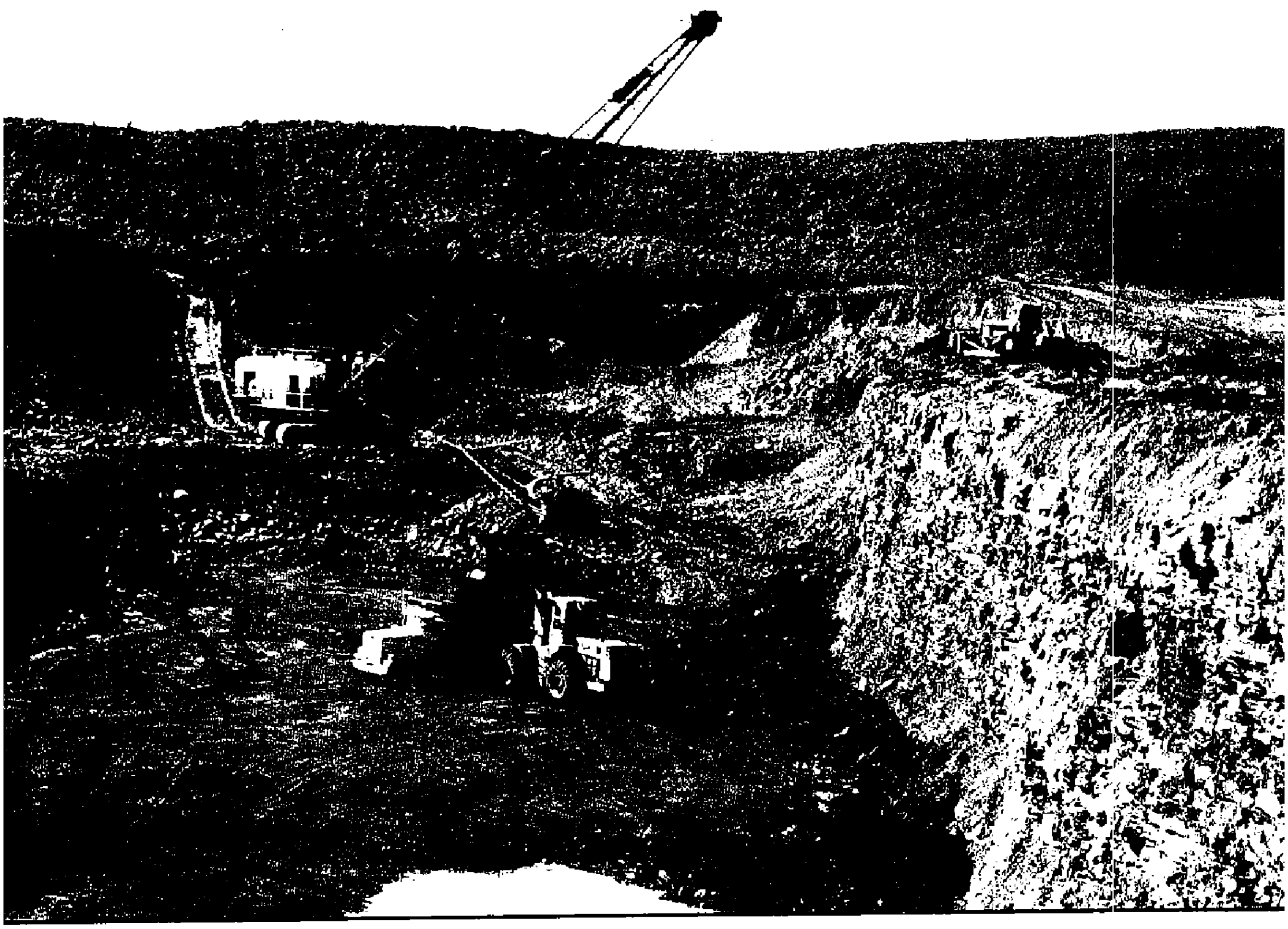
OKLAHOMA GEOLOGY



February, 1994

Vol. 54, No. 1

On The Cover —

New Coal Mine in Le Flore County, Oklahoma

The Wister Mine is a new strip mine located ~7 mi northwest of the town of Wister on the south flank of Cavanal Mountain in west-central Le Flore County. The mine, which opened in the spring of 1993, is operated by the Farrell-Cooper Mining Co.

In late October 1993, when the cover photo was taken, 1,000 tons of coal was being produced daily from the Secor and Secor Rider coal beds. The mine extends for ~1 mi, from the NE¼ sec. 13, T. 6 N., R. 23 E., to the NW¼ sec. 18, T. 6 N., R. 24 E. The highwall, shown in the cover photo in the right foreground of the pit, is ~40 ft high. Overburden is being removed by a dragline (center of photo), and the Secor coal is being loaded onto a truck by a front-end loader from a small stockpile on the floor of the pit. The coal is trucked directly from the mine to the AES Shady Point co-generation plant, where it is used to generate electricity and CO_2. Each round trip requires ~2 hours.

Prior to removal of the overburden, multiple shotholes are drilled (inset photo). Explosive charges are placed in the shotholes and detonated in a timed sequence which

(continued on p. 46)

Shothole rig drilling blast holes in consolidated overburden.

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KLAHOMA GEOLOGY

Notes

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Correlation of the Lower Witteville Coal Bed in the Arkoma Basin, Eastern Oklahoma

LeRoy A. Hemish[1]

Abstract

An unnamed coal bed that occurs in a shale interval within the Bluejacket Sandstone Member of the Boggy Formation (Desmoinesian) in Pittsburg and McIntosh Counties, Oklahoma, is correlated with the Lower Witteville coal bed, which occurs in a similar stratigraphic position in the Cavanal Mountain area, Le Flore County, Oklahoma. Cross sections show that stratigraphic units are about 10 times thinner northward and westward in McIntosh County than they are on Cavanal Mountain, but sequences of lithologic units maintain their validity.

Changes over time in the defined formational boundaries of the Savanna Formation, particularly the Savanna/Boggy Formation contact, have made it somewhat difficult to determine the appropriate stratigraphic position for the Lower Witteville coal. However, new physical evidence gathered by the author during the past 10 years clarifies the stratigraphic relations of the various coal-bearing units and makes it feasible to correlate the Lower Witteville coal throughout the Arkoma basin.

Introduction

The purpose of this paper is to demonstrate the equivalence of an unnamed coal bed, present in McIntosh and Pittsburg Counties, to the Lower Witteville coal bed, named in Le Flore County. The correlation is based on physical evidence showing that the two units occupy a similar stratigraphic position even though separated by a distance of ~50 mi. Figure 1 shows the location of the study area in Oklahoma.

Occurrence of the Lower Witteville coal has not been noted in Haskell and Latimer Counties, the area between Le Flore County and McIntosh and Pittsburg Counties. The coal may be absent, owing to either nondeposition or, more likely, extensive erosion that has removed most of the strata in which the Lower Witteville occurs. Areas where outcrops of the coal bed might be found are limited to the flanks of synclines, generally remote mountainous regions covered by colluvium and vegetation.

The coal bed is of minable thickness (≥0.8 ft) in Le Flore County, on the flanks of the eastern part of Cavanal Mountain, as well as locally in both McIntosh and Pittsburg Counties. Figure 2 shows the counties and data points marking the location and thickness of the Lower Witteville coal. The map also shows the regional extent of exposed strata in which the coal bed is assumed to be present.

Geologic Setting

The study area is entirely within the Oklahoma part of the Arkoma basin (Fig. 1), an elongate tectonic province that extends ~250 mi across parts of eastern Okla-

[1]Oklahoma Geological Survey.

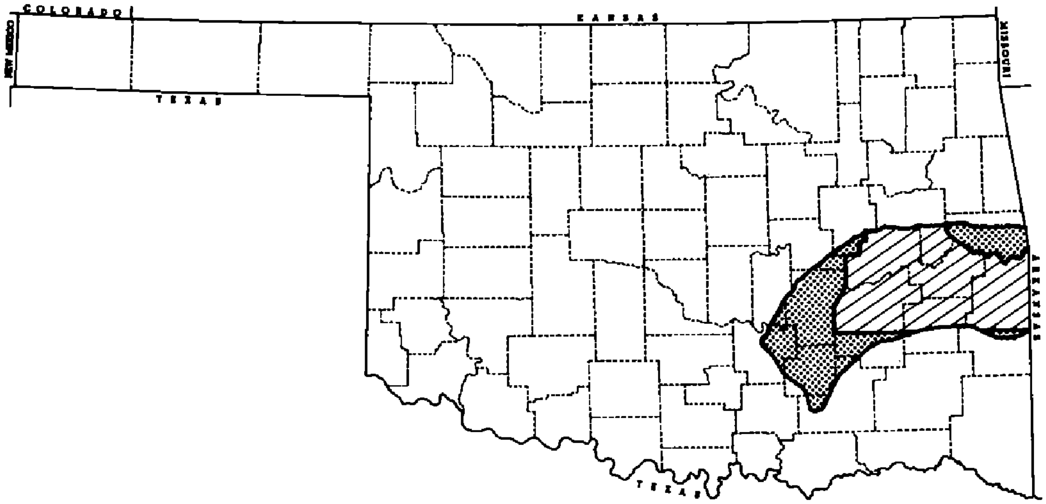


Figure 1. Index map of Oklahoma showing location of study area (ruled) within the Arkoma basin (shaded).

homa and western and central Arkansas. Development of the Arkoma basin began in the Mississippian (Johnson, 1988). Significant structural deformation began in Atokan time and continued into the Permian (Wylie, 1988). Subsidence occurred intermittently through Desmoinesian time in association with the Ouachita orogeny. Cyclic sedimentation in the basin resulted from a series of marine transgressions followed by periods of emergence. Regressive and transgressive phases were characterized by fluvial-deltaic sedimentation and development of widespread coal swamps. Shales make up most of the strata in the basin, although several deltaic complexes, such as those in the Savanna and Boggy Formations, constitute major sandstone units (Johnson, 1988).

The youngest bedrock formation, preserved in all but the extreme western part of the study area, is the Boggy Formation of the early Desmoinesian Krebs Group. Individual formations within the Desmoinesian thicken markedly from north to south in the Arkoma basin (Hemish, 1988a; Johnson, 1988). All of the preserved strata in the study area have been folded. An undetermined amount of erosion has occurred since late Desmoinesian time.

Most of the study area is hilly and is characterized by moderately dipping strata that form anticlines and synclines. Erosion-resistant sandstones form cuestas and hogbacks around the axial portion of the folds. Broad valleys, eroded mostly in shale, separate the ridges. Prominent synclinal features in the region include the Sans Bois Mountains in the west and Cavanal Mountain in the east (Fig. 2). The elevation at the summit of Cavanal Mountain is 2,367 ft (U.S. Geological Survey, 1982). Rocks of the Savanna Formation crop out on the flanks of the mountains, and rocks of the Boggy Formation generally cap the highest ridges. Stratigraphically higher rocks have been eroded away in the area of investigation.

Stratigraphy

General Statement

Figure 3 is a generalized stratigraphic column showing the sequence of strata in the Savanna and Boggy Formations on Cavanal Mountain, the type area for the

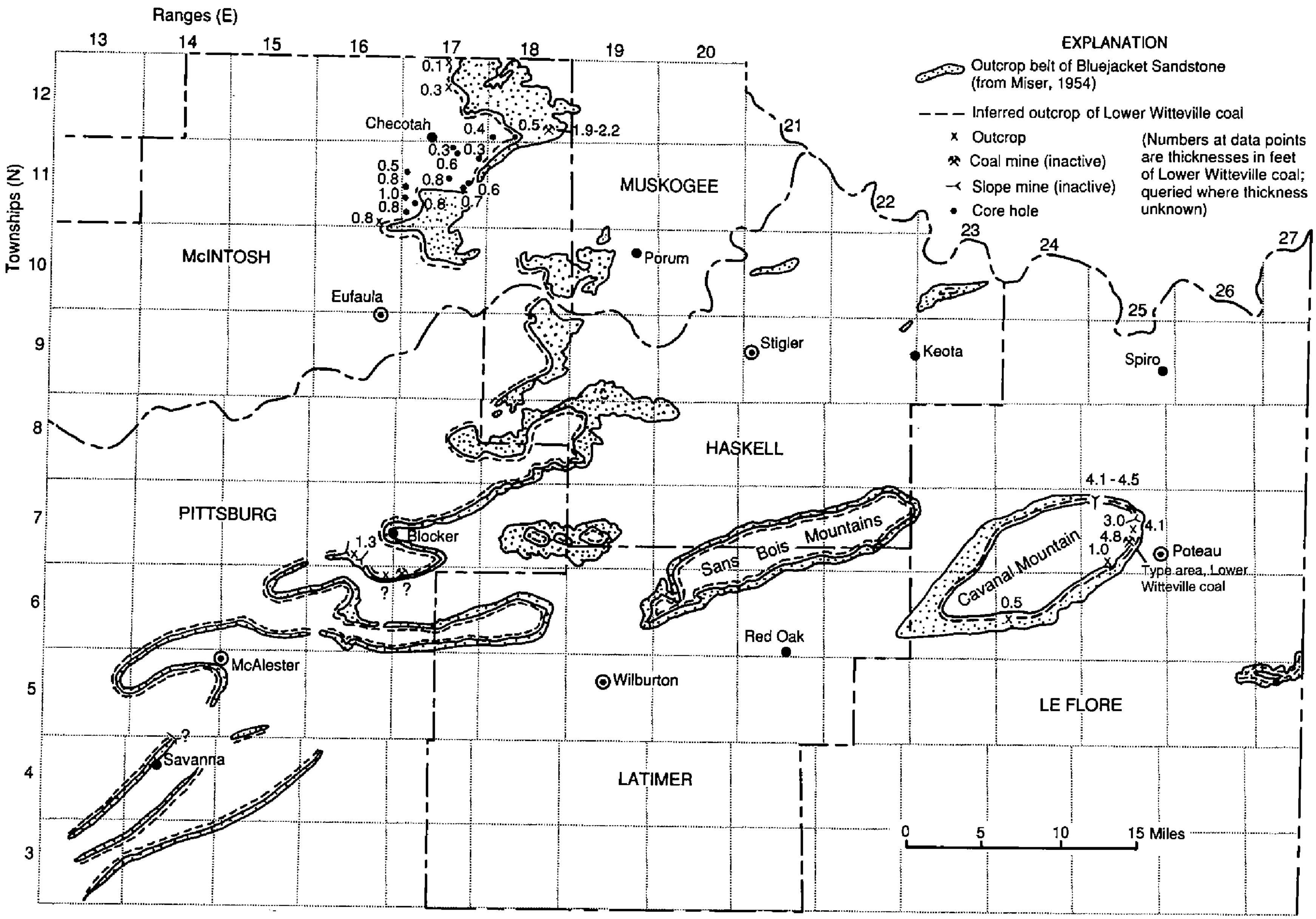


Figure 2. Map of the study area showing the inferred outcrop of the Lower Witteville coal in the Arkoma basin area.

Lower Witteville coal. Figure 4 is a similar column showing the sequence of strata in the western part of the study area, in McIntosh and Pittsburg Counties, where the rock units are generally thinner than in the Cavanal Mountain area. It is proposed in this paper that the name Lower Witteville be applied to an unnamed coal bed that occurs in a stratigraphic position in the western part of the study area similar to the stratigraphic position of the named Lower Witteville of the eastern part of the study area.

History of Usage

The Lower Witteville coal was first described by Taff and Adams (1900, p. 294), when they wrote:

> There are two beds of coal separated by about 250 feet of shale and sandstone, which will be known as the Witteville coal beds, from the mines upon them at Witteville, in the east end of Cavanal Mountain.
>
> The upper Witteville coal is 3 feet 10 inches thick, separated into two nearly equal benches by a thin parting of shale. . . .
>
> The lower Witteville coal is 4 feet 8 inches thick, and is separated into three benches by two variable bands of bone and carbonaceous shale.

Figure 5 shows an outcrop of the Lower Witteville coal in its type area on Cavanal Mountain near Witteville, just west of Poteau (Fig. 2). Figure 6 shows the adit of an abandoned slope mine in the same area where the Lower Witteville coal was mined in the late 1800s and early 1900s. The name "Upper Witteville" was dropped by Knechtel (1949, p. 51) in favor of the name "Secor," which was published earlier by Chance (1890, p. 658, 660, pl. 1). Dane and Hendricks (1936) had previously suggested that the Secor was equivalent to the Blocker and Upper Witteville coal beds. C. C. Branson (Oklahoma Geological Survey, 1954, p. 131) stated that the Upper Witteville coal and the Secor coal are stratigraphically equal. Although only one of the two original Witteville names survived, the term "lower" was never dropped, so the name "Lower Witteville" persists in published literature.

Another named coal bed, the Secor Rider, occurs 1–50 ft above the Secor coal in Le Flore, McIntosh, Muskogee, and Pittsburg Counties (Hemish, 1988c; 1994, p. 46 [this issue]). The coal bed was first recognized by Dane and others (1938, p. 162, 197, 200–201; pls. 14–16), but the bed was not named. Friedman (1974, p. 28) was the first author of a printed document to refer to the coal bed as a "rider" of the Secor. The name "Secor Rider" first was used in a published document by Friedman (1978, p. 23). The name was also used by Hemish (1988c), who reported that the Secor Rider coal occurs as much as 50 ft above the Secor coal in places in Pittsburg County, and that the two coals coalesce ~5 mi northeast of Checotah in McIntosh County.

Stratigraphic Discussion

Confusion regarding the stratigraphic position of the Lower Witteville coal has arisen because the defined boundaries of the Savanna Formation have been changed several times.

Taff (1899) originally defined the Savanna sandstone (Savanna Formation) in the vicinity of Savanna, Pittsburg County. He described the Savanna as "a series of sandstones and shales about 1,150 feet thick. . . . There are five principal sandstone beds, which have different thicknesses, from nearly 50 to 200 feet, the one at the

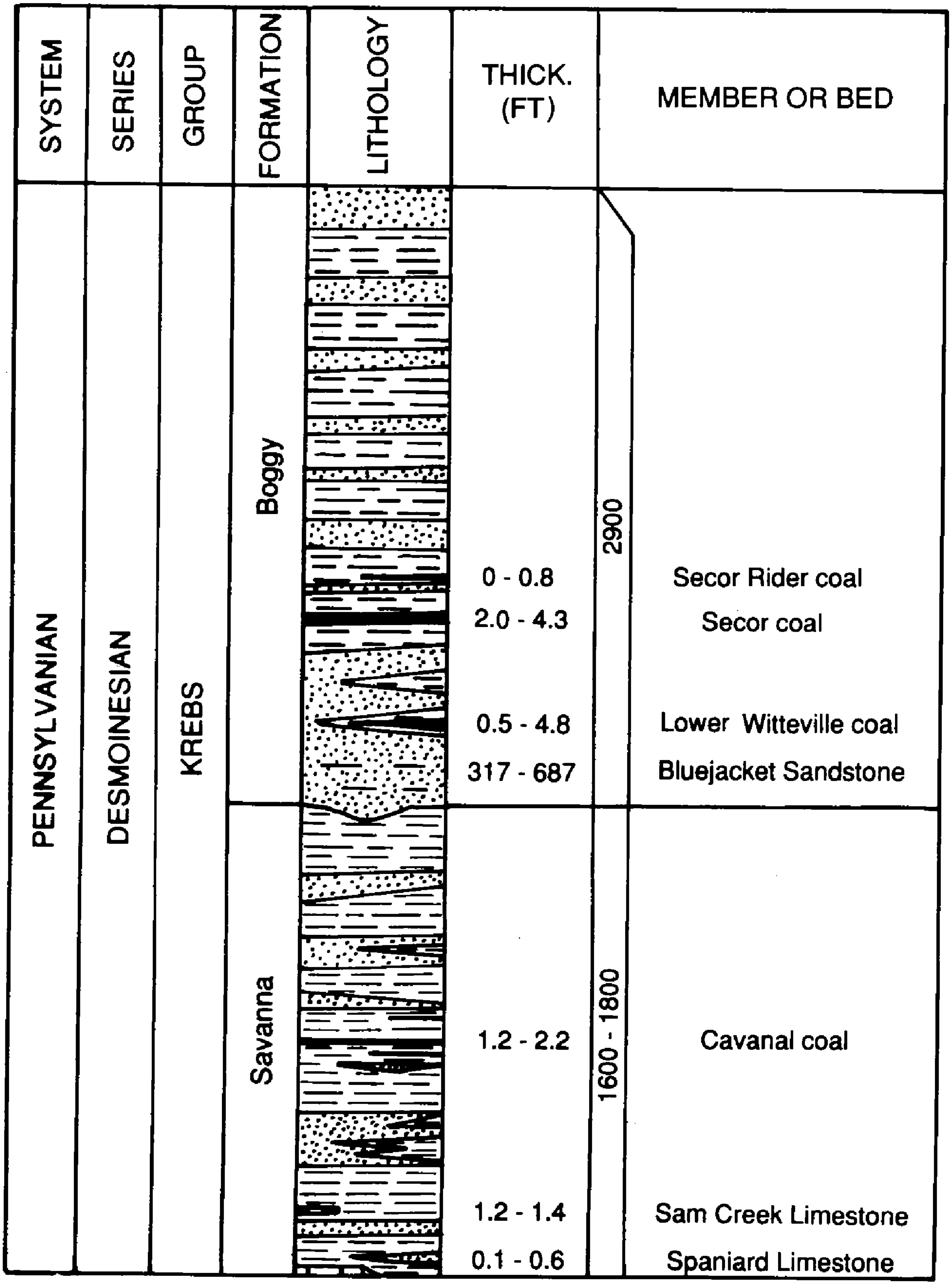


Figure 3. Generalized stratigraphic column showing the Savanna and Boggy Formations in the eastern part of the study area, Cavanal Mountain, Le Flore County. See Figure 11 for explanation of lithologic symbols.

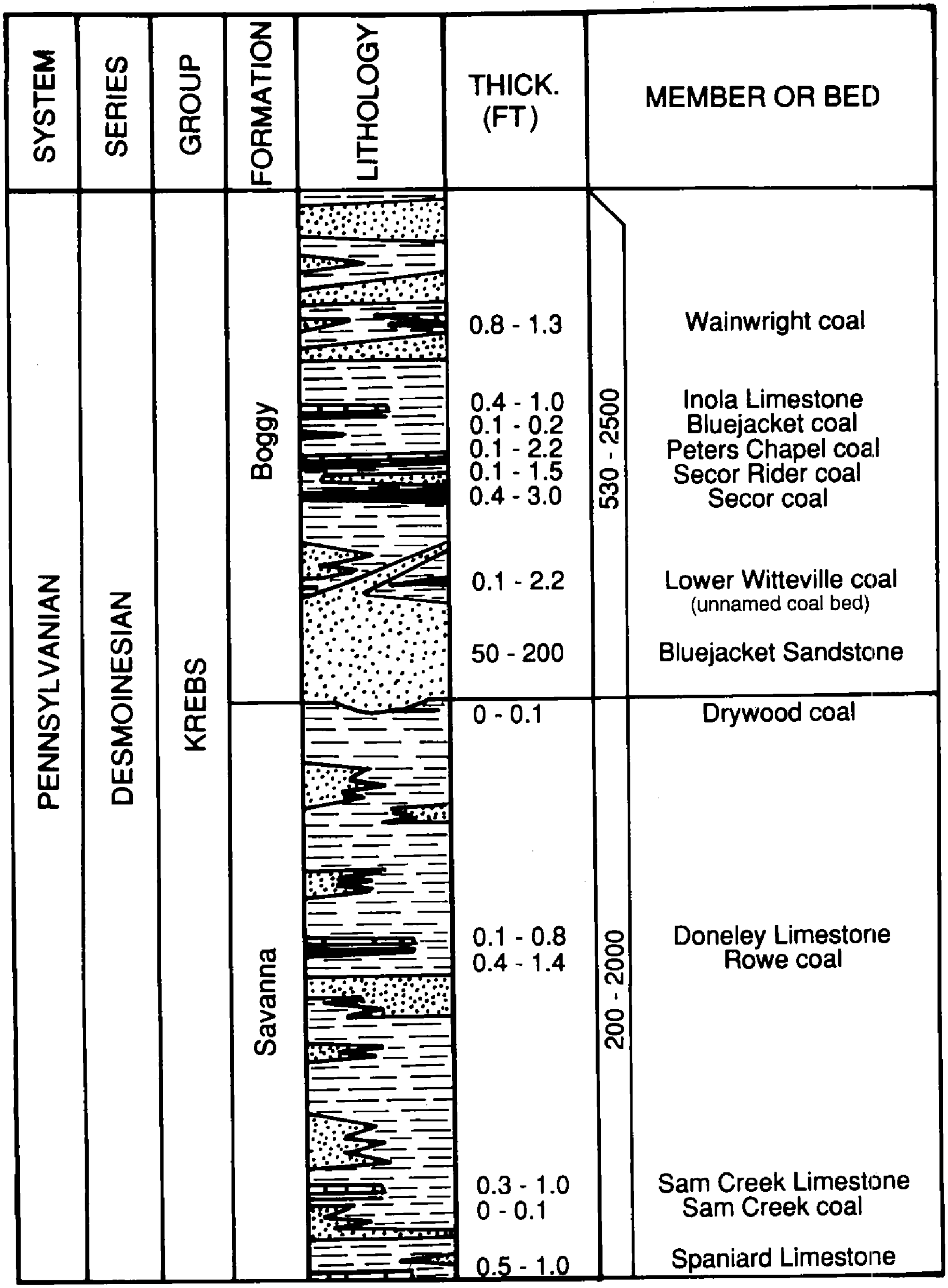


Figure 4. Generalized stratigraphic column showing the Savanna and Boggy Formations in the western part of the study area, McIntosh and northern Pittsburg County. Prior to this report, the Lower Witteville coal was unnamed in the area. See Figure 11 for explanation of lithologic symbols.

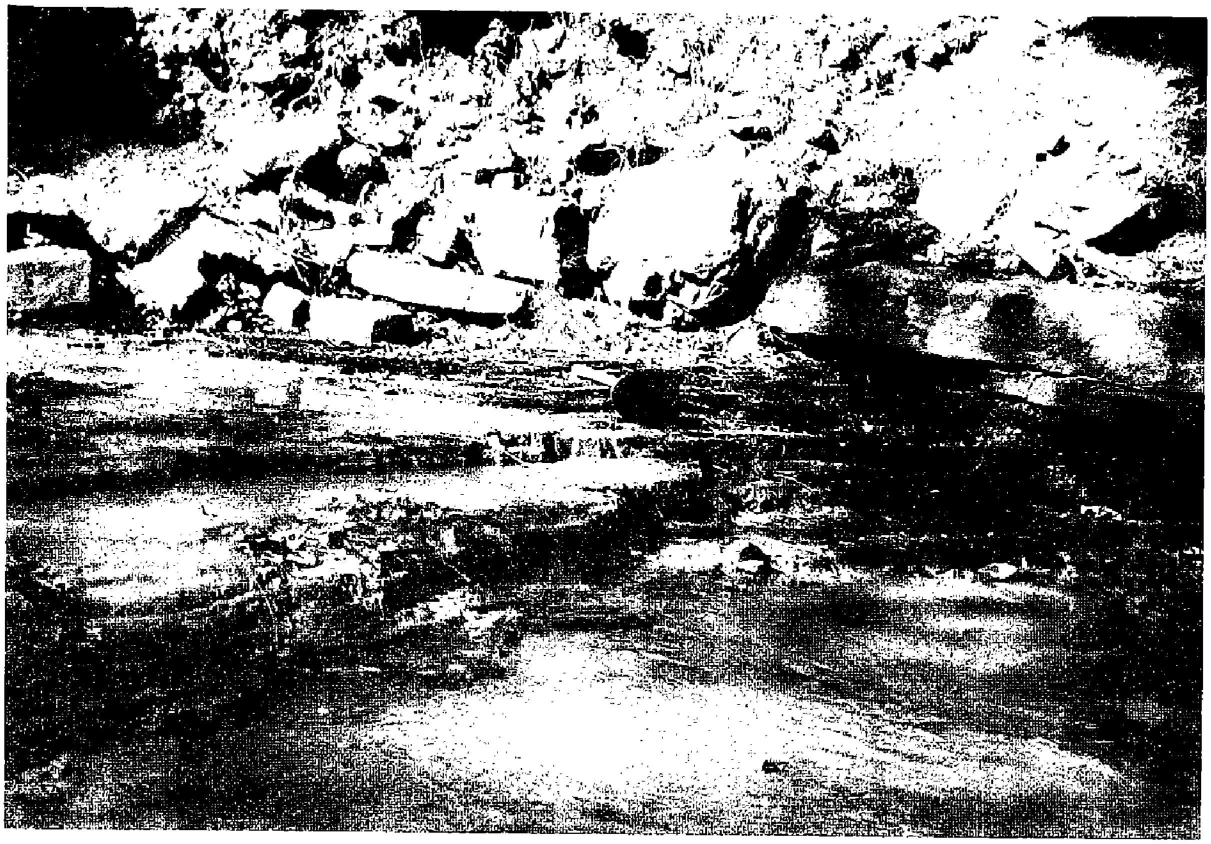


Figure 5. Outcrop of the Lower Witteville coal in its type area on Cavanal Mountain near Witteville. NE¼SW¼SW¼NE¼ sec. 15, T. 7 N., R. 25 E., Le Flore County, Oklahoma.

top and the one at the base being generally thicker than the intermediate ones" (Taff, 1899, p. 437–438). Because a type section was not designated, and because the definition is somewhat vague, various writers have included more or less than the original Savanna of Taff. It would seem from Taff's description that the lower boundary of the Savanna was defined as the base of the lowermost of his "five principal sandstone beds," which generally marks the break in slope at the base of the prominent synclinal mountains in the southern Arkoma basin. The base of the Spaniard Limestone was suggested by Oakes and Knechtel (1948) as a suitable marker for the base of the Savanna Formation in Muskogee County and farther north in Oklahoma. They said that it occupies substantially the same stratigraphic position as Taff's lowermost sandstone. Hemish (1993) recently located a limestone bed in Le Flore County, in a similar stratigraphic position, which he tentatively correlated with the Spaniard Limestone, and used it to define the base of the Savanna Formation there.

Taff and Adams (1900) placed the contact between the Savanna Formation and the overlying Boggy Formation at the top of the Lower Witteville coal bed on Cavanal Mountain. Where the Lower Witteville coal was not known to occur, the Savanna/Boggy contact was placed at the approximate horizon of the coal bed (Taff and Adams, 1900).

Because of the variable nature of the individual beds within the Savanna Formation, there have been various interpretations regarding its upper and lower con-

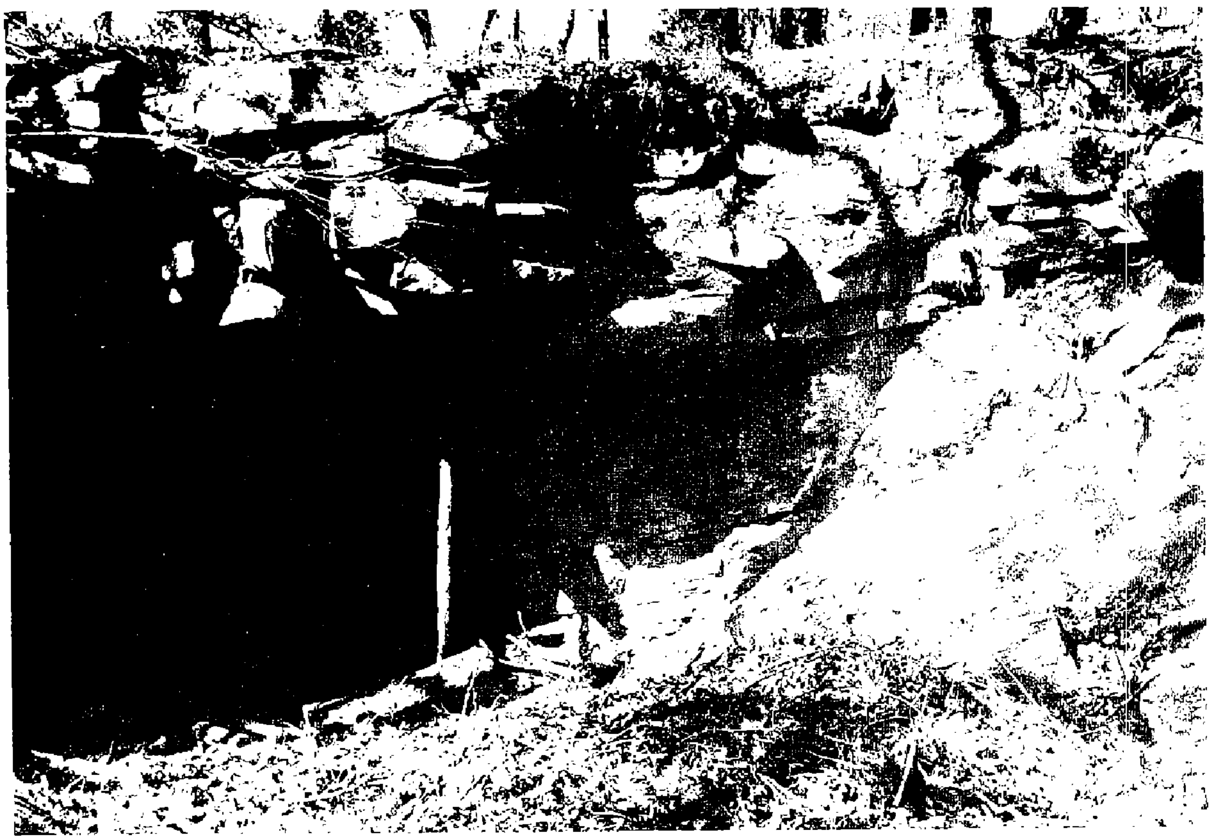


Figure 6. Adit of abandoned slope mine where Lower Witteville coal was mined on Cavanal Mountain near Witteville. SW¼NE¼ sec. 15, T. 7 N., R. 25 E., Le Flore County, Oklahoma.

tacts. Wilson (1935) tentatively included the upper parts of the McAlester Formation and the lower part of the Boggy Formation in the Savanna in an attempt to correlate them with the Savanna rocks in the type area. He placed the base of the Savanna at the base of the Tamaha Sandstone Member of the McAlester Formation, and the top of the Savanna at the top of the Bluejacket Sandstone Member of the Boggy Formation.

Detailed mapping in eastern Oklahoma by U.S. Geological Survey workers in 1934 disclosed that the Bluejacket Sandstone "is equivalent to the lowest sandstone unit of the Boggy shale" (Dane and Hendricks, 1936, p. 312). At that time, however, the thick shale unit underlying the Bluejacket Sandstone was still included as the basal unit of the Boggy Formation. Wilson and Newell (1937, p. 43) left the base of the Savanna Formation at the base of the Tamaha Sandstone and placed the top of the Savanna at the top of the "Spiro" sandstone (p. 50), which marks the base of the thick shale interval below the Bluejacket Sandstone. ("Spiro" has been dropped as an official name for the sandstone unit in the Savanna Formation because currently it is used in Oklahoma as a subsurface term for rocks at the base of the Atoka Formation.)

Subsequent work by Oakes and Knechtel (1948) in Haskell County and Knechtel (1949) in northern Le Flore County connected the mapping of the Muskogee–Porum district (Wilson and Newell, 1937) with the mapping in southern Le Flore County (Hendricks, 1939) and showed that the Tamaha and Keota Sandstones be-long in the McAlester Formation. The McAlester/Savanna contact was defined "as the top of the first shale unit above the Keota Sandstone Member" (Oakes and Knechtel, 1948, p. 48). This definition seems to be in agreement with Taff's (1899) original placement of the McAlester/Savanna contact. The top of the first shale unit above the Keota Sandstone is at the base of the first conspicuous ridge former in the Sans Bois Mountains and at the base of the Spaniard Limestone farther to the north. Workers currently mapping in eastern Oklahoma place the McAlester/Savanna contact at the base of the Spaniard Limestone or, in its absence, at the base of the first mappable sandstone above the Keota Sandstone (Hemish, 1991,1992; Hemish and Mazengarb, 1992; Hemish and Suneson, 1993,1994; Hemish and others, 1990a,b,c).

The Oklahoma Geological Survey (OGS) currently places the contact between the Savanna Formation and the overlying Boggy Formation at the base of the Bluejacket Sandstone Member of the Boggy Formation. Its position was established by Miser (1954) in the course of preparation of the *Geologic Map of Oklahoma.* He found this horizon to be the only one sufficiently extensive to separate the Savanna Formation from the Boggy Formation. Figure 7 shows the different concepts, over time, of the McAlester/Savanna and Savanna/Boggy boundary positions in Oklahoma.

The Boggy Formation was originally defined by Taff (1899) in the McAlester district. Its upper boundary is irrelevant to this paper and does not enter into the discussion. However, the Bluejacket Sandstone Member of the Boggy Formation is a critical unit because, as defined by Knechtel (1949), it contains the Lower Witteville coal in the area of investigation.

The Bluejacket Sandstone Member was named for the town of Bluejacket, Craig County, Oklahoma, in an unpublished manuscript by D. W. Ohern (1914). He said that its typical development is found in the hills west of the town where its total thickness is 50–60 ft. It may occur as a solid mass of sandstone, but usually it is broken up into several beds by intervening shales.

Visher (1988) discussed the history of deposition of the Bluejacket Sandstone in eastern Oklahoma and presented a sand distribution map that extended southward from the Kansas state line to the vicinity of Wilburton, northwestern Latimer County. He interpreted the depositional environment as a complex system related to progradation of large deltaic units.

It has been well established that the Bluejacket Sandstone can be mapped from its type area in Craig County southward into the Arkoma basin. Detailed mapping by the author throughout the study area demonstrates that the sandstone designated as the Bluejacket on Cavanal Mountain is equivalent to the sandstone named in Craig County by Ohern (1914).

According to Knechtel (1949, p. 31), the Bluejacket Sandstone Member of the Boggy Formation crops out on the slopes of Cavanal Mountain where it is a prominent cliff-forming unit made up largely of massive beds of sandstone with interbedded thin sandy beds and shale. He also noted that the Lower Witteville coal occurs in a shale interval ~80 ft from the top of the member on the east side of Cavanal Mountain where the Secor coal is "170 ft above the Bluejacket" (p. 32). In the vicinity of Witteville, he mapped ~500 ft of strata as Bluejacket (p. 31). Figure 8 shows the Bluejacket Sandstone near Witteville.

Webb (1960, p. 27) discussed the Bluejacket Sandstone where it occurs in the Cavanal syncline southwest of Knechtel's mapped area. He said that the unit con-

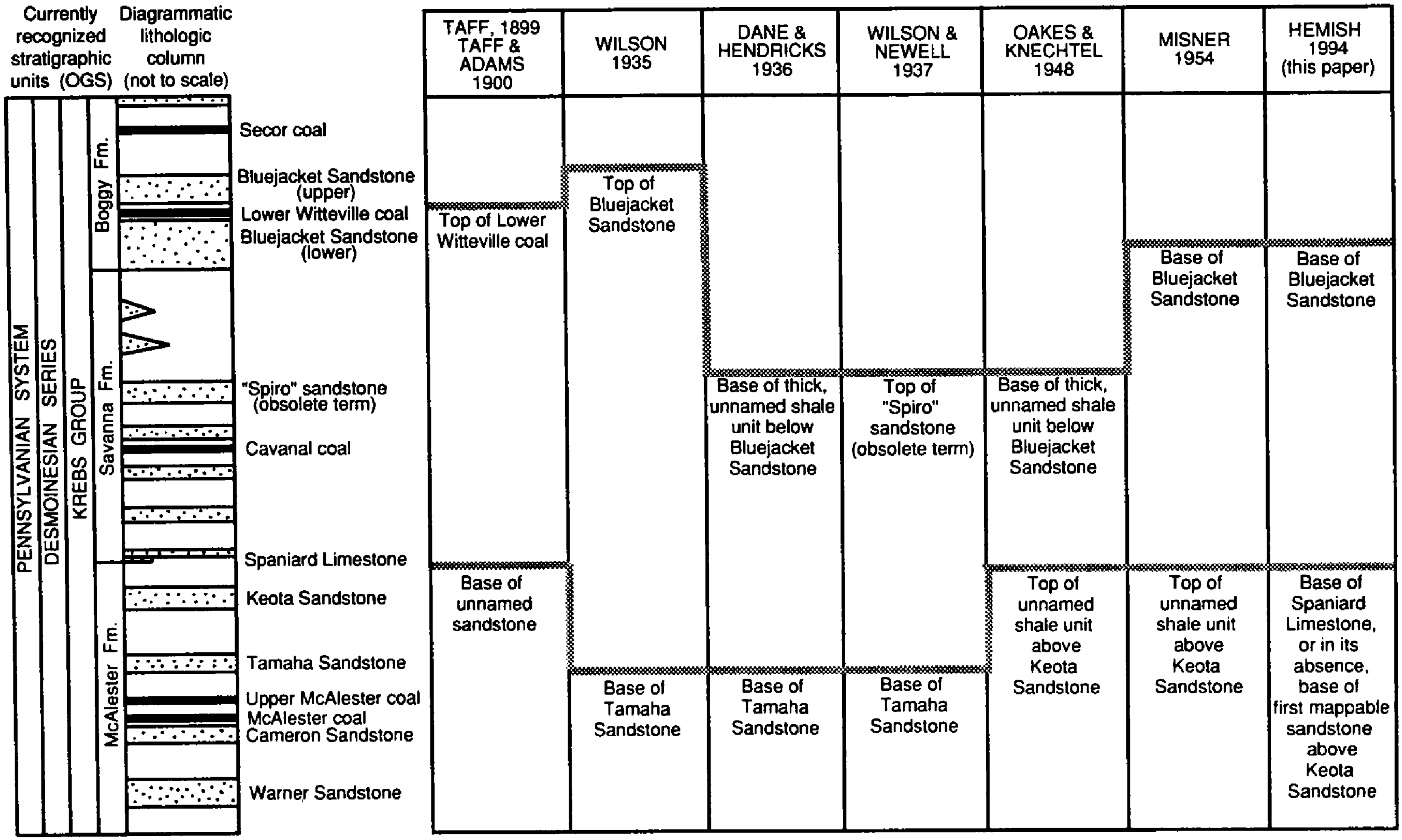


Figure 7. Concepts of McAlester/Savanna and Savanna/Boggy boundary positions in Oklahoma. See Figure 11 for explanation of lithologic symbols.

Figure 8. Upper part of lower unit of Bluejacket Sandstone on Cavanal Mountain near Witteville. SE¼NE¼ sec. 15, T. 7 N., R. 25 E., Le Flore County, Oklahoma.

sists of sandstone, shale, shaly sandstone, and sandy shale. Owing to the variance in lithology and to poor exposures he did not map the member as two sandstone units with an intervening shale as Knechtel had. He said "the amount of shaly sandstone between the upper and lower sandstone units of Knechtel does not warrant separation into three units" (p. 27). A section measured by the author along Little Caston Creek in secs. 17 and 18, T. 6 N., R. 24 E., Le Flore County (within Webb's map area), shows that ~22 ft of strata, which are predominantly shale, separate the lower sandstone unit from the upper (Appendix, measured section Le-6-93-H). The shaly interval includes the Lower Witteville coal. The upper sandstone consists of two resistant units totaling ~19 ft, separated by a nonresistant, covered unit (presumably shale) ~20 ft thick. About 110 ft of predominantly shale separates the upper sandstone unit of the Bluejacket Sandstone from the Secor coal in this area. The lower unit of the Bluejacket Sandstone is ~170 ft thick in this same area.

Vanderpool (1960, p. 17) said that the Bluejacket Sandstone may be divided into three parts in Haskell County: an upper sandy zone, a middle shaly zone, and a lower sandy zone. Although the Secor coal has been mapped in Haskell County above the upper sandy zone, no findings of the Lower Witteville coal in the middle shaly zone have been reported. Neither has the Lower Witteville been found in Latimer County, where Russell (1960) mapped the Bluejacket as a single unit.

Dane and others (1938, p. 162) reported a thickness of about 100–150 ft for the Bluejacket Sandstone interval in northern Pittsburg County. They said the interval included a workable coal bed in places but did not name the bed. They also stated that the Secor coal is present about 50–125 ft above the Bluejacket Sandstone.

Oakes and Koontz (1967, p. 23, 24) reported the Bluejacket to be about 150–200 ft thick in McIntosh County. They described a lower part that is resistant to weathering, massive, cross-bedded, and fine to medium grained. The upper part is less resistant, thin-bedded, and shaly. In northwestern McIntosh County, a shale lens in the upper part of the Bluejacket contains a 4-in.-thick, unnamed coal bed (Oakes and Koontz, 1967, p. 24), which the author interprets to be the Lower Witteville.

The foregoing discussion confirms that in the study area, the Bluejacket Sandstone generally consists of two major sandstone units. If present, the Lower Witteville coal occurs within the intervening shaly unit.

Correlation of the Lower Witteville Coal

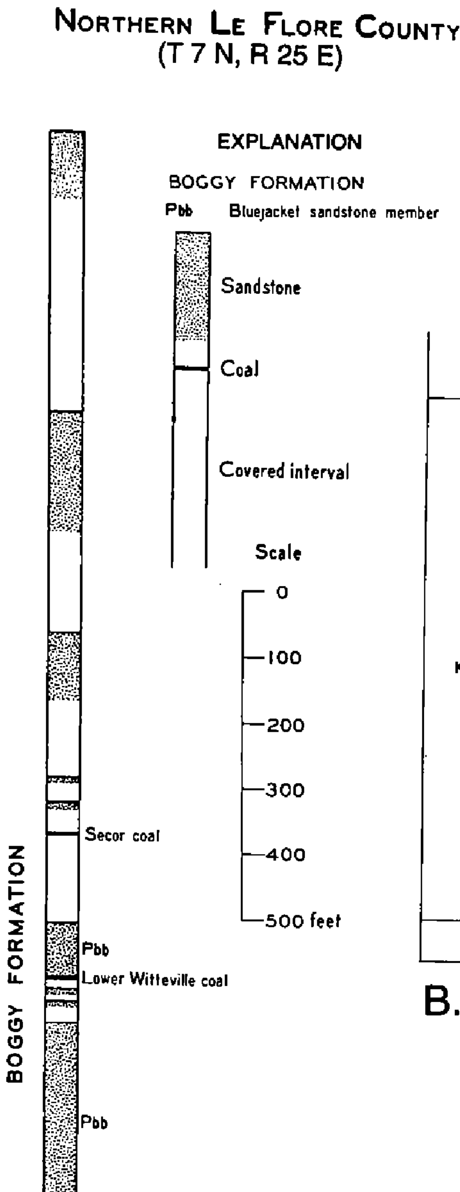
Figure 9 shows various workers' stratigraphic placement of the Lower Witteville coal as well as previous attempts at correlating the Lower Witteville coal with other named beds in Oklahoma. In the author's opinion, sufficient new physical evidence has been acquired in recent years to show that an unnamed coal bed present in the lower part of the Boggy Formation in McIntosh County and northern Pittsburg County correlates with the Lower Witteville coal, named in Le Flore County.

The belief that the Lower Witteville extends beyond Le Flore County did not originate with the author. Hendricks (1937, p. 23, 62) tentatively correlated a coal mined north of Savanna in sec. 3, T. 4 N., R. 14 E., Pittsburg County, with the Lower Witteville coal of the Poteau district, ~70 mi to the east. Trumbull (1957, p. 350) also said that "a coal bed of unknown thickness which may correlate with the Lower Witteville bed occurs near the base of the Boggy Formation" in Pittsburg County.

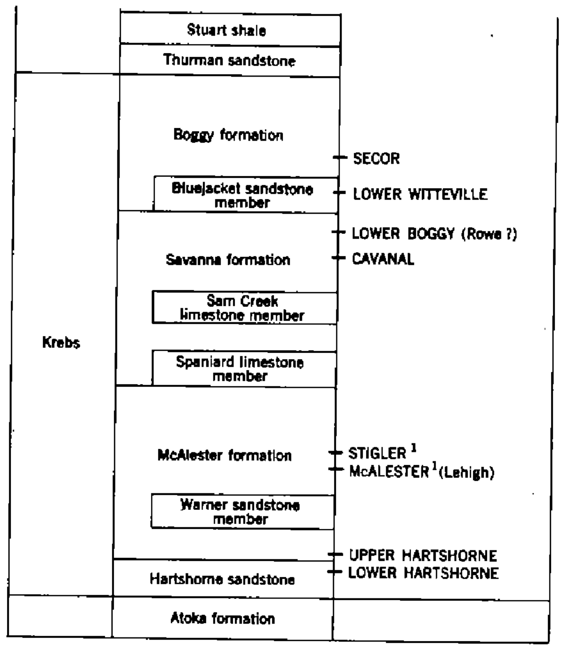
Dane and others (1938, p. 200) mentioned a coal bed that lies 50–75 ft below the Secor coal in the northern part of T. 6 N., R. 16 E., Pittsburg County, but did not attempt to correlate it with any other bed. Recent investigations in northern Pittsburg County and McIntosh County suggest that the coal bed is equivalent to the Lower Witteville of Le Flore County. Figure 10 shows correlations of the Lower Witteville across the outcrop belt of the lower Boggy Formation in the Arkoma basin of Oklahoma.

The discovery of a minable coal bed about 30–50 ft below the Secor coal by coal company explorers in the Checotah–Onapa area of McIntosh County was brought to the attention of the author in the early 1980s. Inquiries about the name of the coal led to further investigations by the author in the Arkoma basin area. A decision about the name had not been reached in 1988 when Hemish stated: "In this report the coal bed will remain unnamed, because further investigations are needed in the Arkoma basin to determine if the coal is correlatable with an already-named bed (Lower Witteville), or if it should be assigned a new name" (Hemish, 1988a, p. 9). At that time, S. A. Friedman (personal communication, 1988) believed that the Lower Witteville occurs at the top of the Savanna Formation and could be tentatively correlated with the Drywood coal (Fig. 9E). The thick sandstone below the Lower Witteville coal in its type area then would be the uppermost sandstone unit of the Savanna Formation, which was the original interpretation set forth by Taff (1899) and Taff and Adams (1900) (Fig. 5).

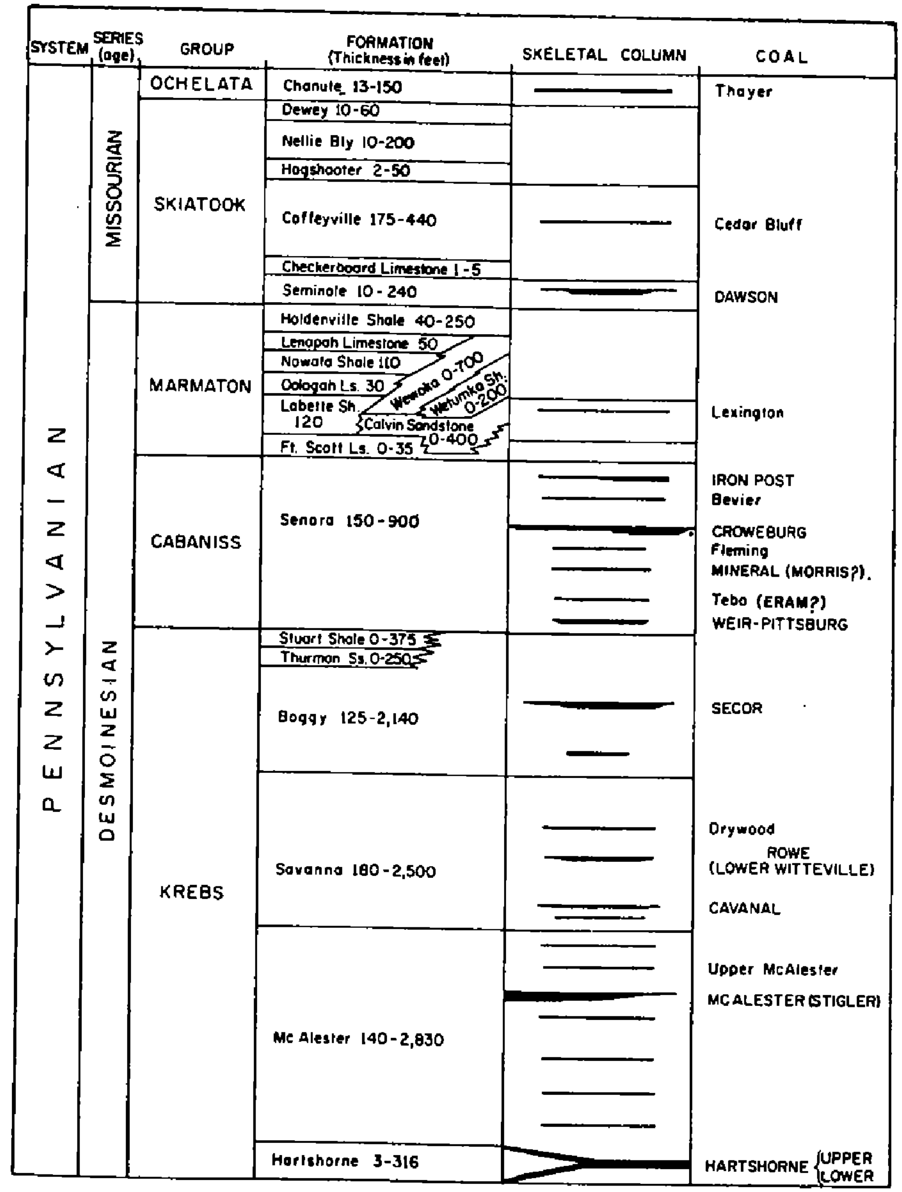
Based on continuous detailed mapping by USGS workers (Dane and Hendricks, 1936), the Bluejacket Sandstone was shown to be correlatable across the shelf area of northeastern Oklahoma, from its type area in Craig County into northern Pitts-


NORTHERN LE FLORE COUNTY
(T 7 N, R 25 E)
EXPLANATION
BOGGY FORMATION
Pbb Bluejacket sandstone member
Sandstone
Coal
Covered interval
Scale
0
100
200
300
400
500 feet
BOGGY FORMATION
Secor coal
Pbb
Lower Witteville coal
Pbb

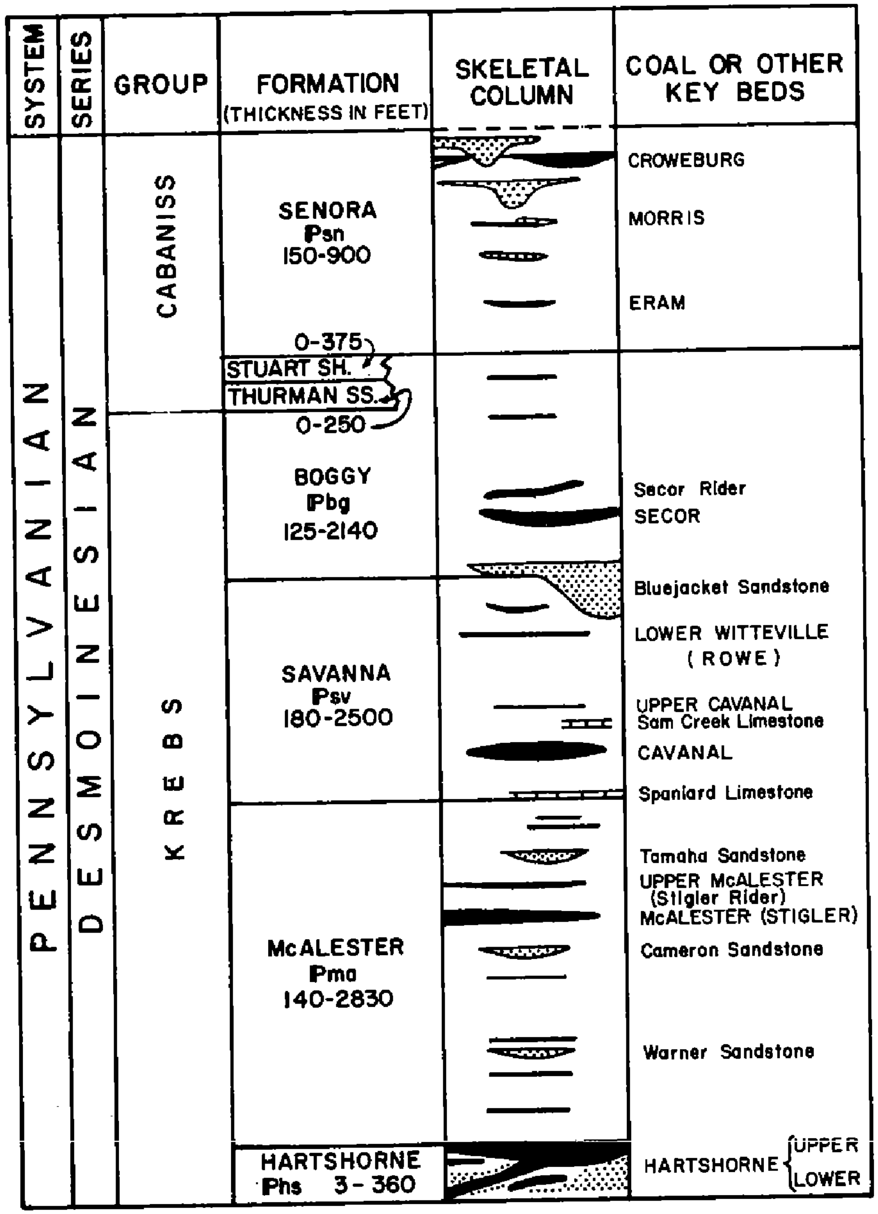
A.


Stuart shale
Thurman sandstone
Boggy formation
Bluejacket sandstone member
Savanna formation
Sam Creek limestone member
Spaniard limestone member
McAlester formation
Warner sandstone member
Hartshorne sandstone
Atoka formation
Krebs
SECOR
LOWER WITTEVILLE
LOWER BOGGY (Rowe ?)
CAVANAL
STIGLER 1
McALESTER 1 (Lehigh)
UPPER HARTSHORNE
LOWER HARTSHORNE

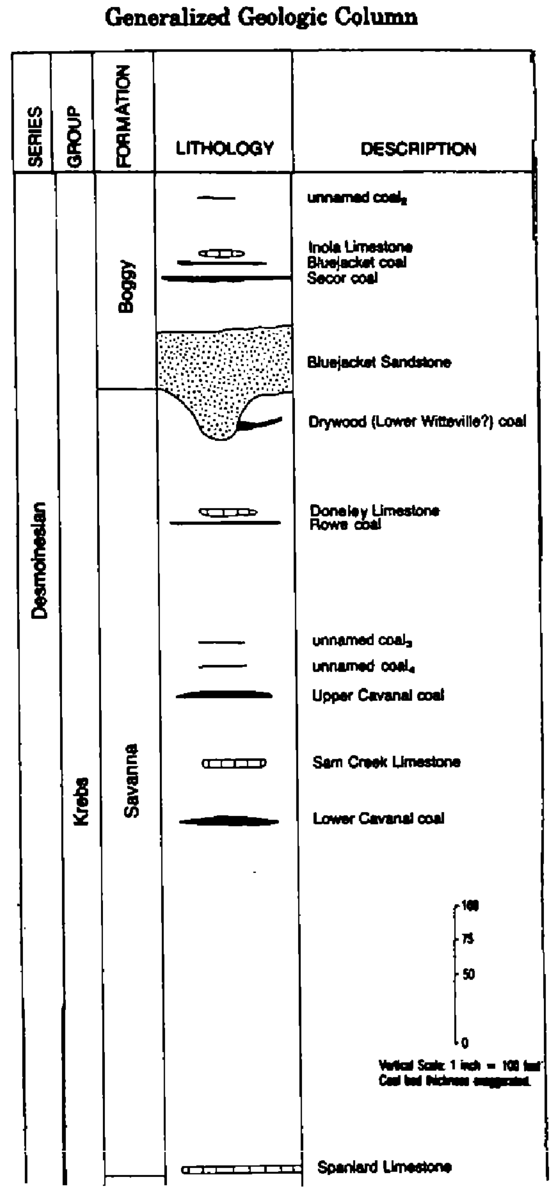
B.


SYSTEM
SERIES (age)
GROUP
FORMATION (Thickness in feet)
SKELETAL COLUMN
COAL
PENNSYLVANIAN
MISSOURIAN
DESMOINESIAN
OCHELATA
SKIATOOK
MARMATON
CABANISS
KREBS
Chanute 13-150
Dewey 10-60
Nellie Bly 10-200
Hogshooter 2-50
Coffeyville 175-440
Checkerboard Limestone 1-5
Seminole 10-240
Holdenville Shale 40-250
Lenapah Limestone 50
Nowata Shale 110
Oologah Ls. 30
Labette Sh. 120
Wewoka 0-700
Wetumka Sh. 0-200
Calvin Sandstone 0-400
Ft. Scott Ls. 0-35
Senora 150-900
Stuart Shale 0-375
Thurman Ss. 0-250
Boggy 125-2,140
Savanna 180-2,500
Mc Alester 140-2,830
Hartshorne 3-316
Thayer
Cedar Bluff
DAWSON
Lexington
IRON POST
Bevier
CROWEBURG
Fleming
MINERAL (MORRIS?).
Tebo (ERAM?)
WEIR-PITTSBURG
SECOR
Drywood
ROWE (LOWER WITTEVILLE)
CAVANAL
Upper McAlester
MCALESTER (STIGLER)
HARTSHORNE UPPER LOWER

C.

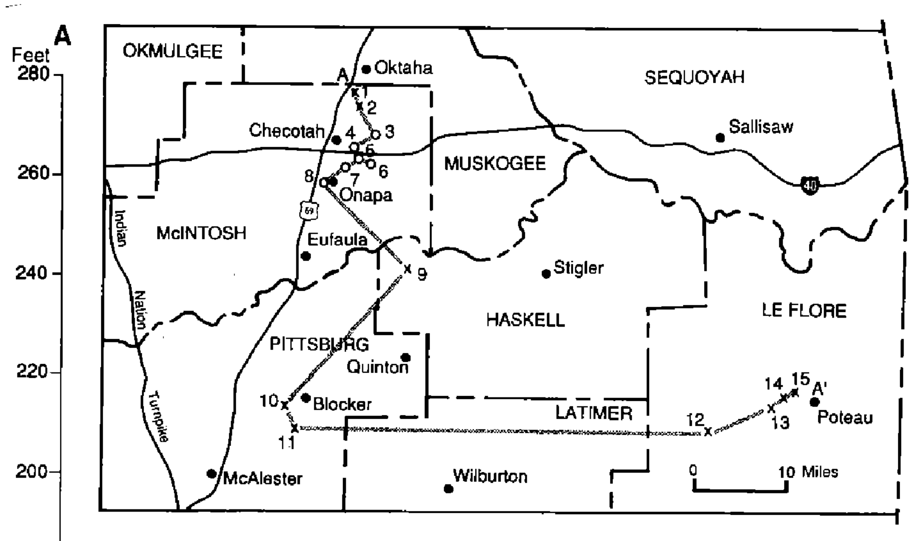


D.



E.

Figure 9. Generalized geologic columns from previous reports on Oklahoma coal showing tentative correlations with the Lower Witteville coal bed. Note the different stratigraphic positions of the Lower Witteville coal in columns A–B, C–D, and E, indicating the need for the present investigation. ***A.***—An excerpt from a measured section by Knechtel (1949, pl. 4) showing the stratigraphic position of the Lower Witteville coal in its type area on Cavanal Mountain in northern Le Flore County, Oklahoma. ***B.***—An excerpt from a geologic column showing the position of coal beds in the Oklahoma coalfield (Trumbull, 1957, pl. 16). ***C.***—A preliminary comprehensive generalized geologic column showing the stratigraphic sequence of Pennsylvanian-age coal beds in Oklahoma (Friedman, 1974, fig. 4). ***D.***—A generalized geologic column showing coals and other key beds of Desmoinesian age in part of the Arkoma basin, eastern Oklahoma (Friedman, 1978, fig. 2). ***E.***—An excerpt from a generalized geologic column by Friedman (1982) showing the stratigraphic position of coal beds in the Savanna and Boggy Formations. See Figure 11 for explanation of lithologic symbols.



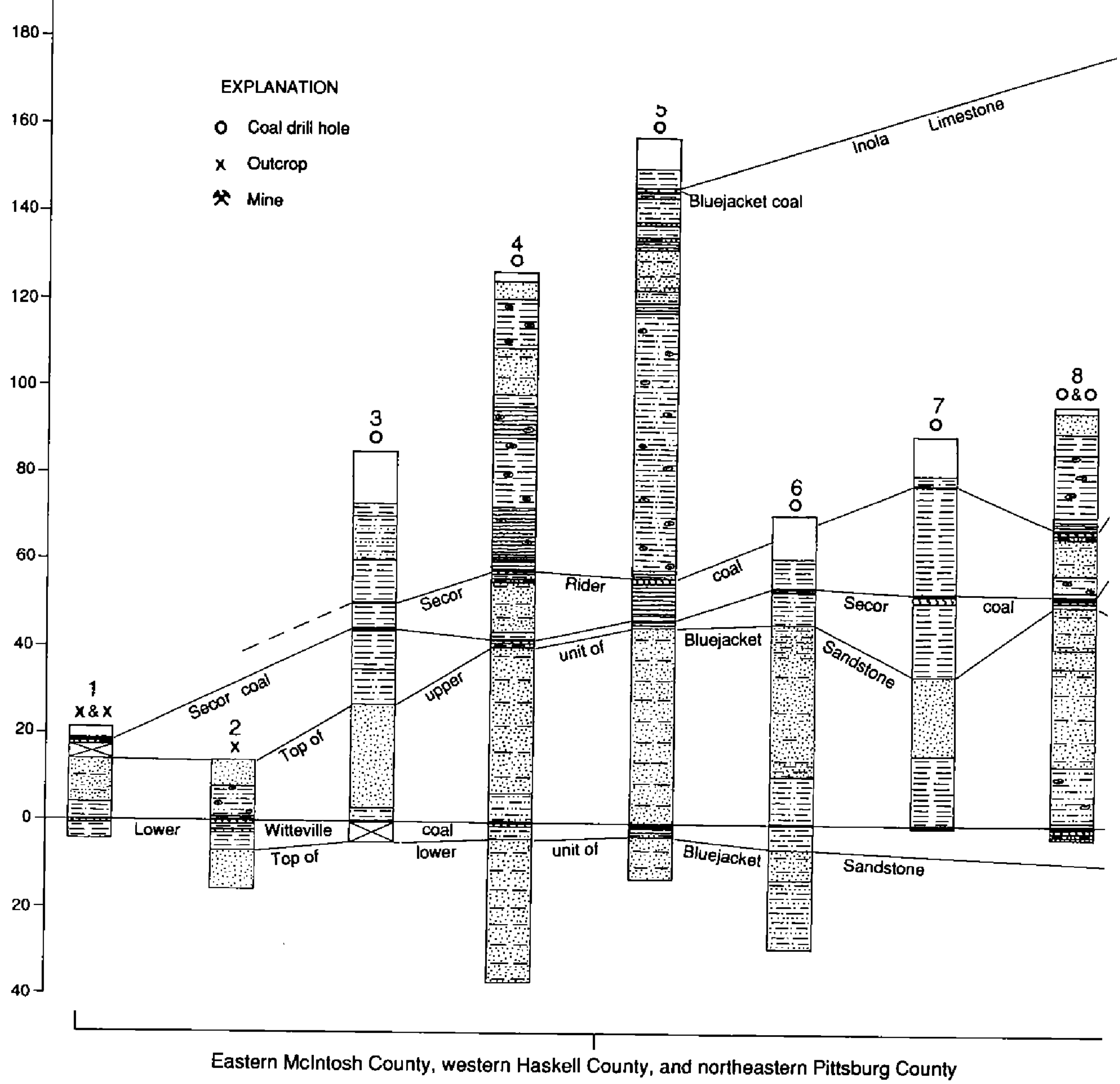
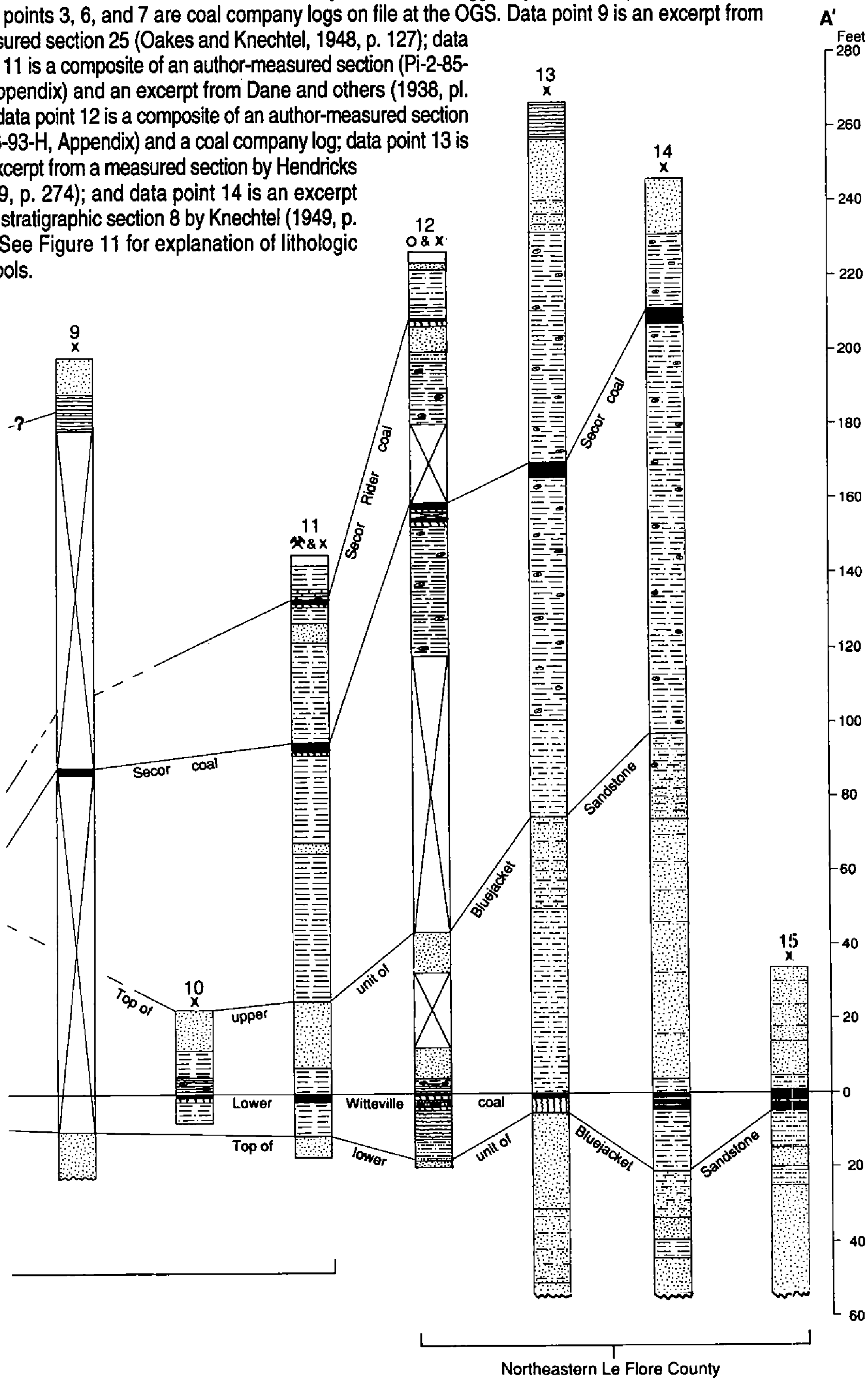


Figure 10. Correlations of key stratigraphic units in the lower part of the Boggy Formation in the Arkoma basin area of Oklahoma. No horizontal scale. The cross section incorporates drill-hole logs, core-hole logs, and measured sections in the study area. Data points 1, 2, 10, and 15 are locations of sections measured by the author (Appendix), and data points

4, 5, and 8 are locations of core-holes drilled by the OGS and logged by the author (Hemish, 1988b). Data points 3, 6, and 7 are coal company logs on file at the OGS. Data point 9 is an excerpt from measured section 25 (Oakes and Knechtel, 1948, p. 127); data point 11 is a composite of an author-measured section (Pi-2-85-H, Appendix) and an excerpt from Dane and others (1938, pl. 14); data point 12 is a composite of an author-measured section (Le-6-93-H, Appendix) and a coal company log; data point 13 is an excerpt from a measured section by Hendricks (1939, p. 274); and data point 14 is an excerpt from stratigraphic section 8 by Knechtel (1949, p. 65). See Figure 11 for explanation of lithologic symbols.



burg County. Recent detailed 7.5′-quadrangle mapping by Hemish (1991,1992); Hemish and Mazengarb (1992); Hemish and Suneson (1993,1994); and Hemish and others (1990a,b,c) shows that the Bluejacket Sandstone can be traced eastward from Pittsburg County to Cavanal Mountain, thus confirming that Knechtel's (1949) mapping is correct, and that the sandstone unit below the Lower Witteville coal is apparently the lower unit of the Bluejacket Sandstone (Fig. 9).

As would be expected, stratigraphic units thin northward out of the Arkoma basin (Oakes and Koontz, 1967, p. 21). Webb (1960, p. 25) said that the greatest sinking of the Arkoma basin in Boggy time must have occurred in a line extending from Cavanal Mountain westward through the Sans Bois syncline. Figures 10 and 11 diagrammatically show the northward thinning and the relationships of the Lower Witteville to other key units.

The Lower Witteville coal bed is thickest on Cavanal Mountain in Le Flore County, where Knechtel (1949, p. 65) reported 4.8 ft with several shale partings. The coal apparently thins laterally and/or pinches out in places to the west on Cavanal Mountain, or it may have been cut out by erosion prior to deposition of the upper Bluejacket Sandstone. Variable thicknesses of the coal bed are also characteristic of the Lower Witteville in Pittsburg and McIntosh Counties. The thickest coal in the western area was observed by the author in a strip mine in eastern McIntosh County, where it was 2.2 ft thick (Fig. 2). The coal thins to 0.1 ft just south of the Muskogee/McIntosh county line (Fig. 2; Appendix, measured section MM-2-86-H), which appears to be the northern limit for deposition of the Lower Witteville coal.

Summary

The Lower Witteville coal originally was named as a bed at the top of the Savanna Formation (Taff and Adams, 1900). Dane and Hendricks (1936) lowered the contact between the Savanna and Boggy Formations to the base of a thick shale bed underlying the Bluejacket Sandstone, thus removing the Lower Witteville from the Savanna Formation. Although Miser subsequently raised the Savanna/Boggy contact upward to the base of the Bluejacket Sandstone, the Lower Witteville remained in the Boggy Formation. So, from 1936 to the present, most mappers have included the Lower Witteville coal in the lower part of the Boggy Formation. However, Friedman (1974,1978) correlated the Lower Witteville coal with the Rowe coal, which is in the middle part of the Savanna Formation. Friedman (1982) subsequently correlated the Lower Witteville with the Drywood coal, which is at the top of the Savanna Formation.

Prior to the time of this report, the Lower Witteville coal was known to be present only on Cavanal Mountain, in T. 7 N., R. 25 E., where it was named. Exploration drilling by coal companies in Pittsburg and McIntosh Counties, core-drilling by the OGS in McIntosh County, and field mapping by the author in the same counties have shown that a coal bed is present in a similar stratigraphic position in both counties. The strata containing the Lower Witteville coal have been eroded across much of the Arkoma basin, and the bed lacks continuity, even in the Cavanal Mountain area. Hence, the argument might be advanced that the evidence for correlation is suggestive rather than conclusive. In the opinion of the author, however, the evidence presented in this paper does make it feasible to correlate the Lower Witteville coal and the coal that occurs in Pittsburg and McIntosh Counties in the lower part of the Boggy Formation.

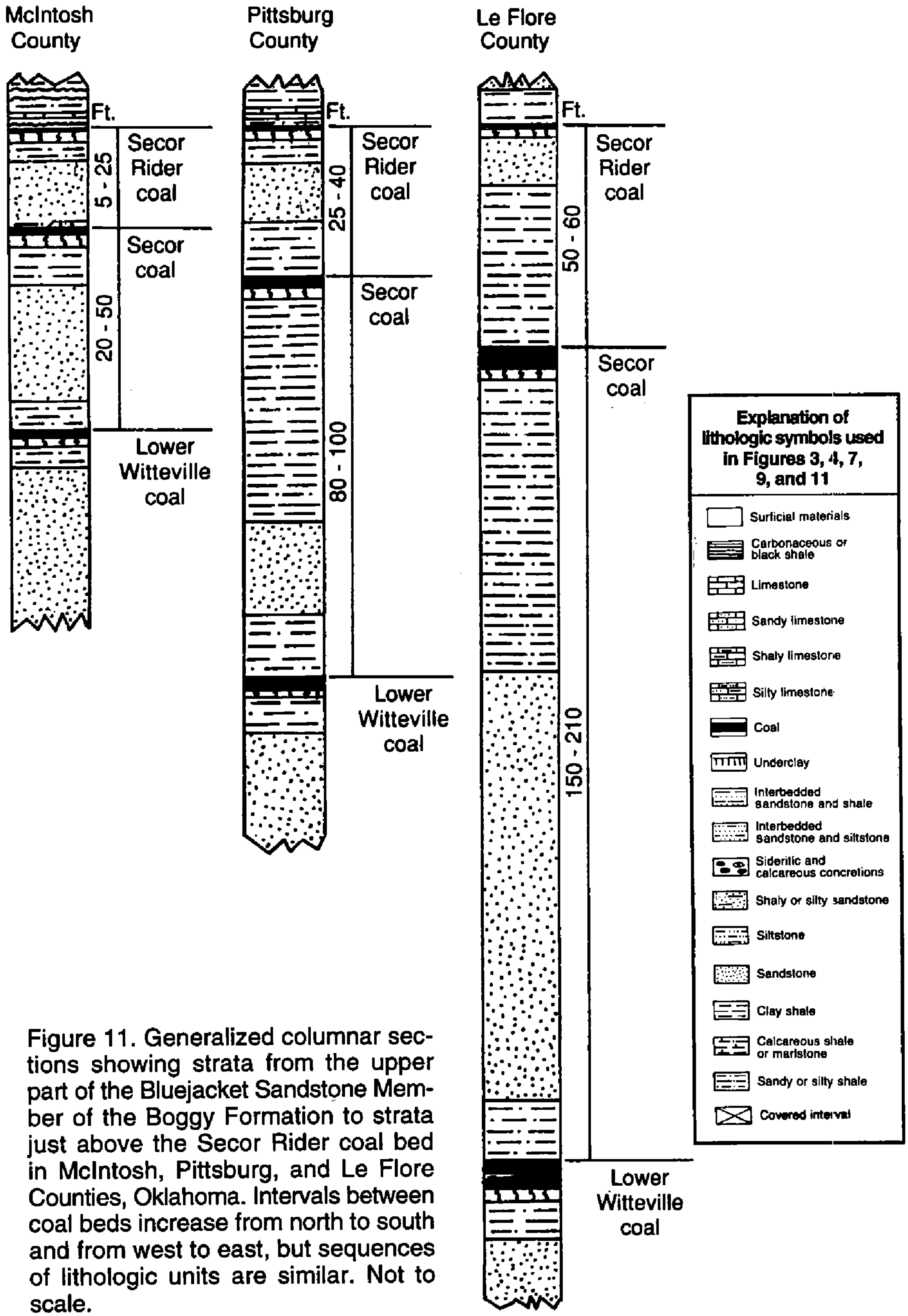


Figure 11. Generalized columnar sections showing strata from the upper part of the Bluejacket Sandstone Member of the Boggy Formation to strata just above the Secor Rider coal bed in McIntosh, Pittsburg, and Le Flore Counties, Oklahoma. Intervals between coal beds increase from north to south and from west to east, but sequences of lithologic units are similar. Not to scale.

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Appendix—Measured Sections

Le-6-93-H

E½SE¼ sec. 18, T. 6 N., R. 24 E., and W½NW¼ sec. 17, T. 6 N., R. 24 E., Le Flore County. Measured along Little Caston Creek from low waterfall to just south of bridge on county road.

	Thickness (feet)
KREBS GROUP	
Boggy Formation:	
25. Sandstone, moderate-brown (5YR 3/4)[1] to moderate-yellowish-brown (10YR 5/4), very fine-grained, medium- to thick-bedded; contains dish-and-pillar structure; cross-bedded, locally fills 6-ft-wide channels incised ~10 in. into underlying strata; thickness variable laterally; lower contact sharp	1.5
24. Siltstone, light-brownish-gray (5YR 6/1), with light-brown (5YR 5/6) staining, micaceous; contains black comminuted plant material; interlaminated with very fine-grained sandstone	2.7
23. Shale, dark-gray (N 3), brittle, flaky; contains ironstone concretions; poorly exposed	17.0
22. Covered interval	21.0
21. Coal, black (N 1), finely cleated, moderately friable; exposed in stream bed; thickness difficult to measure accurately (Secor coal)	1.6
20. Underclay, medium-gray (N 5) with dark-yellowish-orange (10YR 6/6) streaks; contains carbonized plant remains and coaly material	1.0
19. Covered interval	1.8
18. Coal, black (N 1), finely cleated; contains dense, pyritic coal masses in upper part that are as much as 9 × 7 in., and contain well-preserved plant fossils (Secor coal)	0.8
17. Underclay, olive-black (5Y 2/1) with light-brown (5YR 5/6) staining, compact, contains abundant carbonized plant material	1.2
16. Shale, olive-gray (5Y 4/1) to medium-dark-gray (N 4), brittle, flaky, weakly bioturbated; contains grayish-red (10R 4/2) ironstone concretions in discontinuous 1-in.-thick layers	35.0
15. Covered interval	74.0
14. Sandstone, grayish-orange (10YR 7/4) to grayish-red (10R 4/2), very fine-grained, medium- to thick-bedded, irregular-bedded, blocky (upper part of Bluejacket Sandstone Member)	10.5
13. Covered interval	20.0
12. Sandstone, grayish-orange (10YR 7/4) with light-brown (5YR 5/6) and moderate-reddish-orange (10R 6/6) staining, very fine-grained, thin-bedded, cross-laminated in part; includes fossil plant casts and ironstone concretions; breaks into blocky, irregular masses in upper part	8.2
11. Shale, medium-gray (N 5), soft, flaky; contains abundant dark-yellowish-orange (10YR 6/6) clay-ironstone nodules	2.3
10. Shale, brownish-black (5YR 2/1) with pale-brown (5YR 5/2) and dark-yellowish-orange (10YR 6/6) bands, very carbonaceous, soft, flaky; includes well-preserved *Lepidodendron* compressions as well as other plant fossils	2.0
9. Coal, grayish-black (N 2) with light-brown (5YR 5/6) bands, impure, shaly (Lower Witteville coal)	0.5
8. Underclay, light-brownish-gray (5YR 6/1) with moderate-reddish-orange	

(10R 6/6) streaks; slickensided; contains carbonized plant fragments......... 1.1

7. Sandstone, moderate-reddish-brown (10R 4/6) to dark-yellowish-orange (10YR 6/6), very fine-grained, no visible stratification; occurs in pod-like layer that varies laterally from 2 to 6 in. thick; strongly bioturbated; root casts abundant 0.4
6. Shale, medium-dark-gray (N 4) with abundant dark-reddish-brown (10R 3/4) and dark-yellowish-orange (10YR 6/6) ferruginous siltstone layers, weathers to brittle flakes on the outcrop 1.4
5. Coal, black (N 1), impure, very shaly, soft 0.3
4. Underclay, light-gray (N 7) with dark-yellowish-orange (10YR 6/6) bands 0.8
3. Shale, olive-black (5Y 2/1), weathers medium-light-gray (N 6), flaky, carbonaceous; contains well-preserved fossil plant compressions such as fern leaves and *Annularia*; includes abundant dark-reddish-brown (10R 3/4) ironstone concretions 8.0
2. Shale, dark-yellowish-brown (10YR 4/2), noncalcareous, hard, brittle, interbedded with sandy siltstone layers and lenses 1–2 in. thick 5.5
1. Sandstone, light-olive-gray (5Y 6/1), weathers grayish-orange (10YR 7/4) and grayish-red (10R 4/2), very fine- to fine-grained, thin- to medium-bedded; contains black carbonized plant fragments; mostly irregular-bedded, but includes some ripple-marked layers; contact with overlying unit sharp; base covered (upper part of lower unit of Bluejacket Sandstone Member) 1.5

Total thickness of section 220.1

Le-1-86-H

NE¼SW¼SW¼NE¼ sec. 15, T. 7 N., R. 25 E., Le Flore County. Measured along east-flowing stream ~325 yd west of low-water bridge, by LeRoy A. Hemish. (Surface elevation, estimated from topographic map, 750 ft.)

Thickness (feet)

KREBS GROUP

Boggy Formation:

10. Sandstone, dark-yellowish-brown (10YR 4/2), very fine-grained, micaceous, noncalcareous, siltstone in part, thin-bedded, wavy-bedded, ripple-marked; breaks into thin slabs on the outcrop (Bluejacket Sandstone) 20.0
9. Sandstone, dark-yellowish-brown (10YR 4/2); very fine-grained, but coarser than overlying unit; noncalcareous, thin- to medium-bedded in upper 6 ft, massive in lower 3 ft; fills channels at contact with underlying unit (Bluejacket Sandstone) 9.0
8. Siltstone, pale-yellowish-brown (10YR 6/2) with light-brown (5YR 6/4) staining, shaly, fissile, micaceous, laminated, noncalcareous; contains some very fine-grained sandstone 4.2
7. Shale, black (N 1), coaly, flaky; contains abundant compressed plant fossils. 0.5
6. Coal, black (N 1), finely cleated, moderately friable; crops out in stream bank and in bed of stream; under water in middle part of bed; (Knechtel [1949] reported an 8.5-in.-thick shale parting in about the middle of the coal bed) (Lower Witteville coal) 4.1
5. Shale, black (N 1), brittle, carbonaceous; includes iron sulfide-rich fossil *Stigmaria* and other plant fossils 0.5
4. Siltstone, dark-gray (N 3), iron oxide stained, shaly, laminated, noncalcareous, very thin-bedded; grades into underlying unit; includes ovate

ironstone concretions 1–2 in. in diameter	10.0
3. Sandstone, dark-yellowish-brown (10YR 4/2) to pale-yellowish-brown (10YR 6/2), very fine-grained, noncalcareous, medium-bedded, cross-bedded in part; contains ball-and-pillow structures (Bluejacket Sandstone)	5.5
2. Siltstone, dark-gray (N 3) with light-gray (N 7) laminae, flat-bedded, noncalcareous	5.0
1. Sandstone, dark-yellowish-brown (10YR 4/2), very fine-grained to fine-grained, noncalcareous, ripple marked, lower part of unit covered, total thickness not determined (Bluejacket Sandstone)	41.2
Total thickness of section	100.0

Pi-2-85-H

SE¼SW¼SW¼NE¼ sec. 16, T. 6 N., R. 16 E., Pittsburg County. Measured in highwall at southwest end of strip pit operated by Woodside Construction Co., by LeRoy A. Hemish. (Estimated elevation at top of section, 595 ft.)

	Thickness (feet)
11. Clay, moderate-yellowish-brown (10YR 5/4) with moderate-reddish-orange (10R 6/6) and moderate-orange-pink (10R 7/4) streaks and mottles	3.0
10. Shale, brownish-gray (5YR 4/1) with moderate-reddish-orange (10R 6/6) and pale-yellowish-orange (10YR 8/6) bands, weathered; medium-gray (N 5) in lower 4 ft	6.0
9. Limestone, medium-gray (N 5), thin-bedded, hard, highly shaly, very highly fossiliferous, brachiopods abundant along stratification surfaces	2.0
8. Shale, medium-dark-gray (N 4), highly calcareous, fossiliferous, brachiopods abundant	0.3
7. Coal, black (N 1), bright, banded, moderately friable; minor iron oxide on cleat surfaces; includes layers and nodules of pyrite, from ⅛-in. thick to 1 in. in diameter, respectively (Secor Rider coal)	1.0
6. Underclay, medium-gray (N 5), silty; contains abundant black (N 1) carbonized plant fragments	1.0
5. Shale, medium-gray (N 5), silty	4.7
4. Sandstone, medium-gray (N 5) with black (N 1) laminae; very fine-grained; contains thin layers of black (N 1) macerated plant material, well-indurated	5.5
3. Shale, medium-dark-gray (N 4), silty; includes abundant ironstone concretions	26.5
2. Coal, black (N 1), bright, banded, moderately friable; includes white (N 9) calcite on cleat surfaces and pyrite nodules as much as 2 in. long and 0.75 in. in diameter (Secor coal)	2.3
1. Underclay medium-gray (N 5), silty, hard; includes minor black (N 1) carbonized plant fragments	0.7
Total thickness of section	53.0

Pi-3-86-H

NW¼NE¼NE¼NE¼ sec. 33, T. 7 N., R. 16 E., Pittsburg County. Measured in trail directly south of abandoned slope mine on hill overlooking Eufaula Lake, by LeRoy A. Hemish. (Surface elevation, estimated from topographic map, 635 ft.)

	Thickness (feet)
KREBS GROUP	
Boggy Formation:	
6. Sandstone, pale-yellowish-brown (10YR 6/2) to moderate-yellowish-brown (10YR 5/4), iron oxide stained, very fine-grained, thick-bedded, contains Liesegang banding, slump structures and ironstone concretions as much as 2 in. in diameter (Bluejacket Sandstone)	11.0
5. Shale, light-brown (5YR 6/4) to dark-yellowish-orange (10YR 6/6), highly weathered	7.0
4. Shale, black (N 1), highly carbonaceous, contains thin coaly streaks; includes dark-reddish-brown (10R 3/4) ironstone concretions as much as 6 in. long and 2 in. thick	4.6
3. Coal, black (N 1), soft, weathered (Lower Witteville coal)	1.3
2. Underclay, dusky-yellow (5Y 6/4) with moderate-reddish-orange (10R 6/6) and brownish-gray (5YR 4/1) mottling; grades into underlying unit	1.1
1. Shale, dusky-yellow (5Y 6/4), highly weathered, silty in lower part	5.5
Total thickness of section	30.5

MM-1-86-H

NE¼NW¼NW¼NE¼ sec. 15, T. 12 N., R. 17 E., McIntosh County. Measured in road ditch south side of blacktop road just north of church, by LeRoy A. Hemish. (Surface elevation, estimated from topographic map, 610 ft.)

	Thickness (feet)
KREBS GROUP	
Boggy Formation:	
10. Sandstone, grayish-orange (10YR 7/4) to dark-yellowish-orange (10YR 6/6), very fine-grained, thick-bedded, noncalcareous (Bluejacket Sandstone)	6.0
9. Shale, pale-yellowish-brown (10YR 6/2) to moderate-yellowish-brown (10YR 5/4), weathered, silty; includes abundant thin stringers of dark-yellowish-orange (10YR 6/6), well-indurated siltstone that weather to flakes on the outcrop; contains ironstone concretions ~1 in. thick and 1–3 in. in diameter	7.0
8. Shale, moderate-brown (5YR 4/4), clayey, soft	0.1
7. Coal, black (N 1), soft, weathered (Lower Witteville coal)	0.3
6. Underclay, pale-brown (5YR 5/2) with dark-yellowish-orange (10YR 6/6) bands, carbonaceous; includes a 0.5-in.-thick, discontinuous layer of coal near base of unit	0.6
5. Shale, pale-yellowish-orange (10YR 8/6) with pale-brown (5YR 5/2) streaks, clayey; includes carbonaceous material; contains black (N 1) carbonized plant compressions	1.5
4. Coal, black (N 1), soft, weathered (stray coal)	0.1
3. Underclay, pale-brown (5YR 5/2) to moderate-brown (5YR 4/4)	0.3
2. Shale, light-olive-gray (5Y 5/2), clayey	5.1
1. Sandstone, pale-yellowish-brown (10YR 6/2), very fine-grained, noncalcareous, ripple-marked, thin-bedded in upper part, becomes medium-bedded lower in unit; total thickness unknown (Bluejacket Sandstone)	9.0
Total thickness of section	30.0

MM-11-83-H

NE¼SW¼SW¼NW¼ sec. 3, T. 12 N., R. 17 E., McIntosh County. Measured in bank of small stream from ~100 yd south of farm pond east to underpass beneath U.S. Highway 69, by LeRoy A. Hemish. (Estimated elevation at top of section, 565 ft.)

	Thickness (feet)
5. Silt, grayish-brown (5YR 3/2) with moderate-brown (5YR 3/4) mottling, clayey, gravelly; contains abundant broken fragments of coal at contact with underlying unit	3.0
KREBS GROUP	
Boggy Formation:	
4. Coal, black (N 1) with grayish-red-purple (5RP 4/2) coloration on stratification surfaces, bituminous; breaks easily into thin flakes, impure in part; total thickness may be greater if top has been eroded (Secor coal)	0.8
3. Underclay, dark-gray (N 3) with very dark-red (5R 2/6) staining, shaly, ferruginous in part (base covered)	0.5
2. Covered interval	2.2
1. Sandstone, pale-yellowish-brown (10YR 6/2) to reddish-brown (10R 3/4) and grayish-orange-pink (10R 8/2), very fine-grained, thin-bedded, shaly in upper part, ripple-marked; contains some dark-reddish-brown (10R 3/4) ferruginous concretions (Bluejacket Sandstone)	8.5
Total thickness of section	15.0

MM-2-86-H

NW¼SE¼SE¼NW¼ sec. 3, T. 12 N., R. 17 E., McIntosh County. Measured in stream bank on south side of creek ~50 yd east of trail, by LeRoy A. Hemish. (Surface elevation, estimated from topographic map, 565 ft.)

	Thickness (feet)
KREBS GROUP	
Boggy Formation:	
5. Sandstone, pale-yellowish-brown (10YR 6/2) to grayish-orange (10YR 7/4), very fine-grained, noncalcareous, rippled-marked, thin- to medium-bedded, silty and shaly in part, micaceous (Bluejacket Sandstone)	10.0
4. Shale, moderate-yellowish-brown (10YR 5/4), silty; contains moderate-reddish-brown (10R 4/6) concretions as much as 4 in. in diameter; includes thin siltstone layers	4.0
3. Coal, black (N 1), highly weathered, soft; bed is moderate-brown (5YR 3/4) highly carbonaceous shale in exposures laterally along the outcrop (Lower Witteville coal)	0.1
2. Underclay, pale-brown (5YR 5/2) to moderate-brown (5YR 4/4), carbonaceous	0.2
1. Shale, brownish-gray (5YR 4/1) to grayish-orange-pink (5YR 7/2), clayey; contains abundant, well-preserved, black (N 1) carbonized plant compressions; weathered (base covered)	4.0
Total thickness of section	18.3

[1] Rock color classifications (in parentheses) are from the Munsell color system (Rock-Color Chart Committee, 1991).

NEW OGS *Publication*

GEOLOGIC MAP OF THE HEAVENER AND BATES QUADRANGLES, LE FLORE COUNTY. One sheet, scale 1:24,000. Xerox copies. Price: $6, rolled in tube.

The Ouachita COGEOMAP Project is a joint effort of the U.S. Geological Survey, Oklahoma Geological Survey, and Arkansas Geological Commission to prepare a series of new geologic maps of the Ouachita Mountains in Oklahoma and Arkansas. The project includes review and compilation of existing information and maps on the Ouachita Mountains, and new geologic mapping at a scale of 1:24,000 (7.5′ topographic base). The purpose of the mapping is threefold: the new maps should provide a basis for (1) resource exploration and development; (2) land-use planning, such as highway construction; and (3) establishing a foundation for future studies in the area.

Based on existing geologic maps and resource interest and potential, the Oklahoma Geological Survey elected to focus its mapping effort on a west-to-east strip of 7.5′ quadrangles in the Ouachita Mountain frontal belt, starting immediately southeast of Hartshorne, Oklahoma, and ending at the Arkansas state line. The mapping effort was designed to begin where the geologic map by Hendricks and others (1947) ended, and to include the frontal belt quadrangles south of the Choctaw fault. Later, it was decided to map those parts of the Arkoma basin affected by Ouachita tectonics, including quadrangles that contain the Choctaw fault.

Mapping began in 1986. In 1993, the COGEOMAP Project was replaced by a new, expanded STATEMAP Program, which is part of the National Cooperative Geologic Mapping Program. It is expected that mapping in the Ouachita Mountains and Arkoma basin will continue under STATEMAP.

The first three maps (Higgins, Damon, and Baker Mountain) were released in 1989; the Panola, Wilburton, Red Oak, Leflore, and Talihina Quadrangles were released in 1990; the Leflore Southeast and Blackjack Ridge Quadrangles were released in 1991; the Gowen and Summerfield Quadrangles were released in 1992; and the Hodgen, Hontubby/Loving, and the Wister Quadrangles were released in 1993.

The Heavener/Bates Quadrangles, by LeRoy A. Hemish and Neil H. Suneson, are the first maps to be prepared under the STATEMAP Program; they are now available as black-and-white, author-prepared xerox copies, comprising geologic map, cross sections, description and correlation of units, and a list of wells.

COGEOMAP and STATEMAP geologic quadrangle maps of the Ouachita Mountains can be purchased over the counter or by mail from the Survey at 100 E. Boyd, Room N-131, Norman, OK 73019; phone (405) 325-3031, fax 405-325-7069. For mail orders of 1–10 maps, add $1.50 to the cost for postage and handling.

OGS Geologist Receives Distinguished Service Award

Tom Bingham

The Midcontinent Oil and Gas Association presented one of its Distinguished Service awards for 1993 to Tom Bingham, a geologist with the Oklahoma Geological Survey and member of the Association's Oklahoma Nomenclature Committee.

The award was presented to Bingham for his work with industry at the OGS and for his contributions to the Nomenclature Committee. He has been on the committee for seven years, chaired the group for two years, and served as vice-chairman for two years.

The primary responsibility of the Nomenclature Committee is naming and drawing boundaries for new oil and gas fields in Oklahoma, and for redefining boundaries for existing fields as updating becomes necessary.

The award was presented at the 75th Annual Meeting of the Midcontinent Oil and Gas Association, held September 22–23, 1993, in Oklahoma City. Founded in 1917, the Association is the oldest petroleum-industry association in the United States.

SEPM Permian Basin Section Annual Field Trip
San Andres Mountains, New Mexico, April 22–24, 1994

The SEPM Permian Basin Section 1994 Annual Field Trip, held in conjunction with the Roswell Geological Society, will examine classic Paleozoic outcrops in the San Andres Mountains, New Mexico, with emphasis on upper Pennsylvanian stratigraphy and the type section of the Permian San Andres Formation.

The field trip will start and finish at Las Cruces, New Mexico, and be led by David V. LeMone (University of Texas at El Paso), Frank E. Kottlowski (New Mexico Bureau of Mines and Mineral Resources), Lynn S. Soreghan (Amoco Production Co.), and Robert F. Lindsay (Chevron U.S.A. Production Co.).

For further information, contact Bob Lindsay, Chevron U.S.A. Production Co., P.O. Box 1150, Midland, TX 79702; (915) 687-7233, fax 915-687-7666. *The registration deadline is April 1, 1994.*

Upcoming *Meetings*

Simpson and Viola Groups in the Southern Midcontinent, March 29–30, 1994, Norman, Oklahoma. Information: Kenneth S. Johnson, Oklahoma Geological Survey, 100 E. Boyd, Room N-131, Norman, OK 73019; (405) 325-3031, fax 405-325-7069.

Society of Petroleum Engineers/U.S. Dept. of Energy, Improved Oil Recovery Meeting, April 17–20, 1994, Tulsa, Oklahoma. Information: Society of Petroleum Engineers, Box 833836, Richardson, TX 75083; (214) 952-9393, fax 214-952-9435.

Observation of the Continental Crust Through Drilling, International Meeting, April 25–30, 1994, Santa Fe, New Mexico. Information: Earl Hoskins, College of Geosciences and Maritime Studies, Texas A&M University, College Station, TX 77843; (409) 845-3651, fax 409-845-0056.

Geologic Remote Sensing, 10th Thematic Conference, May 9–12, 1994, San Antonio, Texas. Information: Environmental Research Institute of Michigan, Box 134001, Ann Arbor, MI 48113; (313) 994-1200 (ext. 3234), fax 313-994-5123.

Association of Systematics Collections/Society for the Preservation of Natural History Collections Meeting, May 11–15, 1994, St. Louis, Missouri. Information: Association of Systematics Collections, Second Floor, 730 11th St., N.W., Washington, DC 20001; (202) 347-2850, fax 202-347-0072.

Midwest Friends of the Pleistocene, Annual Meeting, May 13–15, 1994, Cincinnati, Ohio. Information: Tom Lowell, Dept. of Geology, University of Cincinnati, Cincinnati, OH 45226; (513) 556-4165.

SEPM Research Conference, "Basinwide Diagenetic Patterns: Integrated Petrologic, Geochemical, and Hydrologic Considerations," May 21–25, 1994, Lake of the Ozarks, Missouri. Information: Society for Sedimentary Geology, P.O. Box 4756, Tulsa, OK 74159; (918) 743-9765.

High-Level Radioactive Waste Management, International Conference, May 22–26, 1994, Las Vegas, Nevada. Information: Tom Sanders, Transactions Office, American Nuclear Society, 555 N. Kensington Ave., La Grange Park, IL 60525; (312) 352-6611.

International Association of Computer Methods and Advances in Geomechanics Meeting, May 23–28, 1994, Morgantown, West Virginia. Information: Society of Petroleum Engineers, Box 833836, Richardson, TX 75083; (214) 952-9393, fax 214-952-9435.

U.S. National Committee on Rock Mechanics, 1st North American Rock Mechanics Symposium, June 1–3, 1994, Austin, Texas. Information: Priscilla Nelson, Dept. of Geotechnical Engineering, University of Texas, Austin, TX 78712; (512) 471-4929, fax 512-471-6548.

Geochronology, Cosmochronology, and Isotope Geology, 8th International Conference, June 5–11, 1994, Berkeley, California. Information: Garniss H. Curtis, Institute of Human Origins–Geochronology Center, 2453 Ridge Road, Berkeley, CA 94709; (510) 845-4003, fax 510-845-9453.

Annotated Bibliography of Graptolite References from Oklahoma, Arkansas, and Adjacent Areas, with a List of Cited Species

This 22-page USGS open-file report was written by Claire Carter.

Order OF 93-0199 from: U.S. Geological Survey, Books and Open-File Reports Section, Federal Center, Box 25425, Denver, CO 80225; phone (303) 236-7476. The price is $4 for microfiche and $3.50 for a paper copy; add 25% to the price for foreign shipment.

Geologic Controls and Resource Potential of Natural Gas in Deep Sedimentary Basins in the United States

Edited by T. S. Dyman, this 295-page USGS open-file report consists of 12 papers and nine over-sized sheets at a scale of 1:5,000,000 (1 in. = ~80 mi).

Order OF 92-0524 from: U.S. Geological Survey, Books and Open-File Reports Section, Federal Center, Box 25425, Denver, CO 80225; phone (303) 236-7476. The price is $10.75 for microfiche and $64.50 for a paper copy; add 25% to the price for foreign shipment.

Porosity, Depth, and Thermal-Maturity Data for Sandstones of the Anadarko Basin, Oklahoma, and Other Selected Locations in the Northern Hemisphere

Written by T. C. Hester and J. W. Schmoker, this USGS open-file report contains 46 pages.

Order OF 93-0230 from: U.S. Geological Survey, Books and Open-File Reports Section, Federal Center, Box 25425, Denver, CO 80225; phone (303) 236-7476. The price is $4 for microfiche and $7.25 for a paper copy; add 25% to the price for foreign shipment.

Bibliography of Oklahoma Hydrology — Reports Prepared by the U.S. Geological Survey and Principal Cooperating Agencies, 1901–93

Compiled by John S. Havens, this volume lists all the reports on the hydrology of Oklahoma that have been issued by the U.S. Geological Survey since 1901. Many of these reports have been prepared in cooperation with State and local agencies. The 61-page bibliography also lists journal articles and reports issued by the principal State cooperators (the Oklahoma Water Resources Board and the Oklahoma Geological Survey) dealing with the hydrology and geology of Oklahoma.

Order OF 93-448 from: U.S. Geological Survey, Water Resources Division, 202 N.W. 66th St., Bldg. 7, Oklahoma City, OK 73116; phone (405) 843-7570, fax 405-843-7712. A limited number of copies are available free of charge.

Oklahoma ABSTRACTS

The Oklahoma Geological Survey thanks the American Association of Petroleum Geologists, the Geological Society of America, and the authors for permission to reprint the following abstracts of interest to Oklahoma geologists.

Nature of Migrabitumen and Their Relation to Regional Thermal Maturity, Ouachita Mountains, Oklahoma

BRIAN J. CARDOTT, Oklahoma Geological Survey, Norman, OK 73019; *TIM E. RUBLE*, School of Geology and Geophysics, University of Oklahoma, Norman, OK 73019; and *NEIL H. SUNESON*, Oklahoma Geological Survey, Norman, OK 73019

Two grahamite and three impsonite localities are within an 82-km-long segment of the Ouachita Mountains of southeastern Oklahoma. Grab samples were collected to study the petrographic and geochemical characteristics of the migrabitumen at the grahamite–impsonite transition and the relation of the migrabitumen to the regional thermal maturity pattern.

Maximum and random bitumen reflectance values increased from 0.75 to 1.80% from west to east, consistent with the regional thermal maturation trend. Mean bireflectance values increased from 0.04 to 0.38%. The two grahamite samples are classified at the grahamite–impsonite boundary with conflicting petrographic (bitumen reflectance) and bulk chemical (volatile matter) maturity indicators.

The regional maturation trend, based on vitrinite reflectance and bitumen reflectance values, was confirmed by a detailed geochemical investigation of bitumen extracts. Although biomarker analyses were influenced by extensive biodegradation effects, molecular parameters based on the phenanthrenes, dibenzothiophenes, and tricyclic terpanes were identified as useful maturity indicators.

Reprinted as published in *Energy Sources*, v. 15, p. 239.

Growth of Authigenic Magnetite during Shale Diagenesis

MATTHEW W. TOTTEN and *KERI A. CUNNINGHAM*, Dept. of Geology and Geophysics, University of New Orleans, New Orleans, LA 70148; and *R. D. ELMORE*, School of Geology and Geophysics, University of Oklahoma, Norman, OK 73019

Paleomagnetic results from Mississippian-aged shales in the Ouachita Mountains of Oklahoma and Arkansas suggest a relationship between shale diagenesis and authigenic magnetite growth. Magnetic susceptibility of shales from the Stanley Group correlates with maximum temperature as calculated from previously reported vitrinite reflectance values. The correlation improves when magnetic susceptibility is normalized to the amount of clay present within each sample. Because magnetic susceptibility is directly related to the quantity of magnetic minerals in the sample, these data suggest growth of a magnetic phase during clay-mineral diagenesis.

Rock magnetic measurements were performed to identify the magnetic mineralogy.

Isothermal remnant magnetization (IRM) acquisition exhibits nearly complete saturation by .2 Tesla. Alternating field (AF) decay shows removal of IRM by 90 millitesla. These results are suggestive of a low coercivity magnetic phase, such as magnetite.

The presence of iron oxides within the most thermally mature samples was confirmed under SEM. EDS spectra show them to be primarily iron and oxygen, signifying and end-member composition which is consistent with an authigenic origin. We interpret the growth of authigenic magnetite to be a consequence of illitization of smectite group clays, which releases octahedrally coordinated cations, including iron.

Reprinted as published in the Geological Society of America *Abstracts with Programs, 1993*, v. 25, no. 6, p. A-199.

Chemical Remagnetization and Paleomagnetic Dating of Fluid Migration Events: Testing the Orogenic Fluid Hypothesis

R. DOUGLAS ELMORE, School of Geology and Geophysics, University of Oklahoma, Norman, OK 73019

Remagnetization, the acquisition of a secondary magnetization, is now recognized as a widespread phenomenon in sedimentary rocks. The recognition that many sedimentary rocks were remagnetized long after deposition has not only led to a reevaluation of the paleomagnetic database, but also has led to a new application of the paleomagnetic method to other areas of earth science. Many secondary magnetizations are tangible evidence of a chemical event (e.g., precipitation of authigenic magnetic phases) caused by rock-fluid interactions. Recent studies demonstrate that isolation of a chemical remanent magnetization (CRM) and comparison of the corresponding pole position to the apparent polar wander path can provide essential constraints on the timing of a diagenetic event.

Many CRMs can be spatially correlated with orogenic belts and temporally related to orogeny. This particularly applies to the numerous Late Paleozoic CRMs that, along with other phenomena such as potassium alteration, are inferred to be genetically related to migration of fluids from the Appalachian and Ouachita Mountains. In this talk several case studies will be presented where paleomagnetic and geochemical results are used to date diagenetic events and test the role of orogenic fluids as agents of remagnetization.

The Ordovician Viola Limestone (southern Oklahoma) contains a pervasive Pennsylvanian CRM and a localized Permian CRM that occurs in a halo around veins mineralized by saline radiogenic fluids. The Permian CRM can be related to alteration by the basinal fluids. The pervasive CRM, which is similar to many other CRMs that have been related to orogenic fluids, occurs in relatively unaltered limestone. The acquisition of this CRM was caused by an as yet unidentified chemical mechanism that was not triggered by externally derived fluids. The Pennsylvanian Belden Formation in Colorado contains a synfolding Cretaceous CRM. Field relationships and geochemical results indicate there is no relation between syndeformational mineralization by radiogenic fluids and the CRM. Preliminary results, however, suggest a connection between the CRM and organic matter in the limestone. Radiogenic Cambrian–Ordovician dolomites near the Ouachita Mountains in southern Oklahoma that have been altered by basinal fluids contain a late Paleozoic CRM. Relatively unaltered dolomites (e.g., with coeval $^{87}Sr/^{86}Sr$ ratios) away from the Ouachitas contain an early Paleozoic magnetization. These results suggest a connection between remagnetization and fluids that migrated from the Ouachita Mountains.

The results of these case studies indicate that basinal fluids can locally cause remagnetization, and the CRMs can be used to date the alteration. Orogenic fluids, however, probably are not a viable mechanism for many CRMs that are pervasive. Understanding the origin of the CRMs will require tests of mechanisms that do not rely on externally derived fluids.

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Integrated Geophysical Models of the Southern Appalachian–Ouachita Continental Margin

G. RANDY KELLER, JULIA L. WHITELAW, and *M. JAMAL*, Dept. of Geological Sciences, University of Texas, El Paso, TX 79968

The margin of North America in the Paleozoic has been the object of renewed interest because of the intriguing tectonic relationships posed by newly proposed plate reconstructions. Seismic data needed to provide constraints on models of the deep structure of this margin are sparse. However, by using deep seismic reflection and refraction profiles, gravity and magnetic data, drilling results, industry seismic data, surface wave dispersion data, and teleseismic waveform modeling in an integrated analysis, models can be constructed with a reasonable degree of confidence. However, in the Southern Appalachian–Ouachita region it should be remembered that the only well-constrained region is the Ouachita Mountains area where COCORP and PASSCAL experiments have been conducted fairly recently. Building on these results, we have constructed a series of models across the southeastern U.S. These models show that the Ouachita Mountains margin is characterized as large crustal blocks lying outboard of the main margin. The main margin is abrupt suggesting that a major component of strike-slip was present during the initial rifting event. The Paleozoic margin appears to be largely intact in this region.

In the Southern Appalachian region, the picture is considerably different, but not as well constrained. There is ambiguity because rift basins and crustal thickening both produce gravity lows. The Valley and Ridge and Blue Ridge regions were found to be underlain by relatively thick (45 km) crust which is associated with the North American craton. However, the original cratonal crust appears to have been thinned by Eocambrian rifting and then thickened by overthrusting to attain today's thickness. The crust begins to thin and become more mafic under the Pediment province. We found the Late Paleozoic suture to be in the same area as proposed by previous workers. We propose that the Eocambrian rifting event produced several large basins which are preserved beneath the thrusts and are associated with large gravity lows.

Reprinted as published in the Geological Society of America *Abstracts with Programs, 1993*, v. 25, no. 6, p. A-177.

Remarkably Uniform Bulk Silicate $\delta^{18}O$ Values of Terrigenous Sedimentary Rocks from the Central Appalachian and Ouachita Geosynclines

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The whole-rock $\delta^{18}O$ values of terrigenous sedimentary rocks in the Appalachian Mountains are surprisingly uniform, irrespective of mineralogy, age, lithology, environment of deposition, or grain size. The bulk silicate (i.e., non-carbonate) portions of 75 Paleozoic shales, siltstones, and sandstones covering an age span from Ordovician to Permian range in $\delta^{18}O$ only from +13.2 to +17.6, with a mean $\delta^{18}O$ of +14.9. Non-marine samples have slightly lower mean $\delta^{18}O$ (+14.7) and are isotopically somewhat more uniform than marine samples (+15.3). In spite of the overall homogeneity, a systematic decrease in bulk silicate $\delta^{18}O$ is observed in shales and siltstones going from the SW (Kentucky, Tennessee) to the NE (central Pennsylvania). This geographic trend in $\delta^{18}O$ correlates with conodont color alteration index (CAI, a measure of organic metamorphism) but not with age, depositional environment, or source region, and there is *no* correlation of bulk silicate $\delta^{18}O$ with conodont CAI for the sandstones. These systematics are interpreted to be the result of oxygen isotope alteration during diagenesis; exchange with diagenetic pore fluids lowered the bulk silicate $\delta^{18}O$ of siltstones and shales by as much as 2.5 to 4.2 per mil, bringing these finer-grained rocks closer to the $\delta^{18}O$ values of the sandstones. These diagenetic changes partly account for the overall oxygen isotopic homogeneity of the Central Appalachian geosynclinal rocks (together with the thorough, grand-scale mixing of terrigenous sediment that occurred in the Appalachian geosyncline over several cycles of sedimentation, uplift, erosion, and reworking of sediments extending over hundreds of millions of years during the Paleozoic era). An analogous study of 14 terrigenous sedimentary rocks from the Ouachita Mountains (Oklahoma, Arkansas) shows a similar range of $\delta^{18}O$ (+13.4 to +16.9, mean = +15.3), but suggests greater inherent oxygen isotopic heterogeneity of source areas compared with the Central Appalachians. This complicates analysis of variation in bulk silicate $\delta^{18}O$ due to diagenesis. However, a significant correlation ($r = 0.95$) is found between vitrinite reflectance (another measure of organic metamorphism) and the difference in bulk silicate $\delta^{18}O$ between interbedded shale and sandstone pairs. Thus, because of their finer grain size, the bulk silicate $\delta^{18}O$ values of the shales were shifted downward more than those of the sandstones during diagenesis.

Reprinted as published in the Geological Society of America *Abstracts with Programs, 1993*, v. 25, no. 6, p. A-203–204.

Differences in Foreland-Basin Subsidence in Response to Contrasting Geometry and Composition of Thrust Loads

BRIAN M. WHITING and *WILLIAM A. THOMAS*, Dept. of Geological Sciences, University of Kentucky, Lexington, KY 40506

Lithospheric flexural response to loading at a thrust belt depends strongly on the composition, density, and water saturation of the thrust belt, because these properties determine the angle and width of the critically tapered wedge geometry of the thrust belt. In order to quantify the effects of different types of orogenic loads and geometries on foreland-basin subsidence, it is necessary to eliminate or minimize the effects of other factors influencing lithospheric flexural response, most notably differences in flexural rigidity. Differences in flexural response to different types of loads are recorded in foreland-basin stratigraphy.

In this study, we evaluate the effects of two different types of orogenic loads on foreland subsidence of otherwise uniform lithosphere. The Black Warrior foreland basin, which is located within the Alabama promontory of North American continental lithosphere, formed in response to two separate thrust loads: (1) the Ouachita accretionary prism along the southwest side of the basin, and (2) thrust-imbricated passive-margin rocks in the Appalachian thrust belt along the southeast side of the basin. Late Precambrian–Cambrian rifting and opening of the Iapetus Ocean was followed by establishment of a passive margin around the Alabama promontory by Late Cambrian time. Formation of the Black Warrior foreland basin was initiated in Meramecian time by northeast-directed convergence of the Ouachita accretionary prism. This was followed in mid-Morrowan time by northwest-directed Appalachian thrusting. Thus, Black Warrior foreland-basin sediments record the effects of emplacement of two different types of orogenic loads along the orthogonal adjacent sides of the Alabama promontory. Further, the maturity of the passive margin at the time of loading (≈200 m.y. between the end of rifting and orogenic collision) justifies an assumption of constant flexural rigidity for the Alabama promontory during foreland-basin subsidence.

In order or quantify effects of contrasting loads on lithospheric flexure and, hence, foreland-basin stratigraphy, we compare subsidence along two profiles through the Black Warrior foreland basin, one each perpendicular to the Appalachian and Ouachita thrust fronts. These subsidence results may be compared to computed flexural deflection profiles for both types of load, using available geologic evidence together with the assumption of critical taper.

Reprinted as published in the Geological Society of America *Abstracts with Programs, 1993*, v. 25, no. 6, p. A-177.

Low-Angle Detachment Geometry of the Late Precambrian–Cambrian Appalachian–Ouachita Rifted Margin of Southeastern North America

WILLIAM A. THOMAS, Dept. of Geological Sciences, University of Kentucky, Lexington, KY 40506

The late Precambrian–Cambrian rifted margin of southeastern North America is framed by northeast-striking rift segments offset by northwest-striking transform faults. Palinspastically restored structural profiles, thickness and composition of synrift rocks, and thickness of postrift strata vary along the trace of the rifted margin. The distribution of these variables suggests application of low-angle detachment models of continental rifting, including specific recognition of upper-plate margins, lower-plate margins, transform faults that offset the rift, and transform faults that bound domains of oppositely dipping low-angle detachments. The trace of the Mississippi Valley–Rough Creek–Rome intracratonic fault system suggests incipient rift segments offset by a transfer-fault system.

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Geology of Deep-Water Sandstones in the Mississippi Stanley Shale at Cossatot Falls, Arkansas

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The Mississippian Stanley Shale crops out along the Cossatot River in the Ouachita Mountains of western Arkansas. Here, exposures of deep-water sandstones and shales, on recently established public lands, present a rare, three-dimensional look at sandstones of the usually obscured Stanley, Cossatot Falls, within the Cossatot River State Park Natural Area, is a series of class IV and V rapids developed on massive- to medium-bedded quartz sandstones on the northern flank of an asymmetric, thrust-faulted anticline.

In western Arkansas, the Stanley Shale is a 10,000-ft (3,200-m) succession of deep-water sandstone and shale. At Cossatot Falls, approximately 50 ft (155 m) of submarine-fan-channel sedimentary rocks are exposed during low-river stages. This section is composed primarily of sets of thinning-upward sandstone beds. With rare exceptions, the sandstones are turbidites, grading from massive, homogeneous, basal beds upward through festoon-cross-bedded thick beds, into rippled medium and thin beds. Sandstone sets are capped by thin shales and siltstones. Regional, north–northwestward paleocurrent indicators are substantiated by abundant, generally east–west ripple crests asymmetric to the north–northwest. Flute casts at the top of the sandstone sequence indicate an additional east–west flow component.

Based on regional, lithologic characteristics, the sandstones at Cossatot Falls appear to be within the Moyers Formation. The Moyers is the upper sandstone unit of the Stanley and is an oil and gas reservoir in the eastern Oklahoma Ouachita Mountains.

Reprinted as published in the American Association of Petroleum Geologists *Bulletin*, v. 77, p. 1583–1584, September 1993.

The Implication of the Oxygen Isotopic Composition of Nodular Chert from the Lower Devonian Carbonate Sequences in Oklahoma and Texas

GUOQIU GAO and *L. S. LAND*, Dept. of Geological Sciences, University of Texas, Austin, TX 78713

Previous studies have suggested that the oxygen isotopic compositions of early diagenetic marine chert, if not altered subsequently, can provide important information about the temperatures and oxygen isotopic composition of paleo-oceans. In this study, we analyzed the oxygen isotopic composition of early diagenetic nodular chert from the lower Devonian shallow water carbonate sequences of the Bois d'Arc Formation of Oklahoma and the Stribling Formation of Texas. The nodular microquartz chert samples, which contain lepisphere-like textures on etching with HF, have surprisingly high oxygen isotopic compositions ranging from +30.9 to 34.0‰ (SMOW). These isotopic values are, in fact, the highest values ever documented for pre-Mississippian cherts.

We interpret that the high oxygen isotopic compositions of the lower Devonian nodular chert from Oklahoma and Texas represent near-primary compositions and that the nodular chert probably formed during early marine diagenesis. Using the relationship $1000 \ln \alpha_{\text{chert-water}} = 3.09 \times 10^6/T^2\ (K) - 3.29$ (Knauth and Epstein, 1976), the temperatures and oxygen isotopic composition of early Devonian seawater from which the nodular chert was formed can be constrained to have been 22°±3°C and 0±2‰ (SMOW), respectively. This implies that the temperatures and oxygen isotopic composition of early Devonian oceans were not very different from those of modern oceans.

Reprinted as published in the Geological Society of America *Abstracts with Programs, 1993*, v. 25, no. 6, p. A-89.

Appalachian Provenance for Paleozoic Ouachita Turbidites Indicated by Nd Isotopes

JAMES D. GLEASON, P. JONATHAN PATCHETT, WILLIAM R. DICKINSON, and *JOAQUIN RUIZ*, Dept. of Geosciences, University of Arizona, Tucson, AZ 85721

A combined Nd and Sr isotopic provenance study of sediments from the Cambrian through Pennsylvanian Ouachita sequence has established tectonic links with the Appalachian Orogen beginning in late Ordovician (Taconic) time. Middle Ordovician turbidites from the southern Appalachians (Tellico Formation), and Silurian turbidites from the Ouachitas (Blaylock Formation), yield identical Nd isotopic signatures (ε_{Nd} = –7 to –8; T_{DM} = 1.4 to 1.6 Ga). Pennsylvanian nonmarine sandstones and shales from the Black Warrior Basin (Alabama), Illinois Basin, and Arkoma Basin (Arkansas and Oklahoma) all yield Nd isotopic signatures identical to Pennsylvanian Ouachita flysch (ε_{Nd} = −8 to −9; T_{DM} = 1.4 to 1.7 Ga). These data reinforce earlier interpretations, based on paleocurrent and petrographic data, for an Appalachian source for the Carboniferous Ouachita flysch. The Nd data now push back the Appalachian–Ouachita connection to the late Ordovician (450 Ma), 150 My before the Ouachita Orogeny.

A remarkable aspect of the Ouachita data set is the dramatic and abrupt early Paleozoic shift in provenance indicated by Nd isotopes. The shift occurs during the late Ordovician between deposition of the Womble Formation (ε_{Nd} = −15; T_{DM} = 2.1 Ga) and Bigfork Formation (ε_{Nd} = −8; T_{DM} = 1.6 Ga). We interpret the early Paleozoic signature to be a mixture of Proterozoic and Archean craton sources lying to the north. The abrupt shift in provenance which occurs at 450 Ma is probably linked to Taconic events in the Appalachians. The late Ordovician through Pennsylvanian signature we interpret to reflect mainly Appalachian sources, and its persistence must reflect a near-continuous feed from the rising Appalachian Orogen via the deep marine Ouachita trough. By Carboniferous time, the craton and its margins were being flooded with orogenic sediments of a single homogenized isotopic signature. This firmly establishes the presence of a long-lived, continent-scale Paleozoic sedimentary dispersal system which was initiated in the late Ordovician by the Taconic Orogeny and culminated with the late Paleozoic Ouachita Orogeny.

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Three-Dimensional Geometry and Kinematics of the Gale–Buckeye Thrust System, Ouachita Fold and Thrust Belt, Latimer and Pittsburg Counties, Oklahoma

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The Gale–Buckeye thrust system consists of a series of blind thrusts and associated folds near the boundary between the Ouachita fold and thrust belt and the Arkoma basin in Oklahoma. A dense grid of high-resolution seismic reflection data, augmented by data from exploration and production wells, provides a unique opportunity to analyze and three-dimensional geometry and kinematics of these structures in detail. Results from our interpretation provide new insight into the extent, style, and sequence of thrusts within the Gale–Buckeye thrust system, and contrast with previous models for the region. Specifically, we recognize two previously unmapped transverse structures in the Gale–Buckeye thrust system: a sharp, left-stepping zone of oblique ramps, and a tear fault within the Gale thrust sheet. These transverse structures are spatially coincident with similar structural trends in lower Paleozoic strata beneath the thrust system as well as outcropping structural trends on the surface. This interpretation extends thrusts in the Gale–Buckeye system to minimum strike lengths of 7–9 mi (11–15 km) and fault length-to-displacement ratios of about 10:1. Furthermore, interpreted structural relationships suggests that the Gale and Buckeye thrusts formed in a backward-stepping manner, a new interpretation for faults in this system.

Measurement of differential transport angles from our interpretations of the Gale–Buckeye thrust system indicates that along-strike displacement variations of the Gale and Buckeye thrusts are consistent with thrusts from other nonmetamorphic fold and thrust belts. Using the differential transport model, we infer that the tear fault in the Gale thrust sheet indicates a region that became segmented to accommodate excessive

along-strike differences in displacement. In addition, we use the model to explain errors in previous interpretations of the Gale–Buckeye thrust system that resulted in the drilling of dry holes. Integrating realistic differential transport angles with our interpretations for extent, style, and sequence of thrusting provides new strategies for hydrocarbon exploration throughout the region.

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Flexural and Gravity Constraints on the Crustal Structure of the Ouachita Mountains and Arkoma Basin, Arkansas and Oklahoma

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The Ouachita orogenic belt and the Arkoma basin of Arkansas and Oklahoma were formed during a mid-to-late Paleozoic convergence. Numerous geological studies have been conducted by the deeper crustal structure is poorly known. The only deep seismic studies have been in western Arkansas and the Llano region of central Texas.

To help determine the crustal structure of the Ouachita orogenic belt of Arkansas and Oklahoma, we analyzed gravity and topographic data using spectral analysis, and forward and inverse modeling. Bouguer gravity anomaly and topographic data gridded at a 2 km interval were projected onto nine profiles striking perpendicular to the trend of the Bouguer gravity minimum associated with the Ouachita Mountains. The slope of linear segments in the gravity spectra indicate major density interfaces at mean depths of 2.5 and 35–40 km. These are interpreted as the top of the pre-basinal basement beneath the Arkoma basin, and the crust/mantle boundary. The admittance calculated from the gravity and topographic profiles suggest a flexural rigidity of 10**24, corresponding to an elastic thickness of 48 km. The shape of the admittance functions indicate a large subsurface load beneath the western Ouachita Mountains, but little subsurface loading beneath the eastern Ouachita Mountains. Inversion results suggest the buried thrust sheet is thickest 30–40 km south of the leading edge of the exposed thrust front.

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Exploration in Mature Areas

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The Choctaw play, Arkoma basin, southeastern Oklahoma, is one of the active exploration plays in the United States. The first wells discovered porous Pennsylvanian Spiro sandstone in "blind-imbricate" thrust plates beneath the hanging wall Choctaw thrust fault. Secondary reservoirs were discovered in the Upper Pennsylvanian (Brazil and Cecil) sandstones and in the Lower Pennsylvanian Wapanucka limestone and Cromwell sandstone.

Amoco Production Company has operated or participated in 65 of the total 102 wells drilled since 1987, with an economic success rate of >65%. Approximately 180 MMcf of natural gas is produced daily from these wells. Amoco's success rate is attributed to the innovative use of technologies to define source characteristics and reservoir/trap configurations.

The following geotechnical problems exist: timing of thrusting relative to generation and expulsion, geothermal history of the basin and source maturity, imaging small

(±450 ac) imbricate plates at depths in excess of 12,000 ft through hanging-wall section dipping >70°, understanding productive analogies in the basin (the giant Red Oak and Wilburton fields), and determination of the paleogeography of the Spiro shelf.

Amoco used various technologies to address these geotechnical problems, including basin modeling, fission track analysis, fluid inclusion analysis, depth migration before stack processing, and palinspastic restoration. The Spiro play has matured and the Atokan sand play is the next viable exploration target. The Atokan sands are depositionally more discontinuous than the Spiro, and further disruption by thrusting creates a very complex geometry. To be successful in this new subtle play, Amoco must continue to apply innovative technologies creatively.

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Geologic Controls on the Occurrence of Methane in Coal Beds of the Pennsylvanian Hartshorne Formation, Arkoma Basin, Oklahoma

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Hartshorne coals have long been known to be extremely gassy because early underground mines in the Arkoma basin were plagued by methane. Mine data, combined with recent advances in coal-bed methane technology, allow us to better quantify this gas resource.

The gas content of Hartshorne coals is controlled by a number of factors, including thickness, thermal maturity, ash content, and reservoir pressure. Hartshorne coal can be generally characterized as being thin (<6 ft), of relatively high thermal maturity (R_o 0.7 to 1.7), and of relatively low ash content (<10%). Very little pressure data are available for the Hartshorne, but it appears that Hartshorne coals are underpressured to normally pressured with no indication of overpressuring. Estimates of gas in place for Hartshorne coal range from 2 to 6 Bcf of gas per 640 ac.

Primary controls on the producibility of methane from the Hartshorne include the hydrology of the coal and its permeability. Conflicting data exist as to the nature of the hydrologic regime of the coal. The existence of dry coal in a variety of structural settings is well established. Free-water production from the coal, where present, tends to be low volume (<10 bbl/day) and of a brackish chloride composition. Permeability is controlled by a number of factors, including cleat intensity and tectonic fracturing. Locally, diagenetic cements may significantly reduce permeability.

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Origin of Pennsylvanian Cyclothems, Ardmore Basin, Oklahoma

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Sedimentologic and biostratigraphic studies were conducted to assess the eustatic and/or tectonic origin of Mid-Pennsylvanian cyclothems in the Deese Group, Ardmore Basin. The lower Deese group can be divided in part into cyclothem-type units separated by thin transgressive limestones and/or dark gray to black shales. The intervals between the marine flooding units are variable, and include a set of four to six thin fining-upward marine sandstones, sets of five thin coarsening-upward delta front sequences, coarsening-upward deltaic/alluvial sequences capped by chert pebble conglomerates, and coarsening-upward delta front and fining-upward delta plain sequences.

Fusulinid and conodont biostratigraphy indicates that the lower Deese Group correlates with Desmoinesian intervals in the Midcontinent which contains Kansas type cyclothems interpreted as glacial eustatic in origin. The biostratigraphic results and the pattern of cycles do not allow a direct correlation with the individual eustatic cyclothems in the Midcontinent although the results suggest a likely eustatic influence on the Deese Group (supported by the apparent five-fold bundling). In contrast, the occurrence in some intervals of thick coarse chert pebble conglomerates, which increase in thickness and grain size to the southeast, suggest that these units are tectonic in origin and related to uplift of the Ouachita Fold Belt. This belt is located in the subsurface just to the southeast of the Ardmore Basin.

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Balanced Cross Sections of the Arbuckle–Ardmore Region, Southern Oklahoma: Implications for Strike-Slip Deformation

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The structures of the Arbuckle Mountains and Ardmore Basin have long been considered definitive examples of strike-slip deformation. These interpretations are questionable, however, because estimates of the amount of strike-slip on the main fault (the Washita Valley Fault) vary from as little as 3 miles to as much as 40 miles, and COCORP and other subsurface data show that the major faults of the area dip only 40–50°.

This paper presents a series of highly constrained, balanced and palinspastically restored vertical cross sections which show that the observed structures may be entirely dip-slip compressional structures. The overall structure is that of a large-scale passive duplex. The master "strike-slip" fault, which appears to reverse its dip and sense of throw along strike, is interpreted as the roof and floor thrusts bounding a plunging basement wedge. The Arbuckle Anticline itself is interpreted as a fault-bend fold in the hanging wall of the roof thrust. The apparent releasing bend in the apparent master strike-slip fault appears to be a triangle zone in the foot wall of the roof thrust. The apparent positive flower structures adjacent to the Arbuckle Anticline are interpreted as second-order, detached isoclinal folds in the roof sequence of the duplex. These new interpretations suggest that many of the structural criteria thought to be characteristic of strike-slip structures, are in fact characteristic of dip-slip passive duplexes involving basement.

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Multiple Stratigraphic Indicators of Major Strike-Slip on the Eola Fault, Subsurface Arbuckle Mountains, Oklahoma

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The study area for this paper is in Garvin, Stephens and Grady Co., Oklahoma, and includes Townships 1 to 4 North and Ranges 2 to 6 West, exclusive of the three northeasternmost townships and the area south of the Washita Valley Fault. The Eola Fault is the northernmost major fault in the study area that has the same orientation as the major faults in the Arbuckle Mountains. The Eola Fault bisects the deep portion of the Eola Oil Field (T. 1 N., R. 2 and 3 W.) into a north and south block. At least 9 wells have cut the fault, and there are more than 200 wells within 1 mile on either side of the fault to define stratigraphic relationships. The fault is a linear steeply southwest dipping fault that trends N75°–80°W over the 8 mile length of the Eola Field. On the east end of the field the fault has 1,500′ apparent normal separation, while on the east end it has 2,000′ of apparent reverse separation. Cross sections show that the Eola Fault had ceased movement while the Washita Valley Fault to the south was still active. Juxtaposition of markedly different stratigraphy across the fault in at least 10 units indicate that lateral movement is a major constituent of displacement on the fault.

More than 650 well logs have been used to construct isochore maps of units that change consistently from east to west across the study area. Displacement of contour lines are then used to show the amount of lateral offset on the Eola Fault. Isochore maps of the Net Clean Sycamore Siltstone, Hunton Limestone, and Tulip Creek Shale each show 16 miles of left lateral strike-slip on the Eola Fault. A map of the presence of a hot shale in the upper part of the Lower Sylvan Shale does not give a definite amount of offset, but is consistent with the 16 miles of left lateral strike-slip deduced from the other three maps.

By combining the structure maps, fault maps, and isochore maps, the Eola Fault is shown to have 16 miles of left lateral strike-slip plunging 3° to the west, with less than ½ mile of either reverse or normal displacement. The findings of this study are consistent with a wrench fault model of deformation for the Arbuckle Mountain Region. Other models may be proposed which also explain the left lateral strike-slip on the Eola Fault, but no models of structural deformation should be proposed for this area which do not take this major displacement into consideration.

This is an abstract of a paper as presented at the AAPG Mid-Continent Section Meeting, October 10–12, 1993, Amarillo, Texas, and differs from the earlier abstract of the paper as published in the American Association of Petroleum Geologists *Bulletin*, v. 77, p. 1575, September 1993.

Remagnetization of the Basal Cambrian Aquifer in the Arbuckle Mountains, Southern Oklahoma

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Remagnetization is a common phenomenon observed in many sedimentary rocks and recently there have been numerous reports of secondary magnetizations in igneous rocks. One commonly invoked remagnetization mechanism is migration of orogenic fluids through aquifers. In this paper we present paleomagnetic results from the Reagan Sandstone (Late Cambrian), the basal aquifer in the Paleozoic section, and the underlying Middle Cambrian Colbert Rhyolite Porphyry (525 Ma) in the Arbuckle Mountains. Some samples of relatively unaltered rhyolite contain a magnetization that resides in magnetite and a fold test, although not conclusive, suggests this component could be primary. A pole position, based on preliminary data, is 13°S, 153°E.

An altered zone at the top of the rhyolite and rhyolite clasts in the Reagan Sandstone contain a component that resides in hematite. A conglomerate test indicates that this component is secondary. Because this component has only been found along one flank of a fold, it is not constrained by a fold test and it could either be Cambrian–Ordovician or Late Paleozoic in age. This magnetization is probably related to either migration of fluids in the basal Reagan or weathering processes during deposition of the Reagan. In-

vestigations are currently underway to test these hypotheses and to determine if the remagnetization is related to Late Paleozoic secondary magnetizations that commonly occur in the overlying Paleozoic carbonates in the Arbuckle Mountains.

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Relationship of Facies and Sequence Stratigraphy to Paleokarst and Fracture Overprints in the Carbonates of the Arbuckle Group in the Evaluation of Exploration and Horizontal Drilling Potential

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The mid-continent region, especially in Oklahoma and Arkansas, contains thick dolomite Paleozoic carbonate sections with karstic character. These sections commonly exhibit strong structural overprints, including intense fracturing, due primarily to Pennsylvanian orogenies.

The Arbuckle Group is composed of multiple parasequences that are the results of cyclic peritidal deposition on a broad shallow shelf. Sequence stratigraphy evaluation indicates that significant unconformities or disconformities occur within the Arbuckle Group along third-order sequence boundaries.

Arbuckle carbonates were subjected to very early dolomitization (Ordovician through Devonian). Sequences in which intercrystalline porosity was developed with little or no vuggy porosity usually have low permeability and effective porosity; however, these dolomitic sequences are quite susceptible to fracturing, and they may produce in structural traps. These fractured sequences in the Arbuckle also are particularly susceptible to karstification associated with multiple unconformities especially in areas where there has been significant orogenic activity, such as the Criner uplift in southern Oklahoma. Fracturing and subsequent karstification have significant influence on porosity development and can produce extremely heterogeneous reservoirs.

Exploration for oil and gas in the Arbuckle Group at best has been a difficult task. Problems with seal and source along with complex diagenetic and structural histories still plague efforts to understand Arbuckle reservoir development. There is new evidence that dolomitization, fracturing, and karstification may be related to particular sequence positions and their related facies and disconformities. Innovative advances in geologic concepts, such as sequence stratigraphy, and in techniques, such as horizontal drilling, may lead to new discoveries in the Arbuckle Group.

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Two Middle Pennsylvanian Tonsteins in Kansas

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Two Middle Pennsylvanian tonsteins (volcanic ashes altered to kaolinitic claystone) have been found in southeastern Kansas. The lower of the two tonsteins is present in an unnamed black fissile shale in the Cabaniss Formation of the Cherokee Group, a few meters above the Croweburg coal. This black shale is equivalent to the Mecca Quarry Shale of Indiana and Illinois, and the Oakley Shale of Iowa. Thickness of the volcanic ash bed is generally about one cm and it was observed as a continuous bed in several surface coal mines in Crawford and Cherokee counties, Kansas, and in adjacent Vernon County, Missouri. The tonstein was present in all mines in these counties with an exposure of this black shale unit. The volcanic ash bed is also present as a layer less than one cm thick in a core from Leavenworth County, Kansas, about 160 km north of the mine localities. An attempt is being made to obtain a radiometric age from a sparse layer of very fine sand-sized phenocrysts present at the base of the bed. The second tonstein is present in the Anna Shale, a black fissile shale member of the Pawnee Formation in the Marmaton Group. This ash bed is present about 35 m stratigraphically higher than the first ash bed, has a thickness of only 1–2 mm, but was detected in six outcrops over a lateral distance of about 80 km in Crawford, Bourbon, and Labette counties.

Preliminary attempts to detect these two tonsteins in equivalent strata in Indiana and Illinois have not been successful. Next year we will try to trace them into adjacent states. Compared to other North American tonsteins, their occurrence in black shales rather than coal is somewhat unusual. Because of their stratigraphic importance, a search should be made for other tonsteins in black shales associated with Mid-Continent coal beds.

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Mobilization of Uranium in the Central Oklahoma Aquifer

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Geochemical processes result in high concentrations of dissolved uranium (>20 μg/L, the drinking-water standard proposed by the U.S. Environmental Protection Agency, 1991) in water in the Central Oklahoma aquifer, though the rock matrix is not uranium rich. The rocks are early Permian red lenticular sandstone and mudstone that dip gently westward. The western third of the aquifer is confined. Analysis of 164 water samples from 141 wells and 8 test holes showed that 35 samples contained 20 to 318 μg/L uranium. High dissolved-uranium concentration is common in (1) confined parts of the aquifer and (2) unconfined parts of the aquifer where mudstone is more abundant than sandstone. Minerals in the aquifer that contain potentially soluble uranium include sparse uranium-oxides and uranyl vanadates in reduction zones, authigenic ferric iron oxides, and possibly clays.

Oxidation, dissolution, and desorption result in transfer of uranium from the solids into solution. Most water in the aquifer contains dissolved oxygen, which favors oxidation of uranium^{+4} solids to form the soluble uranyl ion. Dissolution of uranyl vanadates and desorption of the uranyl ion from iron oxides and clays are enhanced by formation of uranyl-carbonate ion complexes. In parts of the aquifer where high concentration of dissolved uranium is present, carbonate-ion activity is high as a consequence of reactions between ground water and rock components. The reactions include dissolution of dolomite and calcite and exchange of resulting calcium and magnesium for sodium in mixed-layer clays. These reactions cause a progressive change in water chemistry from a calcium magnesium bicarbonate type in unconfined parts of the aquifer to a high-pH (>8.5) sodium bicarbonate type in confined parts of the aquifer where ground water is isolated from atmospheric carbon dioxide. In clayey, shallow parts of the aquifer where soil-zone carbon dioxide is available, the reactions result in water with a near-neutral pH but with a high alkalinity (300 to 650 μg/L). Increasing pH or alkalinity increases the carbonate-ion activity and enhances uranyl-carbonate complex formation, mobilizing uranium.

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New Coal Mine in Le Flore County *(continued from p. 2)*

blasts much of the overburden into the cut from which the coal has been removed. This method, called "cast blasting," is an efficient way to initiate reclamation, as it eliminates the need to handle a large part of the overburden more than once.

The Secor and Secor Rider coals are beds in the Boggy Formation, present ~153 ft above the Lower Witteville coal at the mine site (see article on Lower Witteville coal, Appendix, measured section Le-6-93-H, this issue, for detailed stratigraphic section). The following composite section was measured by the author in different pits at the Wister Mine.

Measured Section Le-5-93-H

SE¼NW¼NE¼ sec. 13, T. 6 N., R. 23 E., and SW¼SW¼NW¼ sec. 18, T. 6 N., R. 24 E., Le Flore County. Measured in highwalls of active strip mine operated by Farrell-Cooper Mining Co. Rock color classifications (in parentheses) are from the Munsell color system (Rock-Color Chart Committee, 1991).

	Thickness (feet)
KREBS GROUP:	
Boggy Formation:	
12. Shale, medium-dark-gray (N 4), upper 3 ft weathered to dark-yellowish-orange (10YR 6/6)	10.0
11. Coal, black (N 1), bright, well-developed cleat system, dark-yellowish-orange (10YR 6/6) iron oxide staining on cleats (Secor Rider coal)	0.7
10. Shale, dark-gray (N 3), carbonized plant fragments in upper part	1.8
9. Sandstone, very fine-grained, medium-light-gray (N 6), weathers moderate-yellowish-brown (10YR 5/4)	2.0
8. Shale, dark-gray (N 3) with medium-gray (N 5) sideritic nodules and stringers	36.0
7. Coal, black (N 1), well-developed cleat system, moderately friable; includes a 0.3-ft-thick dark-gray (N 3), carbonaceous shale parting in middle of unit (upper split, Secor coal)	1.6
6. Shale, dark-gray (N 3)	2.1
5. Shale, grayish-black (N 2), very carbonaceous	1.8
4. Coal, black (N 1), impure, very shaly, well-developed cleat system (middle split, Secor coal)	1.7
3. Underclay, medium-gray, slickensided	2.0
2. Shale, dark-gray (N 3)	4.4
1. Coal, black (N 1), well-developed cleat system, moderately friable (lower split, Secor coal)	0.9
Total thickness of section	65.0

The Secor coal is split into several units in the Wister Mine, but the splits tend to converge to the east. Knechtel (1949, p. 51) said that on the east and north side of Cavanal Mountain, near Poteau, the coal is ≥3 ft thick and is free from partings. However, more recent observations by S. A. Friedman (personal communication, 1994) in active mines indicate that partings of claystone and shale are abundant on the north and southeast sides of Cavanal Mountain.

The lower split of the Secor is mined in the Wister Mine. It is ~0.9 ft thick, and has an ash content of 13.9%, a sulfur content of 2.4%, and a heat value of 12,956 Btu. The middle split is not mined because of an excessively high ash content. The upper split, ~4 ft stratigraphically higher than the middle split, is mined. It has a total thickness of 1.6 ft, which includes a 0.3-ft-thick carbonaceous shale parting. The coal bench below the parting has an ash content of 15.3%, a sulfur content of 5.37%, and a heat value of 12,892 Btu. The coal bench above the parting has an ash content of 19.6%, a sulfur content of 5.20%, and a heat value of 12,017 Btu. The Secor Rider, also mined, which occurs stratigraphically ~40 ft above the top of the Secor, is the best quality coal. Its thickness ranges from 0.5 to 0.8 ft. Its contents of ash (3.91%) and sulfur (0.92%), and its heat value of 14,213 Btu, make it very useful for blending with the Secor to improve average quality. (Analytical data, from grab samples, were provided by the Farrell-Cooper Mining Co.)

Because of plentiful reserves in the area and good demand for the coal, the outlook for continued operation of the Wister Mine is excellent.

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