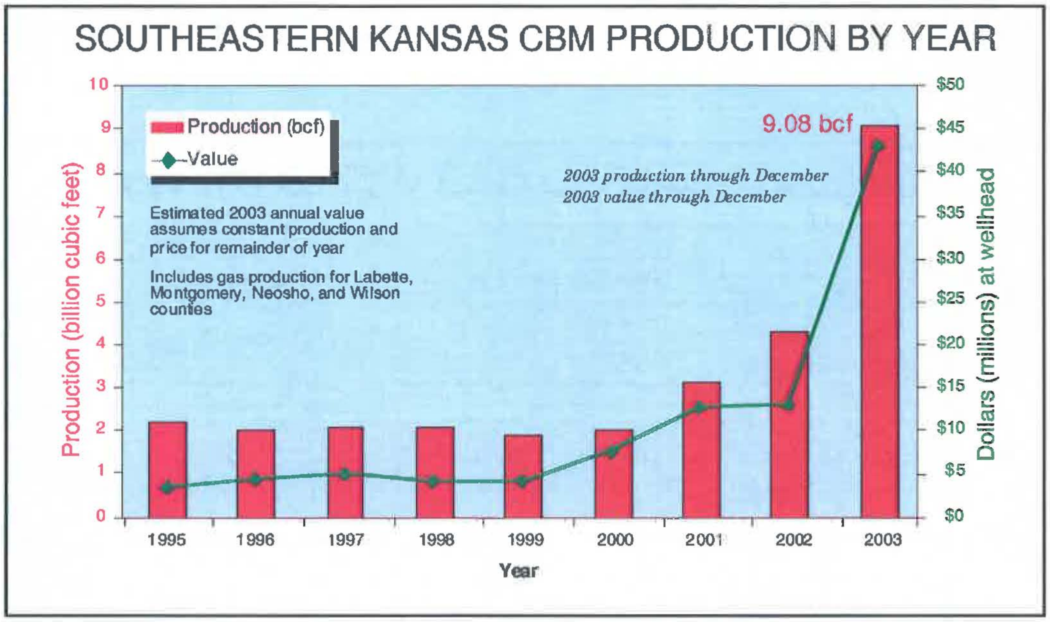

Figure 4. The surge in drilling for coalbed gas wells has been quickly followed by an increase in gas production in southeastern Kansas. Most of this new production is from Labette, Montgomery, Neosho, and Wilson Counties.

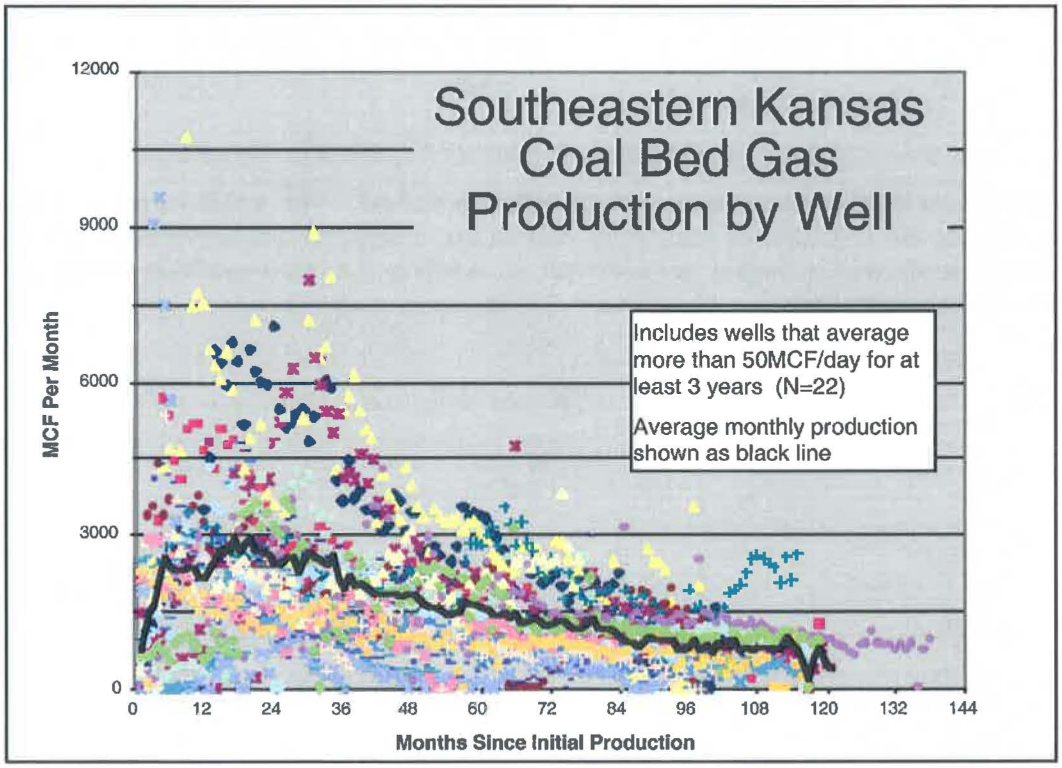

Figure 5. Production is reported in Kansas by lease name, customarily with the monthly production and number of wells producing from the lease. In order to gain an understanding of individual coalbed-well production characteristics, only single-well leases were used for this diagram. Production appears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

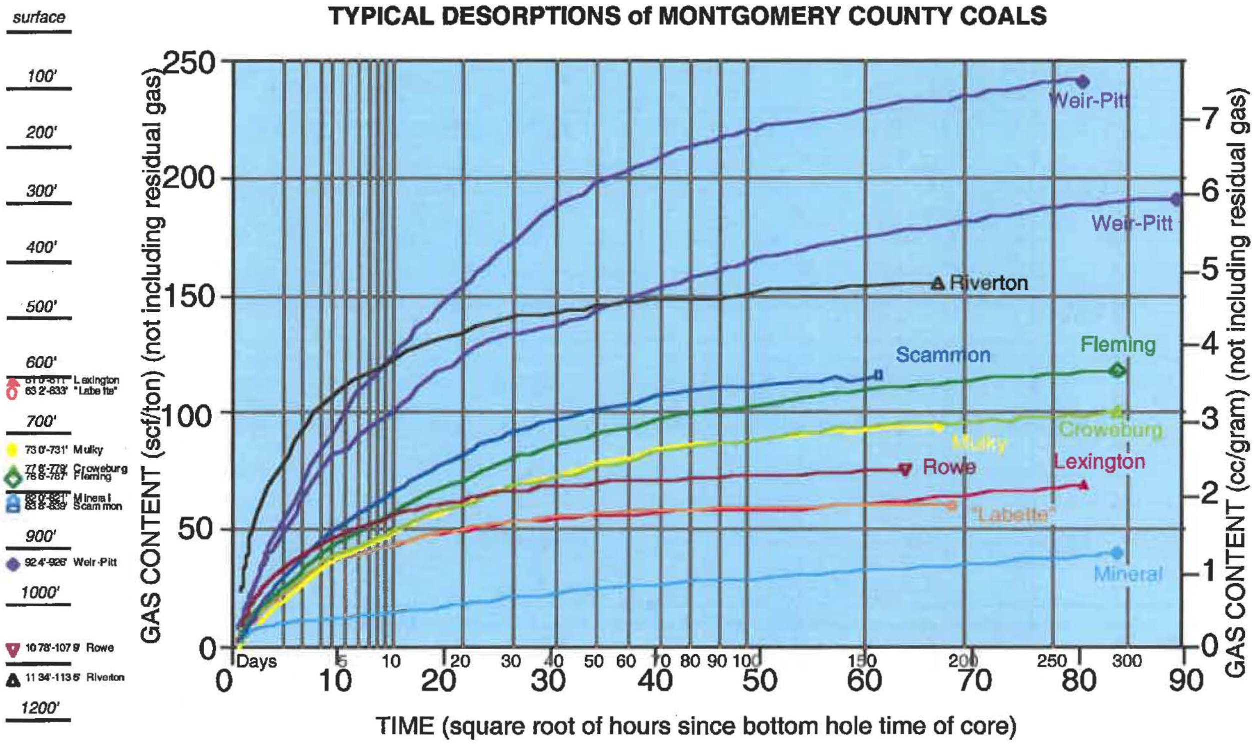

Figure 6. Desorption diagram for coals from a well in central Montgomery County, KS. Deeper coals (Weir-Pittsburg, Riverton) have the greatest gas content. Gas content is on an as-received basis, and does not include residual gas.

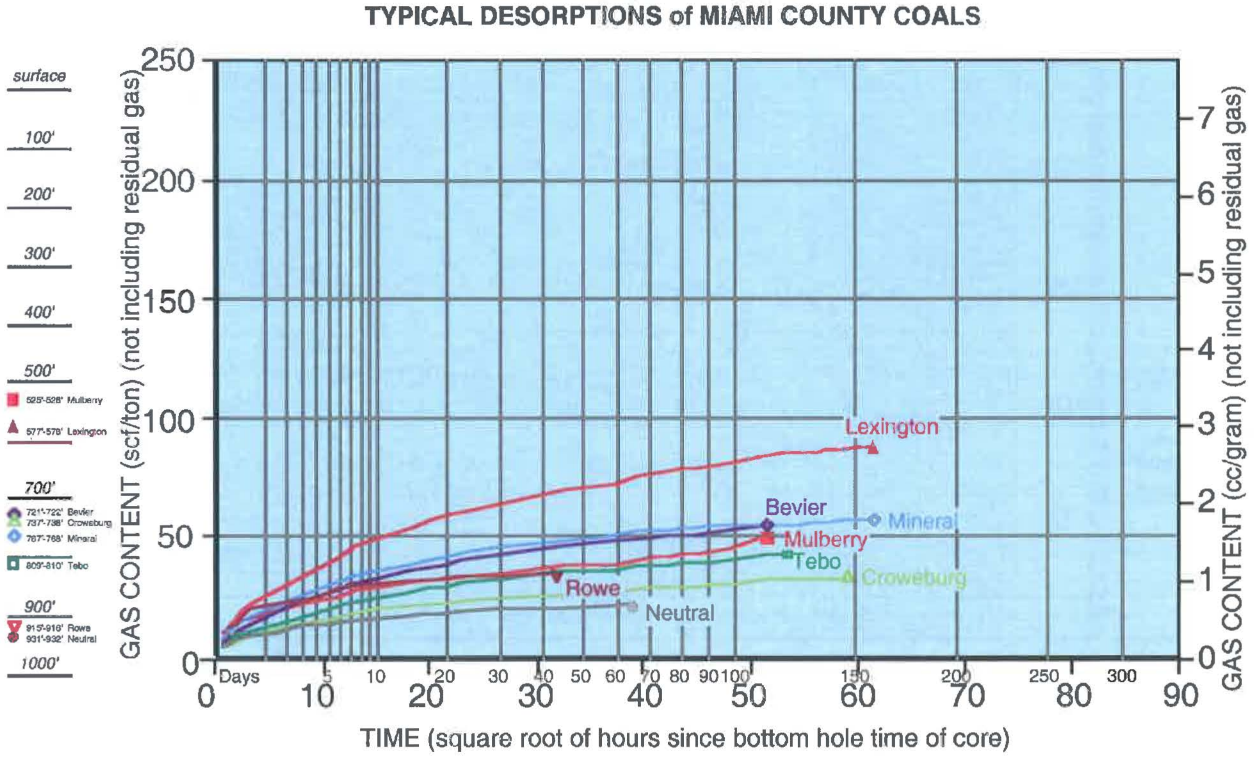

Figure 7. Desorption diagram for coals from a well in northern Miami County, KS. Less gas content is recorded for this locality (on the southeastern flank of the Bourbon arch) than farther south in the Cherokee basin. Gas content is on an as-received basis, and does not include residual gas.

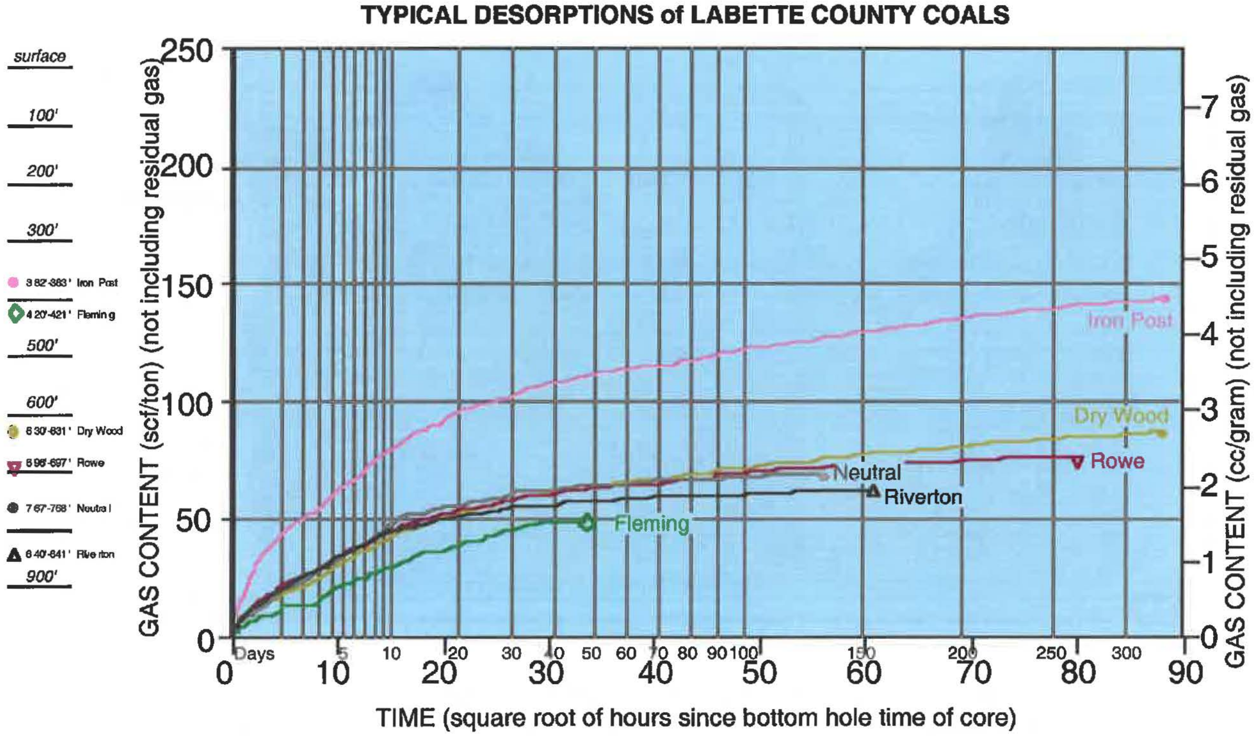

Figure 8. Desorption diagram for coals from a well in southern Labette County, KS. Shallower burial probably decreases the gas content of the coals at this locality (just 15 miles [25 km] southeast of the Montgomery County well). Nevertheless, the Iron Post coal at 380-ft depth has substantial gas content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

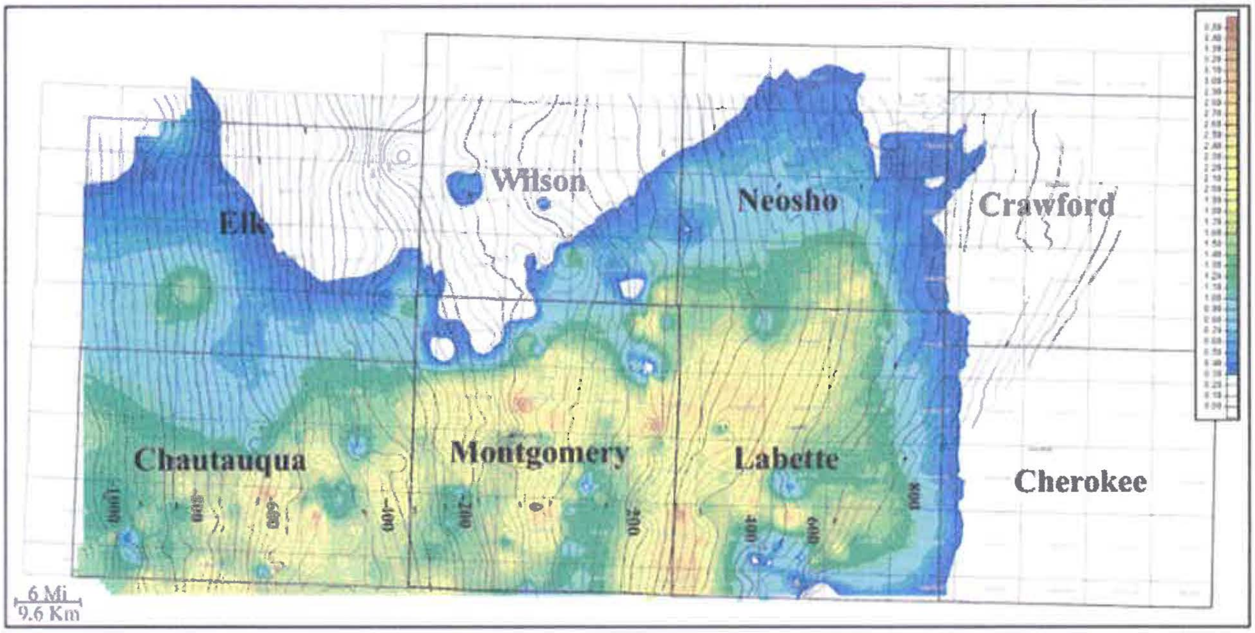

Figure 9. Isopach of Iron Post coal overlain with contours of the top of the Iron Post coal structure (isopach-color interval: 0.1 ft; structure CI: 25 ft). Modified from Lange, 2003, p. 104.

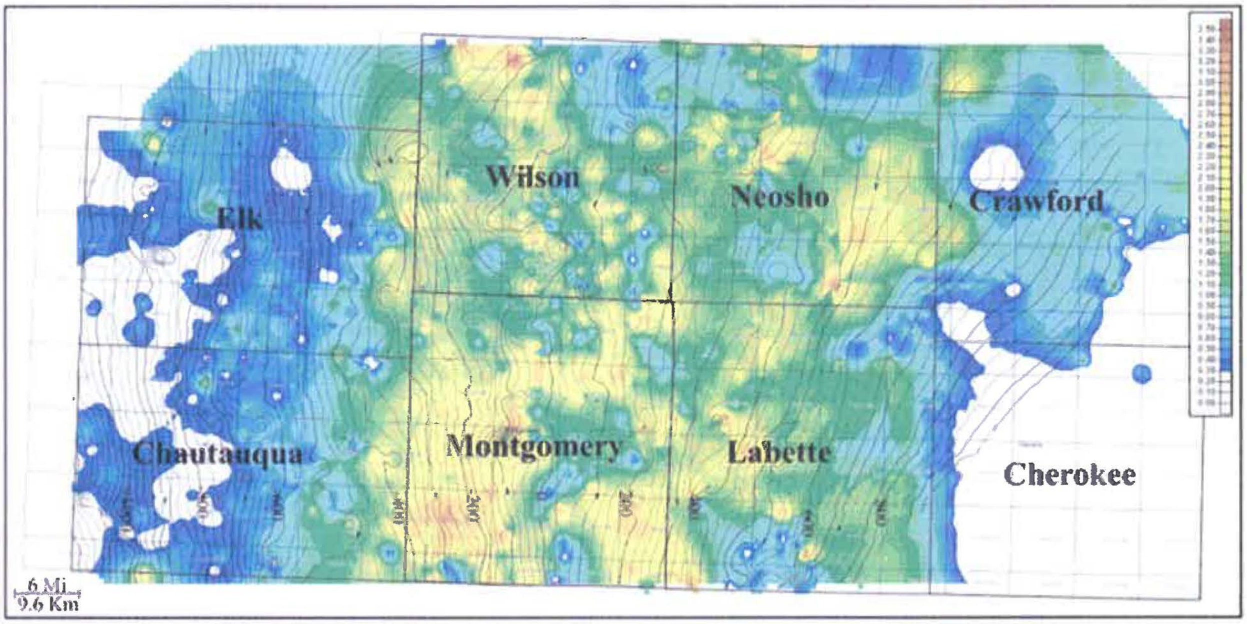

Figure 10. Isopach of Croweburg coal overlain with contours of the bottom of the Croweburg coal structure (isopach-color interval: 0.1 ft; structure CI: 25 ft). Modified from Lange, 2003, p. 97.

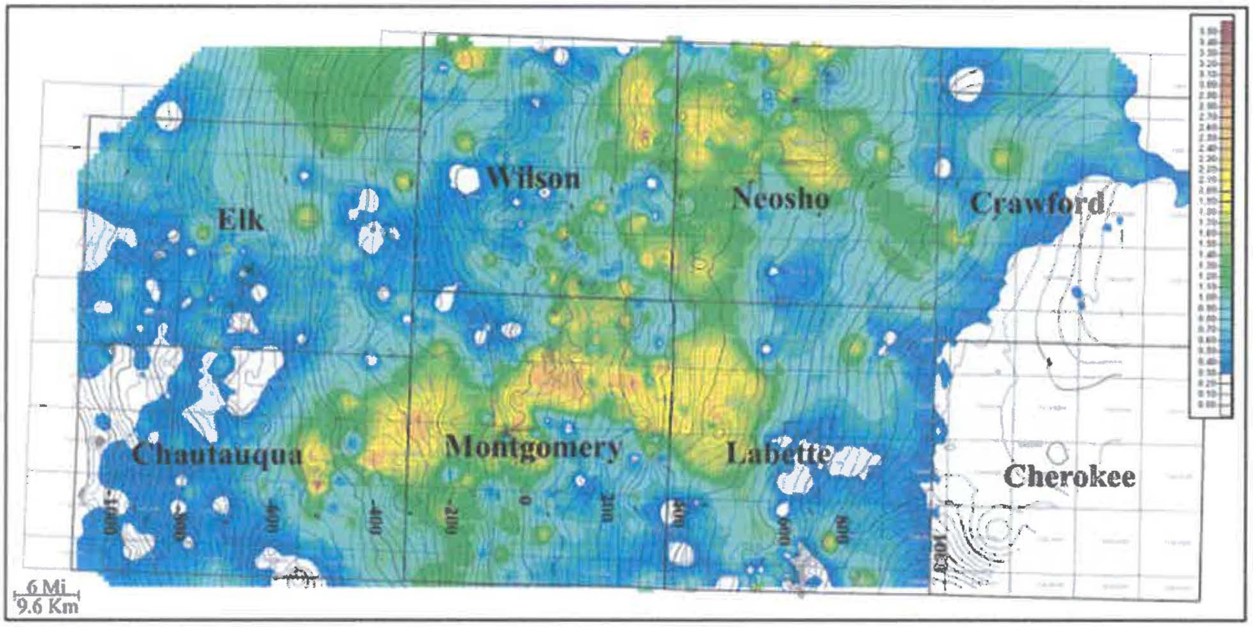

Figure 11. Isopach of Mulky coal overlain with contours of the top of the Breezy Hill Limestone structure (isopach-color interval: 0.1 ft; structure CI: 25 ft). Modified from Lange, 2003, p. 106.

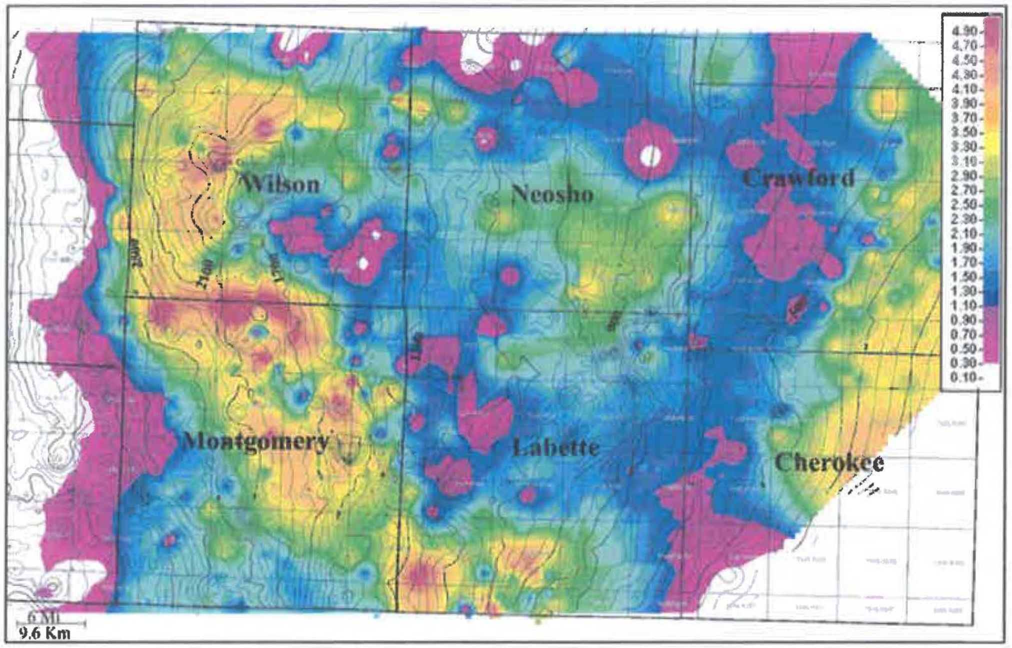

Figure 12. Isopach of Weir-Pittsburg coal overlain with contours of the top of the Mississippi limestone structure (isopach-color interval: 0.1 ft; structure CI: 25 ft). Modified from Lange, 2003, p. 82.

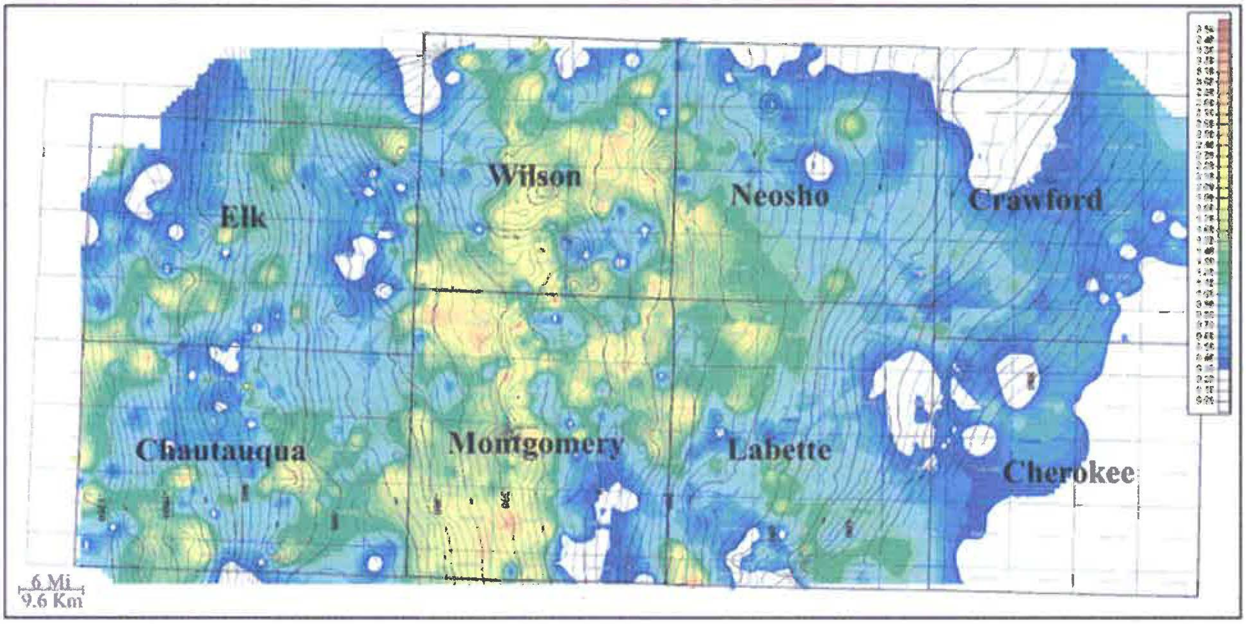

Figure 13. Isopach of Tebo coal overlain with contours of the bottom of the Tebo coal structure (isopach-color interval: 0.1 ft; structure CI: 25 ft). Modified from Lange, 2003, p. 86.

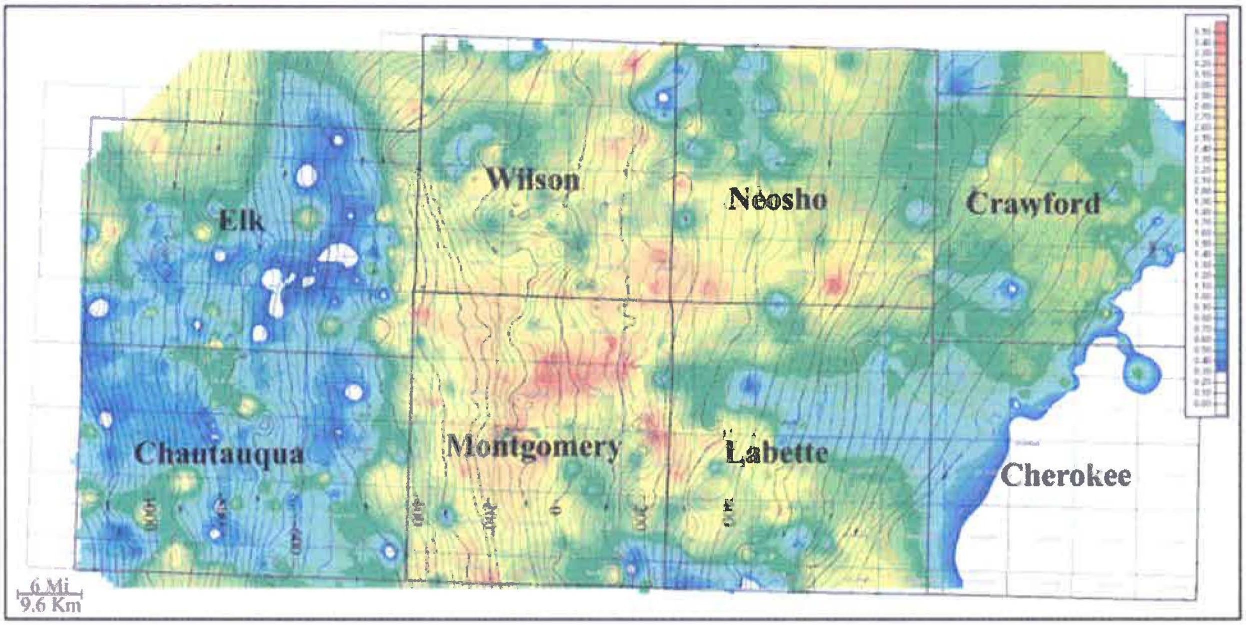

Figure 14. Isopach of Mineral coal overlain with contours of the top of the Mississippian limestone structure (isopach-color interval: 0.1 ft; structure CI: 25 ft). Modified from Lange, 2003, p. 92

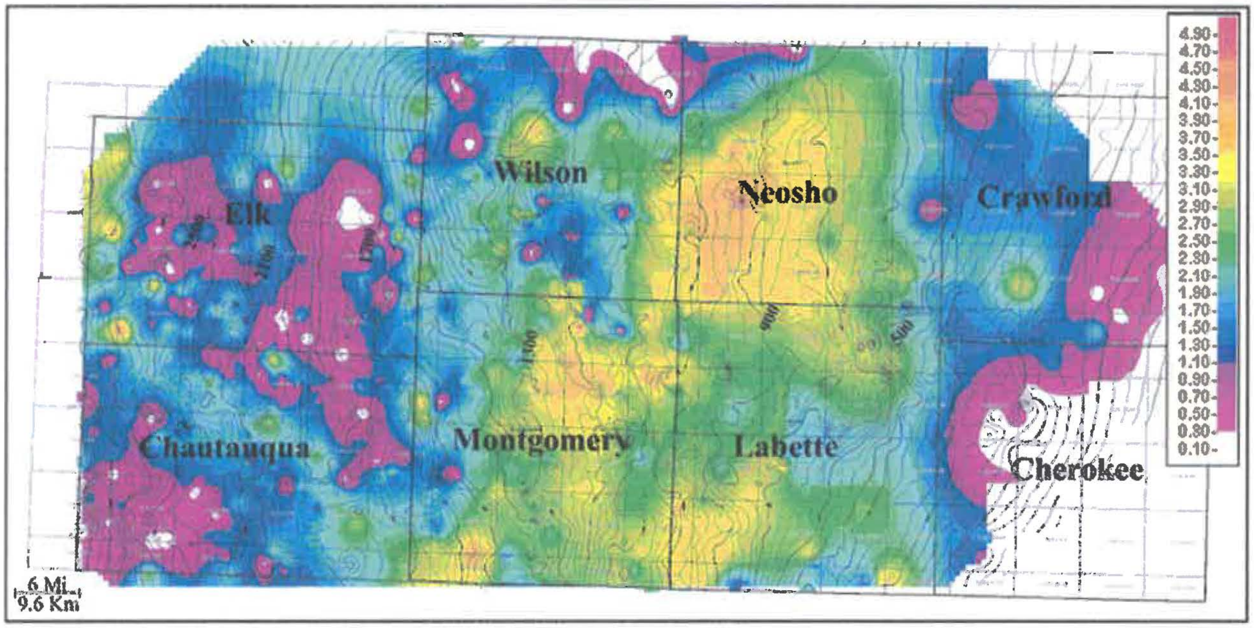

Figure 15. Isopach of Riverton coal overlain with contours of the top of the Mississippian limestone structure (isopach-color interval: 0.1 ft; structure CI: 25 ft). Modified from Lange, 2003, p. 76.

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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