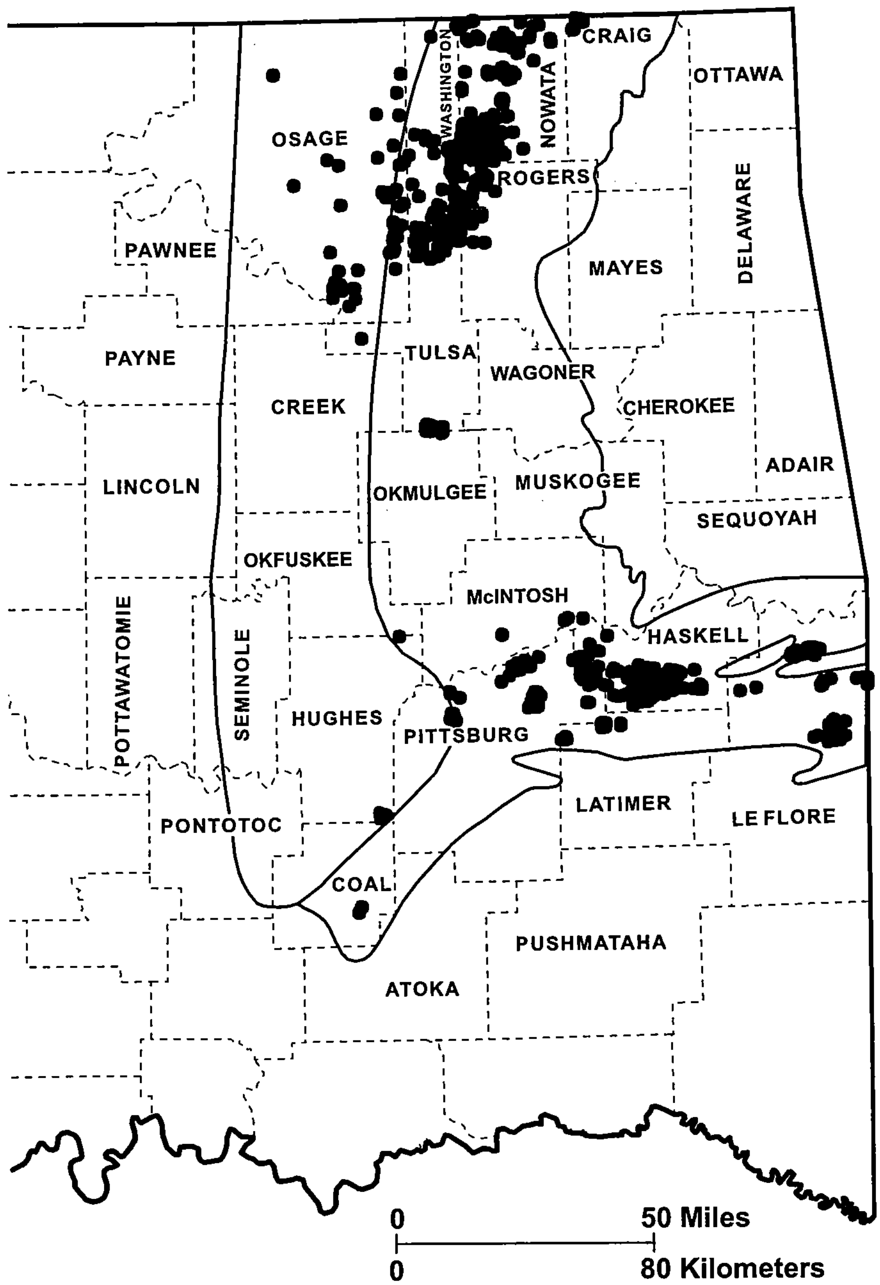
OKLAHOMA GEOLOGICAL SURVEY
OPEN-FILE REPORT OF 2-2000
(Supplement to Open-File Report OF 6-99)

OKLAHOMA COALBED-METHANE WORKSHOP



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OKLAHOMA COALBED-METHANE WORKSHOP

Compiled by
Brian J. Cardott

Co-sponsored by
Oklahoma Geological Survey,
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and Tulsa Geological Society

Tulsa, Oklahoma
May 24, 2000

OKLAHOMA GEOLOGICAL SURVEY
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OKLAHOMA COALBED-METHANE WORKSHOP

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Coal stratigraphy of the northeast Oklahoma shelf area.

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Hemish, L.A., 2000, Coal stratigraphy of the northeast Oklahoma shelf area, in Oklahoma coalbed-methane workshop: Oklahoma Geological Survey, Open-File Report OF 2-2000, p. 1-12.

COAL STRATIGRAPHY OF THE NORTHEAST OKLAHOMA SHELF AREA

LeRoy A. Hemish, Oklahoma Geological Survey

INTRODUCTION

Studies of the coal geology of the northern part of the northeast Oklahoma shelf area were carried out by the author, mostly during the late 1970s and early 1980s. The objective of these studies was to evaluate the coal resources and reserves of northeast Oklahoma shelf area that are available for surface mining . Reports of the studies were published by the Oklahoma Geological Survey (Hemish, 1986; 1989a; 1990). This report focuses mainly on the coal stratigraphy from those earlier reports in Craig, Nowata, Rogers, Mayes, Tulsa, Wagoner, and Washington counties. The data were compiled from 2,000 drill and core logs, provided mostly by coal companies, and from 247 sections measured by the author. These were supplemented by other measured sections from earlier studies.

The study area comprises about 1,800 mi^2 situated in the northern part of the coal belt of eastern Oklahoma (Fig. 1). The coal-producing area of the six counties lies mostly within the Claremore Cuesta Plains geomorphic province. The region is characterized by resistant sandstones and limestones that dip gently westward and northwestward, forming cuestas between broad shale plains. Because of the low dip of the beds, the northeast Oklahoma shelf area is particularly amendable to strip mining.

GEOLOGY

The six-county study area lies around the western edge of the Ozark uplift (Fig. 1). Strata dip very gently westward and northwestward at ~1°. Major deformation in the region occurred during Middle Pennsylvanian time; folds and faults associated with the deformation are of early Desmoinesian age (Huffman, 1958, p. 89). Small- and intermediate-scale anticlines and synclines, and minor faults observed in surface coal mines in the area are manifestations of the deformation.

Rose diagrams were constructed from 37 Brunton-compass measurements of cleat direction in Craig and Nowata counties (Fig. 2A); from 20 measurements in Rogers and Mayes counties (Fig. 2B); and from 28 measurements in Tulsa and Wagoner counties (Fig. 2C). Weighted averages of the 85 combined measurements show that the face cleats strike N47°W, and the butt cleats strike N49°E.

Stratigraphy

General Statement

All of the minable coal horizons in the study area are in rocks of Desmoinesian (Middle Pennsylvanian) geologic age. These rocks consist mostly of sandstone, siltstone, limestone, and shale. Coal constitutes a minor percentage of the whole.

The names of the stratigraphic units and the rock types included are shown in Figure 3. Thirty-four named coal beds and several unnamed coal beds are present in the northeast Oklahoma shelf area. Many of the coals were named either in Kansas or Missouri, particularly those that have any real economic potential at this time. Hemish (1987) presented a compendium of coal nomenclature in which he discussed the origin of the coal names and identified their stratigraphic position in relation to associated markers. The coal beds themselves are excellent markers, and coal-bed nomenclature is very useful in stratigraphic work.

The coal beds are separated by marine and nonmarine strata, indicating that they were laid down under cyclical conditions. According to Heckel (1991) vegetation which subsequently formed coal grew in coastal swamps near epeiric seas that covered northeastern Oklahoma during Desmoinesian time. Fluctuations of seal level caused oscillatory transgressions and regressions of the sea over the area. Channel sandstones, black shales, and interchannel coals here represent environments associated with deltas. Just as the shoreline oscillated back and forth, so did the delta environment. This accounts for the distribution, geometry, and relationships of the various rock units preserved across the area. Burial of these sediments resulted in alteration of vegetal matter to coal. Differential compaction of coals, shales, and sandstones account for much of the pinch-out and minor structures in the area.

Nine coal beds that have the requisite thickness for surface mining are present in the northern part of the shelf area of northeast Oklahoma. From oldest (lowest) to youngest (highest) they are: Rowe coal, Drywood coal, Bluejacket coal, Weir-Pittsburg coal, Mineral coal, Fleming coal, Croweburg coal, Iron Post coal, and Dawson coal (Fig. 3). Seven of these beds produce coal bed methane in the northeast Oklahoma shelf area. There are 208 completions in the Rowe; 1 in the Drywood; 13 in the Bluejacket; 16 in the Weir-Pittsburg; 18 in the Croweburg; 27 in the Iron Post; and 10 in the Dawson. Additionally, gas is produced from three coal beds that are of no commercial importance for surface mining in Oklahoma. They are the Riverton (10 wells), the Bevier (11 wells), and the Mulky (270 wells) (B. J. Cardott, personal communication, 2000). Reported gas production from the Mulky coal is enigmatic. Hemish (1986, p.18) reported occurrence of the Mulky in Oklahoma in only three drill holes in secs. 13 and 22, T. 23 N., R. 19 E., northern Craig County, where its maximum thickness is 10 inches. Occurrence of the Mulky coal downdip to the west in Nowata, Washington, and Osage counties has not been verified by coring. It seems probable that the methane is being produced from the Excello black shale. If present, the Mulky occurs at the base of the Excello Shale (Hemish, 1986, fig. 4).

Krebs Group

The oldest of the groups that include coal-bearing rocks in the study area has been named the Krebs Group (Fig. 3). The Krebs Group has been subdivided into four formations, the Hartshorne Formation, the McAlester Formation, the Savanna Formation, and the Boggy Formation. Thin and discontinuous coals are present in the shelf area in the oldest two formations in the Krebs Group, but they have no importance for surface mining.

Two commercially important named coals and several thin, discontinuous unnamed coals are present in the Savanna Formation. The Rowe coal, which occurs near the middle of the Savanna (Fig. 3) is stratigraphically the lowest coal having surface-mining value in the study area. It has been mined chiefly in the area southeast of the town of Inola in the extreme southern part of Rogers County, where it ranges from 10 to 28 inches in thickness at a depth of <100 ft. It thins to the north, and in Craig County it has limited economic promise only in small areas. The outcrop line of the Rowe coal is shown in Figure 4.

The other commercial coal in the Savanna Formation is the Drywood coal, which occurs near the top of the formation (Fig. 3), just below the Bluejacket Sandstone. The Drywood has been mined in past years in Craig County in sec. 13, T. 26 N., R. 19 E., where it was measured at 3 feet in thickness. The thickness of the Drywood coal varies, and along most of its outcrop boundary (Fig. 5) it is not of mineable thickness. Core-drilling in northeastern Craig County shows that in some places channels that were filled by the Bluejacket Sandstone have cut into or completely through the Drywood coal (Hemish, 1989b, fig, 5).

The Boggy Formation is the youngest formation in the Krebs Group. It contains only one coal bed having commercial value in the study area--the Bluejacket coal (Fig. 3), which occurs above the Bluejacket Sandstone and below the Inola Limestone. The Bluejacket coal is absent throughout all of Craig County except for a small area in the extreme southwestern corner. The Bluejacket bed is of mineable thickness in eastern Rogers County and west-central Mayes County in T. 22 N., Rs. 17 and 18 E., where it ranges from 10 to 18 inches in thickness. Although the bed has not been mined in recent years, past underground mining is evidenced by several abandoned, caved-in drift openings in sec. 16, T. 22 N., R. 18 E. The outcrop line of the Bluejacket coal is sown in Figure 6.

Cabaniss Group

The Cabaniss Group is represented by only the Senora Formation on the platform area of northeast Oklahoma (Branson and others, 1965, p. 34). It includes the strata between the base of the Weir-Pittsburg coal and the base of the Fort Scott Formation (Fig. 3). Ten named coal beds are present in the Senora Formation, of which five are economically important for surface mining. Four of the other five beds--the Bevier, the Mulky, the Scammon (tentatively identified), and the Tebo--are too thin to be mined in Oklahoma but are mined in Kansas and Missouri. The RC bed is known to be present only in Rogers and Wagoner counties (Hemish, 1989a, 1990).

The oldest commercial coal in the Senora Formation is the Weir-Pittsburg. It crops out in a diagonal line from northeast to southwest across Craig County but is unmappable in southern Rogers County (Fig. 4). It is the thickest coal bed occurring in the study area, with reported thicknesses ranging from 1.5 feet to 2.0 feet in northeastern Rogers County and northwestern Mayes County. It has a recorded maximum thickness of 6.2 feet at a depth of more than 400 feet in northwestern Craig County in T. 29 N., R. 18 E. The Weir-Pittsburg has been mined extensively in the past west of Welch, in Craig County, and in more recent times near Estella, in Craig County, and around the town of Chelsea in northeastern Rogers County and northwestern Mayes County.

The Mineral coal (Fig. 3) occurs stratigraphically above the Chelsea Sandstone and, in northern Craig County below the Russell Creek Limestone. In Rogers County exposures of the Mineral coal are difficult to find. Reported thicknesses vary from 6 inches to more than 2 feet. West of Chelsea, in Rogers County, the Mineral coal is from 1 to 1.5 feet thick and has been mined by Peabody Coal Company in past years. The Mineral was mined in the late 1970s in northern Craig County where it reaches its maximum thickness of 27 inches. Typically, it is 14 to 18 inches thick in that area. The outcrop line of the Mineral coal is shown in Figure 6.

The Fleming coal is present in Oklahoma only in the northern one-third of Craig County (Fig. 6). The Fleming is extremely variable in thickness. It locally attains thicknesses of 18 inches but tends to thin abruptly within a short distance. Its stratigraphic position is approximately midway between the underlying Mineral coal and the overlying Croweburg coal (Fig. 3); therefore, the Fleming coal is sometimes mined with one or the other, or with both.

The Croweburg coal crops out in a nearly continuous line extending diagonally from northeast to southwest through the middle of Craig County, the southeast corner of Nowata County, and the middle of Rogers County (Fig. 5). It averages about 18 inches in thickness and has long been prized for its high quality. The Croweburg has been extensively strip mined along the outcrop belt throughout Craig, Nowata, and Rogers counties, often to depths as great as 60 to 70 feet.

The Croweburg coal is readily identified in the field by the overlying succession of beds (Fig. 3). It is directly overlain by light-gray silty shale that varies in thickness from as much as 50 feet in Nowata County and northern Rogers County, to about 30 feet in southern Rogers County, and to about 10 feet in northern Craig County. The light-gray shale is overlain by black, fissile shale containing phosphatic nodules. The black shale is overlain in turn by the Verdigris Limestone, a persistent, dark-gray fossiliferous limestone, about 2 to 8 feet thick, that weathers yellow-brown.

The Iron Post coal is the uppermost commercial coal in the Senora Formation. It crops out across Craig, Nowata, and Rogers counties in an irregular line roughly parallel to the outcrop line of the Croweburg coal (Fig. 4). The Iron Post coal lies about 30 to 50 feet above the Verdigris Limestone and is overlain by a few inches to a few feet of black and gray shale containing phosphatic nodules (Kinnison Shale). The shale is overlain in turn by an impure, dense, fossiliferous brown-weathering limestone, 2 to 10 feet thick, known as the Breezy Hill. Another black, phosphatic shale, 4 to 8 ft. thick (Excello Shale), separates the Breezy Hill Limestone from the base of the Blackjack Creek Limestone, the lowermost unit of the Marmaton Group. If present, the Mulky coal occurs at the base of the Excello Shale.

Marmaton Group

The Marmaton Group overlies the Cabaniss Group and is at the top of the Desmoinesian Series (Fig. 3). Only one coal of economic importance is present in the study area--the Dawson coal, which crops out in western and north-central Tulsa County, northwestern Rogers County, and central Nowata County (Fig. 5).

CONCLUSIONS

Depositional Environments

Operators who work in the northeast Oklahoma shelf area frequently find the task of identifying methane-producing coal beds frustrating. Examination of existing logs and careful research of available literature do not always provide the answers. Why?

To find the answers one must go back through geologic time and revisit the depositional environment. As discussed previously, epeiric seas periodically covered much of a large land mass that is now the Midcontinent of the United States. About 60 cycles of glacial-eustatic marine transgression and regression were recognized in the mid-Desmoinesian to mid-Virgilian along the Midcontinent outcrop belt (Heckel, 1989, p. 160). Differences in water depth during high stands, in the position of the shoreline during lowstands, in the encroachment of detrital clastics during regression, and in the thickness of the limestone facies formed at intermediate stands resulted in variations in the basic sequence of lithologic units. Stratigraphic patterns that resulted from periodic waxing and waning of glaciations show variable thicknesses, dependent on time. Delta shifting, which operated wherever the shoreline stood for a sufficient period of time, also introduced stratigraphic sequences that interrupted the typical cyclical successions.

The typical vertical succession of lithologic units consists of 1) terrestrial blocky mudstone often capped with coal, fluvial-deltaic sandstone and shale; overlain by 2) thin transgressive marine limestone; overlain by 3) thin black phosphatic shale, deposited in deep water; overlain by 4) thicker regressive, shoaling-upward marine limestone capped by terrestrial mudstone paleosol or fluvial-deltaic clastics (Heckel, 1989, p. 162).

However, and particularly in Oklahoma, ideal successions are seldom found in the stratigraphic record. Examination of pl. 6, cross sections A-A' and B-B' (Hemish, 1986) show that shelf geology is not "layer cake". Coal beds and other markers are not always continuous. In places coals merge to form one bed; in others a bed may split to form two or more beds. In critical areas markers may be absent. Lithologic intervals between markers may be extremely variable. (A shale 20 ft. thick in one log may be 80 ft. thick in another). Sandstone channels often cut out markers and interrupt the typical cyclical succession of beds.

Surface to Subsurface Correlations

Changing depositional environments related to sea level fluctuations are the main cause of the problems facing workers attempting to make accurate interpretations of the stratigraphy in the subsurface. The only sure way to correlate beds from surface to subsurface is through close-spaced drilling. However, because of the availability of existing logs in the shelf area exploration expenses can be greatly reduced, and interpretations can be made with a reasonable degree of confidence. Construction of paleogeographic maps where sufficient data are available can lead to a better understanding of the distribution of coal beds in the subsurface, and hence, more accurate application of existing nomenclature.

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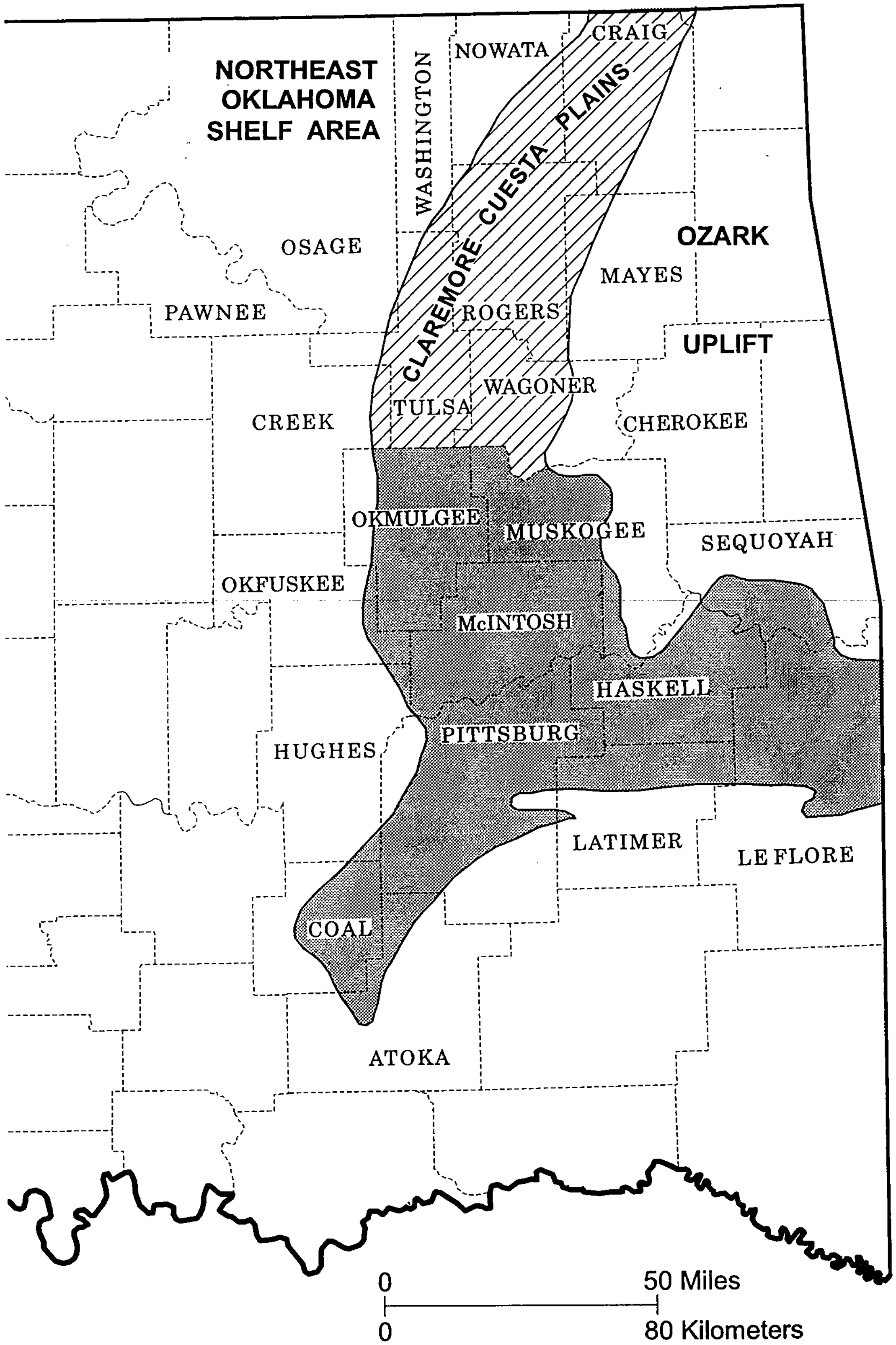

Figure 1. Index map of eastern Oklahoma, showing the eastern Oklahoma coal field; the six-county area of this report (ruled); and the geologic and geomorphic provinces discussed in the text.

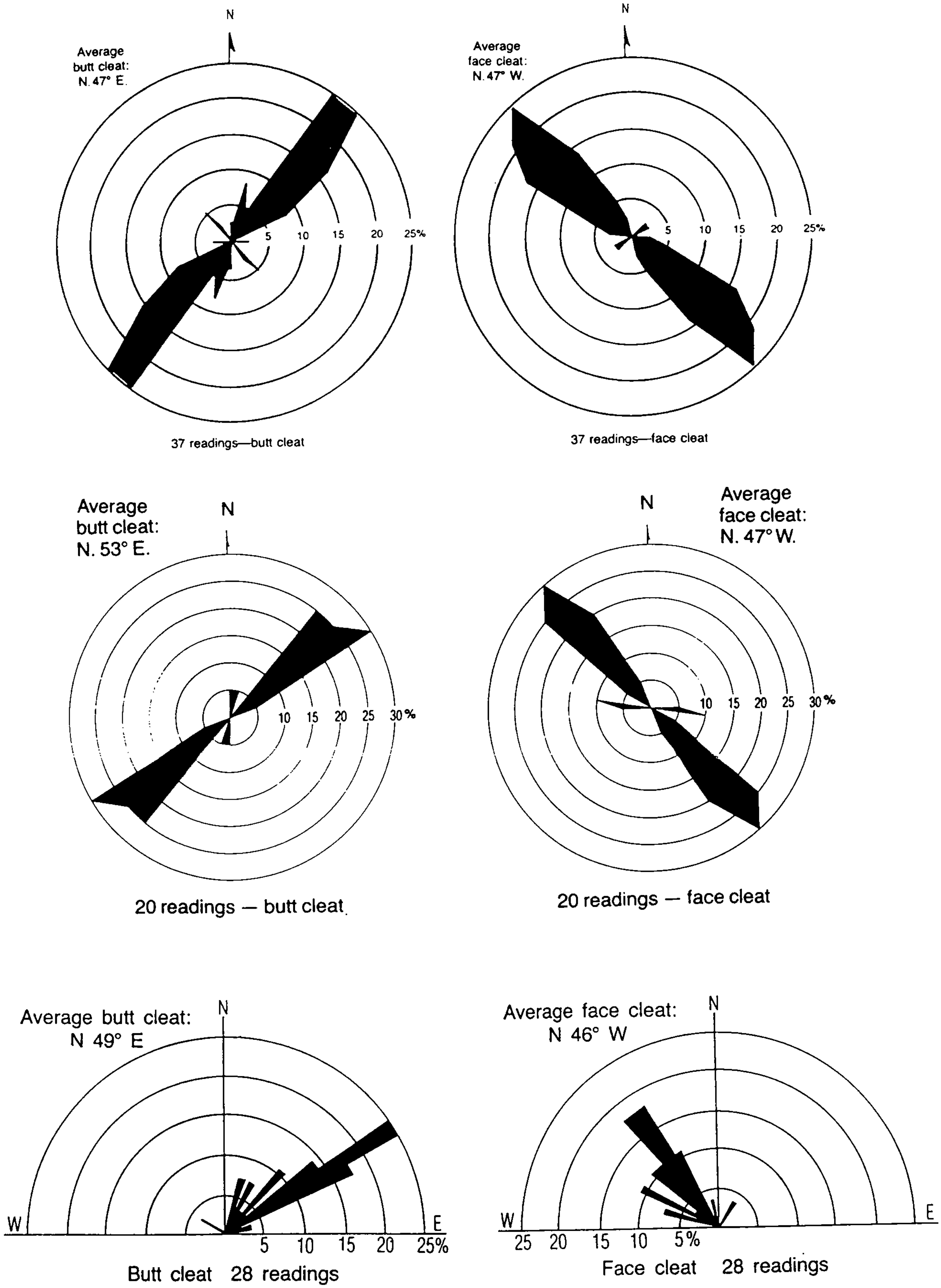

Figure 2. A—Rose diagrams of cleat orientations in coal beds of Craig and Nowata counties (from Hemish, 1986, fig. 7, app. 4).

B—Rose diagrams of cleat orientations in coal beds of Rogers and Mayes counties (from Hemish, 1989a, fig. 8, app. 4).

C—Rose diagrams of cleat orientations in coal beds of Tulsa and Wagoner counties (from Hemish, 1990, fig. 8, app. 4).

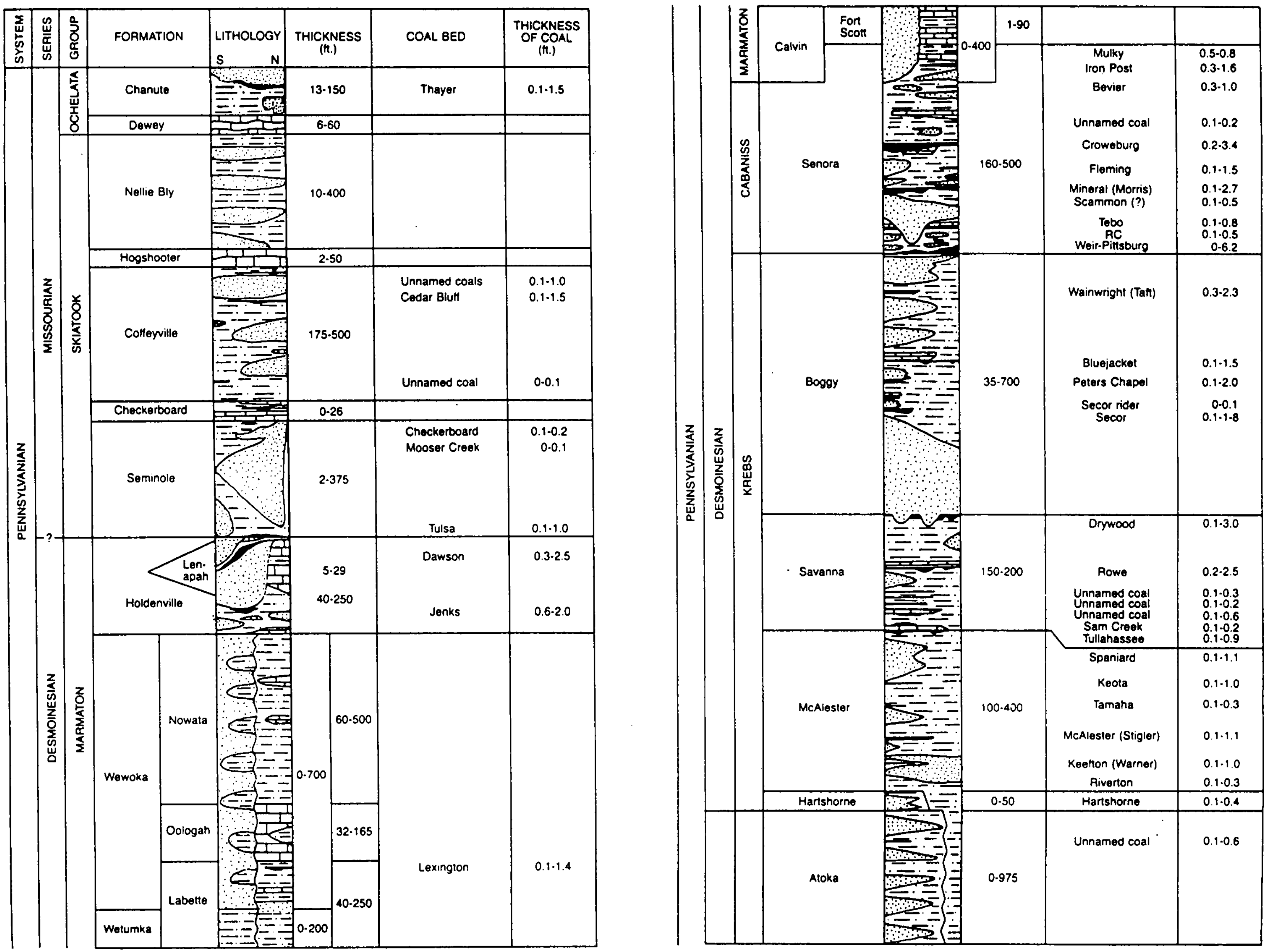

Figure 3. Generalized stratigraphic column of coal-bearing strata of the northeast Oklahoma shelf (from Hemish, 1988, figure 6).

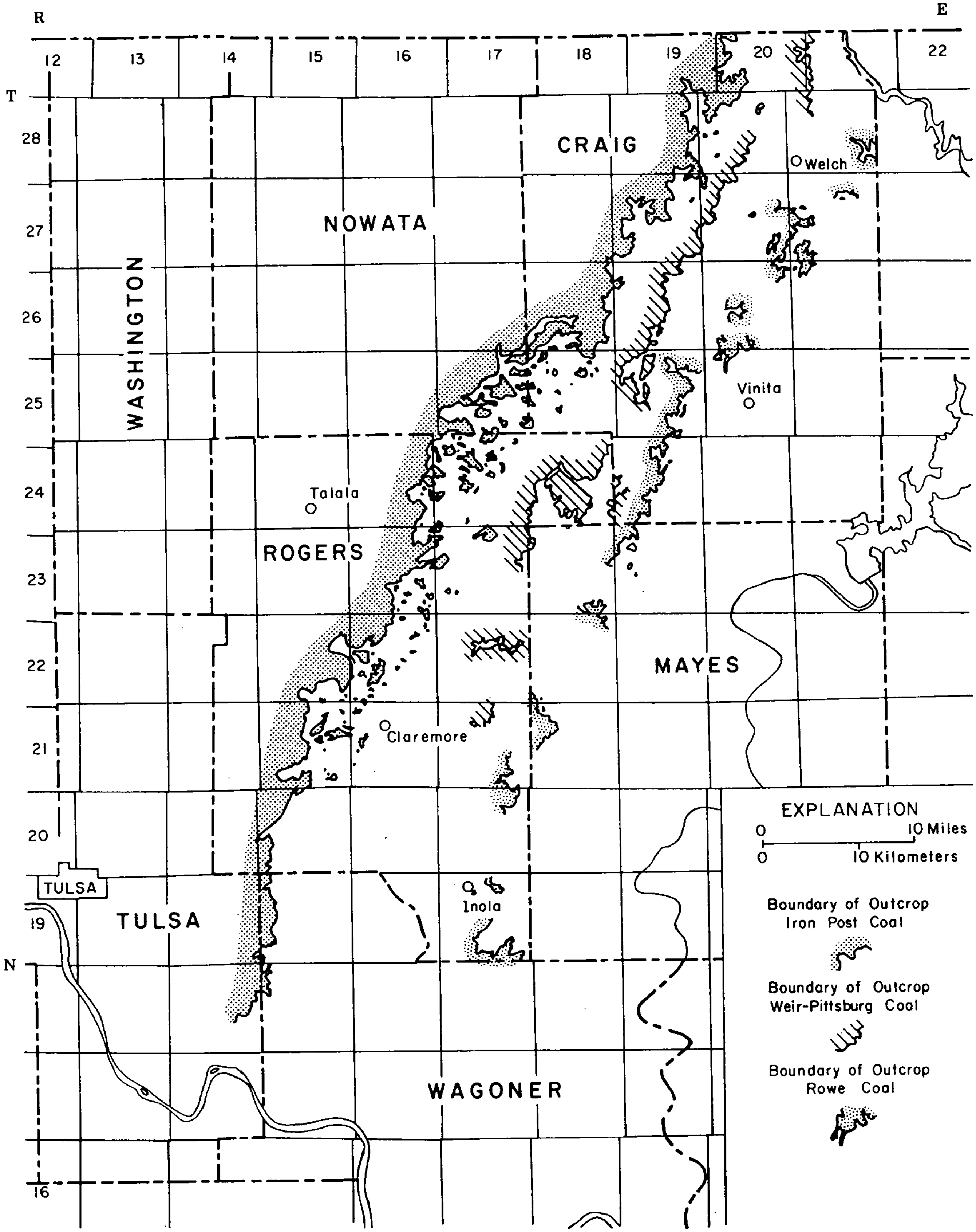

Figure 4. Coal outcrop map of the northeast Oklahoma shelf area showing the boundary lines of the Iron Post, Weir-Pittsburg, and Rowe coal beds (from Hemish, 1984, fig. 3).

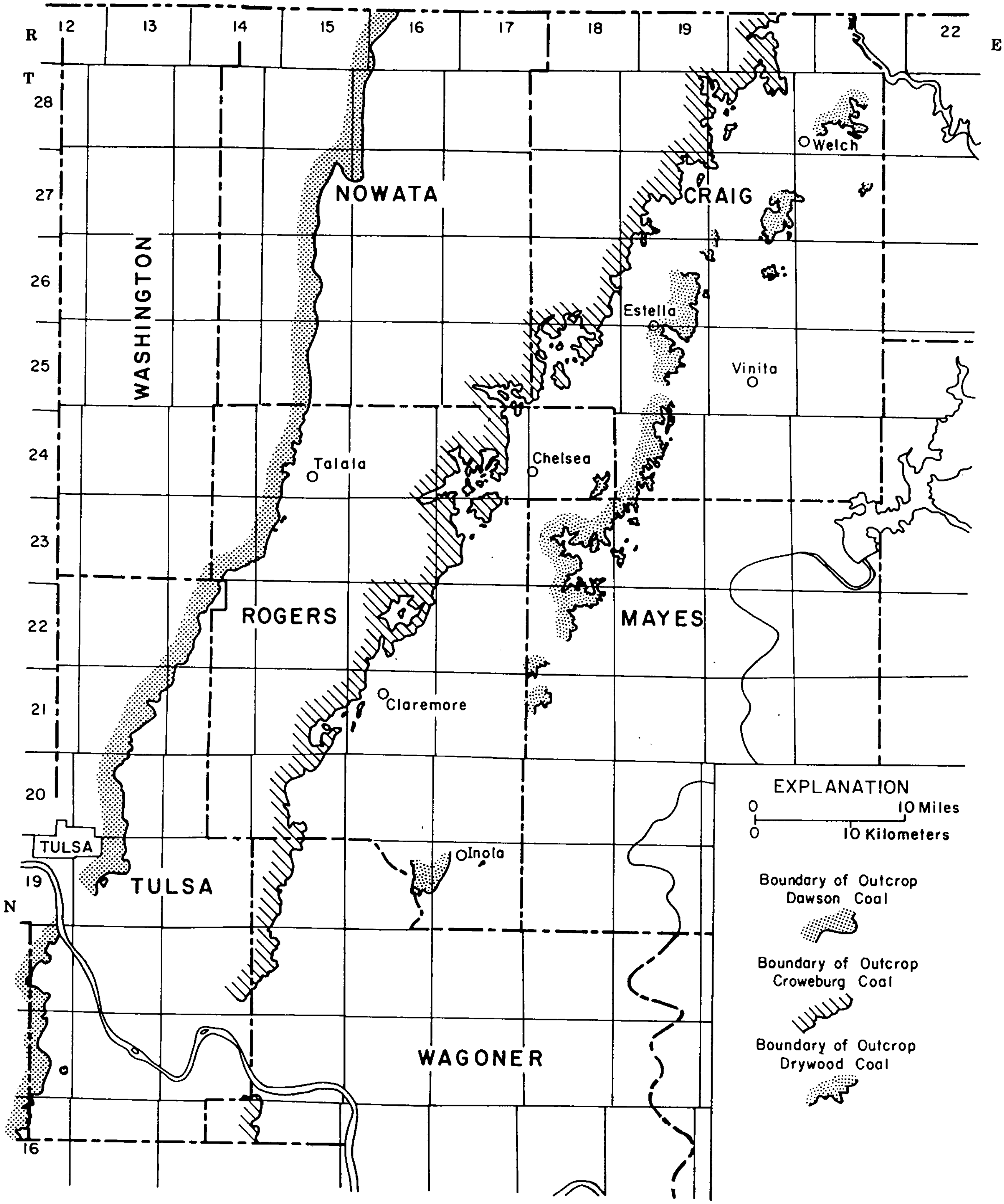

Figure 5. Coal outcrop map of the northeast Oklahoma shelf area showing the boundary lines of the Dawson, Croweburg, and Drywood coal beds (from Hemish, 1984, fig. 2).

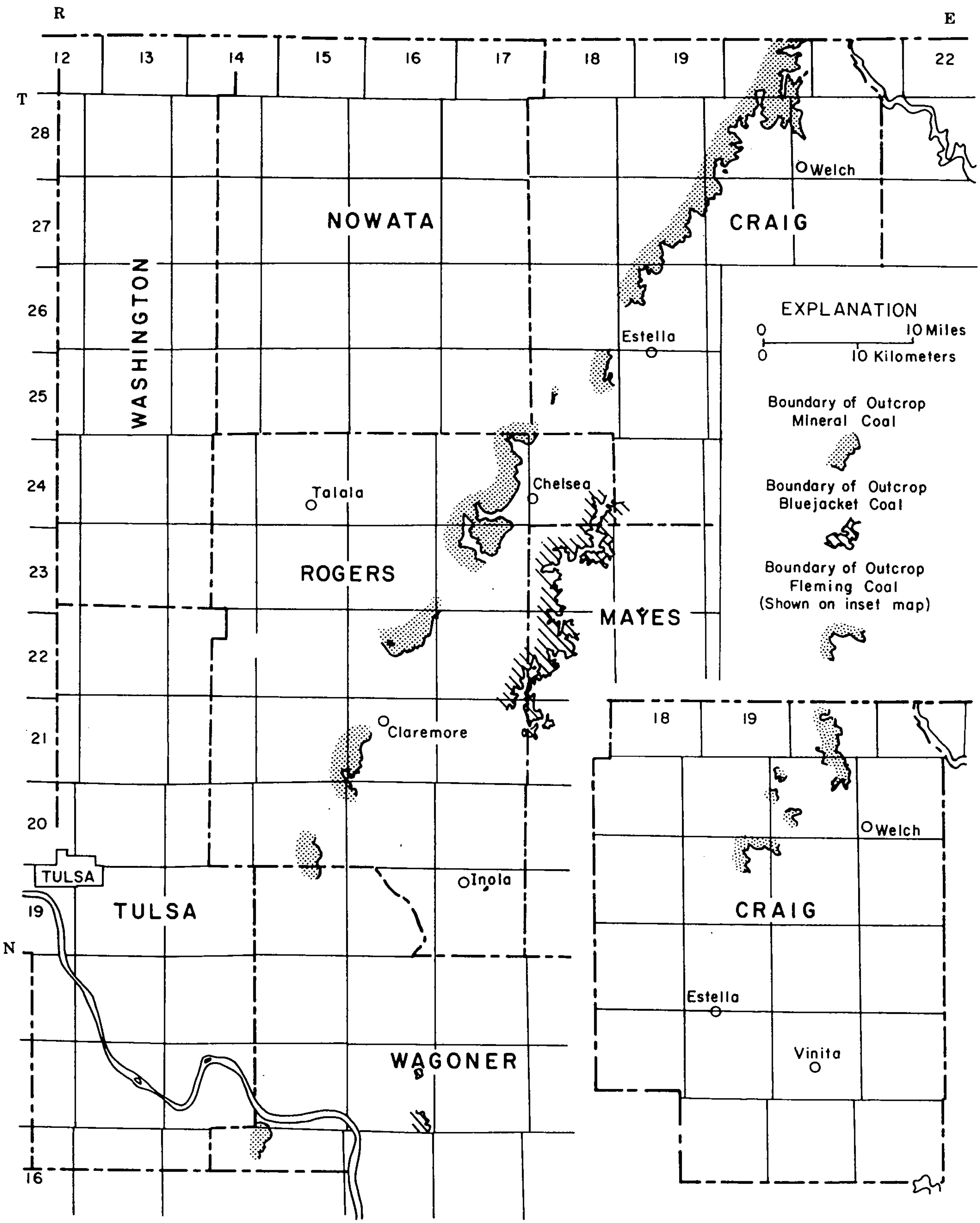

Figure 6. Coal outcrop map of the northeast Oklahoma shelf area showing the boundary lines of the Fleming, Mineral, and Bluejacket coal beds (from Hemish, 1984, fig. 4).

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2

Coalbed methane activity in Oklahoma

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Cardott, B.J., 2000, Coalbed methane activity in Oklahoma, in Oklahoma coalbed-methane workshop: Oklahoma Geological Survey, Open-File Report OF 2-2000, p. 13-35.

COALBED METHANE ACTIVITY IN OKLAHOMA

Brian J. Cardott, Oklahoma Geological Survey

This report is an update of Cardott (1999) based on 964 completions in the Coalbed-Methane Completions table of the Oklahoma Coal Database.

ABSTRACT

Coalbed-methane (CBM) drilling activity in Oklahoma began in 1988 with 7 wells drilled to the Hartshorne coal bed (Desmoinesian; Middle Pennsylvanian) in the Kinta gas field of the Arkoma basin. CBM completions are separated into two regions in the State, the northeast Oklahoma shelf and the Arkoma basin. Completions in the Mulky and Rowe coal beds (Desmoinesian; Middle Pennsylvanian) began activity on the northeast Oklahoma shelf in 1994. By the end of March 2000, there were 964 CBM completions reported in Oklahoma, 377 in the basin and 587 on the shelf. The CBM completions are evaluated by coal bed, depth, initial potential gas rate, and initial produced water rate for each region.

INTRODUCTION

The Oklahoma coalfield in eastern Oklahoma is in the southern part of the western region of the Interior Coal Province of the United States (Campbell, 1929). The coalfield is divided into the northeast Oklahoma shelf and the Arkoma basin (Friedman, 1974; Fig. 1). The commercial coal belt (Fig. 1) contains coal beds of mineable thickness ($\geq$ 10 in. [25 cm] thick and $<$ 100 ft [30 m] deep for surface mining); coal beds in the noncommercial coal-bearing region (Fig. 1) are too thin, of low quality, or too deep for mining. CBM production has occurred in both areas.

Figures 2 and 3 are generalized stratigraphic columns of the northeast Oklahoma shelf and Arkoma basin, showing the range in coal thickness measured from surface exposures and shallow-core samples. Coal beds are 0.1–6.2 ft (0.03–1.9 m) thick on the shelf, and 0.1–7.0 ft (0.03–2.1 m) thick in the basin. The thickest known occurrence of coal in the Oklahoma coalfield is the Hartshorne coal (10 ft thick) in Latimer County (sec. 35, T.6N., R.18E.; Hemish, 1999) where the upper and lower Hartshorne coal beds come together.

Figure 4 shows the rank of coal beds in the Oklahoma coalfield, generalized for all coal beds at or near the surface. Coal rank ranges from high-volatile bituminous on the shelf and western part of the Arkoma basin to medium- and low-volatile bituminous in the eastern part of the Arkoma basin in Oklahoma. Rank increases from west to east and with increasing depth in the Arkoma basin. As an example of increasing rank with depth, the Hartshorne coal is medium-volatile bituminous rank at 2,574 ft (785 m) deep in the Continental Resources 1-3 Myers well in Pittsburg County (sec.3, T.7N., R.16E.) in the high-volatile bituminous area in Figure 4 (see Fig. 13 for location of well).

Commercial production of CBM in Oklahoma began in 1988 with methane production from the Hartshorne coal (depth range of 611–716 ft [186–218 m]; initial-potential gas rate per well of 41–45 MCFGPD [thousand cubic feet of gas per day]) from seven wells in the Kinta gas field (sec. 27, T.8N., R.20E.) in Haskell County by Bear Productions. Bear Productions was the only CBM operator in Oklahoma from 1988–1990.

The following discussion of Oklahoma CBM completions 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 and may not conform to usage accepted by the Oklahoma Geological Survey. Since not all of the wells are reported as CBM wells, some interpretation was necessary. Dual completions, including perforations of more than one coal bed, were made in some wells. Therefore, not all of the wells are exclusively CBM completions. This summary is incomplete since some wells may not have been known to be CBM wells or were not reported by 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 data for this report were from the Coalbed-Methane Completions table of the Oklahoma Coal Database. Each record (well completion) in the table includes operator, well name, API number, completion date, location (county, field name, TRS, latitude/longitude), coal bed, production depth interval, initial gas potential and produced water, pressure information, and comments. The database is available at the Oklahoma Geological Survey. A searchable version of the Coalbed-Methane Completions table is available on the internet as a link from the OGS web site: http://www.ou.edu/special/ogs-pttc/.

Through March 2000, there were 964 CBM completions reported in Oklahoma, 377 in the basin and 587 on the shelf (Fig. 5). The CBM play began in the basin in 1988, with a peak of 71 completions in 1992. There were 5 CBM completions on the shelf in 1994. In 1995 there were 23 completions in the basin and 42 completions on the shelf, signaling increased activity on the shelf. As of March 2000, there were 49 completions in the basin and 197 completions on the shelf reported in 1998; there were 54 completions in the basin and 105 completions on the shelf reported in 1999. Many more wells are shown for 1997 and 1998 than shown in Cardott (1999, figure 5) because of the lag between when some wells are drilled and when they are reported. There are expected to be more wells for 1999 when all wells are reported.

NORTHEAST OKLAHOMA SHELF

Figure 6 shows the locations of 587 CBM completions on the shelf reported by 38 operators through March 2000. CBM completions on the shelf have been reported in Craig, Nowata, Osage, Rogers, Tulsa, and Washington counties. In ascending order, the coal beds producing methane on the shelf are the Riverton (McAlester Formation), Rowe and Drywood (Savanna Formation), and Bluejacket (Boggy Formation) in the Krebs Group; Weir-Pittsburg, Croweburg, Bevier, Iron Post, and Mulky (Senora Formation) in the Cabaniss Group; and Dawson (Holdenville Formation) in the Marmaton Group of Desmoinesian (Middle Pennsylvanian) age (Fig. 2). The commercial coal beds on the shelf are 0.8–6.2 ft (0.2–1.9 m) thick, average 2.0 ft (0.6 m) thick, and dip westward ½° to 2° (Friedman, 1999).

Figure 7 shows the depth range of CBM completions on the shelf. Coal beds were perforated at depths-to-top of coal of 216–2,428 ft (66–740 m; average of 941 ft [287 m] from 584 wells). There are 2 significant modes apparent in Fig. 7. Most of the wells on the shelf are in the Mulky coal (270 wells; depth range of 216–1,732 ft [66–528 m]). The Mulky coal is the uppermost coal bed in the Senora Formation and occurs at the base of the Excello Shale Member (Hemish, 1987). The Mulky coal ranges from bituminous coal to carbonaceous shale with increasing amounts of mineral matter (carbonaceous shale contains >50% mineral matter by weight or <30% carbonaceous matter by volume, Schopf, 1956; impure coal contains 25–50% mineral matter by weight, ASTM, 1994). The next most important CBM reservoir on the shelf is the Rowe coal (208 wells, depth range of 747–1,810 ft [228–552 m]). The deepest

CBM completion on the shelf (2,428 ft) is in the Weir-Pittsburg coal in Osage County (Calumet Oil Co., 7 Catlett well, sec. 32, T.28N., R.8E.). There were 71 CBM completions on the shelf that perforated two to four coal beds. Only the uppermost coal depth was used in Fig. 7.

Initial-potential CBM rates for wells on the shelf range from a trace to 260 MCFGPD (average of 27 MCFGPD from 517 wells; Fig. 8). As shown in Figures 11 and 20 below, initial gas rates do not demonstrate the full potential of the well. CBM production decline curves typically follow 3 stages: dewatering, stable production, decline (Schraufnagel, 1993). Initial gas rates in the Mulky coal range from a trace to 125 MCFGPD, and in the Rowe coal range from 2–260 MCFGPD. Figure 9 shows the locations of 270 CBM wells in the Mulky coal, highlighting 29 wells (11%) that had initial gas rates of 50–125 MCFGPD. Figure 10 shows the locations of 208 CBM wells in the Rowe coal, highlighting 49 wells (24%) that had initial gas rates of 50–260 MCFGPD. Four of the five wells having the highest initial potential gas rates on the shelf were from the Rowe coal in T.25N., R.14E. These 4 wells initially produced 130–260 MCFGPD and 30–90 barrels of water per day (BWPD) from depths of 1,136–1,190 ft (346–363 m).

Gas production in Oklahoma is reported by lease. Therefore, it is difficult to obtain gas production data by well. However, many of the CBM wells on the shelf are on single-well leases. Typical production-decline curves of 3 wells (believed to be single-well leases) in Nowata and Rogers counties illustrate production histories for wells with initial potential rates of 7–36 MCFGPD and 12–120 BWPD (Fig. 11; gas production data came from the Natural Resources Information System of the Oklahoma Geological Survey). Following a period of 3 to 12 months of erratic production in some wells, production can stabilize at more than 1 million cubic feet of gas per month. The maximum monthly production for the 3 wells selected is 4,664 MCFG, an average of 155 MCFGPD, attained 12 months after completion in the 1 Mitchell well (Fig. 11B).

Initial produced water on the shelf ranged from 0–1,201 BWPD (average of 60 BWPD from 492 wells; Fig. 12, excluding one well with 1,201 BWPD). Most of the water is believed to be formation water and not water from fracture stimulation. Based on poor water quality, these wells require nearby disposal wells for the produced water. Water volume is not metered. Therefore, the volume of disposed water and the effect of water production on gas rate is not known. Data on water quality is not available.

ARKOMA BASIN

Figure 13 shows the locations of 377 CBM completions in the basin reported by 37 operators through March 2000. CBM completions in the basin have been reported in Coal, Haskell, Hughes, Latimer, Le Flore, McIntosh, and Pittsburg counties. In ascending order, the coal beds producing methane in the 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 (Middle Pennsylvanian) age (Fig. 3). Most (94%) of the CBM completions in the Arkoma basin are from the Hartshorne coal beds (355 completions). The commercial coal beds in the basin are 1–10 ft (0.3–3 m) thick and dip 3° to nearly vertical in eroded, narrow anticlines and broad synclines that trend northeastward (Friedman, 1999).

Figure 14 shows the depth range of CBM completions in the basin. Coal beds were perforated at depths-to-top of coal of 598–3,726 ft ([182–1,136 m]; average of 1,431 ft [436 m] from 366 wells). The 3 deepest CBM completions (3,632–3,726 ft [1,107–1,136 m]) in the basin are in the Hartshorne coal in Hughes County (T.4N., R.11E.; Fig. 13). There are 14 CBM completions in the basin that perforated two to three coal beds. Only the uppermost coal depth was used in Fig. 14.

Initial-potential CBM rates for wells in the basin range from a trace to 595 MCFGPD (average of 80 MCFGPD from 321 wells; Fig. 15). Most (78%) of the wells produced 10–120 MCFGPD (249 completions). The highest initial-potential gas rates are from the Hartshorne coal. The first horizontal CBM completion in Oklahoma was by Bear Productions in August 1998. By the end of March 2000, there were 20 horizontal CBM completions in Haskell, Le Flore, and Pittsburg counties reported by 4 operators (Bear Productions, 5 wells; Brower Oil & Gas Co., 1 well; Continental Resources, 1 well; Mannix Oil Co., 13 wells; Fig. 16, some sections have more than one horizontal CBM well). Initial-potential CBM rates of the horizontal wells were 60–595 MCFGPD. Higher CBM rates are possible in horizontal wells by drilling perpendicular to the face cleat to drain a larger area than a vertical well. Vertical CBM wells exhibit an elliptical drainage pattern due to the directional permeability of the cleat (Diamond and others, 1988).

Initial produced water in the basin ranged from 0–147 BWPD (average of 11 BWPD from 256 wells; Fig. 17). Most (81%) of the wells produced less than 20 BWPD (207 completions). Most Arkoma basin CBM completions are on the flanks of anticlines (Figs. 18, 19) and have relatively little produced water. An undisclosed amount of initial water production is frac water (introduced during fracture stimulation).

A Hartshorne CBM field study in the Spiro Southeast Gas Field (T.9N., R.25E.) indicated "The average daily gas production per well ranged from 6 to 127 MCFGPD, with an average of 50 MCFGPD. Gas production from all 28 wells was about 1,400 MCFGPD...Cumulative gas production from September 1994 through March 1998 was 1,178,372 MCF." (Andrews, Cardott, and Storm, 1998, p. 62). Production decline curves showed an increase in production through restimulation (using freshwater and sand) and servicing the water pump (Fig. 20). The best well (26-1 Rice-Carden) had a peak of 6,631 MCFG (220 MCFGPD) in the fifth month of production (Fig. 20A).

CONCLUSIONS

The Oklahoma CBM play began in the Arkoma basin in 1988. The play spread to the northeast Oklahoma shelf in 1994. Through March 2000, there were 964 CBM completions reported in Oklahoma, 377 in the basin and 587 on the shelf. There were 56% more completions on the shelf than in the basin. The primary CBM objectives were the Hartshorne coal beds in the basin and the Mulky and Rowe coal beds on the shelf. There were 30% more completions in the Mulky coal than in the Rowe coal.

The range in depth of the CBM completions was 216–2,428 ft ([66–740 m]; average of 941 ft [287 m] from 584 wells) on the shelf, and 598–3,726 ft ([182–1,136 m] average of 1,431 ft [436 m] from 366 wells) in the basin.

Initial-potential gas rates ranged from a trace to 260 MCFGPD (average of 27 MCFGPD from 517 wells) on the shelf, and a trace to 595 MCFGPD (average of 80 MCFGPD from 321 wells) in the basin. The maximum initial gas rate was from a horizontal well in the Hartshorne coal in Haskell County at a true vertical depth of 824 ft (251 m).

Produced water ranged from 0–1,201 BWPD (average of 60 BWPD from 492 wells) on the shelf, and from 0–147 BWPD (average of 11 BWPD from 256 wells) in the basin.

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 technique to the specific coal bed.

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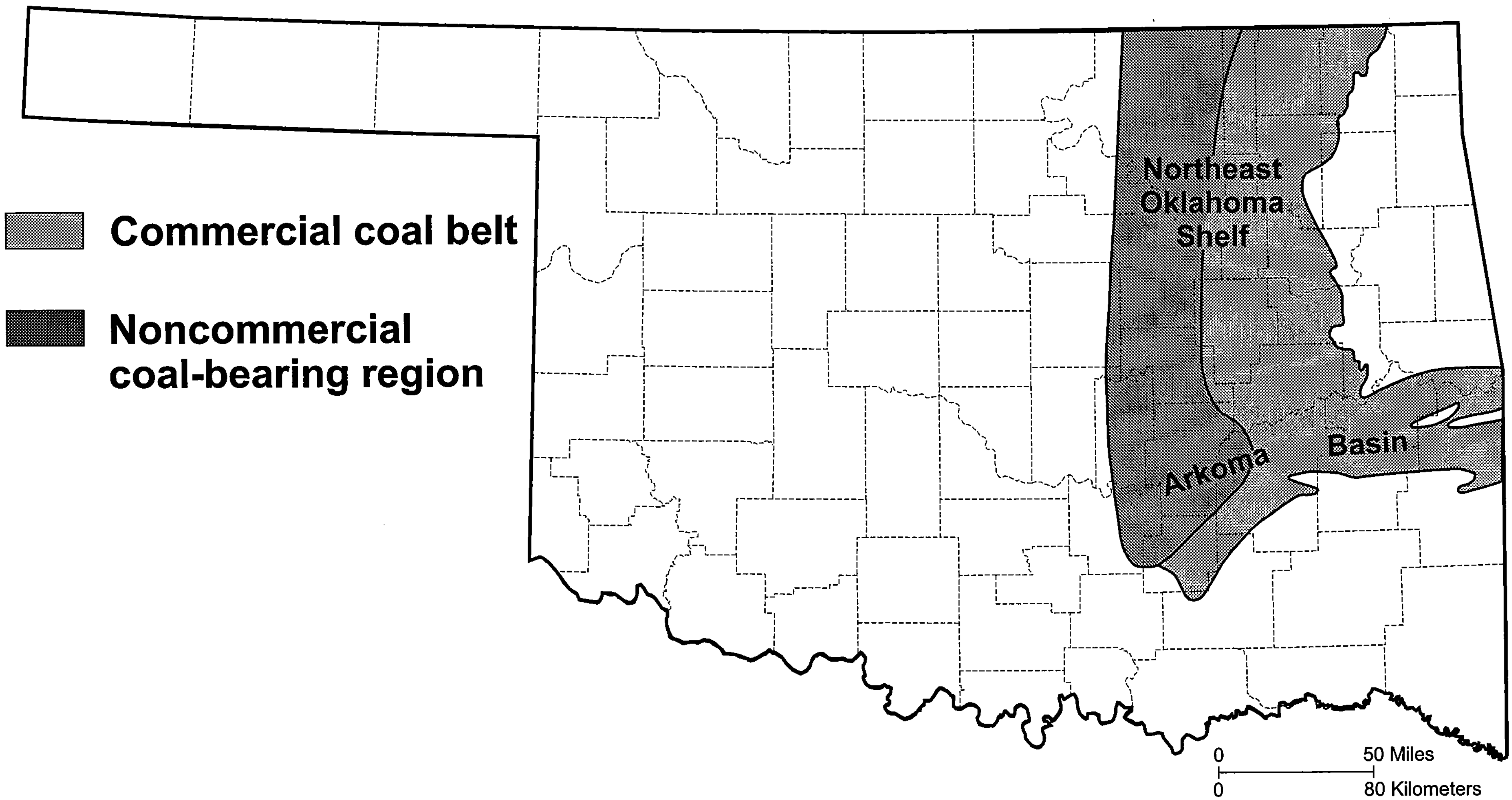


Figure 1. Map of Oklahoma coalfield (modified from Friedman, 1974, figure 5).

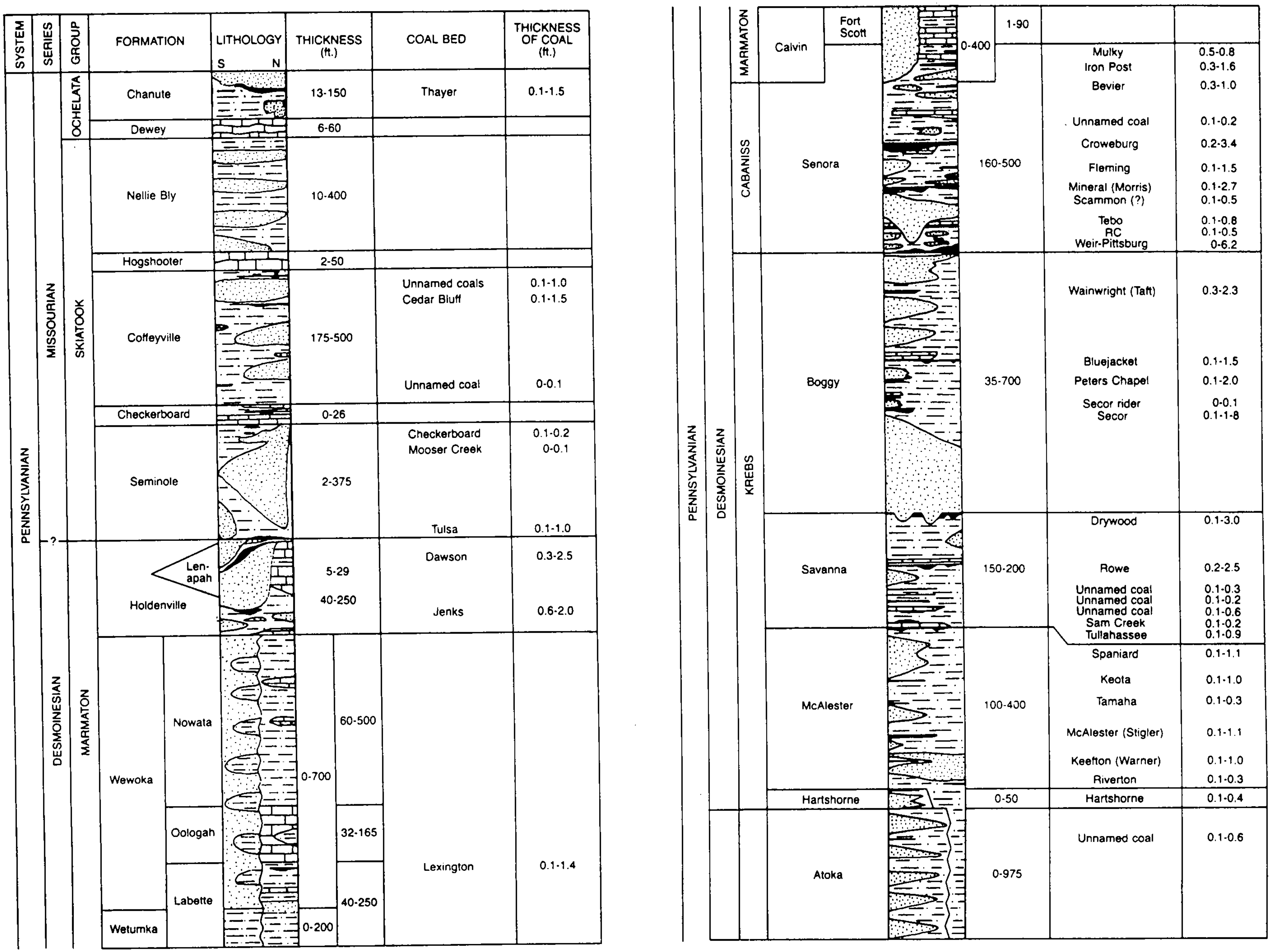


Figure 2. Generalized stratigraphic column of coal-bearing strata of the northeast Oklahoma shelf (from Hemish, 1988, figure 6).

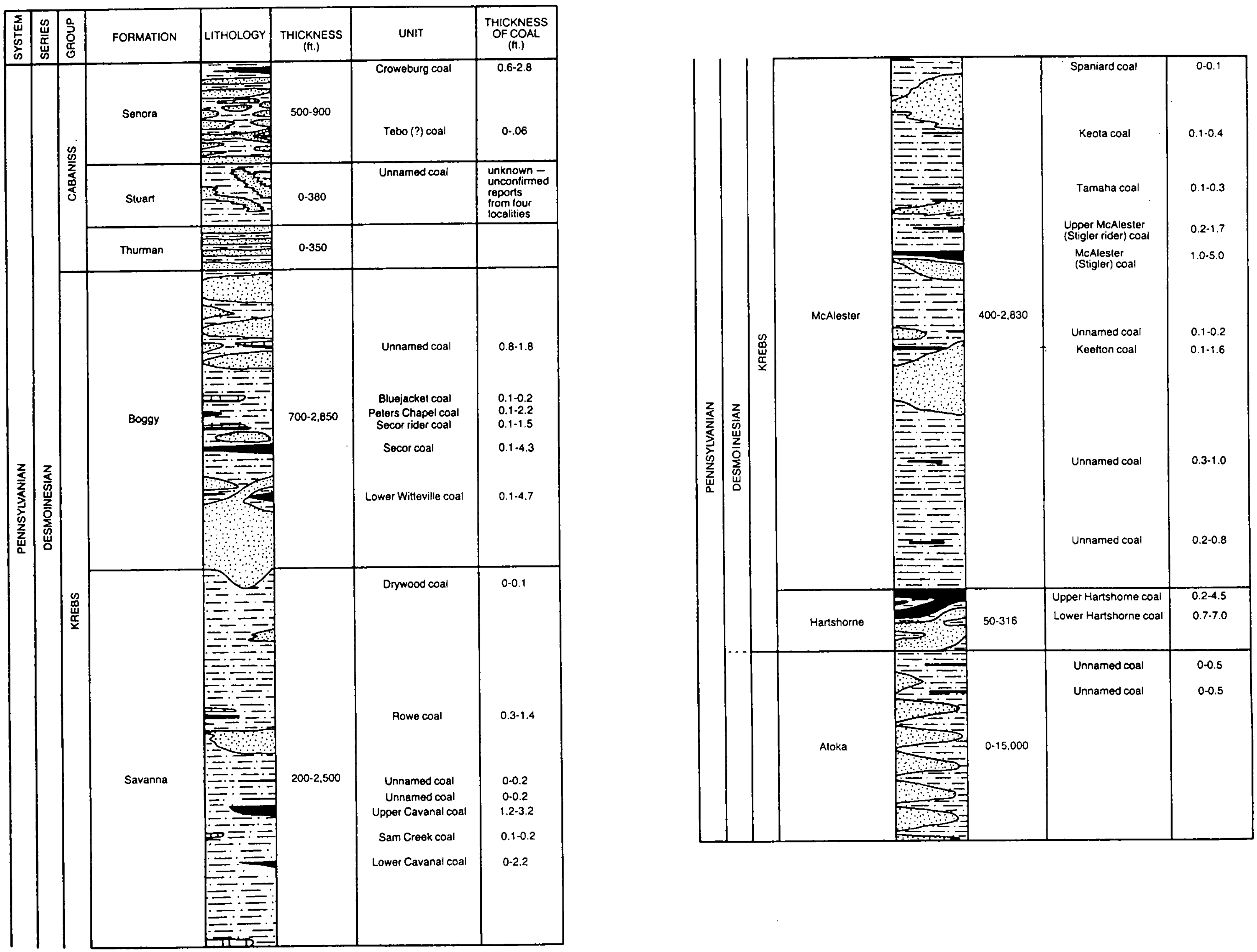


Figure 3. Generalized stratigraphic column of coal-bearing strata of the Arkoma basin (from Hemish, 1988, figure 5).

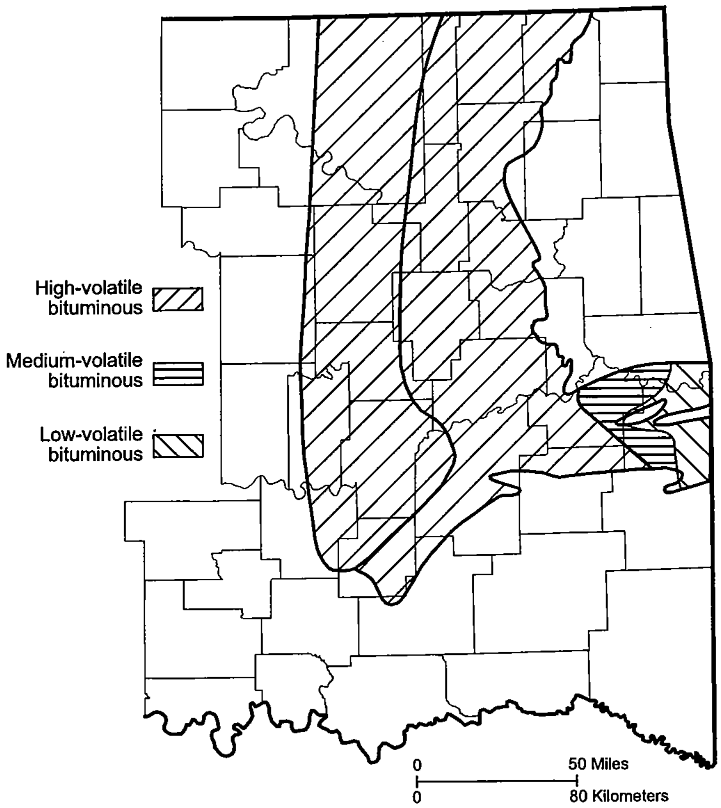


Figure 4. Map of the Oklahoma coalfield showing generalized rank of coal beds near surface (modified from Friedman, 1974, figure 20, and Andrews and others, 1998, figure 34).

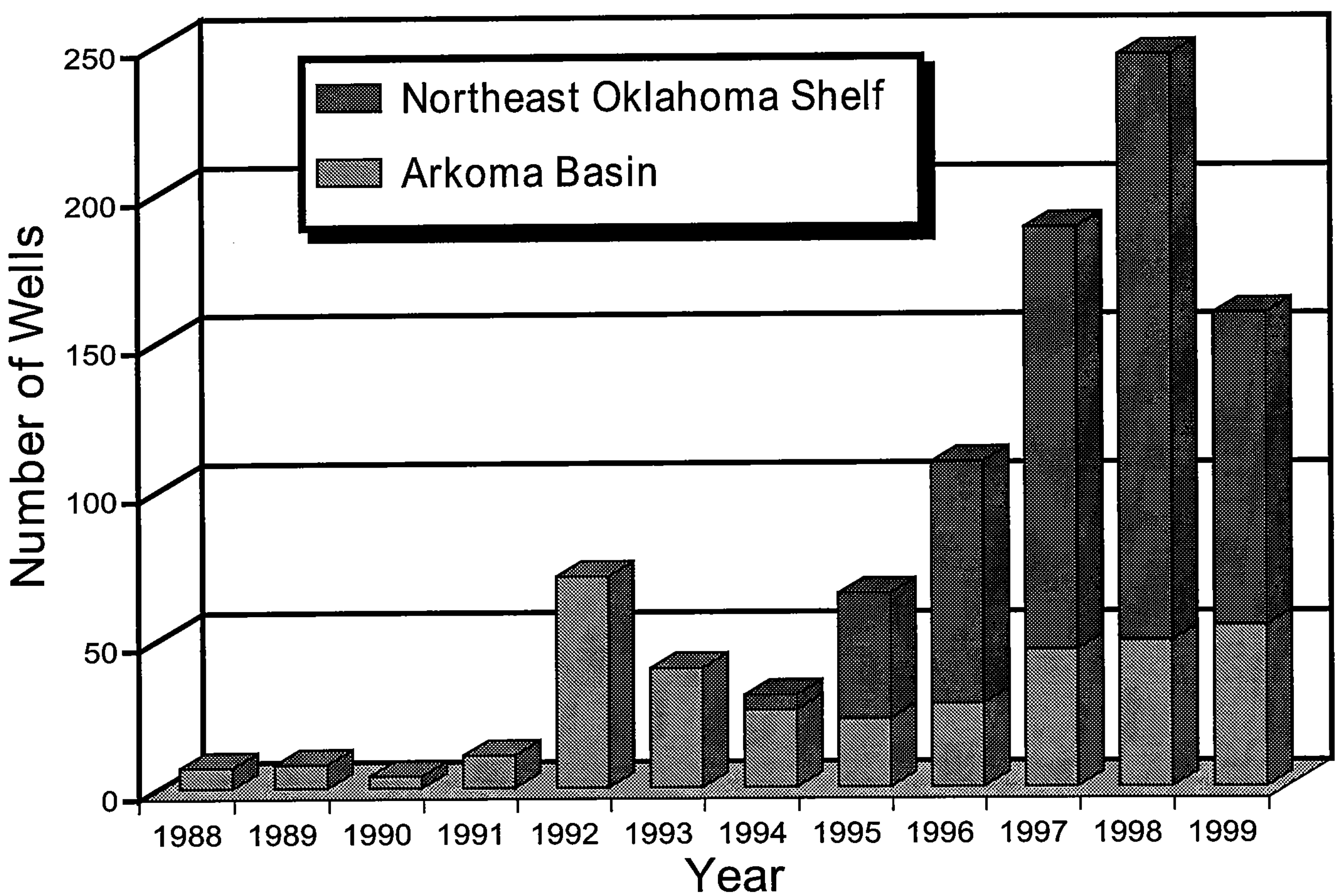


Figure 5. History of Oklahoma coalbed-methane completions.

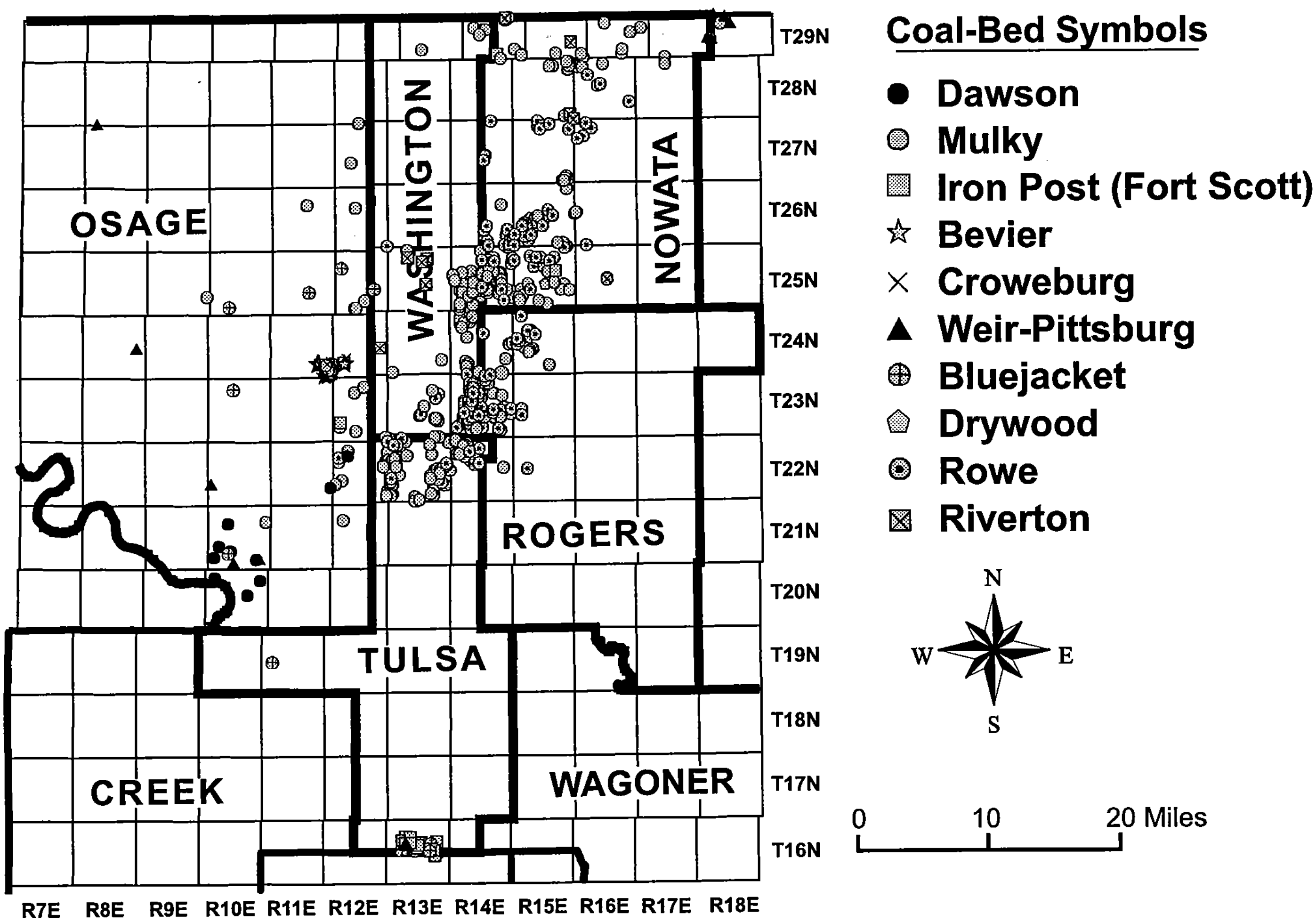


Figure 6. Map showing coalbed-methane completions by coal bed on the northeast Oklahoma shelf.

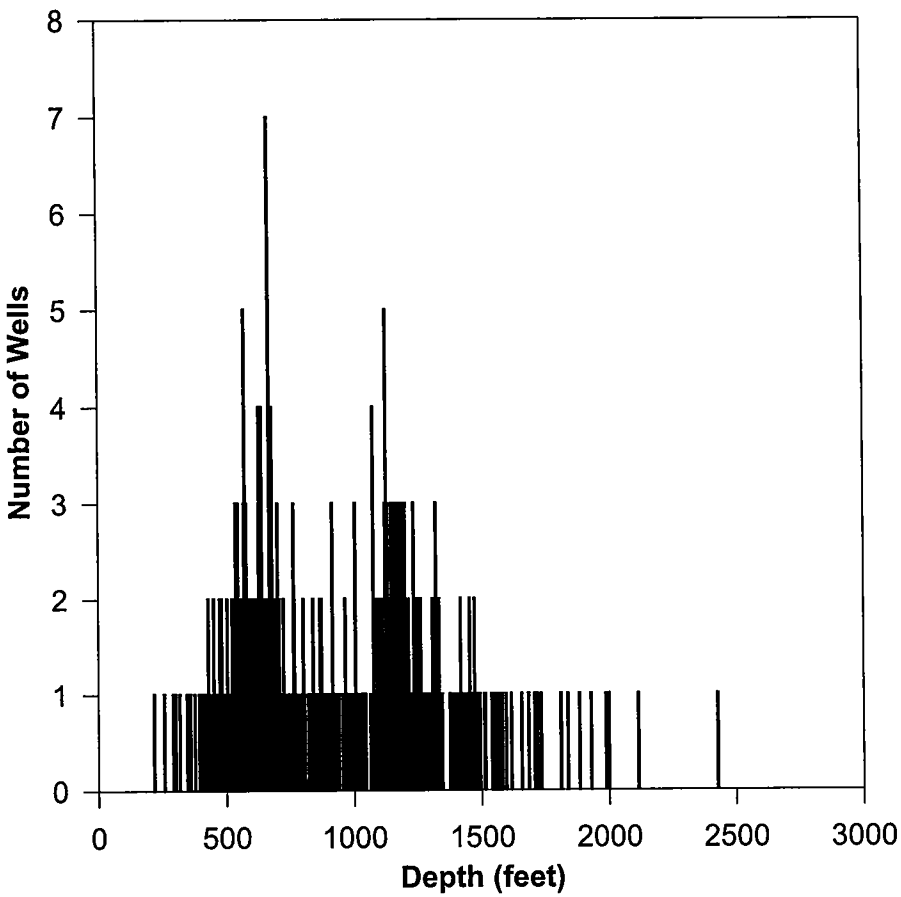


Figure 7. Histogram of coalbed-methane completions by depth on the northeast Oklahoma shelf.

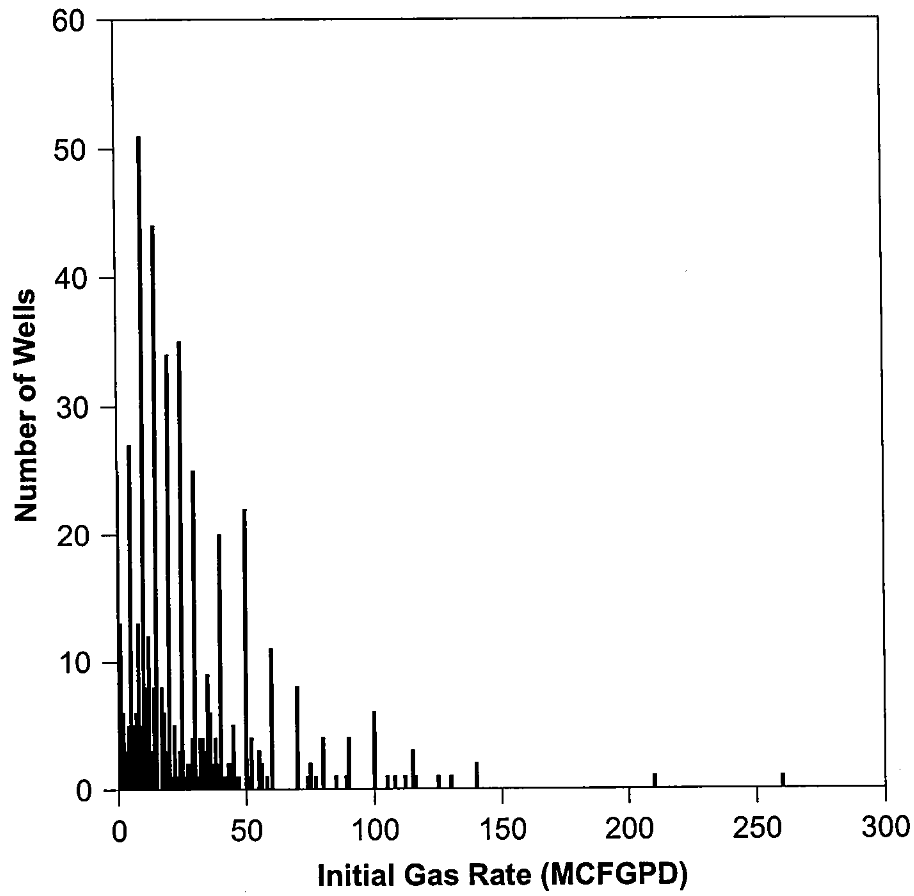
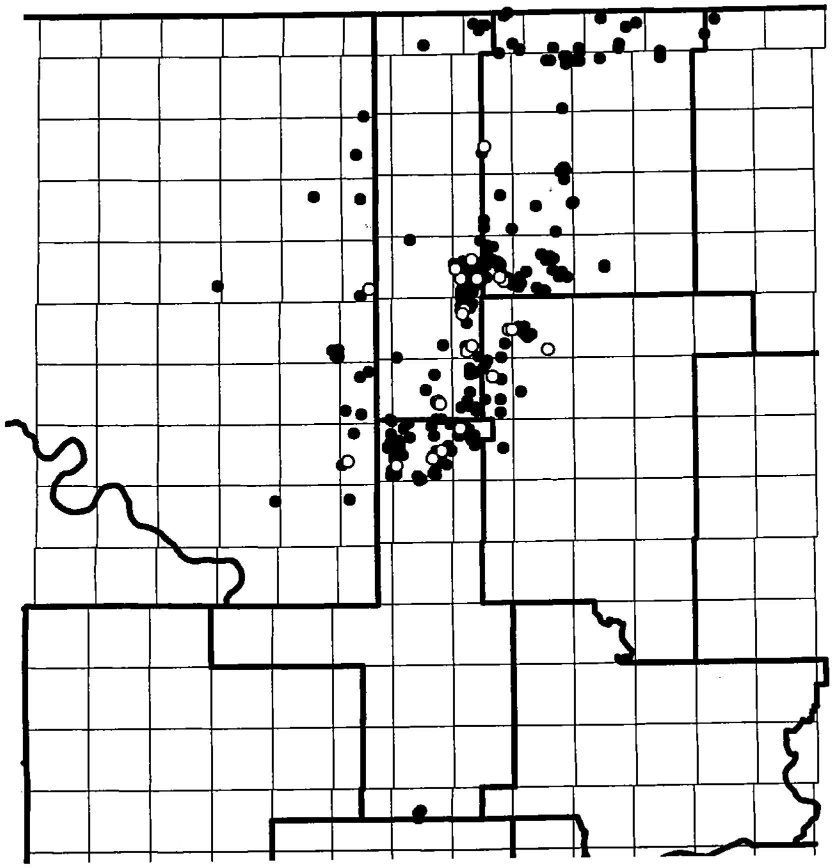


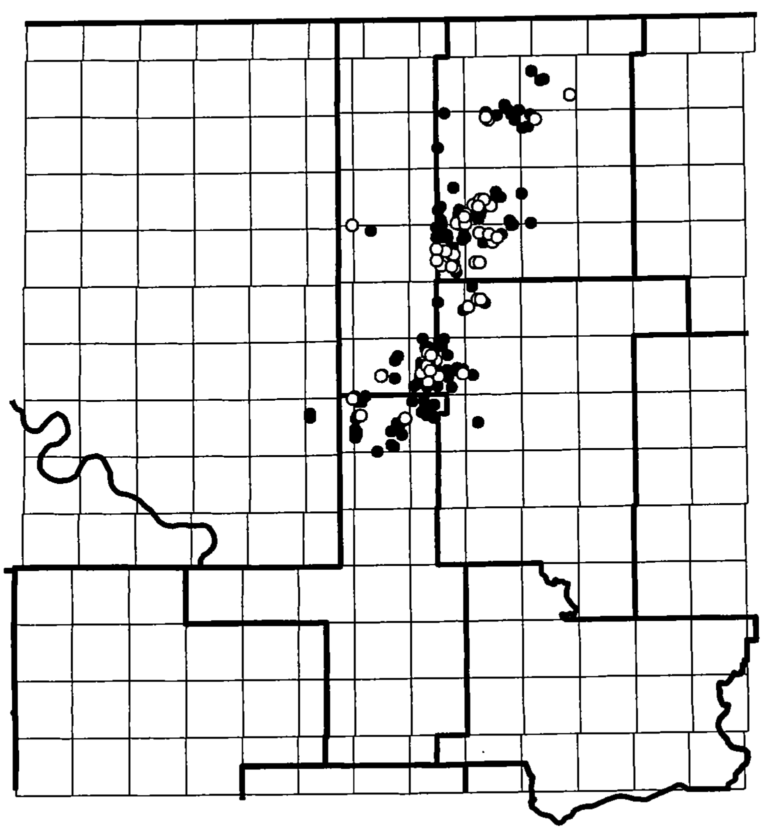
Figure 8. Histogram of coalbed-methane completions by initial potential gas rate on the northeast Oklahoma shelf.



• Mulky

o Mulky
50–125 MCFGPD

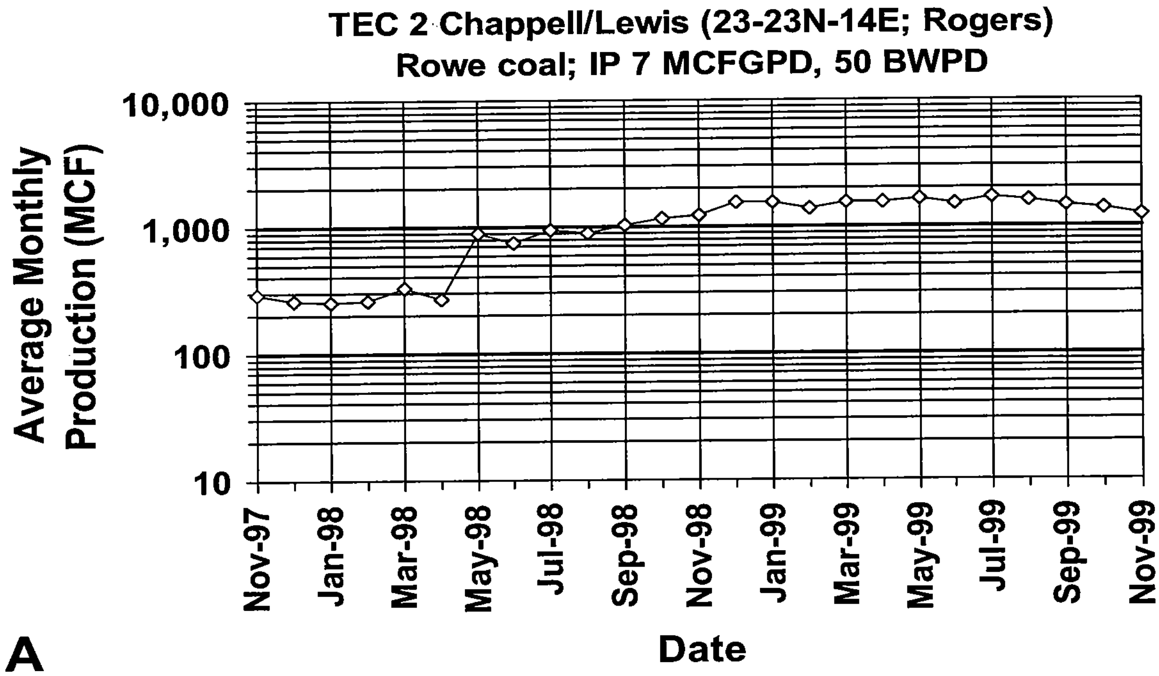
Figure 9. Map showing coalbed-methane completions of the Mulky coal on the northeast Oklahoma shelf.



• Rowe

o Rowe
50–260 MCFGPD

Figure 10. Map showing coalbed-methane completions of the Rowe coal on the northeast Oklahoma shelf.



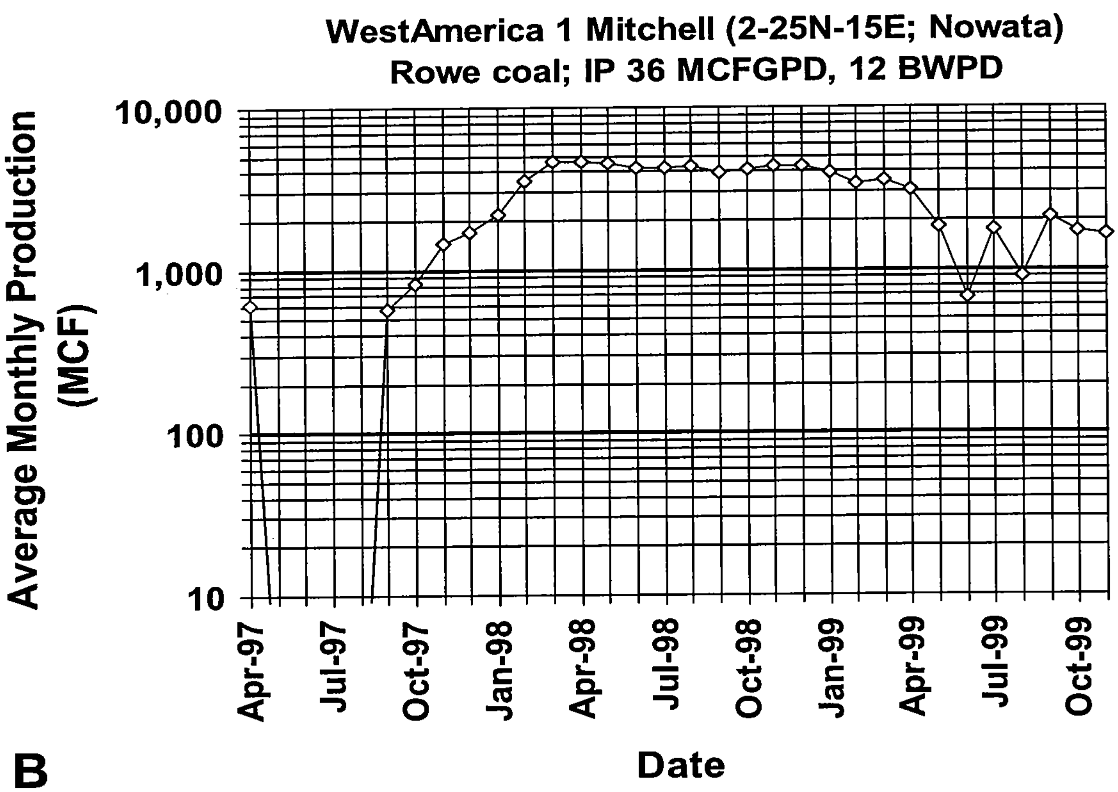


Figure 11. (Above and next page). Gas-production decline curves. (A) TEC Resources 2 Chappell/Lewis well. (B) WestAmerica 1 Mitchell well. (C) Dome Engineering T-1 Webster well.

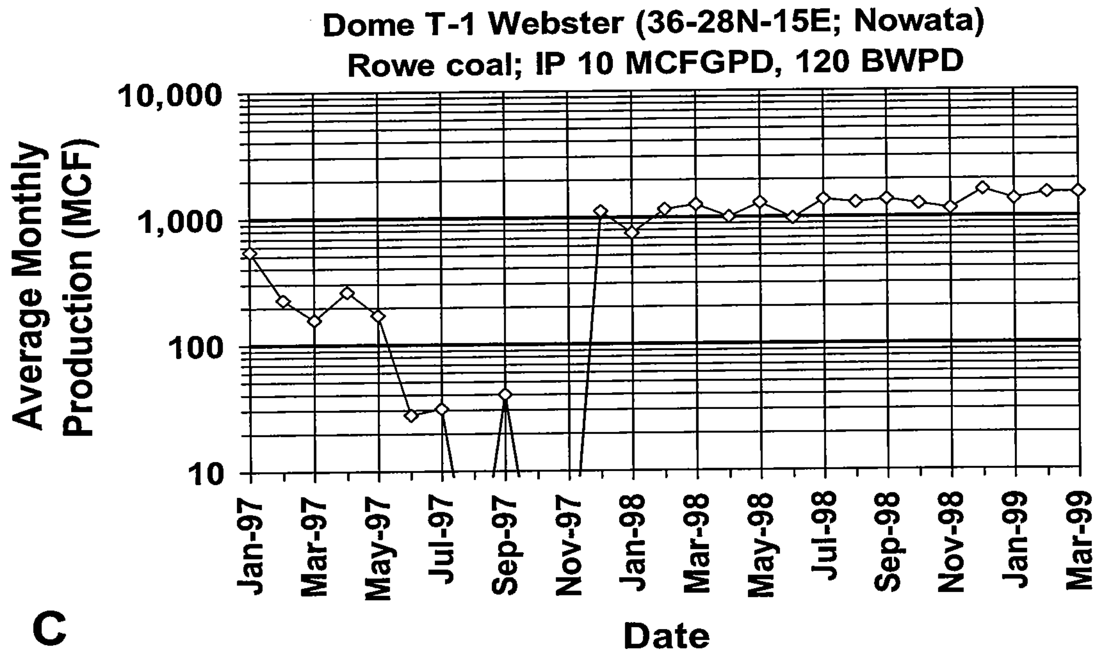


Figure 11. (Continued)

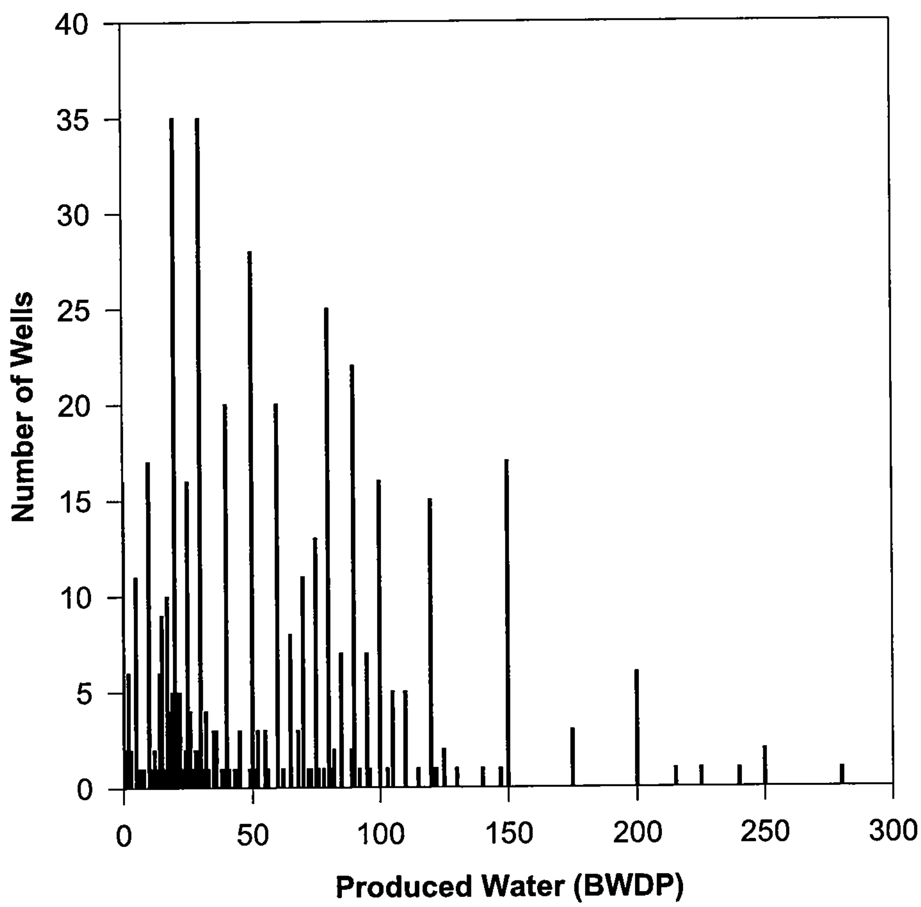


Figure 12. Histogram of coalbed-methane completions by produced water on the northeast Oklahoma shelf.

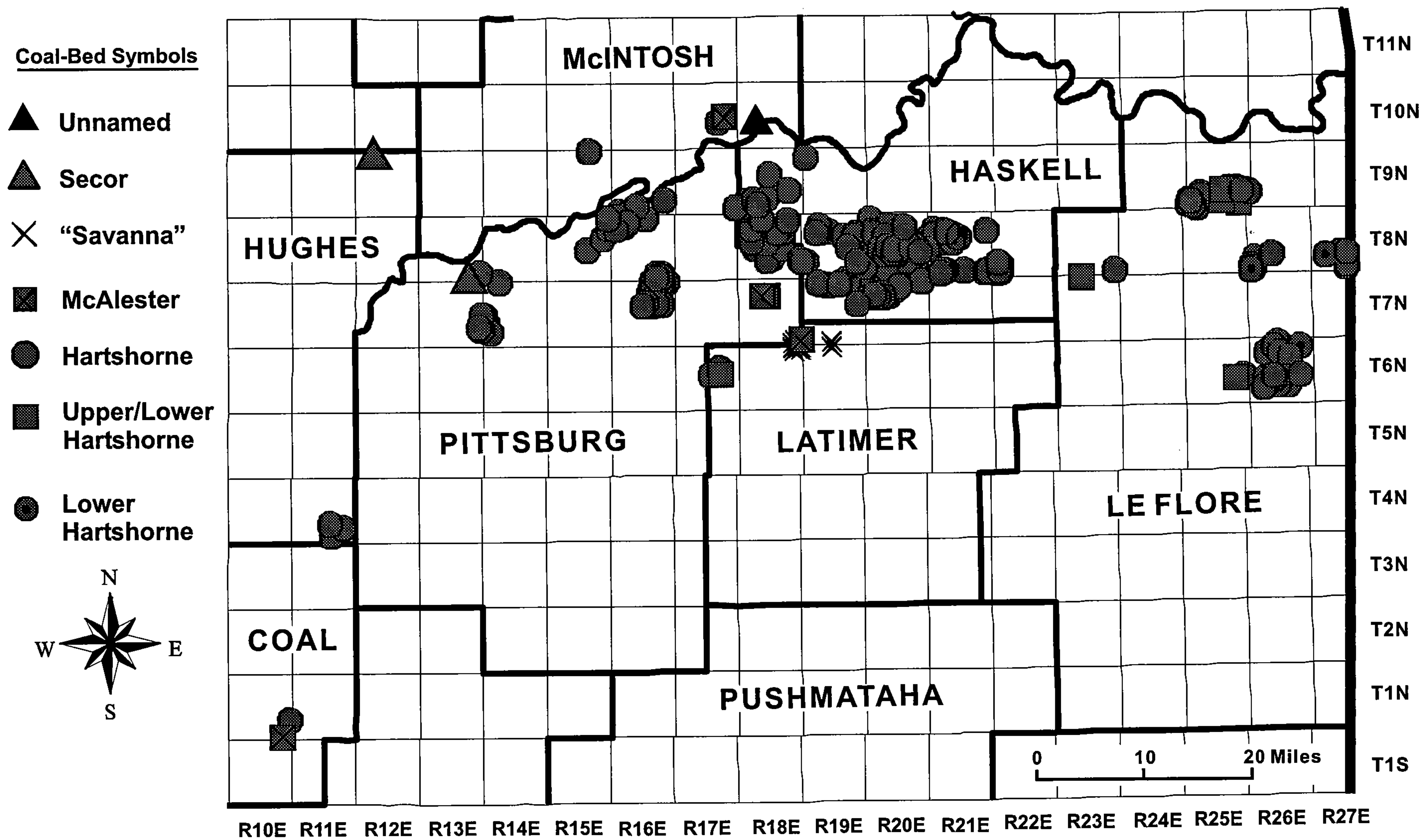


Figure 13. Map showing coalbed-methane completions in the Arkoma basin.

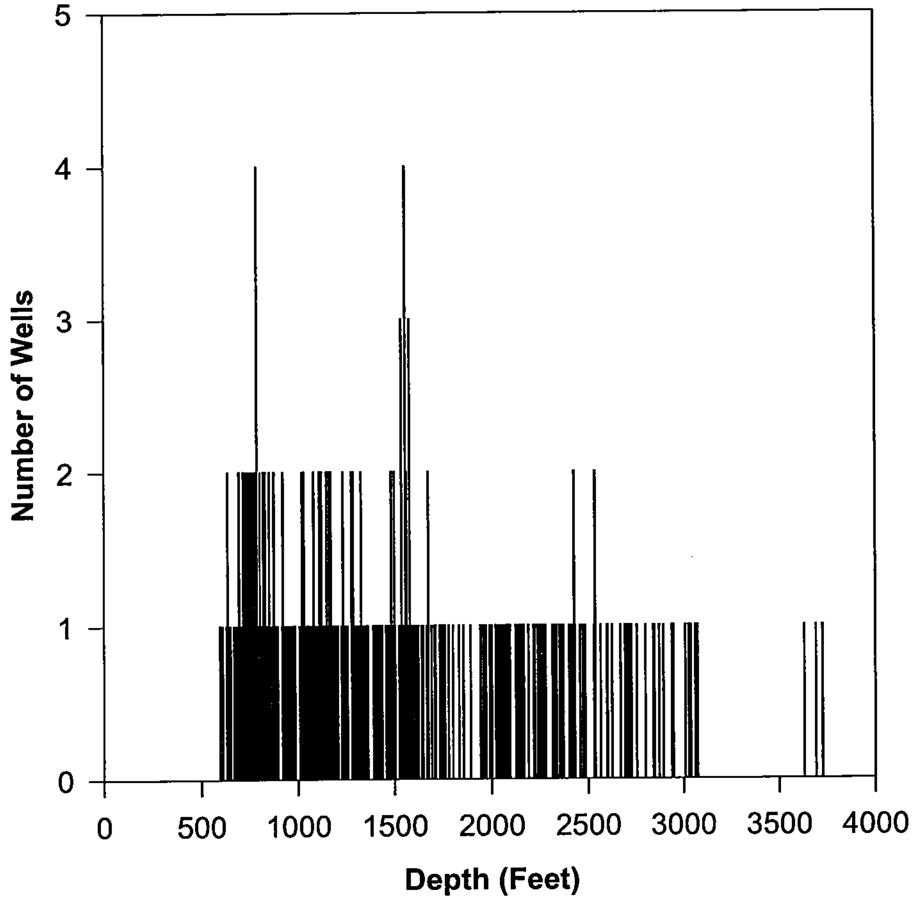


Figure 14. Histogram of coalbed-methane completions by depth in the Arkoma basin.

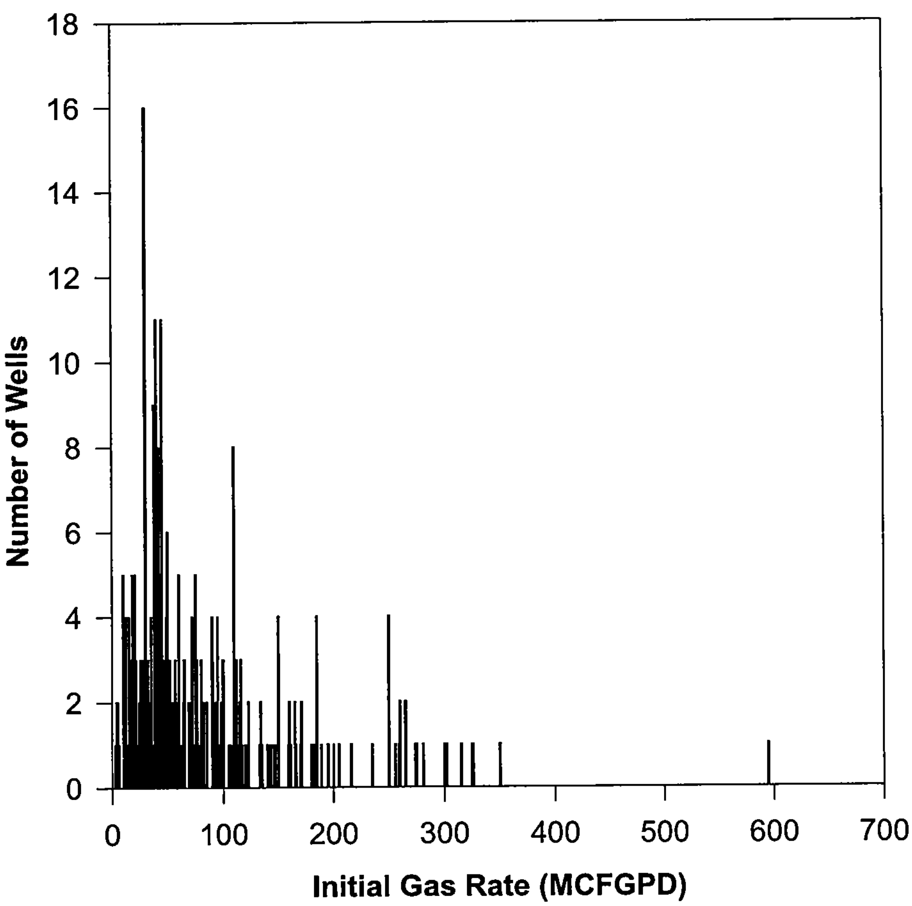


Figure 15. Histogram of coalbed-methane completions by initial potential gas rate in the Arkoma basin.

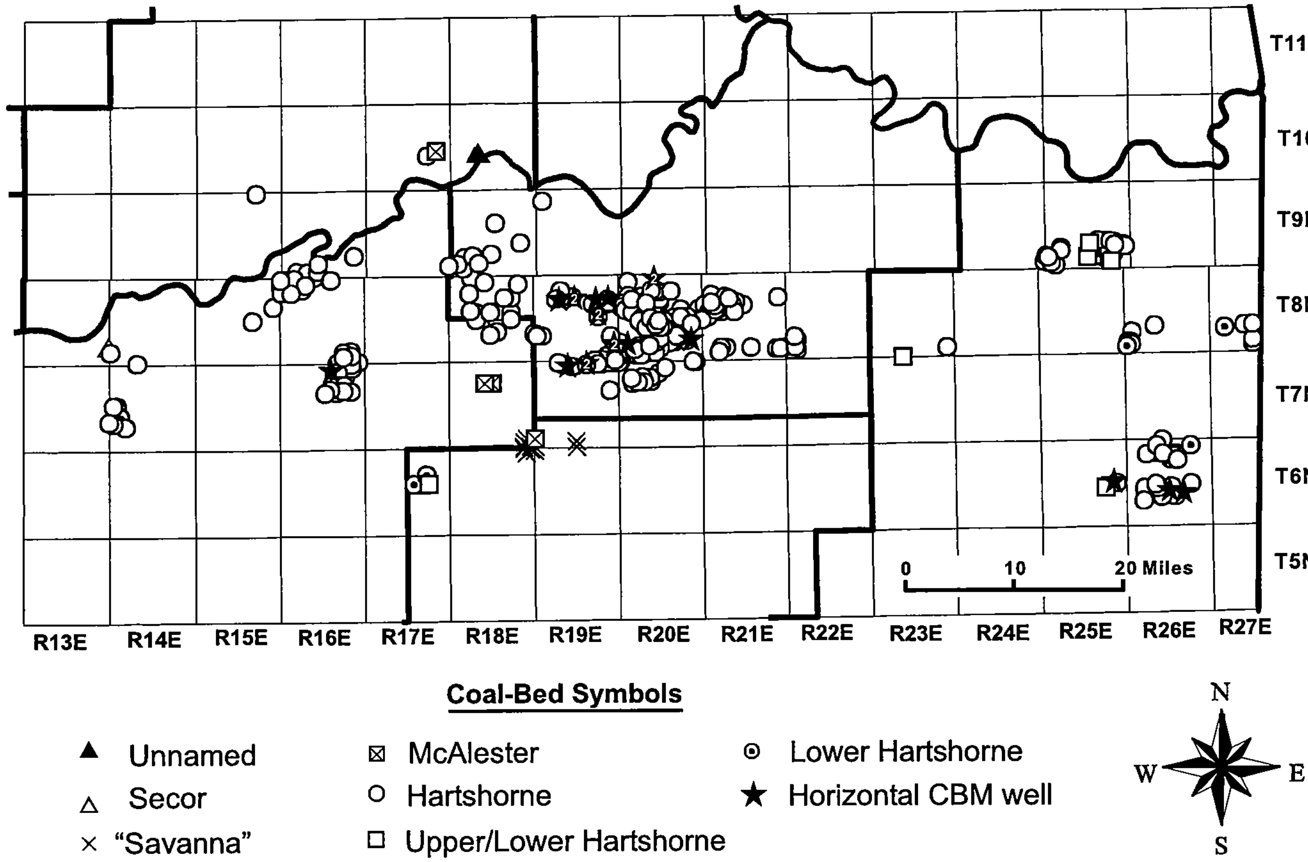


Figure 16. Map showing horizontal coalbed-methane completions in the Arkoma basin. (Two horizontal CBM completions in a section are designated by 2)

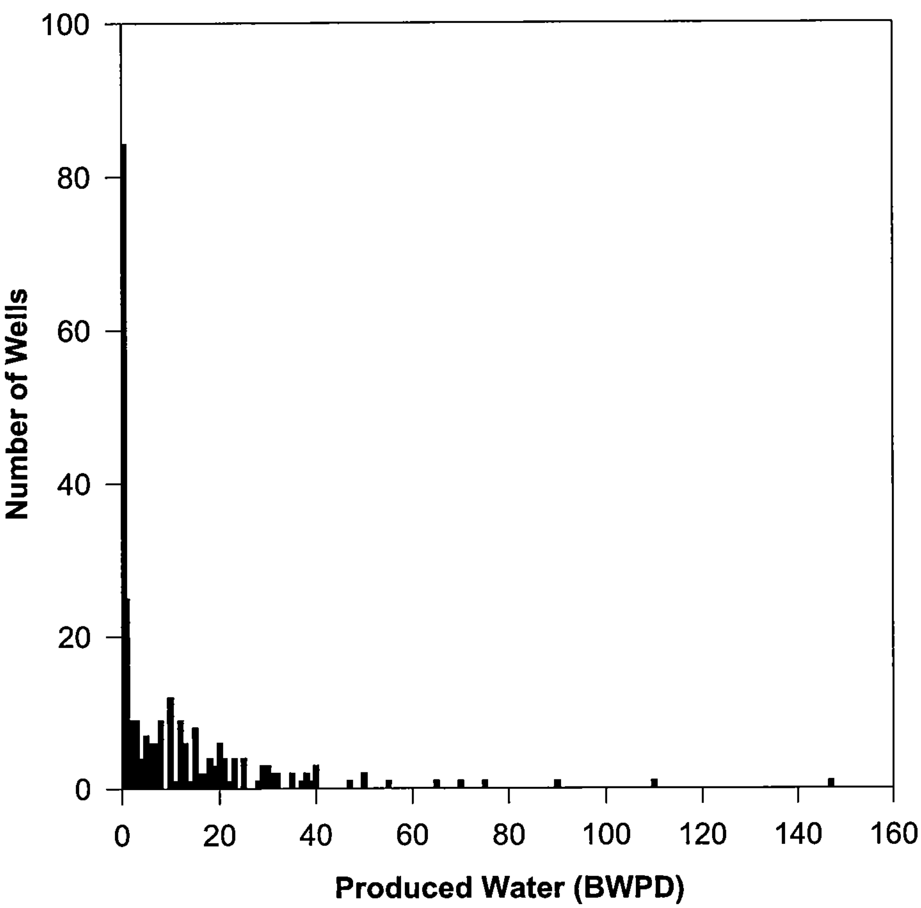


Figure 17. Histogram of coalbed-methane completions by produced water in the Arkoma basin.

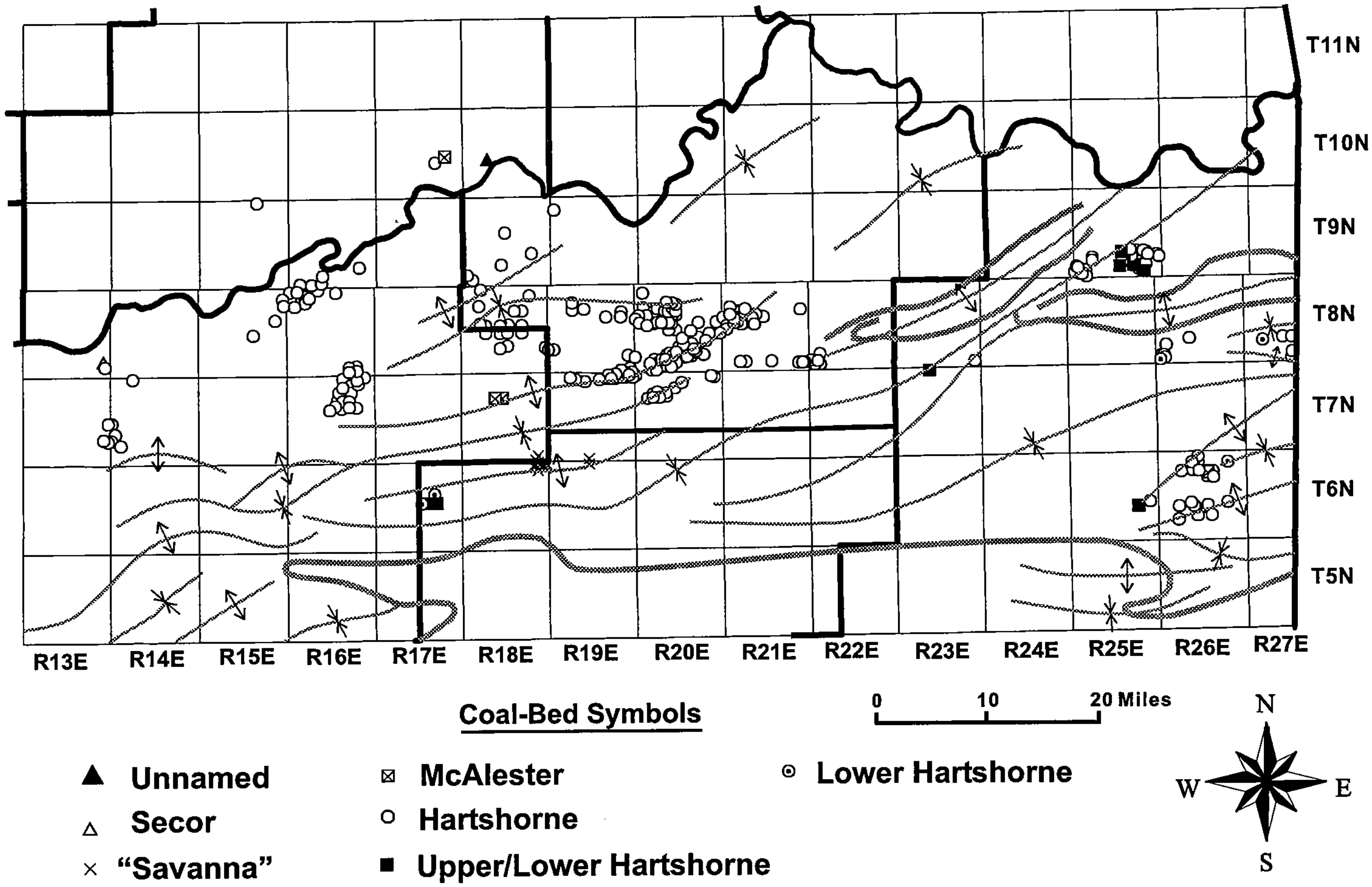


Figure 18. Map showing major surface folds, Hartshorne coal outcrop, and coalbed-methane completions in the Arkoma basin, Oklahoma. (Structure was modified from Arbenz, 1956, 1989, plate 8; Berry and Trumbly, 1968, figure 1; and Suneson, 1998, figure 10).

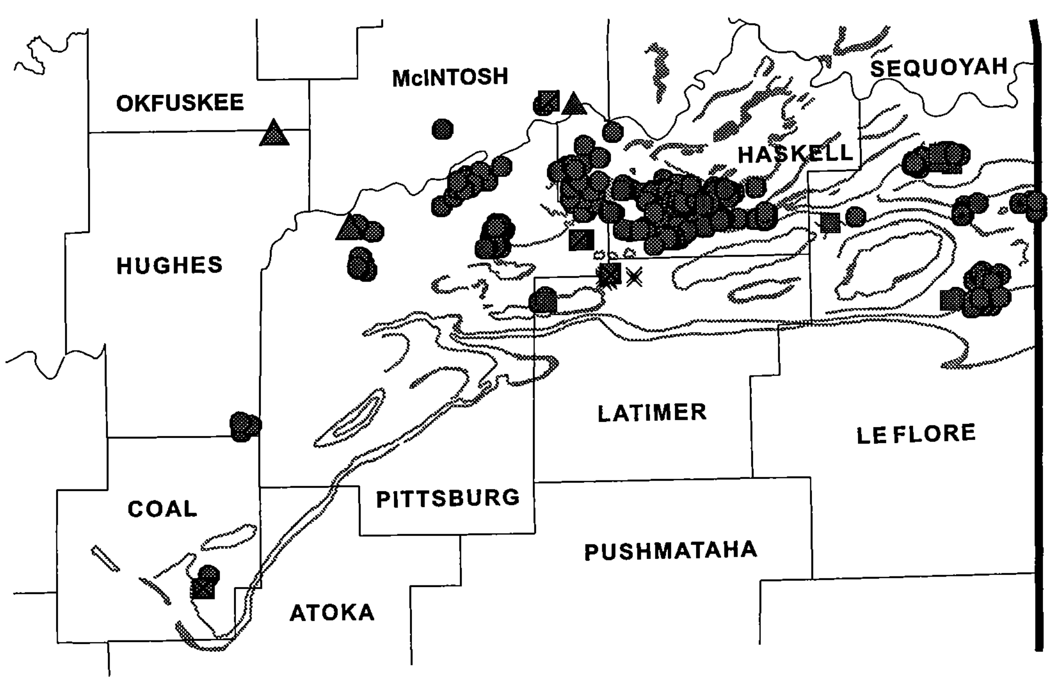
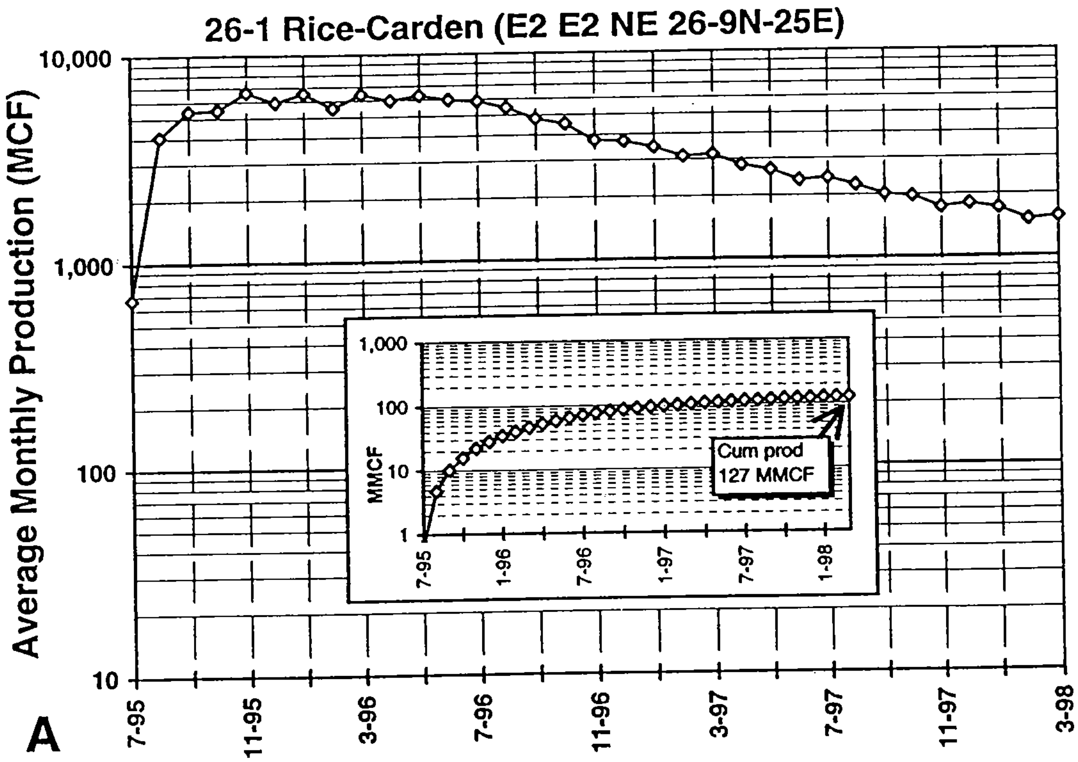


Figure 19. Map showing coalbed-methane completions on coal outcrop and subcrop in the Arkoma basin (base map modified from Friedman, 1982).



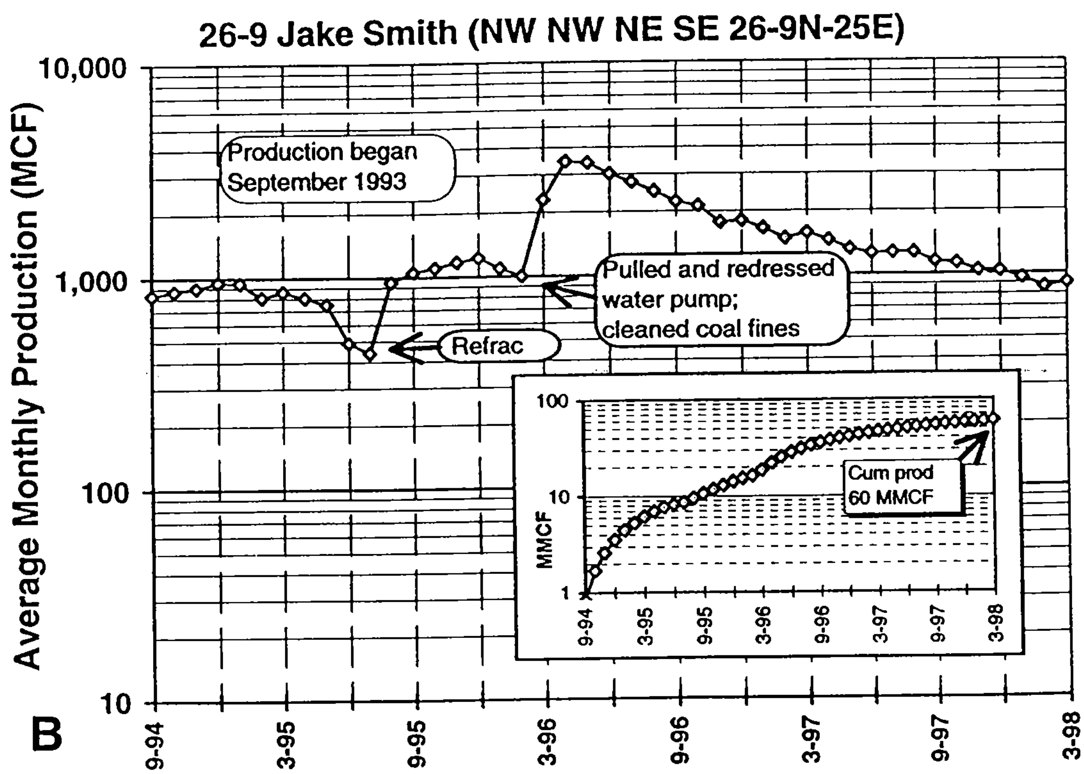


Figure 20. (Above and next page). Gas-production decline curves (from Andrews and others, 1998). (A) OGP Operating 26-1 Rice-Carden well.
(B) CWF Energy 26-9 Jake Smith well. (C) CWF Energy 26-13 Rhodes well.

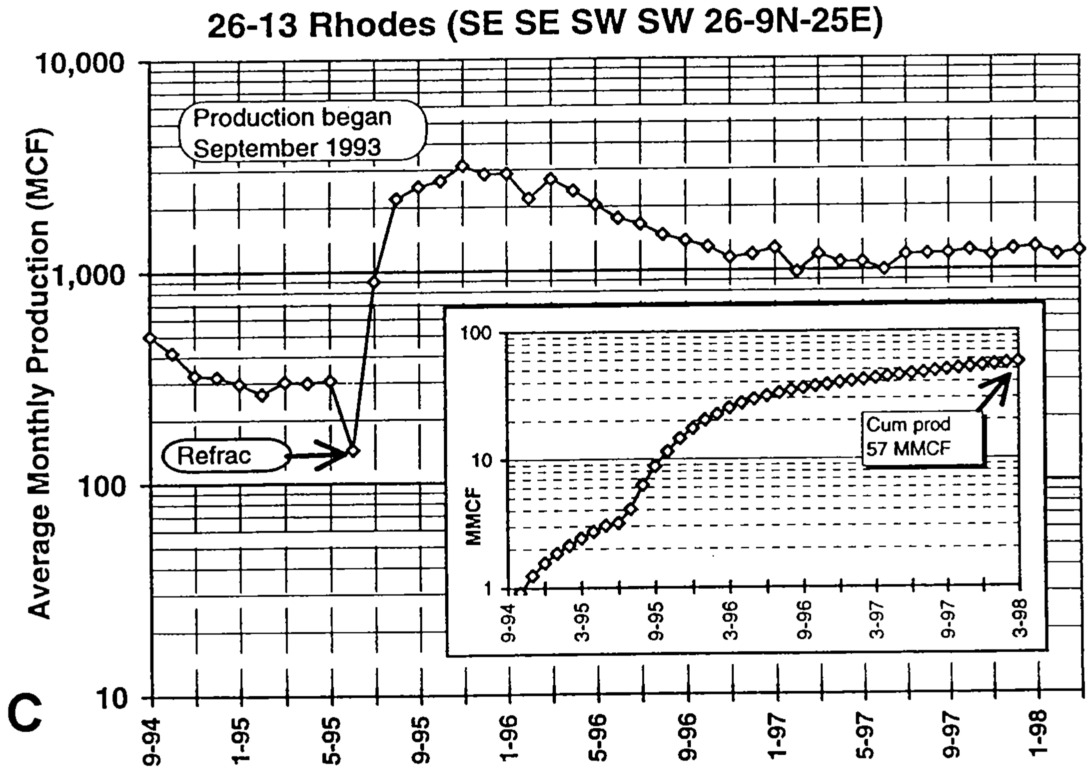


Figure 20. (Continued)

OKLAHOMA GEOLOGICAL SURVEY
OPEN-FILE REPORT OF 2-2000

3

Coalbed methane completion practices on the Cherokee Platform

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Stoeckinger, W.T., 2000, Coalbed methane completion practices on the Cherokee Platform, in Oklahoma coalbed-methane workshop: Oklahoma Geological Survey, Open-File Report OF 2-2000, p. 36-51.

WHAT'S HAPPENING

Single zone completions the norm:

(Weir, Rowe, Riverton Coals, and Mulky)

New Wells:

If you set 7" surface, you must drill 6¼" or smaller hole.

If you set 8–5/8" surface, you can drill 6¾" or larger, as 7–7/8" for the main hole.

Set 8–5/8" and go for 6¾" main hole. It costs the same ....

Re-Completions:

1. Handicap yourself 50% because you must use poor plumbing of ancient operators.
2. Mostly 2–7/8" casing in Kansas, mostly 4½" in Oklahoma.

New Casing Size:

1. Mostly 4½" using thin walled casing if cementing to surface, but something heavier if tagging cement on bottom.
2. Might consider 5" plus, if water is abundant and larger downhole pumps needed.

Never, ever, use 2–7/8" as is still common in Kansas.

Cementing New Holes:

1. Normal: use 14 lbs/gal, Class A or 50/50 poz, and bring it to the surface.

2. Many Others: tag across the coal 25 sacks of light weight 50/50 poz with abundant lost circulation materials. Must have already set surface casing below fresh water depth (about 200 feet).

3. Newest Wrinkle: run 14 lb/gal latex cement with or with LCM and bring it to the surface.

Bite-the-bullet and use something that will never, ever, invade the open fractures of a coal. Don't be penny-wise and dollar-foolish. Open-hole-completions sound good, BUT, local operators are not prepared to handle the removal of both water and coal fines in the open hole.

Perforating the Casing:

1. Normal: 4 shots per foot, using carrier gun with 3/8" diameter holes.

2. A few souls: 8 shots per foot, using carrier gun with ½" diameter holes.

3. Only in Kansas: strip jets.

4. A rare few; cut the casing using fine sand, and wallow out the coal and cement.

Use the ½" diameter holes, it costs the same as 3/8". More holes are better than less. Less depth of penetration is better than more. Use 60% phase gun, if available.

STIMULATION AFTER PERFORATING:
(This subject is as emotional as discussing politics.)

1. Normal: water only, no gel. Nitrogen popular in Kansas. Slick-water down tubing.
2. Size: mini-fracs (less than 500 bbls). Fracs over 1,500 bbls no longer popular.
3. Sand: none at all or in concentrations less than 1 lb/gal, 20/40 most popular.
4. Treating Pressures: very high (1,200 to 3,000 psi). Leak off: usually extreme (more than 20 psi/min)
5. ISIP's: Low at the beginning, high at the end. Don't always reflect fracture gradient.
6. Frac Gradient: less than 1 psi per foot below 1,000 feet, much above that at shallower depths.
7. Near-wellbore tortuosity is main culprit for very high-treating pressures, next in line is perforation friction. You can fix one but not the other.
8. After-frac leakoff: If well does NOT go on a vacuum, don't expect a barn-burner. If it does within minutes, you have a very permeable coal, and most importantly, you haven't screwed it up, yet.

Coals as the Weir, Rowe, Riverton are gassy, and naturally very permeable, and are capable of draining 100 acres or more if you don't mess it up with the completion.

The key to success is to recognize where the coal is permeable, then go for it. It it's impermeable, fold your tent because no completion will give you the happiness you so richly deserve.

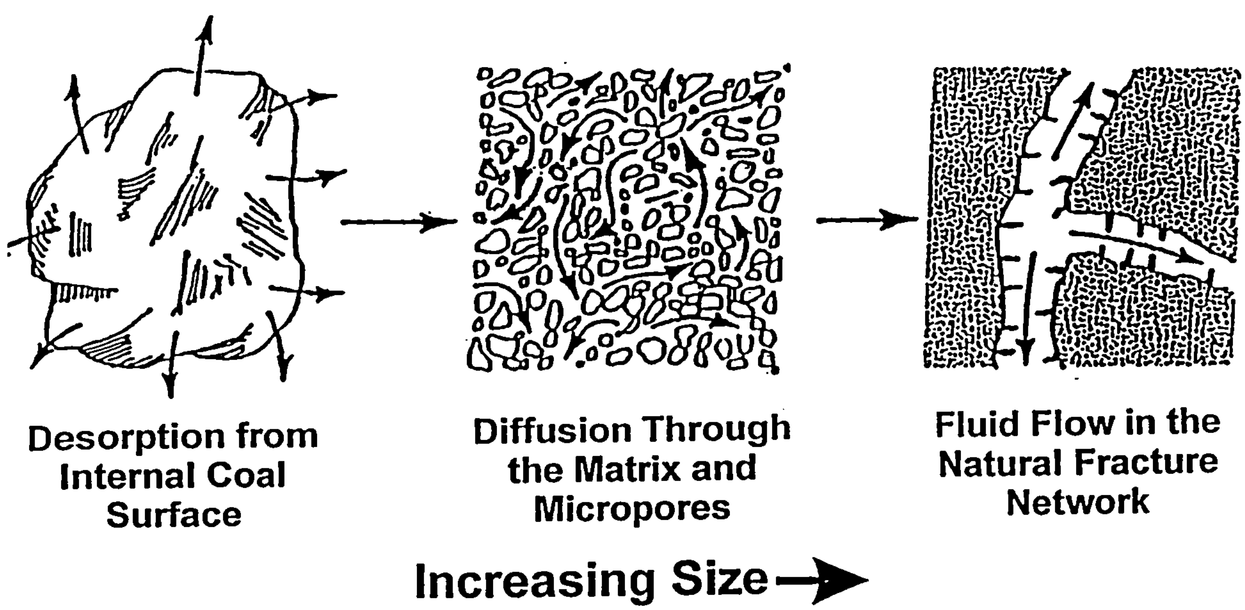
As far as the frac size and design: go step-by-step and pay attention, and use the least costly way to achieve an economic flow (40 Mcfgpd makes money, but 200 Mcfgpd is better). Sometimes acid and 100 bbls of water is enough. You can always get rougher.

Lastly: The best technique in one area is most probably not transportable to another!

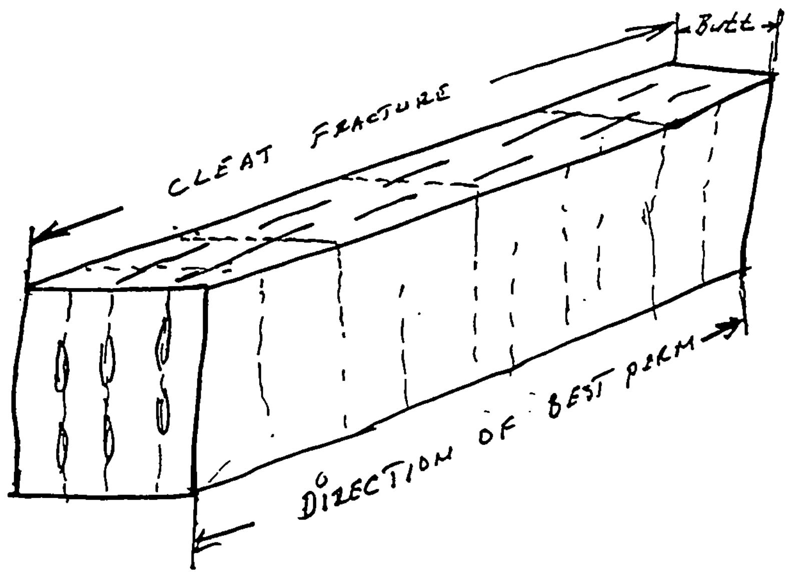
UNIQUE ASPECTS OF COAL

- Permeable Coals are Friable
- Coals are Cleated and/or Naturally Fractured
- Most Coals are Shallow
  - Complex Fracture Geometry
- High Treating Pressures

Methane Production



Wicks, D.E., et. al., 1989 proceedings CBM Symposium, Tuscaloosa, fig 2, p. 14, paper # 8912.



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DRILLING CONSIDERATIONS

- All Coalbed Wells Must Be Stimulated to Be Economic
- Drilling Program Designed Around Completion/Stimulation Programs

CASING PROGRAM

- Burst Pressure of Casing Should Be Designed to Withstand Fracturing Pressures
  - Treating Pressures for Coals Higher Than Typical Formations
  - Coal Wells Often Need to be Treated at High Rates to Overcome Leakoff
  - Casing Size Needs to be Big Enough for Zonal Isolation and Production Equipment
- Sufficient Rathole Needed to Place Pumping Equipment Below Perforations

LET'S DO SOME CEMENTING .....

Assume: 1000' to the coal & coal is very permeable with wide, open fractures filled with salty water.

Let's use Class A cement weighing 14 lbs/gal (or .73 psi per foot.

Pore press in the coal's fractures is 400 psi (.4 psi/ft).

Column of cement brought to the surface will exert 730 psi into fractures that contain only 400 psi. That's over-pressuring the fracture by 330 psi.

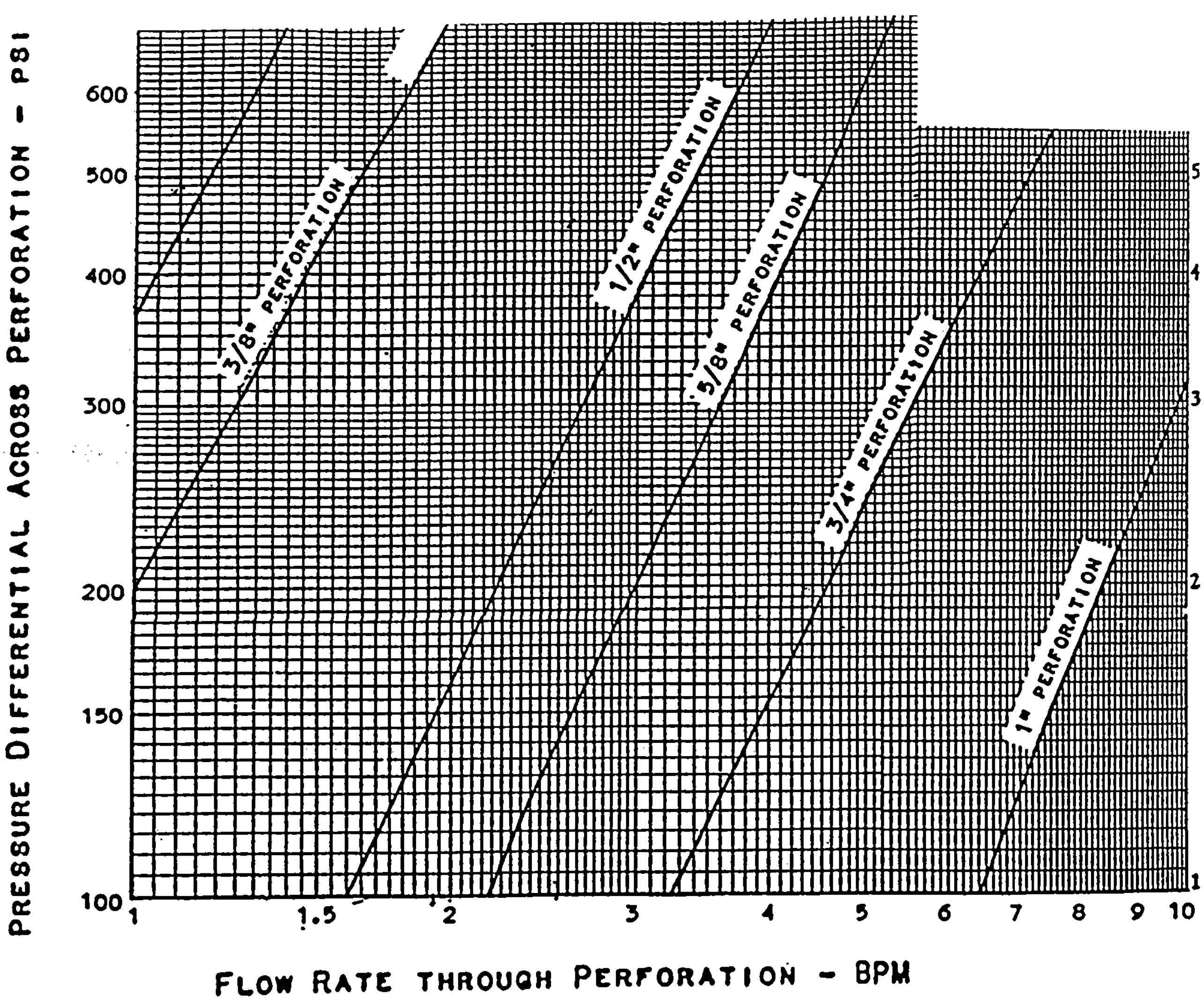
Question: can you push cement into a crack if you exert 330 psi at its face ???

Answer: Yes, and all the way back to the crack's end.

Let's tag 25 sks across the coal for a coverage of 300'

The excess pressure is now only 120 psi, but still too high and the coal's fractures will be invaded by slurry

THE CONCLUSION: in this part of the world, cementing will always exert excess pressure at the coal's fracture face. Minimize that damage or invasion by whatever means, unless you think you can frac past the damage. Good luck.



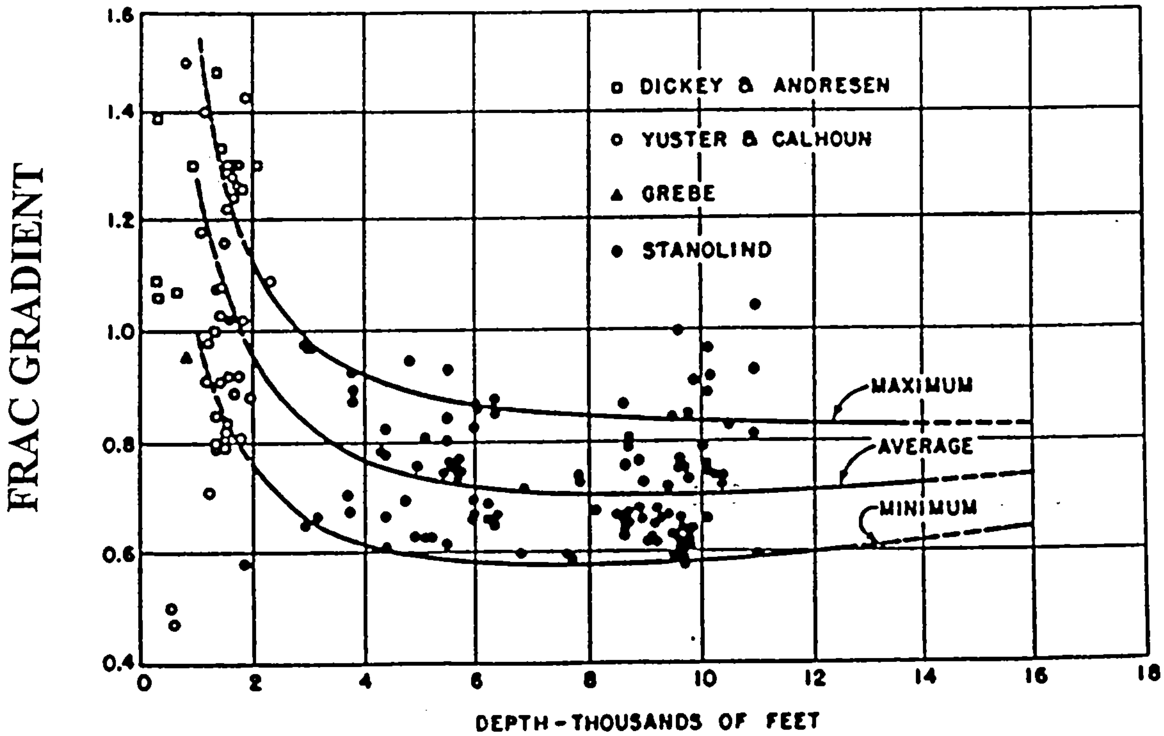
Howard, G.C. & Fast, C.R., 1970, Hydraulic fracturing, SPE of AIME, fig 7.10, p104

FRACTURE TREATMENT DESIGN CONSIDERATIONS

- A Highly Conductive Fracture Must be Created Under In-Situ Conditions to Minimize Bottomhole Producing Pressure and Effectively Dewater the Coal.
- Due to Complexities When Fracturing Coals, the Engineer Must be Prepared to Make Changes to the Fracture Treatment On Site. Thus, Real-Time Analysis and Treatment Diagnostics are Critical.

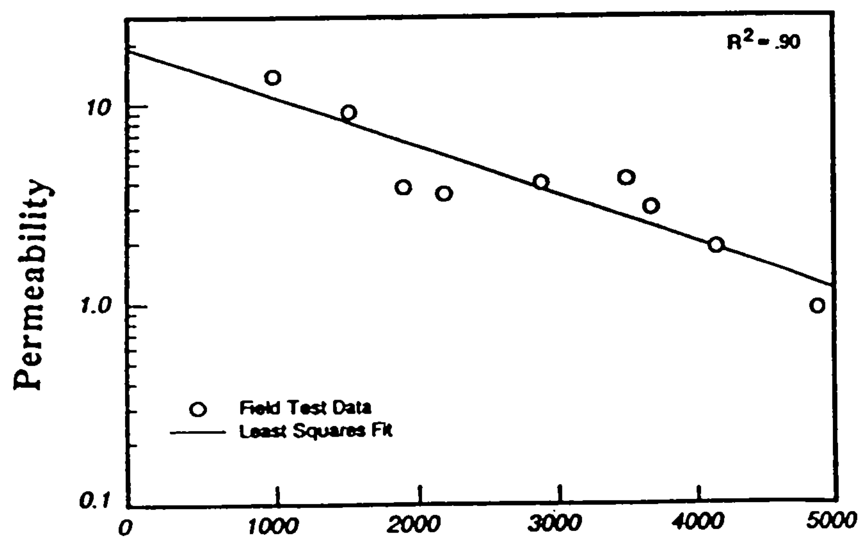
FRACTURE TREATMENT DESIGN CONSIDERATIONS

- Large Increases in Production Should Not Be Expected With Increasingly Larger Treatments
- Optimization of Fracture Treatments Should Focus on Costs
  - Perform Real-Time Fracture Analysis to Minimize Pad Volumes, Observe Trends
  - Evaluate Benefits of Different Fluids and Proppants
  - Remove Near-Wellbore Tortuosity to Lower Treating Pressures, Alleviate Potential Problems
- Completions Should Ensure Good Communication of Reservoir (Natural Fractures) With Wellbore



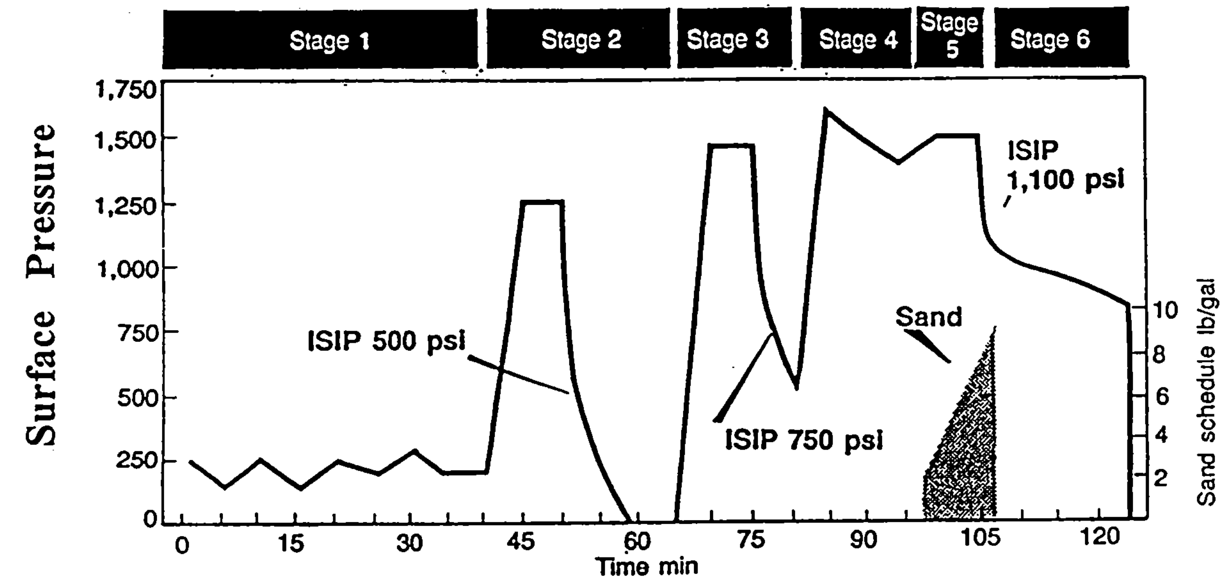
Howard, G.C. & Fast, C.R., 1970, Hydraulic fracturing, SPE of AIME

Permeability Vs. Closure Pressure Taurus Cedar Cove Area - Black Warrior Basin Model



CLOSURE PRESSURE

SAND FRAC RESULTS ON DISCOVERY WELL*



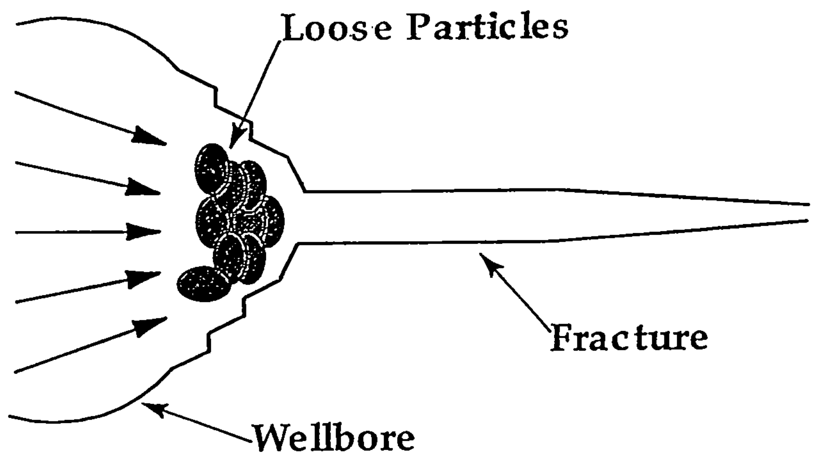
*1 S. Miller coalbed methane discovery well, IP 90 b/d of water and 110 Mcfd of gas
Source: Stroud Oil Properties

Oil and Gas Journal, 1992, v. 90, no.15, p.90-91.

NEAR-WELLBORE TORTUOSITY

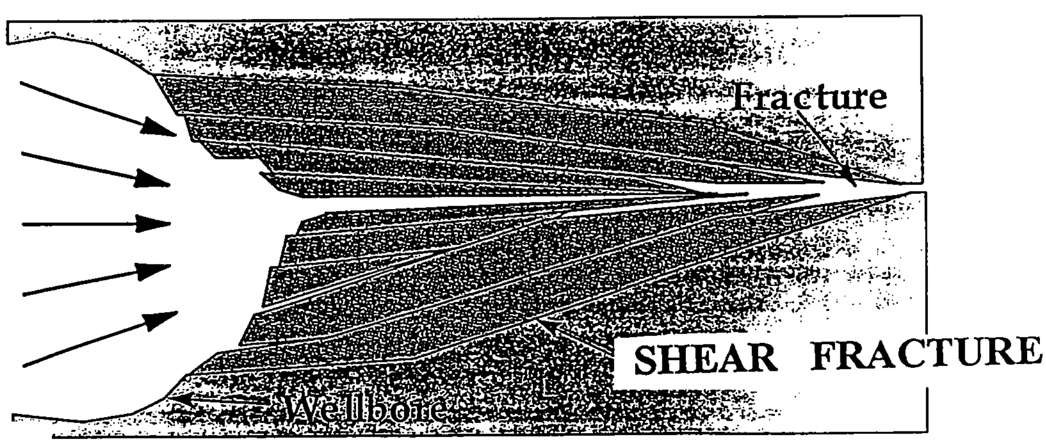
- **Width Restriction Near Wellbore**
- **Causes of Tortuosity in Coal Wells**
  - **Shear Failure**
  - **Plastic Deformation**
  - **Multiple Fractures**
  - **Opening Natural Fractures**
  - **Turning Fractures**

Particle Plugging in Fracture

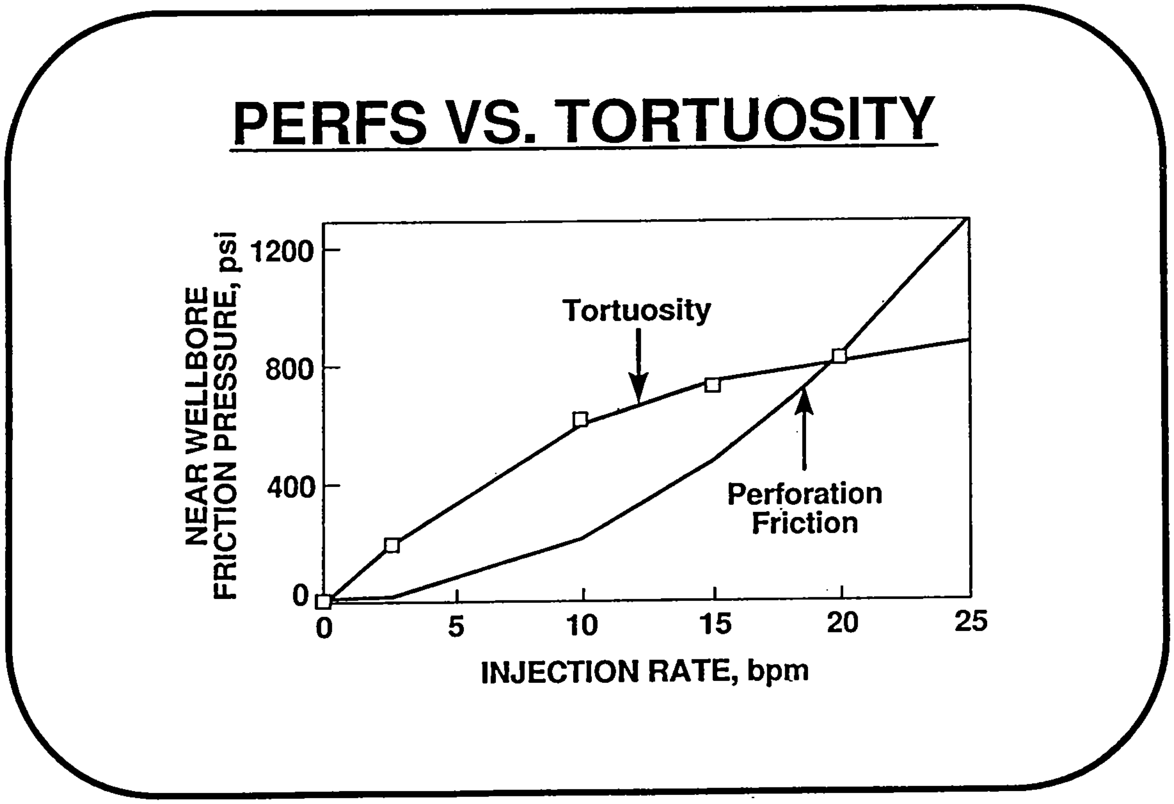


GRI 95/0003

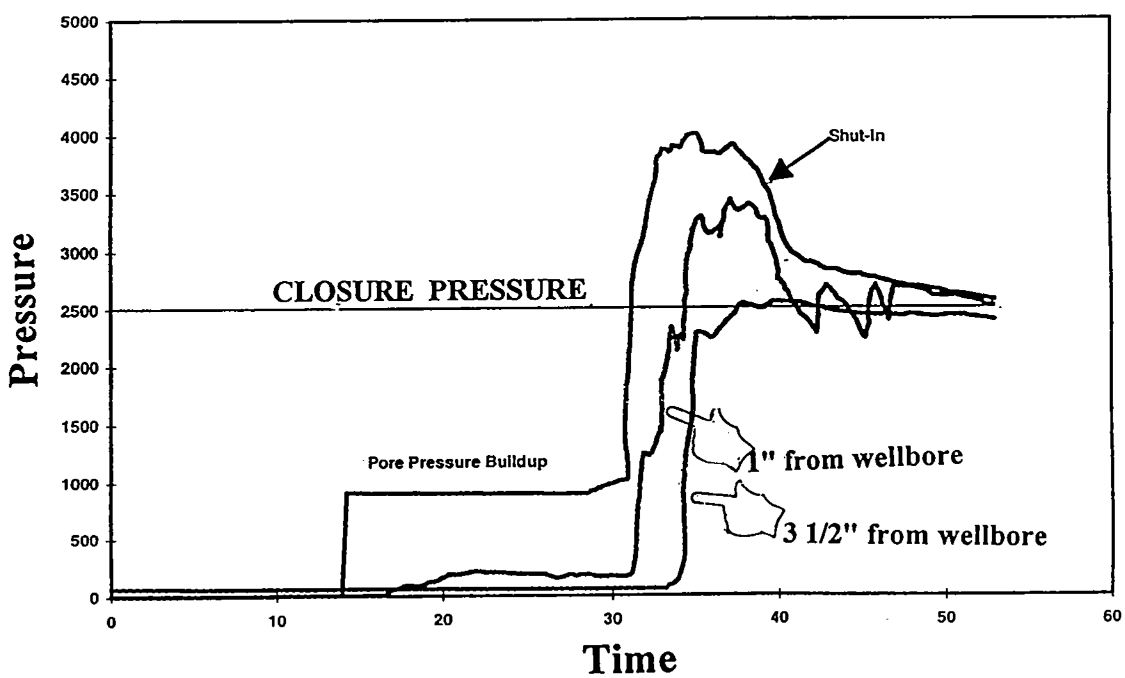
Shear Fracturing Due to Pore Pressure Buildup



GRI 95/0003

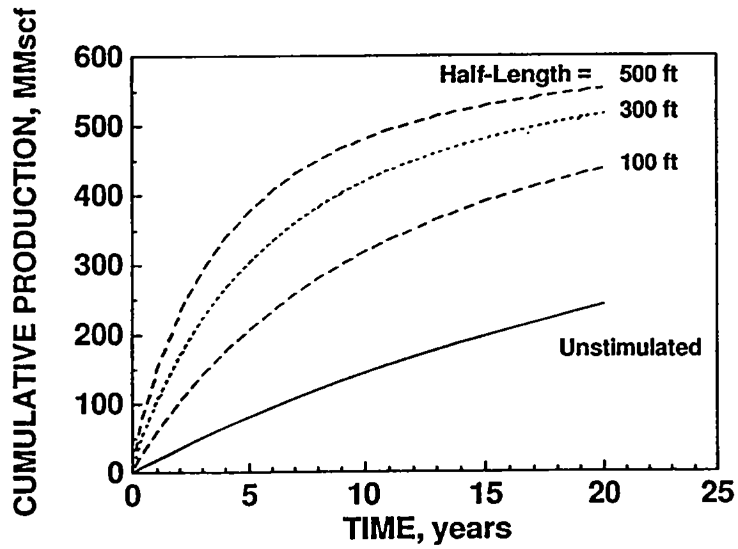


Wright, C.A., 1997, SPE paper 29989.



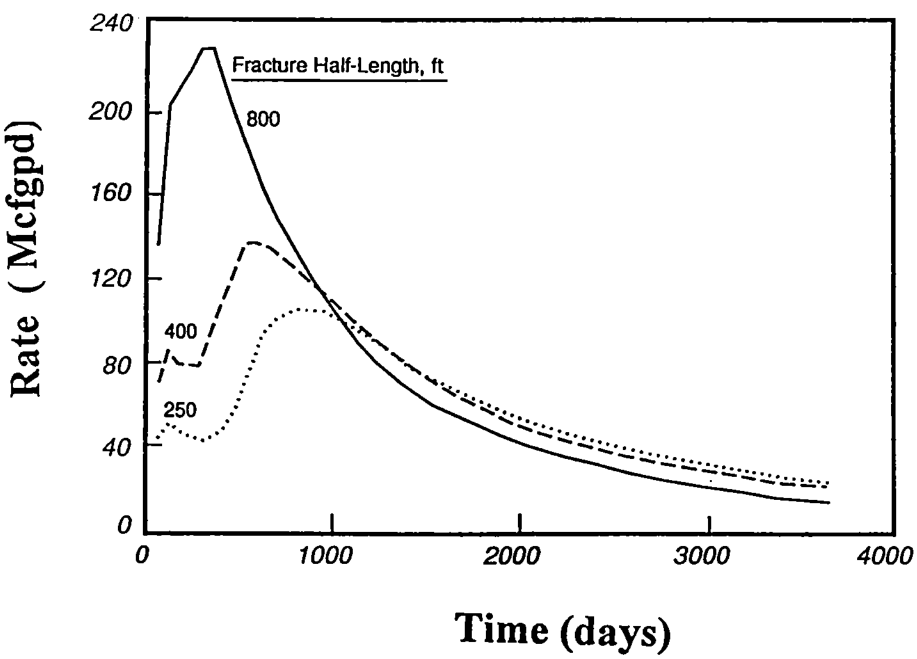
GRI topical report, 1994, CBM stimulation techniques, GRI-95/0003.

PRODUCTION FORECASTS



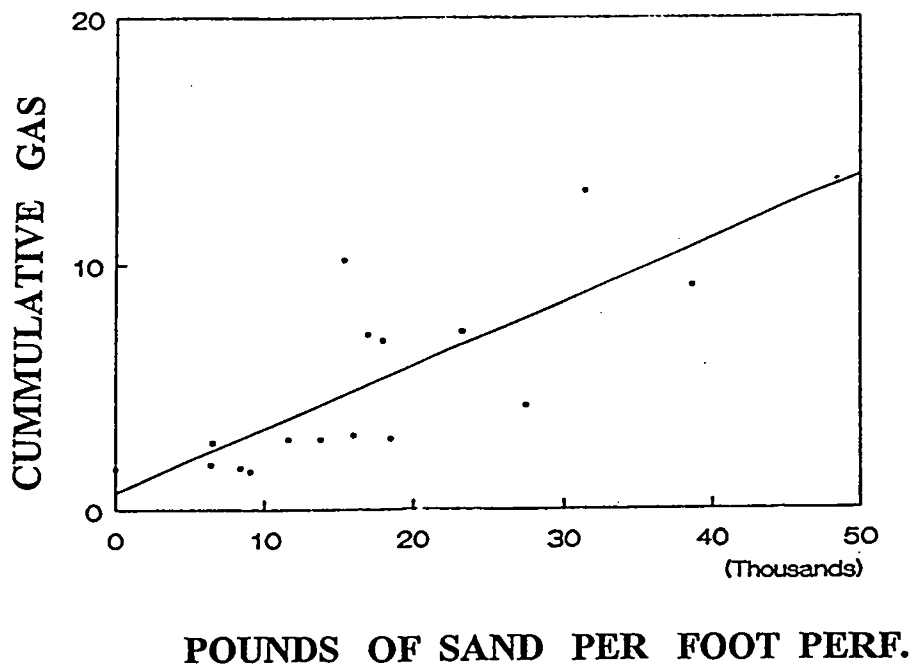
Zuber, M., et al, 1996, workshop sponsored by SPE, CBM engineering methods, S.A. Holdtich and Asso., fig 6-5, Denver, CO.

Sensitivity of Gas Production Rate to Hydraullic Fracture Half-Length - Black Warrior Basin Model



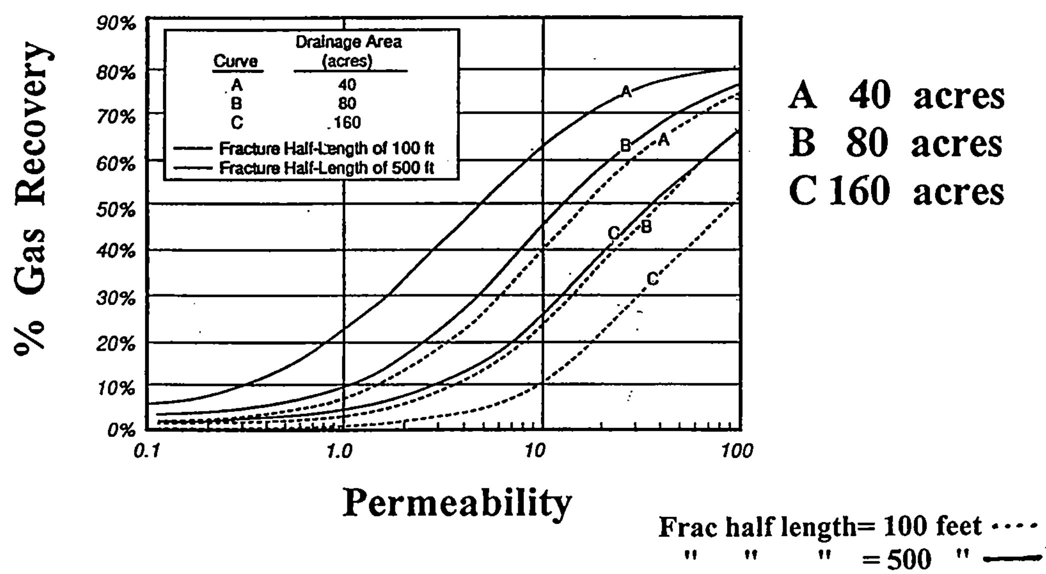
Sawyer, W.K., et al, 1987, CBM symposium, Tuscaloosa, paper # 8763, fig. 16.

PRODUCTION ANALYSIS OF THE ORIGINAL AREA
CEDAR COVE FIELD, BLACK WARRIOR BASIN



Palmer, I.D., 1992, Review of CBM well stimulation, SPE paper # 22395. &
Palmer, I.D., 1993, SPE paper # 22914.

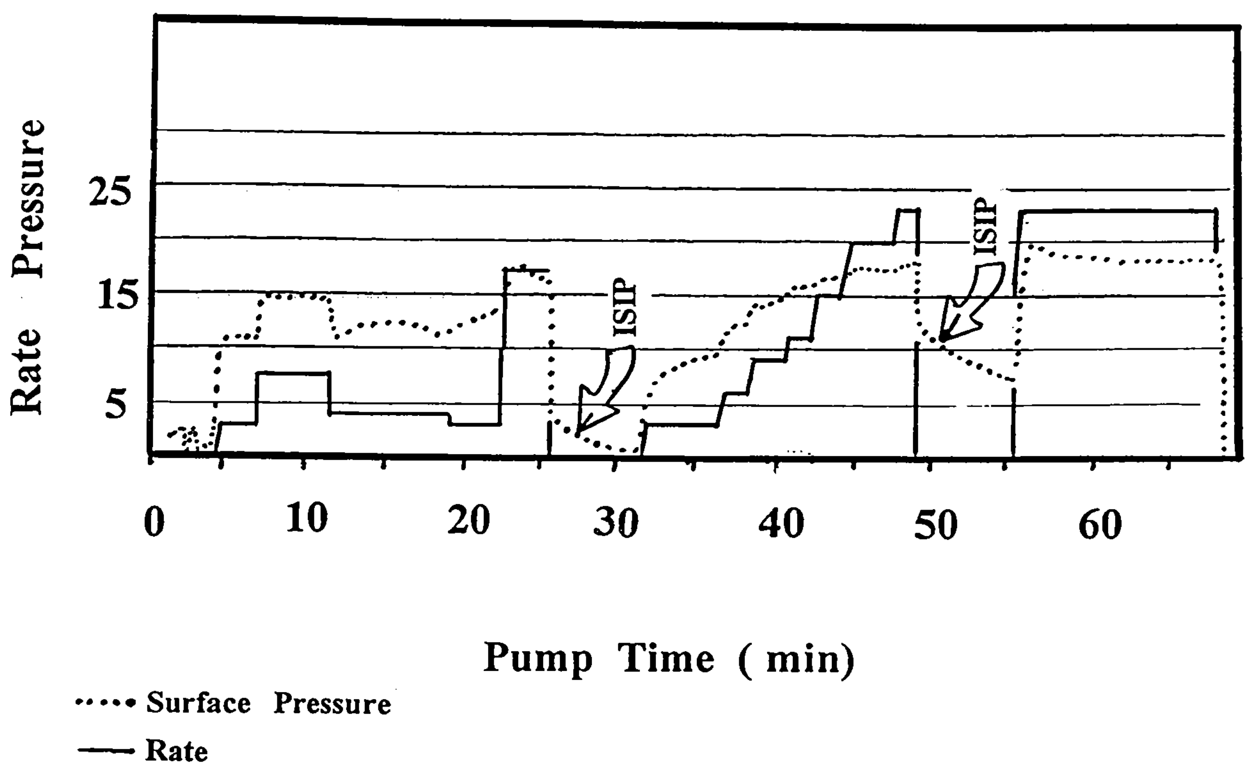
Illustration of the Relationship Between Permeability, Fracture Half-Length, Well Spacing and 5-Year Gas Recovery



Saulsberry, J.L., 1993, CBM symposium, Tuscaloosa, paper # 9365, fig 6.

TABLE 1

ISIP		BREAKDOWN		TREATING	
EARLY	LATE	RATE	PRESSURE	RATE	PRESS.
400	1000 psi	5 bpm	1850 psi	20 bpm	2000 psi
750	1000 "	6 "	1700 "	17 "	1700 "
600	1200 "	5 "	1800 "	16 "	2000 "
600	780 "	4 "	1000 "	17 "	2000 "
400	1400 "	3 "	1200 "	21 "	1800 "
625	700 "	3 "	1200 "	22 "	1800 "



OKLAHOMA GEOLOGICAL SURVEY
OPEN-FILE REPORT OF 2-2000

4

Hartshorne CBM play in Oklahoma: selected production and economic viability

Matthew A. Biddick
Fractal Oil Company
Norman, OK

Biddick, M.A., 2000, Hartshorne CBM play in Oklahoma: selected production and economic viability, in Oklahoma coalbed-methane workshop: Oklahoma Geological Survey, Open-File Report OF 2-2000, p. 52-81.

Hartshorne CBM Play in Oklahoma: Selected Production And Economic Viability

Matthew A. Biddick
Fractal Oil Company

Abstract

The modern coalbed- methane play in the Hartshorne coal of the Arkoma basin, Oklahoma has been ongoing since 1988 with the advent of Bear Productions, Inc.s' pioneering efforts at the Kinta Anticline in Haskell County. Other operators are now conducting projects around the basin which have wells with several years of production. We can now evaluate a little more clearly the economic viability of the Hartshorne CBM play in Oklahoma. This paper will take a cursory look at some of the considerations operators face in this play and at a few of the older, targeted projects in the Arkoma basin.

Introduction

Production of methane from coal seams in Oklahoma via vertical wells dates back to the 1920's with gas production from the "Fears Coal" at the Canadian Dome in Pittsburgh County (Section 5-8N-16E & Section 32-9N-16E). At about the same time and into the 1930's at the Kinta Anticline, gas production from the Hartshorne Formation was initially attributed to "broken sand & coal" of the Hartshorne. All wells were completed openhole; later wells did not drill the entire Hartshorne section and were stopped just below the coal. Modern drilling in the 1980's and 1990's would show, through openhole logs, that no quality sand reservoir was present in the original producing area.

Several of the 1930's vintage wells at the Kinta Anticline (8N-20E, Haskell County) have documented sales of gas. It is in this locale that Bear Productions, Inc. began the modern era of coalbed- methane production in Oklahoma. The principals of Bear were born and raised for two generations in the immediate vicinity of the apex of the Kinta Anticline. They had first-hand knowledge of several of the original wells, which had remained unplugged, emitting gas on an intermittent basis since cessation of commercial gas sales. The fact that it was methane being emitted was substantiated through the lighting of the gas flow from time-to-time when things were a little slow for the teenage population of the area. One well in particular is said to have flowed gas continuously, and could be lit anytime, since at least 1950 (Johnson #1 W/2 W/2 NW/4 Section 26-8N-

20E). It was this well that the principals of Bear flow tested in 1987 at approximately 40 MCFGPD at 20 psi. This well is said to have had a shut-in pressure of approximately 180 psi. The original bottomhole pressure in the Hartshorne, as reported in the 1920's, was as high as 295 psi. This particular well's initial shut-in pressure was reported at 245 psi in 1927. The Johnson #1 has reported cummulative gas sales of 69,000 MCF. It is known that it was abandoned and venting gas since at least 1950. It seems almost too fantastic to think that this well possibly vented over 500,000 MCF in the intervening years between its abandonment and 1987 when Bear personnel tested it.

Economic Considerations

With any gas, or oil, production, profitability depends upon production rate, ultimate volume, competitive costs, and a reliable, cost effective market for the gas. Another important consideration for CBM production is to achieve an economy of scale, whereby the operator realizes cost savings and lowers his cost per MCF produced. Economy of scale is vital to the success of a CBM project in the Hartshorne coal. Proper reservoir development requires multiple wells per section in order to drop the pressure in the coal and desorb the gas. An economy of scale is realized when the coal is adequately developed. For any prospective CBM project in the Hartshorne coal(s), an operator must be ready to commit the resources necessary to get the project off the ground. A well density of 4 wells/section is a good beginning with 8 wells/section deemed to be the optimum density.

An operator of a CBM project can calculate production costs on a per MCF of gas produced basis. Because of high water handling costs (especially early in the life of a well), usually mandatory compression costs, normal transportation and marketing fees, and typically low production volumes relative to conventional gas reservoirs, the lease operating expenses (LOE) of a CBM well are high on a per MCF of gas produced basis. A net gas price worksheet follows in this paper that illustrates these costs along with the "bite" per MCF that royalty and the severance tax take when beginning with a $2.00/MMBTU price. This worksheet attempts to account for normal LOE. Workovers for other problems such as pump failures, motor failures, electrical problems, etc., are not taken into consideration. Such problems are "lumps" that will extend payout of the well in which they occur by a month or two for each occurrence. An illustration of payout scenarios is provided for three different completed well costs ($40,000.00; $50,000.00; $60,000.00). These costs are deemed to be achievable for wells drilled and completed in a single Hartshorne coal at depths from 800' - 1,200'. A second payout scenario is provided using a price of $2.50/MMBTU which illustrates the dramatic impact just a 50 cent increase in price has on the payout of a CBM well.

Production Overview of Selected Projects

As of April, 2000, approximately 358 completions in the Hartshorne coal were catalogued in the coalbed methane database maintained by Brian Cardott at the Oklahoma Geological Survey. It is known that operators over the years have perforated and tested the Hartshorne coal from time-to-time when completing in the Hartshorne sand. The coal was not considered a target in and of itself. Even today, Hartshorne coal production is being commingled with gas production from other zones. It is safe to say that the Hartshorne coal is being produced from more than 358 wells in the Arkoma basin. However, there are probably no more than a half dozen "projects" where the Hartshorne coal is the primary target and where the production of gas from the coal is the primary business motivation. At this time other projects are just gathering steam, including the first attempt at CBM production from the Hartshorne coal primarily via horizontal wells. Four of the projects with the longest production history are Bear Productions, Inc. at the Kinta Anticline, Redwine Resources at the north flank of the Kinta Anticline, Continental Resources in 7N & 8N- 16E, Pittsburgh County, and SJM, Inc. at the Canadian Dome in 8N & 9N-15E & 16E, Pittsburgh County. The production data presented in this report is current through September, 1999, which is the most current data available from commercial vendors at this writing.

FOUR KEYS TO ECONOMIC CBM PRODUCTION:

1. Gas Production Rate & Ultimate Volume
2. Competitive Costs
3. Reliable & Cost Effective Market
4. Economies of scale

GAS PRODUCTION RATE / ULTIMATE VOLUME

- Production rate should be in proportion to drill depth and payout period desired;
- Ultimate reserves proportionate to drill costs

COMPETITIVE COSTS

1. ACREAGE COST
   - lease Hartshorne rights only
   - farm-ins (CBM is NRI sensitive)

2. COST OF DRILLING/DRILL DEPTH
   - ultimate reserves limit depth

3. COMPLETION TECHNIQUE: COST/SIZE OF FRAC
   - straight nitrogen with better inherent permeability
   - sand/water frac for rest but don't overdo it

4. PROXIMITY TO MARKET & ATTENDANT LINE PRESSURE
   - ultimate recoverable reserves must support all gathering system costs

5. LIFTING COSTS
   - handling load water is large initial cost; typically declines
   - get an excellent pumper
   - use electric motors on pumping units - less down time

RELIABLE & COST EFFECTIVE MARKET

- In current environment, reliability not usually a problem, but can be

- CBM cannot sustain pipeline piracy, i.e., gathering/transportation costs must be reasonable.

ECONOMIES OF SCALE

1. Allows operator to lower cost per MCF produced and sold.

    a. Put pumper on salary

    b. Spread compression cost

    c. Better prices on equipment/services due to centralized location and multiple orders

    d. Less travel time and consequent work time loss

    e. Justify lower admin. & overhead charges

NET GAS PRICE WORKSHEET

GIVEN $2.00/MMBTU [$2.00/MCF FOR CBM]
FOR A 10-WELL, 500 MCFGPD PROJECT
COSTS PER MCF PRODUCED

	$2.00	Wellhead Price/MCF
-	.14	Severance Tax
-	.25	Pipeline Gathering
-	.30	Royalty
-	.10	Compression ($1500/mo.)
-	.12	Pumper ($175/well)
-	.22	Water Disposal (hauling) 1 BW / 7.5 MCF
-	.10	Electricity, Overhead, Charts
	.77	Net $/MCF

PAYOUT SCENARIO

FOR A 1000' HARTSHORNE CBM WELL WITH THREE DIFFERENT COMPLETED WELL COSTS

$40,000 / .77/MCF = 51,948 MCF TO PAYOUT

51,948 MCF / 50 MCFGPD = 1039 Days [2.85 yrs.]

$50,000 / .77/MCF = 64,935 MCF TO PAYOUT

64,935 MCF / 50 MCFGPD = 1299 Days [3.55 yrs.]

$60,000 / .77/MCF = 77,922 MCF TO PAYOUT

77,922 MCF / 50 MCFGPD = 1558 Days [4.3 yrs.]

EVERY $10,000 SPENT TAKES 9 MONTHS TO RECOVER.

PAYOUT SCENARIO II

USING $2.50/MMBTU (MCF)

$40,000 / $1.14/MCF = 35,088 MCF TO PAYOUT

35,088 MCF / 50 MCFGPD = 701 Days [1.9 yrs.]

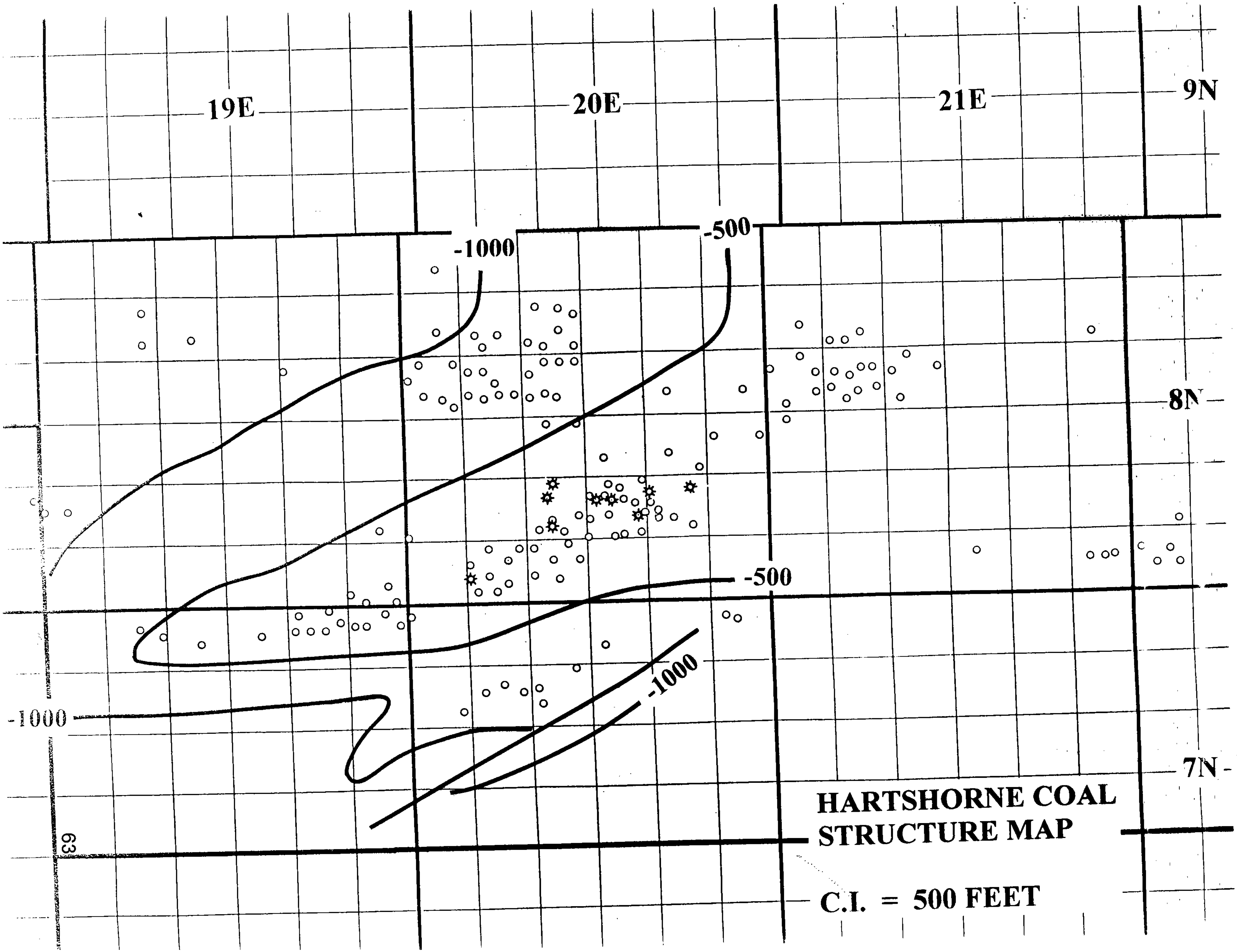
$50,000 / $1.14/MCF = 43,860 MCF TO PAYOUT

43,860 MCF / 50 MCFGPD = 877 Days [2.4 yrs.]

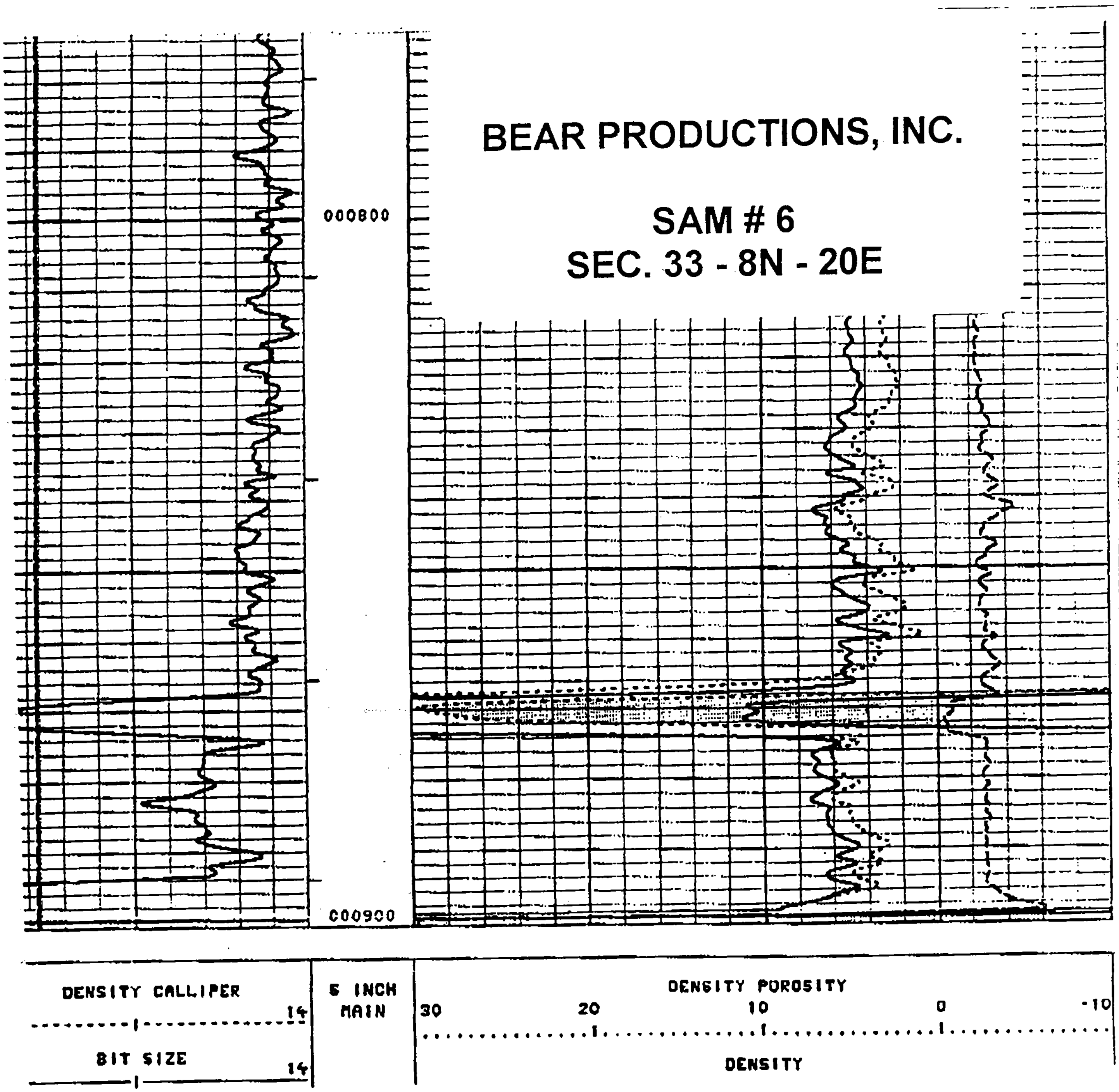
$60,000 / $1.14/MCF = 52,632 MCF TO PAYOUT

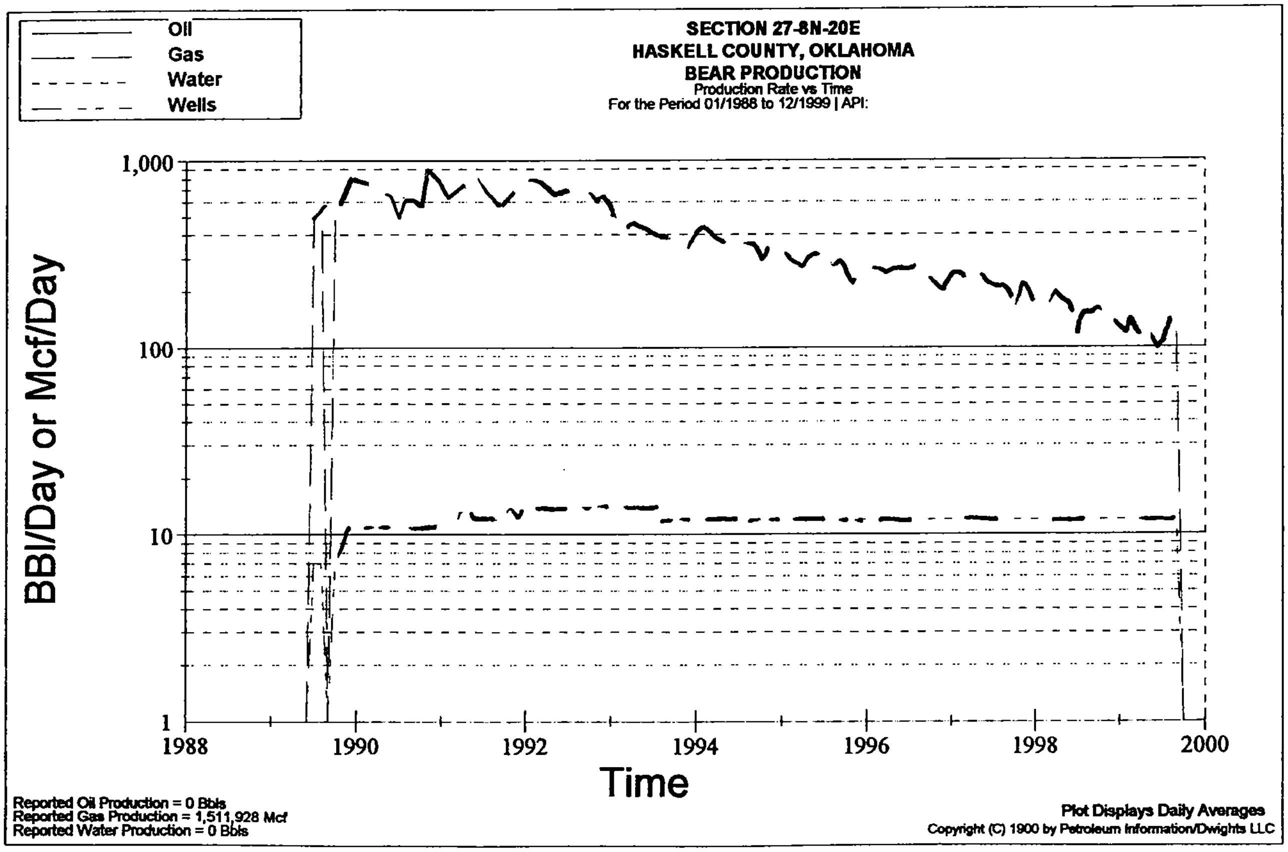
52,632 MCF / 50 MCFGPD = 1053 Days [2.9 yrs.]

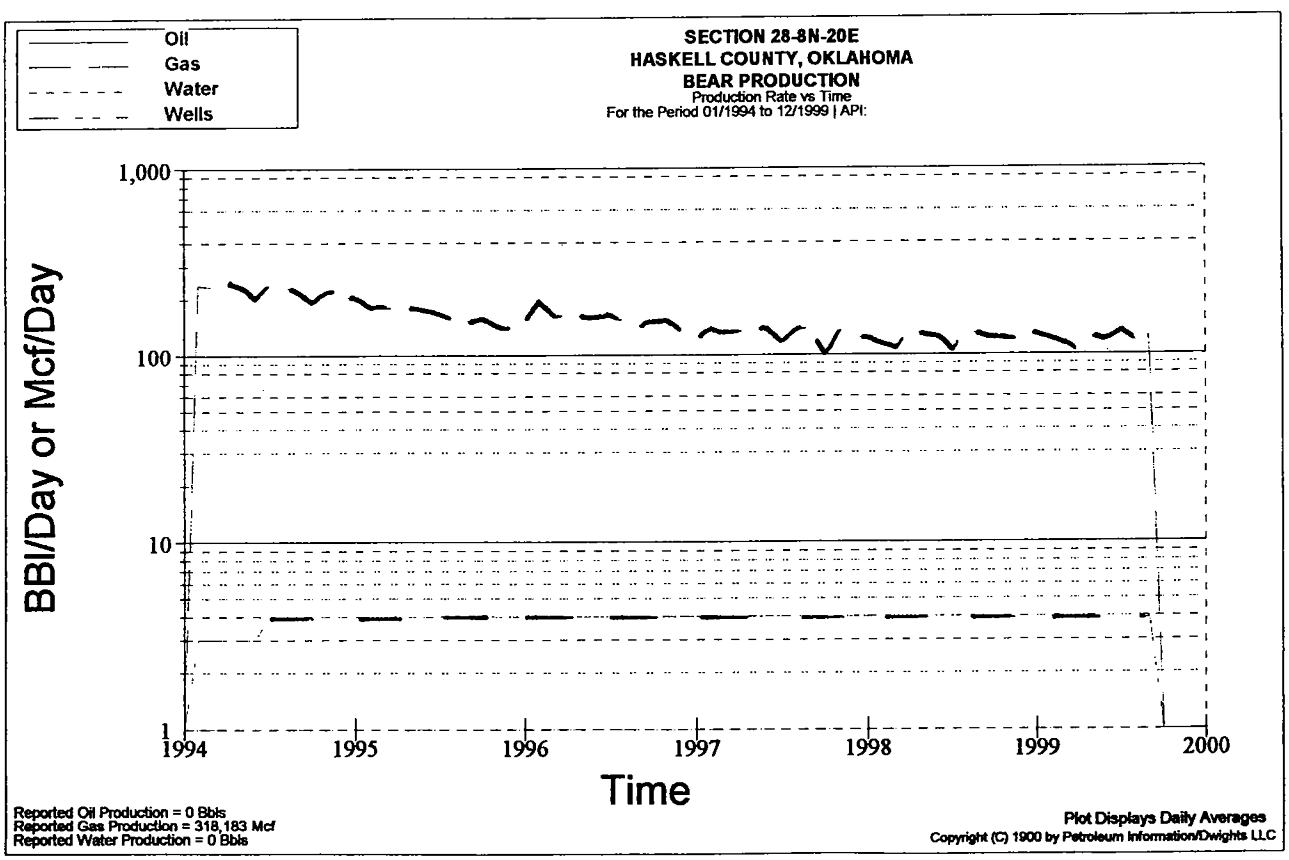
EVERY $10,000 SPENT TAKES 6 MONTHS TO RECOVER.

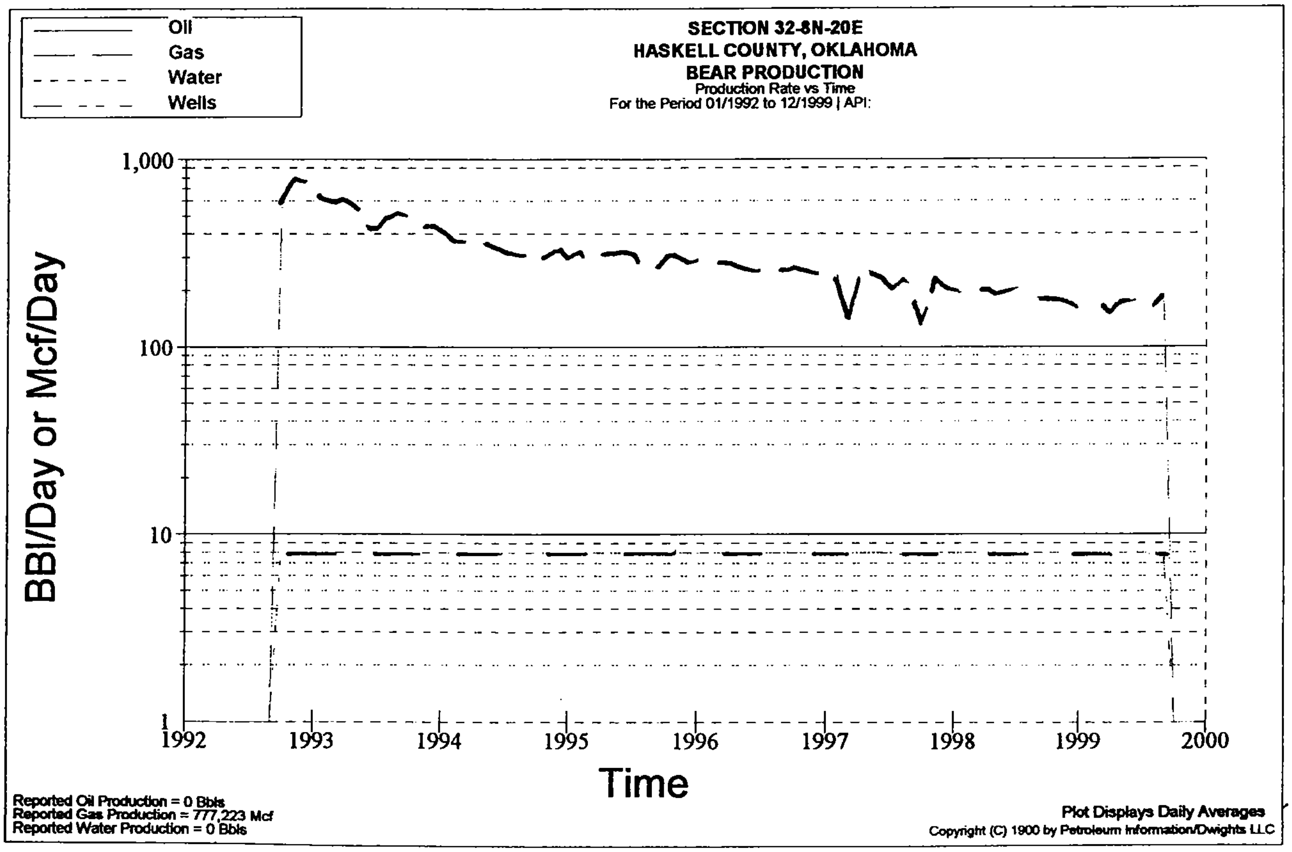


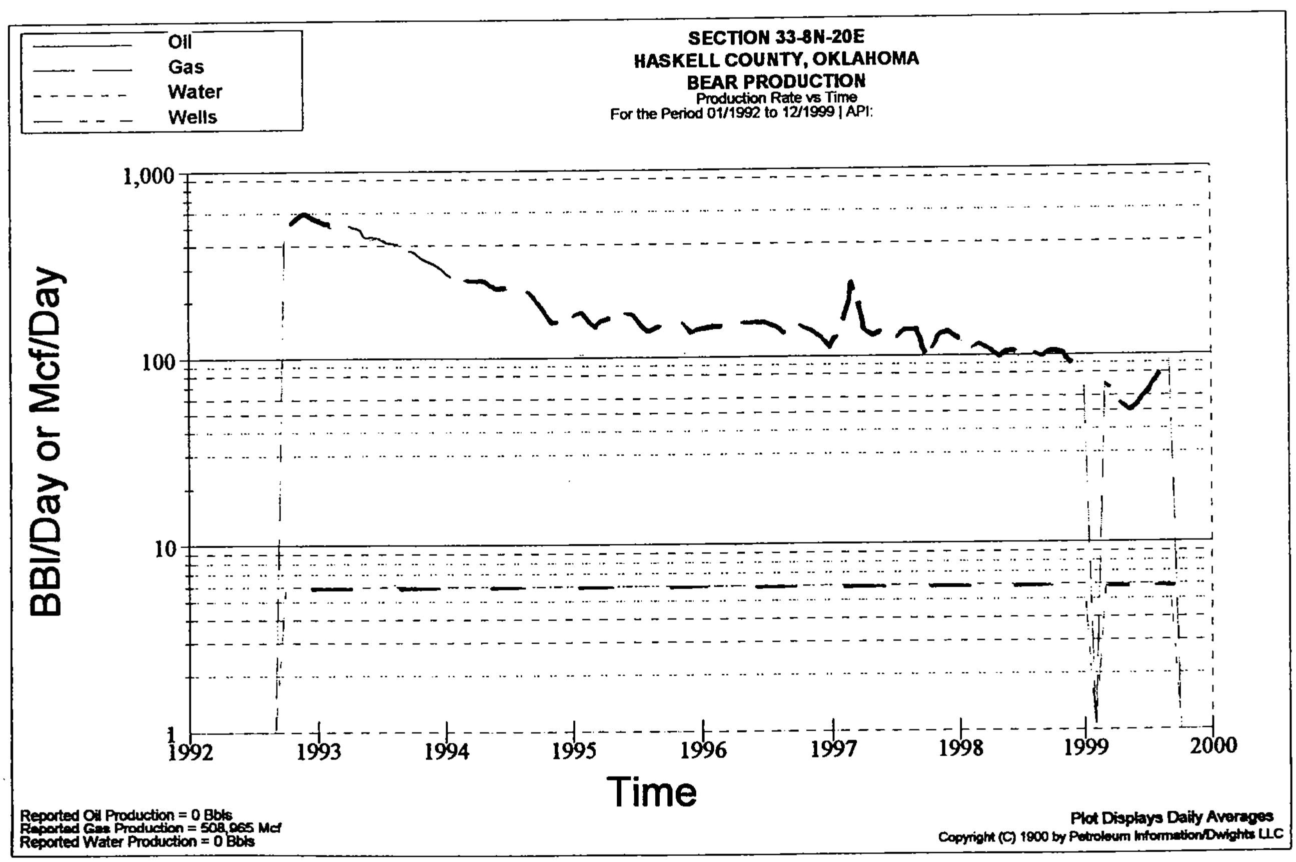
19E
20E
21E
9N
8N
7N
-1000
-500
-500
-1000
-1000
HARTSHORNE COAL
STRUCTURE MAP
C.I. = 500 FEET

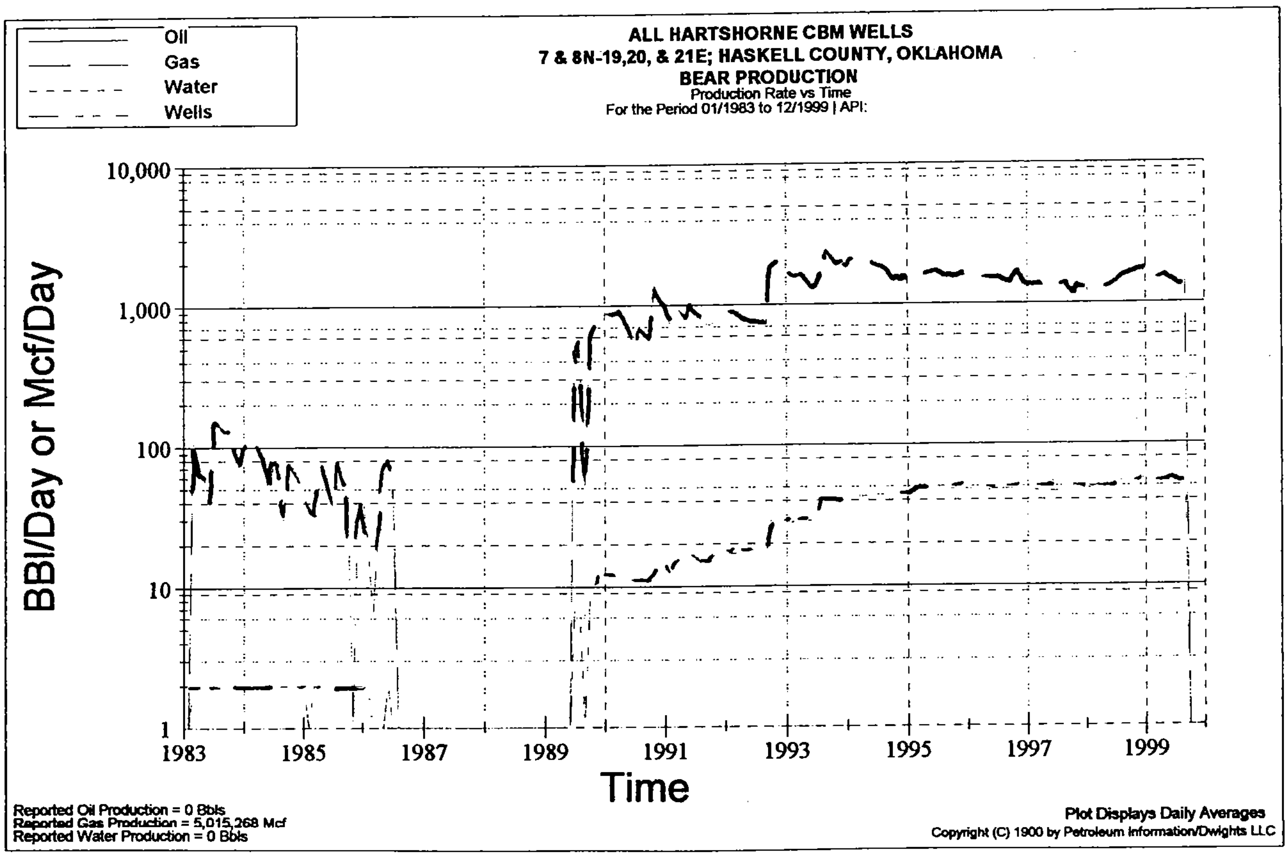

BEAR PRODUCTIONS, INC.
SAM # 6
SEC. 33 - 8N - 20E
000800
000900
DENSITY CALLIPER
14
BIT SIZE
14
5 INCH
MAIN
DENSITY POROSITY
30
20
10
0
-10
DENSITY


Oil
Gas
Water
Wells
SECTION 27-8N-20E
HASKELL COUNTY, OKLAHOMA
BEAR PRODUCTION
Production Rate vs Time
For the Period 01/1988 to 12/1999 | API:
BBl/Day or Mcf/Day
1,000
100
10
1
1988
1990
1992
1994
1996
1998
2000
Time
Reported Oil Production = 0 Bbls
Reported Gas Production = 1,511,928 Mcf
Reported Water Production = 0 Bbls
Plot Displays Daily Averages
Copyright (C) 1900 by Petroleum Information/Dwights LLC


Oil
Gas
Water
Wells
SECTION 28-8N-20E
HASKELL COUNTY, OKLAHOMA
BEAR PRODUCTION
Production Rate vs Time
For the Period 01/1994 to 12/1999 | API:
BBl/Day or Mcf/Day
1,000
100
10
1
1994
1995
1996
1997
1998
1999
2000
Time
Reported Oil Production = 0 Bbls
Reported Gas Production = 318,183 Mcf
Reported Water Production = 0 Bbls
Plot Displays Daily Averages
Copyright (C) 1900 by Petroleum Information/Dwights LLC


Oil
Gas
Water
Wells
SECTION 32-8N-20E
HASKELL COUNTY, OKLAHOMA
BEAR PRODUCTION
Production Rate vs Time
For the Period 01/1992 to 12/1999 | API:
1,000
100
10
1
BBl/Day or Mcf/Day
1992
1993
1994
1995
1996
1997
1998
1999
2000
Time
Reported Oil Production = 0 Bbls
Reported Gas Production = 777,223 Mcf
Reported Water Production = 0 Bbls
Plot Displays Daily Averages
Copyright (C) 1900 by Petroleum Information/Dwights LLC


Oil
Gas
Water
Wells
SECTION 33-8N-20E
HASKELL COUNTY, OKLAHOMA
BEAR PRODUCTION
Production Rate vs Time
For the Period 01/1992 to 12/1999 | API:
1,000
100
10
1
BBl/Day or Mcf/Day
1992
1993
1994
1995
1996
1997
1998
1999
2000
Time
Reported Oil Production = 0 Bbls
Reported Gas Production = 508,965 Mcf
Reported Water Production = 0 Bbls
Plot Displays Daily Averages
Copyright (C) 1900 by Petroleum Information/Dwights LLC


Oil
Gas
Water
Wells
ALL HARTSHORNE CBM WELLS
7 & 8N-19,20, & 21E; HASKELL COUNTY, OKLAHOMA
BEAR PRODUCTION
Production Rate vs Time
For the Period 01/1983 to 12/1999 | API:
BBl/Day or Mcf/Day
10,000
1,000
100
10
1
1983
1985
1987
1989
1991
1993
1995
1997
1999
Time
Reported Oil Production = 0 Bbls
Reported Gas Production = 5,015,268 Mcf
Reported Water Production = 0 Bbls
Plot Displays Daily Averages
Copyright (C) 1900 by Petroleum Information/Dwights LLC

PROJECT SUMMARY: BEAR PROD.

DATE OF FIRST PRODUCTION: 1989

LOCATION: 7 & 8 N - 19, 20, & 21 E

COUNTY: HASKELL

COAL THICKNESS: 3 - 4 FEET

DEPTH RANGE: 600 - 1,120 FEET

NUMBER OF WELLS: 65

COMPLETION METHOD: NITROGEN FRAC

PRODUCTION RANGE (IND. WELL): UP TO 150 MCFGPD

AVG. DAILY PROD. PER WELL: 26 MCF

AVG. DAILY PROD. /FIELD: 1,499 MCF

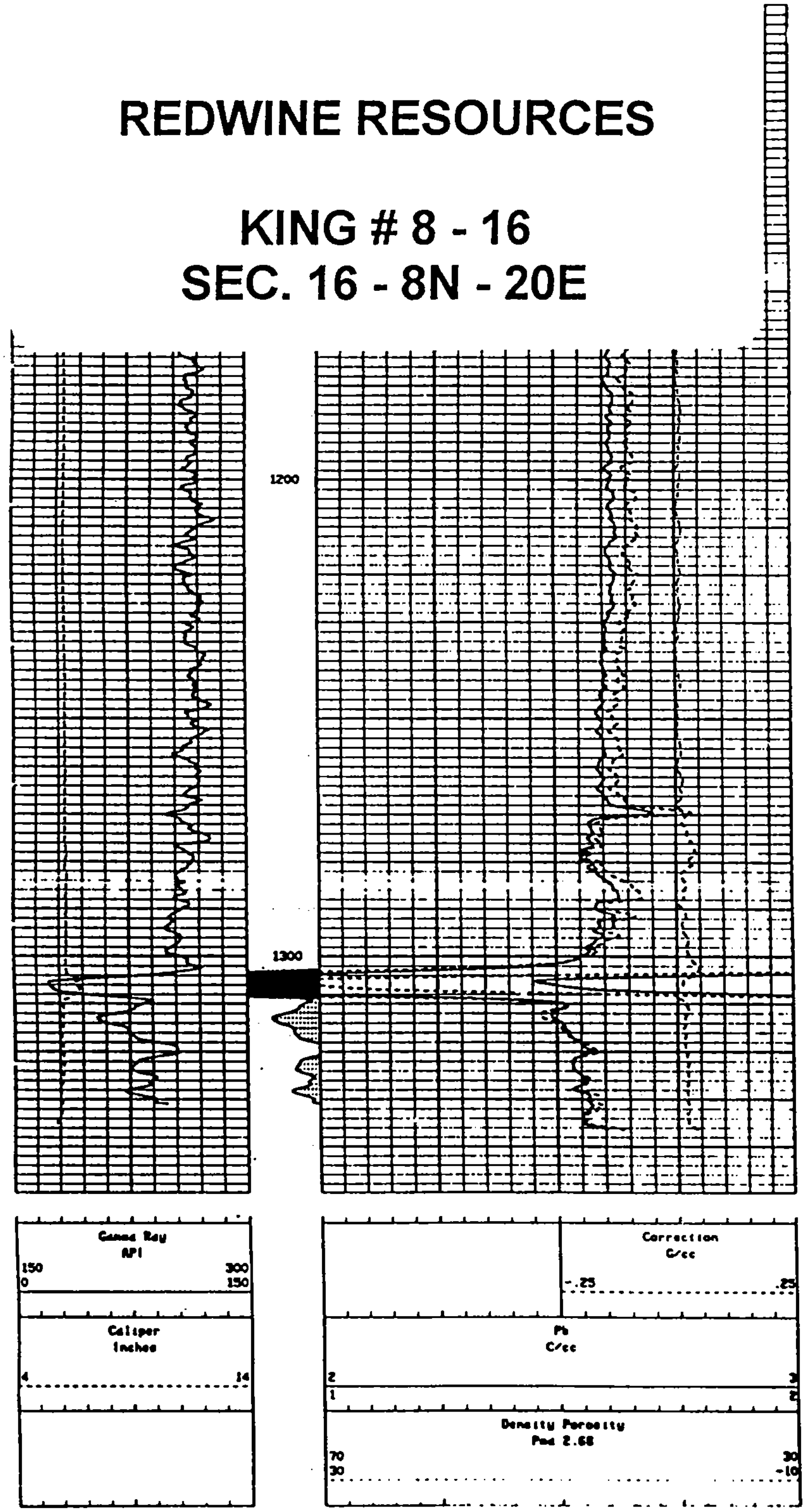
CUMULATIVE PRODUCTION: 5,100,656 MCF

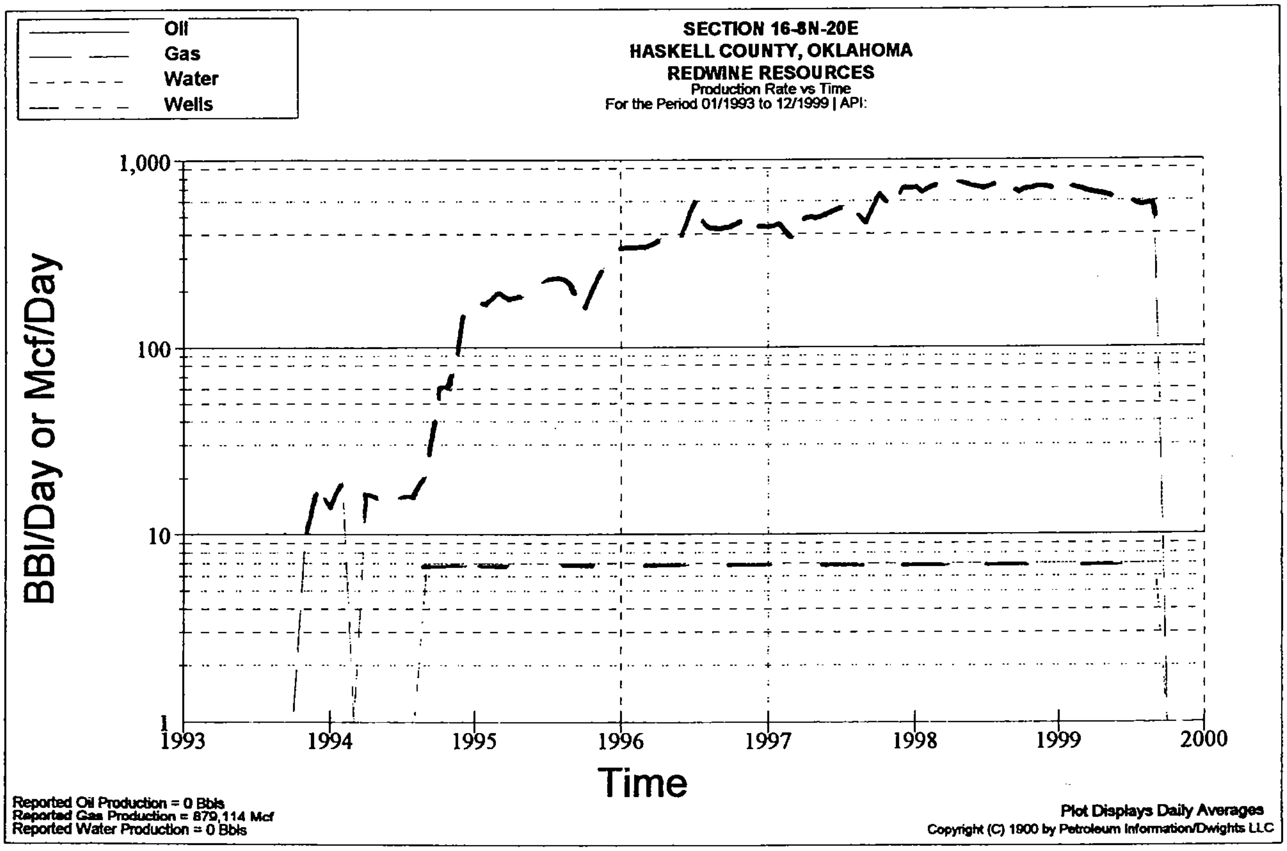
CUM. PROD. RANGE (IND. WELL): UP TO 160,000 MCF

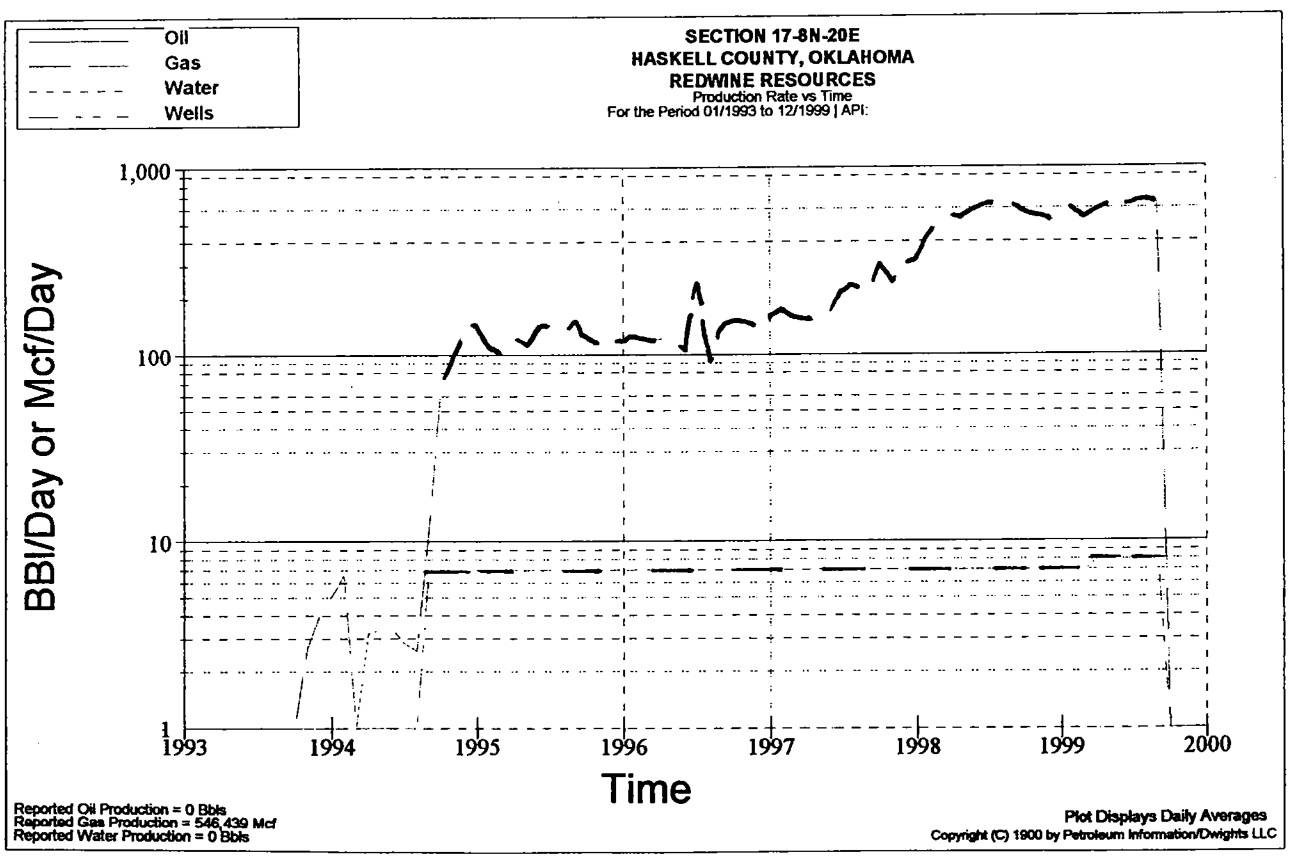
AVG. CUM. PROD. PER WELL: 78,471 MCF

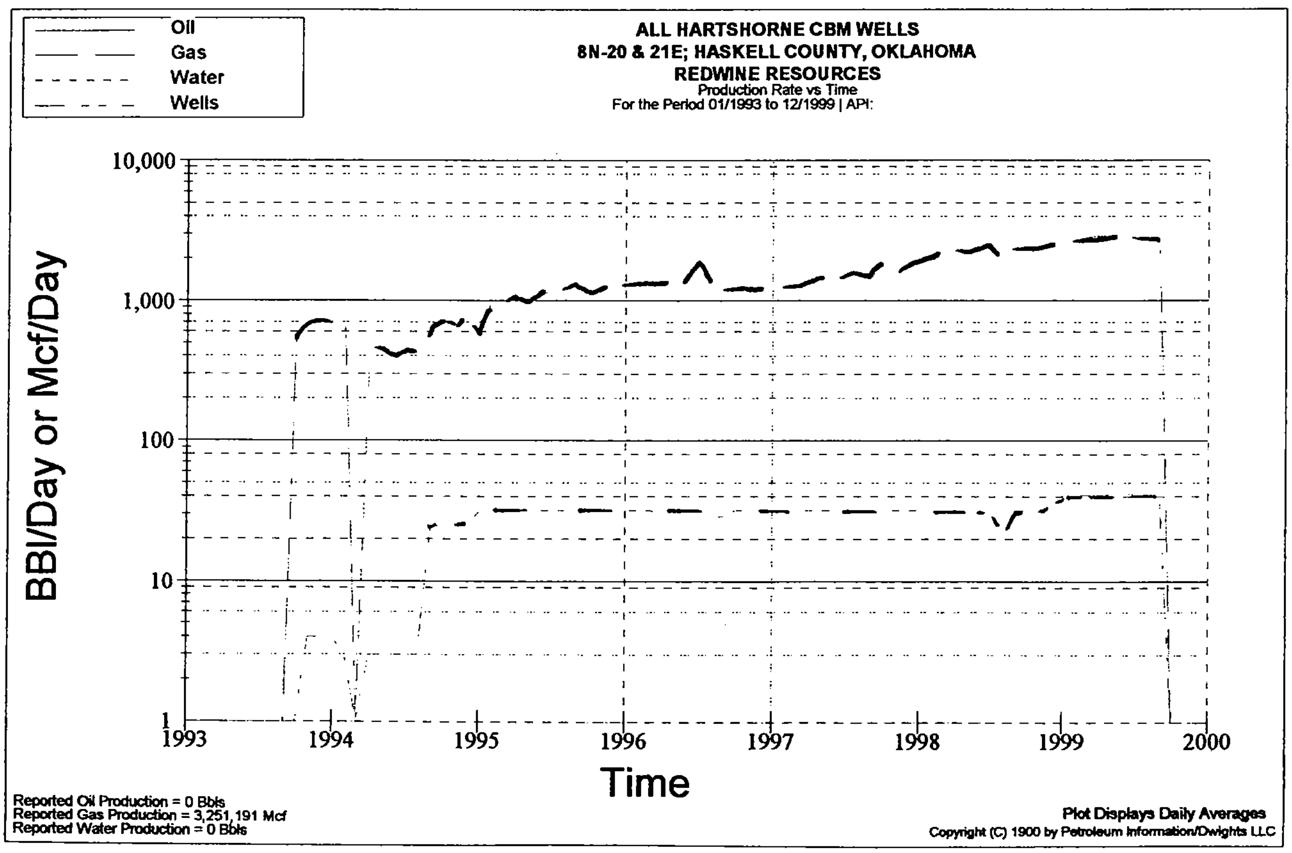
REDWINE RESOURCES

KING # 8 - 16
SEC. 16 - 8N - 20E




Oil
Gas
Water
Wells
SECTION 16-8N-20E
HASKELL COUNTY, OKLAHOMA
REDWINE RESOURCES
Production Rate vs Time
For the Period 01/1993 to 12/1999 | API:
BBl/Day or Mcf/Day
1,000
100
10
1
1993
1994
1995
1996
1997
1998
1999
2000
Time
Reported Oil Production = 0 Bbls
Reported Gas Production = 879,114 Mcf
Reported Water Production = 0 Bbls
Plot Displays Daily Averages
Copyright (C) 1900 by Petroleum Information/Dwights LLC


Oil
Gas
Water
Wells
SECTION 17-8N-20E
HASKELL COUNTY, OKLAHOMA
REDWINE RESOURCES
Production Rate vs Time
For the Period 01/1993 to 12/1999 | API:
BBl/Day or Mcf/Day
1,000
100
10
1
1993
1994
1995
1996
1997
1998
1999
2000
Time
Reported Oil Production = 0 Bbls
Reported Gas Production = 546,439 Mcf
Reported Water Production = 0 Bbls
Plot Displays Daily Averages
Copyright (C) 1900 by Petroleum Information/Dwights LLC



Oil
Gas
Water
Wells
ALL HARTSHORNE CBM WELLS
8N-20 & 21E; HASKELL COUNTY, OKLAHOMA
REDWINE RESOURCES
Production Rate vs Time
For the Period 01/1993 to 12/1999 | API:
10,000
1,000
100
10
1
1993
1994
1995
1996
1997
1998
1999
2000
BBl/Day or Mcf/Day
Time
Reported Oil Production = 0 Bbls
Reported Gas Production = 3,251,191 Mcf
Reported Water Production = 0 Bbls
Plot Displays Daily Averages
Copyright (C) 1900 by Petroleum Information/Dwights LLC

PROJECT SUMMARY: REDWINE

DATE OF FIRST PRODUCTION: 1993

LOCATION: 8N - 20 & 21 E

COUNTY: HASKELL

COAL THICKNESS: 3 - 5 FEET

DEPTH RANGE: 700 - 1650 FEET

NUMBER OF WELLS: 56

COMPLETION METHOD: SAND/WATER FRAC

PRODUCTION RANGE (IND. WELL): UP TO 200 MCFGPD

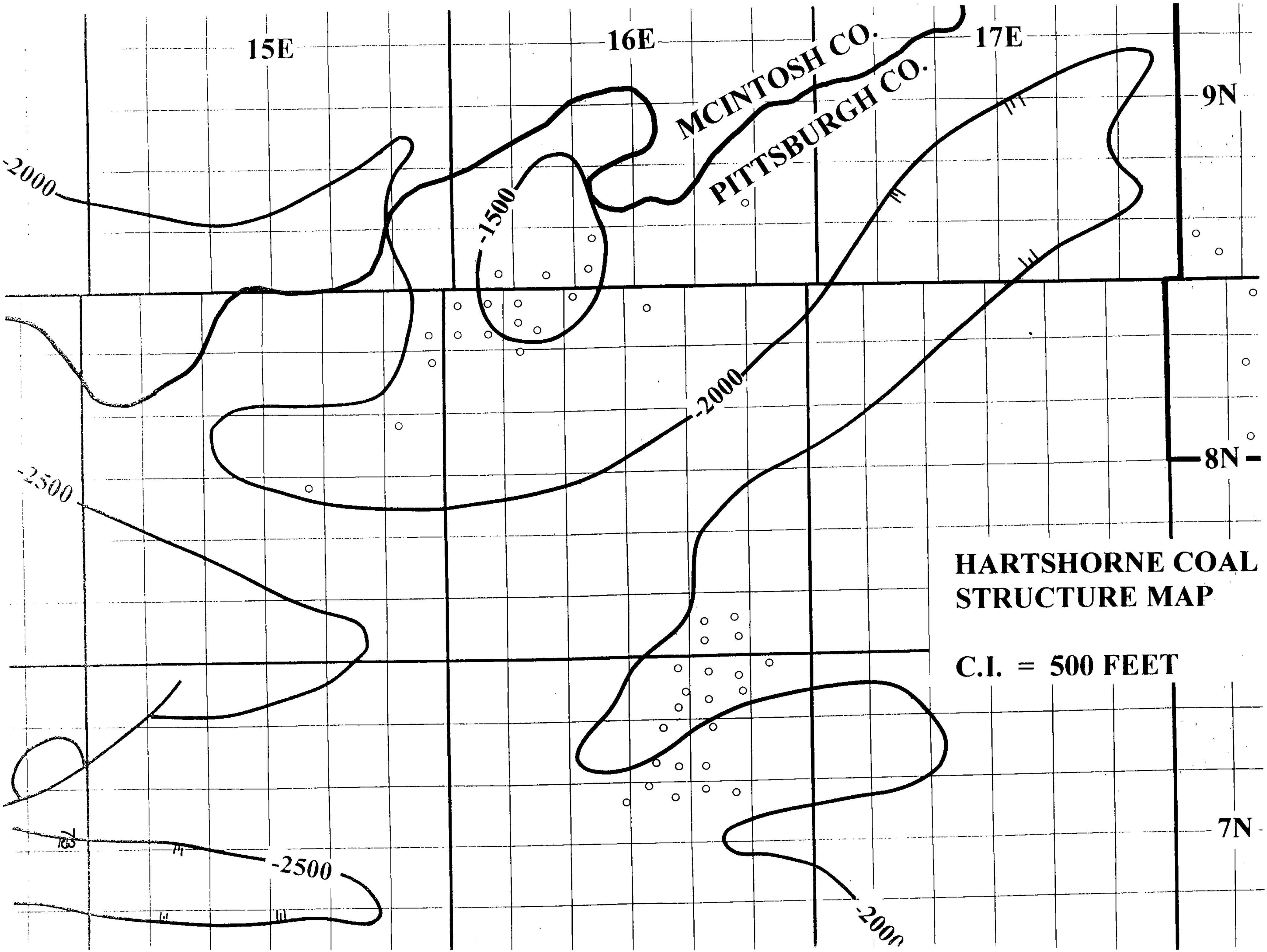
AVG. DAILY PROD. PER WELL: 50 MCF

AVG. DAILY PROD. /FIELD: 2,776 MCF

CUMULATIVE PRODUCTION: 3,251,191 MCF

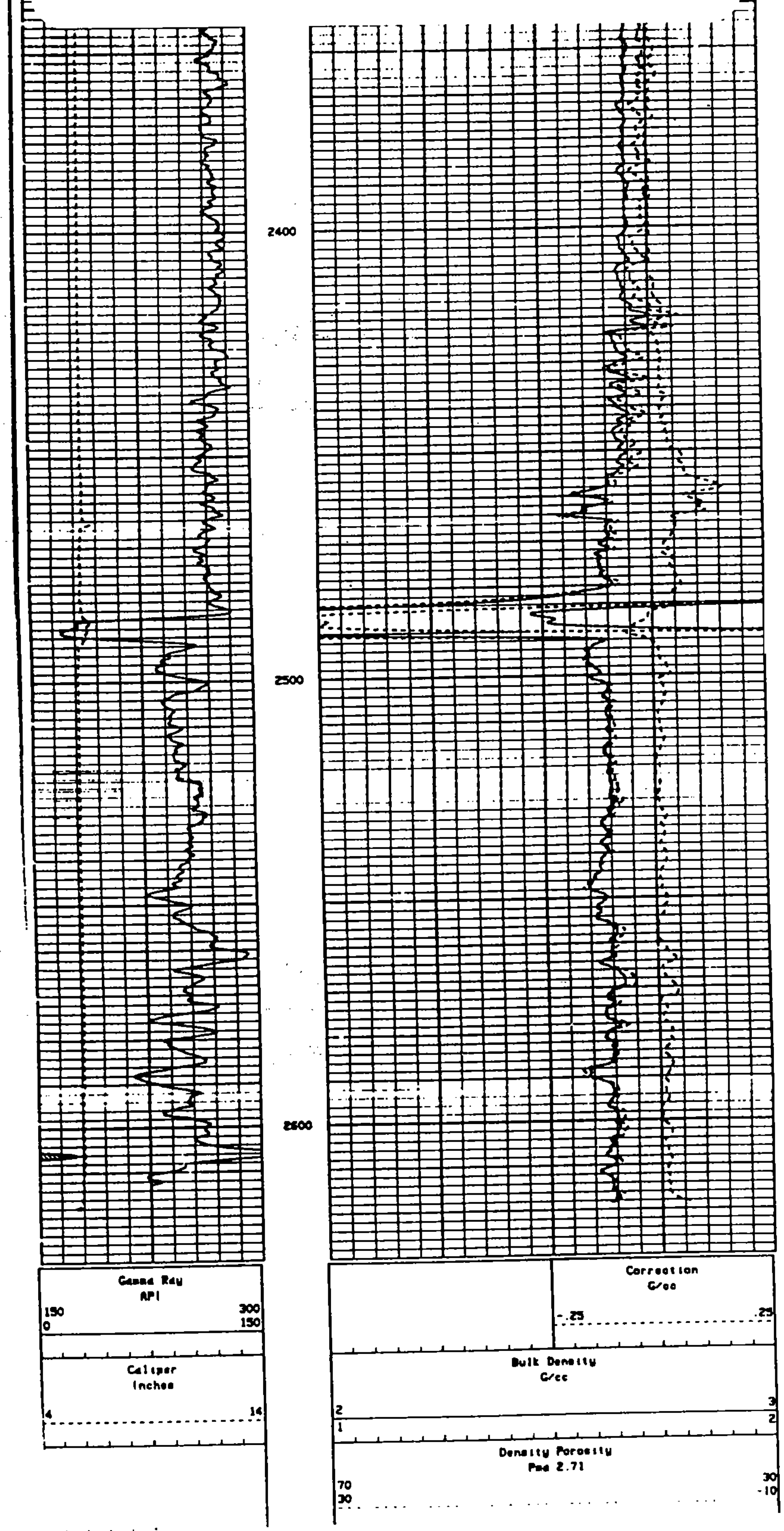
CUM. PROD. RANGE (IND. WELL): MTR'D BY LSE.

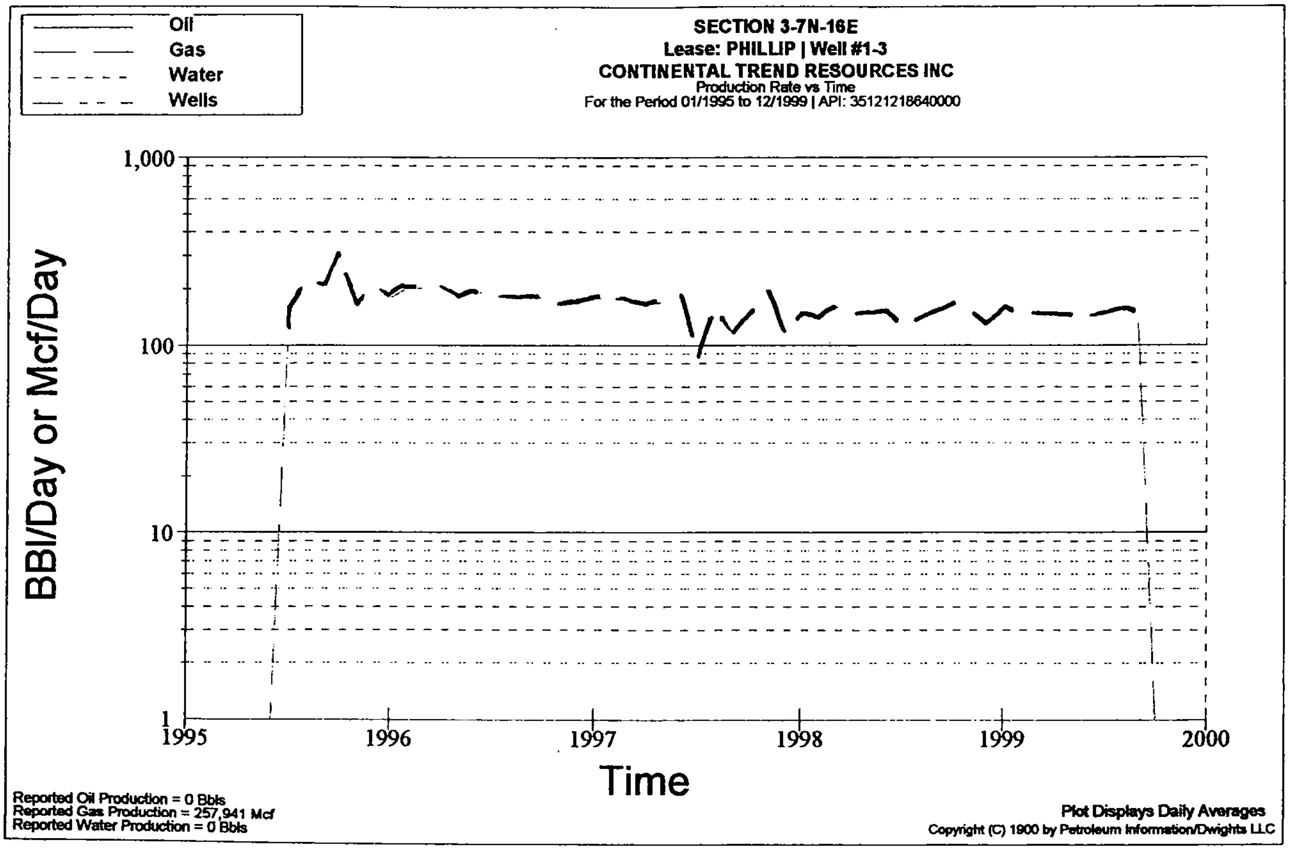
AVG. CUM. PROD. PER WELL: 58,057 MCF


HARTSHORNE COAL
STRUCTURE MAP
C.I. = 500 FEET
15E
16E
17E
9N
8N
7N
MCINTOSH CO.
PITTSBURGH CO.
-1500
-2000
-2000
-2000
-2500
-2500

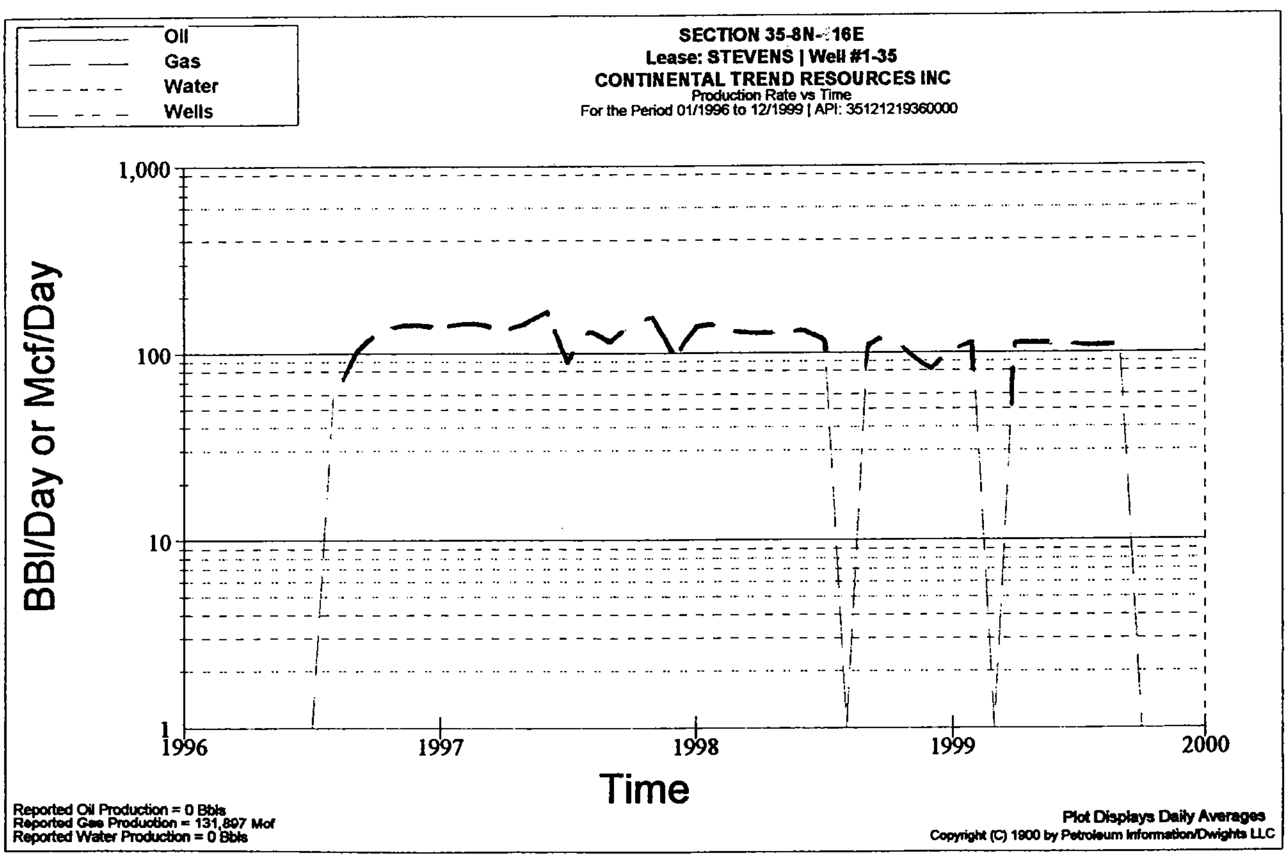
CONTINENTAL RESOURCES

PHILLIP # 1 - 3
SEC. 3 - 7N - 16E

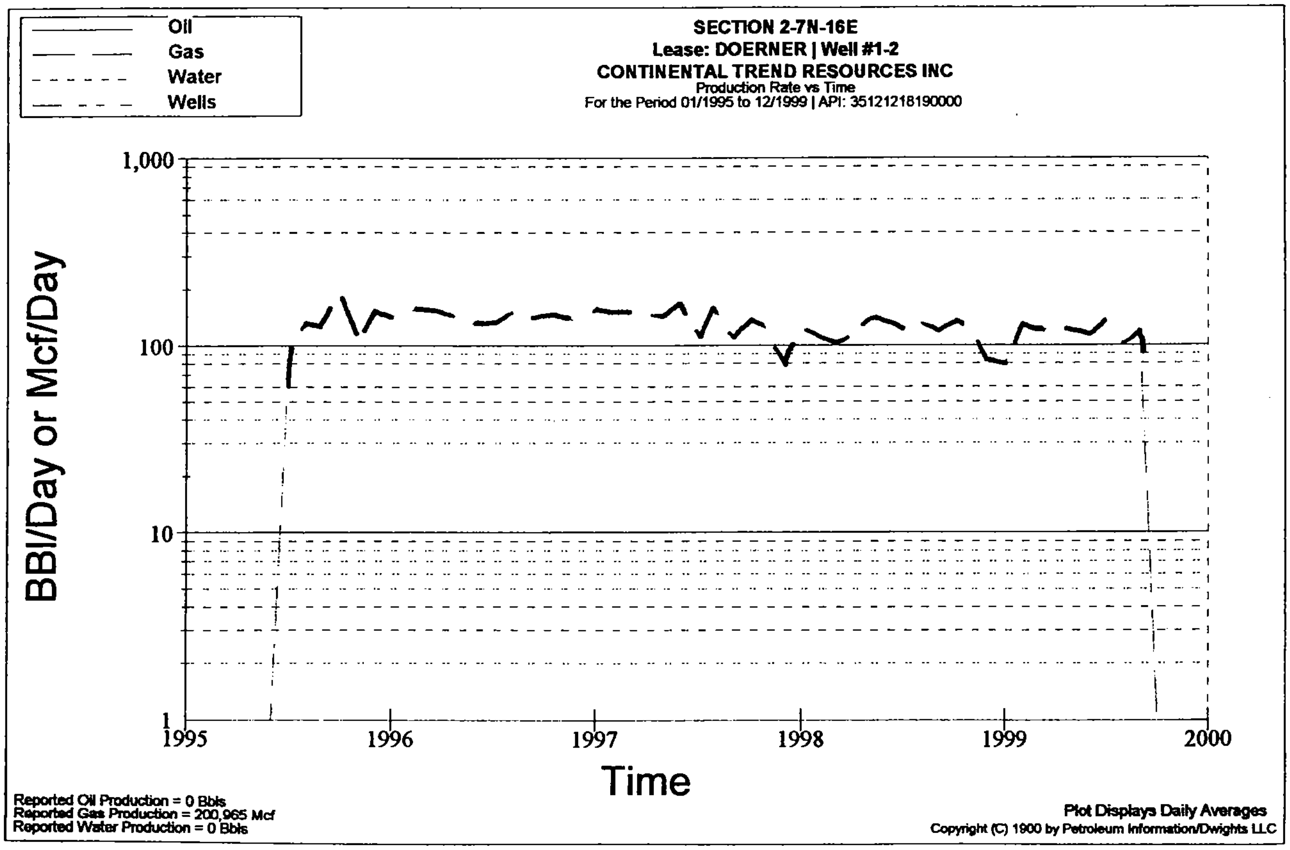




Oil
Gas
Water
Wells
SECTION 3-7N-16E
Lease: PHILLIP | Well #1-3
CONTINENTAL TREND RESOURCES INC
Production Rate vs Time
For the Period 01/1995 to 12/1999 | API: 35121218640000
BBl/Day or Mcf/Day
1,000
100
10
1
1995
1996
1997
1998
1999
2000
Time
Reported Oil Production = 0 Bbls
Reported Gas Production = 257,941 Mcf
Reported Water Production = 0 Bbls
Plot Displays Daily Averages
Copyright (C) 1900 by Petroleum Information/Dwights LLC



Oil
Gas
Water
Wells
SECTION 35-8N-16E
Lease: STEVENS | Well #1-35
CONTINENTAL TREND RESOURCES INC
Production Rate vs Time
For the Period 01/1996 to 12/1999 | API: 35121219360000
BBl/Day or Mcf/Day
1,000
100
10
1
1996
1997
1998
1999
2000
Time
Reported Oil Production = 0 Bbls
Reported Gas Production = 131,897 Mcf
Reported Water Production = 0 Bbls
Plot Displays Daily Averages
Copyright (C) 1900 by Petroleum Information/Dwights LLC


Oil
Gas
Water
Wells
SECTION 2-7N-16E
Lease: DOERNER | Well #1-2
CONTINENTAL TREND RESOURCES INC
Production Rate vs Time
For the Period 01/1995 to 12/1999 | API: 35121218190000
1,000
100
10
1
1995
1996
1997
1998
1999
2000
BBl/Day or Mcf/Day
Time
Reported Oil Production = 0 Bbls
Reported Gas Production = 200,965 Mcf
Reported Water Production = 0 Bbls
Plot Displays Daily Averages
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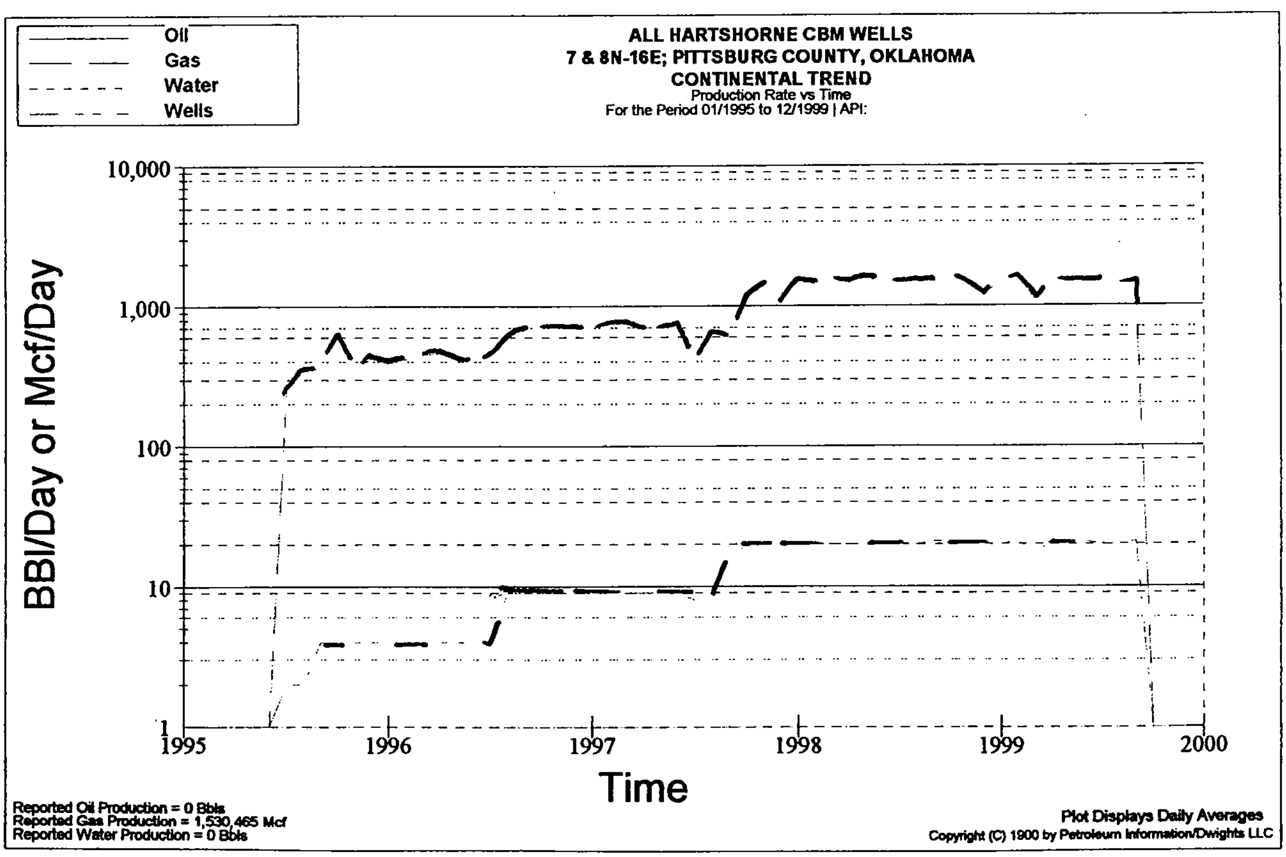

Oil
Gas
Water
Wells
ALL HARTSHORNE CBM WELLS
7 & 8N-16E; PITTSBURG COUNTY, OKLAHOMA
CONTINENTAL TREND
Production Rate vs Time
For the Period 01/1995 to 12/1999 | API:
10,000
1,000
100
10
1
1995
1996
1997
1998
1999
2000
BBl/Day or Mcf/Day
Time
Reported Oil Production = 0 Bbls
Reported Gas Production = 1,530,465 Mcf
Reported Water Production = 0 Bbls
Plot Displays Daily Averages
Copyright (C) 1900 by Petroleum Information/Dwights LLC

PROJECT SUMMARY: CONTINENTAL TREND RESOURCES

DATE OF FIRST PRODUCTION: 1995

LOCATION: 7 & 8 N - 16 E

COUNTY: PITTSBURGH

COAL THICKNESS: 5 - 8 FEET

DEPTH RANGE: 1,892 - 3,081 FEET

NUMBER OF WELLS: 21

COMPLETION METHOD: SAND/WATER FRAC

PRODUCTION RANGE (IND. WELL): UP TO 149 MCFGPD

AVG. DAILY PROD. PER WELL: 70 MCF

AVG. DAILY PROD. /FIELD: 1,477 MCF

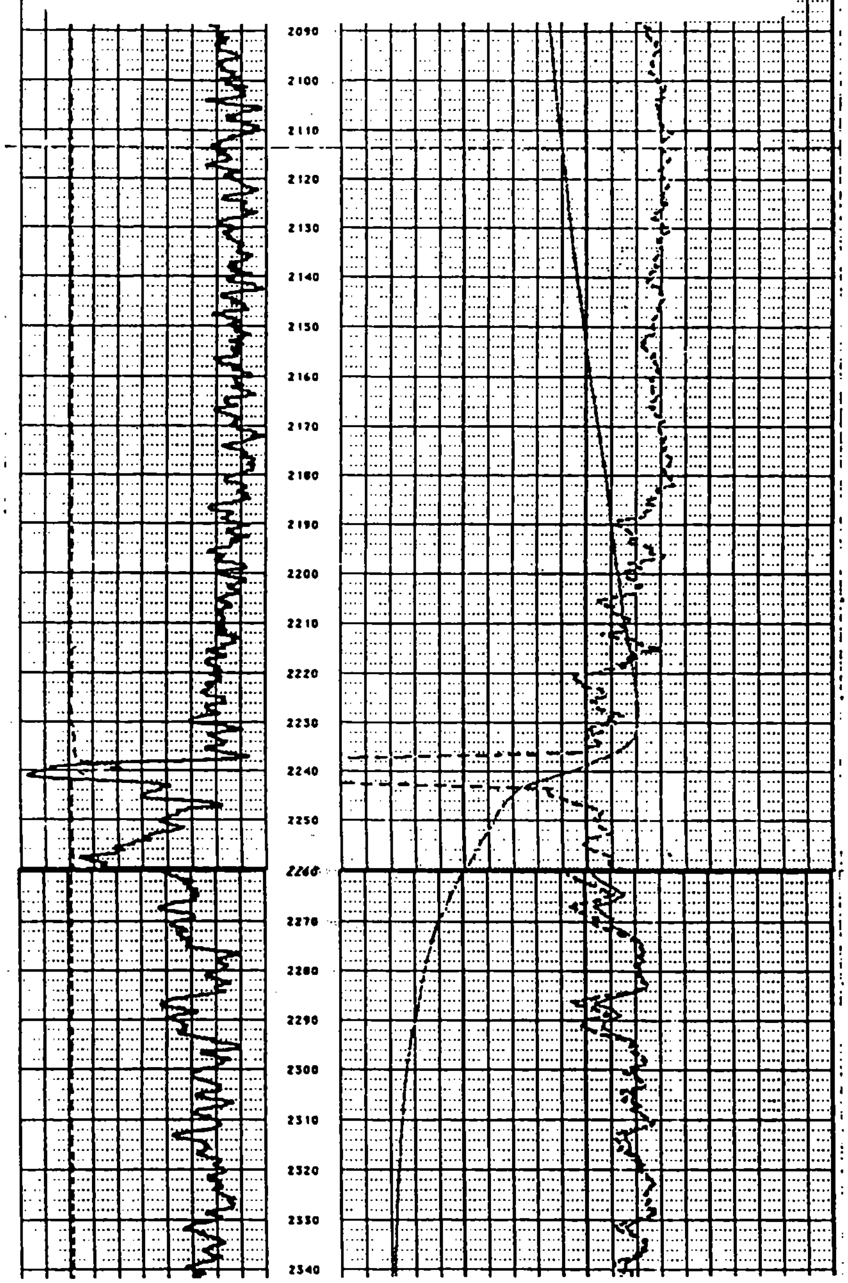
CUMULATIVE PRODUCTION: 1,530,465 MCF

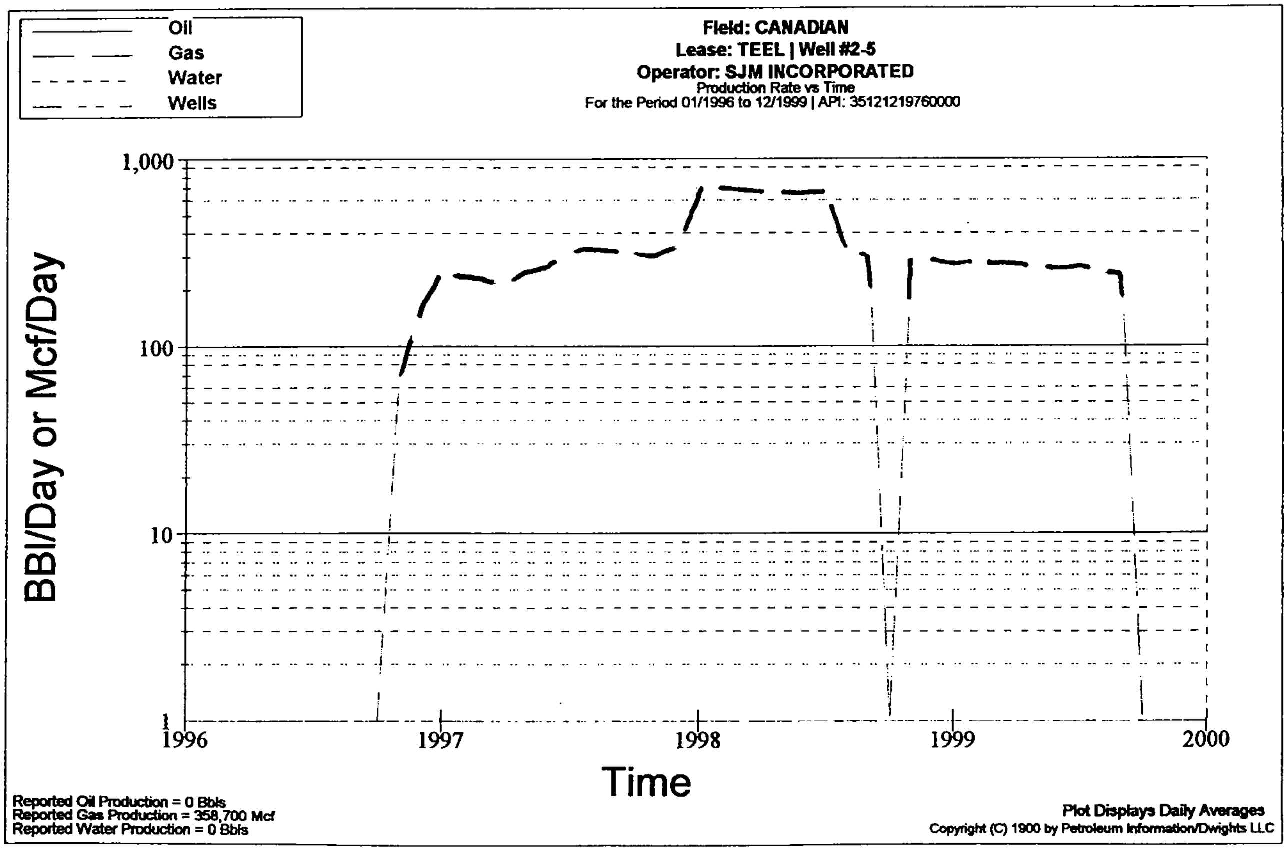
CUM. PROD. RANGE (IND. WELL): UP TO 257,000 MCF

AVG. CUM. PROD. PER WELL: 72,879 MCF

SJM, INC.

RITCHIE # 1 - 6
SEC. 6 - 8N- 16E





Oil
Gas
Water
Wells
Field: CANADIAN
Lease: TEEL | Well #2-5
Operator: SJM INCORPORATED
Production Rate vs Time
For the Period 01/1996 to 12/1999 | API: 35121219760000
BBl/Day or Mcf/Day
1,000
100
10
1
1996
1997
1998
1999
2000
Time
Reported Oil Production = 0 Bbls
Reported Gas Production = 358,700 Mcf
Reported Water Production = 0 Bbls
Plot Displays Daily Averages
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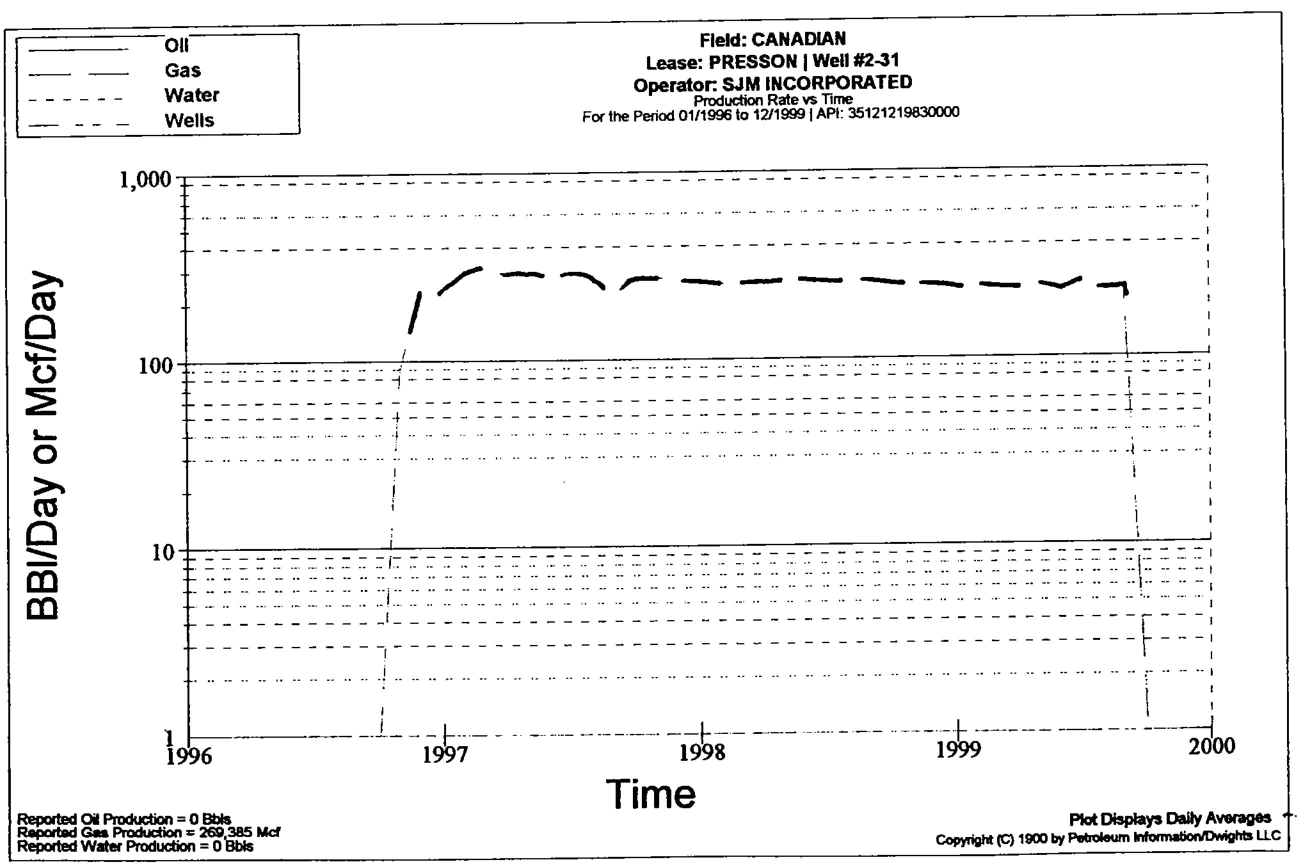

Oil
Gas
Water
Wells
Field: CANADIAN
Lease: PRESSON | Well #2-31
Operator: SJM INCORPORATED
Production Rate vs Time
For the Period 01/1996 to 12/1999 | API: 35121219830000
BBl/Day or Mcf/Day
1,000
100
10
1
1996
1997
1998
1999
2000
Time
Reported Oil Production = 0 Bbls
Reported Gas Production = 269,385 Mcf
Reported Water Production = 0 Bbls
Plot Displays Daily Averages
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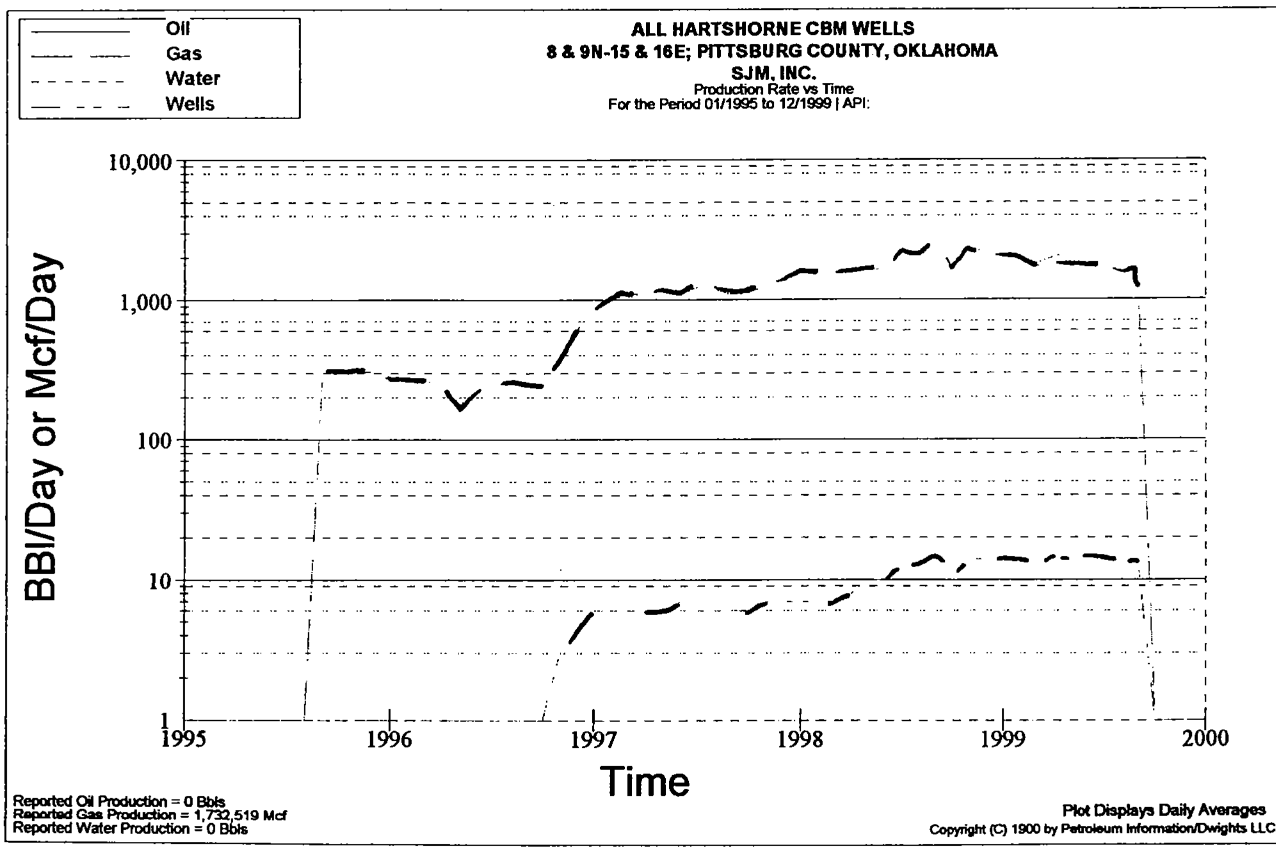

Oil
Gas
Water
Wells
ALL HARTSHORNE CBM WELLS
8 & 9N-15 & 16E; PITTSBURG COUNTY, OKLAHOMA
SJM, INC.
Production Rate vs Time
For the Period 01/1995 to 12/1999 | API:
10,000
1,000
100
10
1
BBl/Day or Mcf/Day
1995
1996
1997
1998
1999
2000
Time
Reported Oil Production = 0 Bbls
Reported Gas Production = 1,732,519 Mcf
Reported Water Production = 0 Bbls
Plot Displays Daily Averages
Copyright (C) 1900 by Petroleum Information/Dwights LLC

PROJECT SUMMARY: SJM, INC.

DATE OF FIRST PRODUCTION: 1995

LOCATION: 8 & 9 N - 15 & 16 E

COUNTY: Pittsburgh

COAL THICKNESS: 4 - 6 Feet

DEPTH RANGE: 1940' - 2420'

NUMBER OF WELLS: 17

COMPLETION METHOD: Sd/Wtr. Frac; Nitrogen Frac

PRODUCTION RANGE (IND. WELL): up to 270 MCFGPD

AVG. DAILY PROD. PER WELL: 105 MCF

AVG. DAILY PROD. /FIELD: 1,790 MCF

CUMULATIVE PRODUCTION: 1,732,519 MCF

CUM. PROD. RANGE (IND. WELL): up to 359,000 MCF

AVG. CUM. PROD. PER WELL: 101,913 MCF