OKLAHOMA GEOLOGY

Oklahoma Geological Survey Vol. 53, No. 3 June 1993

On the cover—

Outcrop of the Sam Creek(?) Limestone in Le Flore County, Oklahoma

An excellent exposure of a limestone bed tentatively identified as the Sam Creek Limestone Member of the Savanna Formation (Pennsylvanian) was found in an unnamed tributary of Caston Creek, NW¼SW¼NE¼ sec. 27, T. 6 N., R. 24 E., Le Flore County. The discovery was made during the course of mapping the Summerfield, Oklahoma, 7.5′ Quadrangle as part of the Ouachita COGEOMAP Project. No limestone bed occupying a similar stratigraphic position has been identified in the subsurface or observed in outcrop previously in Le Flore County. Recognition of the Sam Creek(?) Limestone in this part of the Arkoma basin is significant because of its importance as a stratigraphic marker. The outcrop shown on the cover is its southeasternmost known occurrence. It is 1.3 ft thick, fossiliferous, blocky, well jointed, and dips 14° NW at this site. Further information on other occurrences of the Sam Creek(?) Limestone in Le Flore County is given in a paper in this issue (p. 84–111).

LeRoy A. Hemish

Oklahoma Geology Notes, ISSN 0030-1736, is published bimonthly by the Oklahoma Geological Survey. It contains short technical articles, mineral-industry and petroleum news and statistics, abstracts, notices of new publications, and announcements of general pertinence to Oklahoma geology. Single copies, $1.50; yearly subscription, $6. Send subscription orders to the Survey at 100 E. Boyd, Room N-131, Norman, OK 73019. Short articles on aspects of Oklahoma geology are welcome from contributors; general guidelines will be sent on request.

This publication, printed by the Oklahoma Geological Survey, Norman, Oklahoma, is issued by the Oklahoma Geological Survey as authorized by Title 70, Oklahoma Statutes 1981, Section 3310, and Title 74, Oklahoma Statutes 1981, Sections 231–238. 1,500 copies have been prepared for distribution at a cost of $1,176 to the taxpayers of the State of Oklahoma. Copies have been deposited with the Publications Clearinghouse of the Oklahoma

OKLAHOMA GEOLOGY NOTES

CONTENTS

OKLAHOMA
GEOLOGICAL
SURVEY

VOL. 53, NO. 3

JUNE 1993

SPANIARD(?) AND SAM CREEK(?) LIMESTONES IN LE FLORE COUNTY, OKLAHOMA

LeRoy A. Hemish[1]

Abstract

The Spaniard and Sam Creek Limestone Members of the Savanna Formation (Pennsylvanian), have been tentatively identified in Le Flore County, in the eastern part of the Arkoma basin of Oklahoma, in T. 6 N., Rs. 24 and 25 E. The outcrop belt of the Spaniard(?) Limestone, which marks the base of the Savanna Formation, extends for a distance of >9 mi, roughly paralleling U.S. Highway 271 in the Summerfield and Wister 7.5′ Quadrangles. The outcrop belt of the Sam Creek(?) Limestone, which is stratigraphically about 150–170 ft above the Spaniard(?) Limestone, extends for a distance of ~3 mi just south of U.S. Highway 271 in the Summerfield 7.5′ Quadrangle. Neither of the two limestones had been mapped previously south of T. 10 N., R. 19 E., in Muskogee County.

Introduction

The purpose of this paper is to record the discovery of the Spaniard(?) and Sam Creek(?) Limestone Members of the Savanna Formation in an area where they were previously unknown. Several good exposures of the two limestones were found during the course of detailed field mapping of the Summerfield and Wister, Oklahoma, 7.5′ Quadrangles, as part of the Ouachita COGEOMAP Project. Figure 1A is an excerpt from the geologic map of the Summerfield Quadrangle (Hemish and Mazengarb, 1992), showing the outcrop traces of the Spaniard(?) and Sam Creek(?) Limestones. Figure 1B is an excerpt from the geologic map of the Wister Quadrangle (Hemish and Suneson, 1993), showing the eastern extent of the outcrop trace of the Spaniard(?) Limestone. Strikes and dips measured on the rocks show a diminishing northwestward dip toward the axis of the Cavanal syncline (off the maps). Dip measurements on the Spaniard(?) and Sam Creek(?) Limestones range from 8 to 18°. The discovery of the two limestones in Le Flore County is significant because of their importance as stratigraphic markers—in surface mapping as well as in subsurface work.

Spaniard Limestone

The Spaniard Limestone Member of the Savanna Formation was named from Spaniard Creek in the NE¼ sec. 11, T. 13 N., R. 18 E., Muskogee County, (Fig. 2 [X[1]]), by S. W. Lowman (1932) in an unpublished manuscript from which Wilson (1935, p. 510) quoted the following measured section:

---

[1]Oklahoma Geological Survey.

	Ft	In.
Limestone: dark-gray, fine-grained, weathers brown	1	2
Shale: dark-[gray] to black, fossiliferous, weathers buff	0	6
Shale: blue-gray, fossiliferous, calcareous	1	6
Total	3	2

The Spaniard Limestone is exposed sporadically throughout the northeastern Oklahoma shelf area where its base marks the boundary between the McAlester Formation and the overlying Savanna Formation (Figs. 2[X³]; 3). The following measured section from Hemish (in preparation) exemplifies the Spaniard Limestone and associated strata as seen in the northeastern Oklahoma shelf area (Fig. 2[X⁴]):

MM-105-82-H

NE¼NW¼SW¼NW¼ sec. 20, T. 13 N., R. 18 E., Muskogee County (Oktaha 7.5′ Quadrangle). Measured in ravine from gravel road eastward down slope, by LeRoy A. Hemish. (Estimated elevation at top of section, 580 ft.)

	Thickness (ft)
KREBS GROUP	
Savanna Formation:	
Shale, grayish-brown, fissile, weathers to small flakes on the outcrop	8.0
Limestone, brownish-gray to grayish-purple, weathers grayish-orange-pink; very dark-red and ferruginous in lower 1 in., impure, silty; very fossiliferous, brachiopods abundant (Spaniard Limestone Member)	1.3
McAlester Formation:	
Shale, yellowish-gray with orange mottling, calcareous, weathered	1.0
Covered interval	1.7
Sandstone, greenish-gray to grayish-brown, very fine-grained, thin- to medium-bedded, hard, noncalcareous, ripple-marked in part; contains abundant burrows and trails (top of Keota Sandstone Member).................	4.0
Shale, moderate-yellowish-brown with orange streaks, weathered, poorly exposed	11.0
Limestone, dark-gray, impure, carbonaceous, very fossiliferous	0.5
Coal, black, soft, weathered (Keota coal)	0.3
Underclay, light-brownish gray	0.2
Shale, grayish-brown, silty (base covered)	12.0
Total	40.0

The northernmost exposure of the Spaniard Limestone was mapped by Branson and others (1965, pl. 1) just south of the town of Bluejacket in the SW¼ sec. 21, T. 27 N., R. 21 E., Craig County (Fig. 2[X⁶]). The northernmost documented occurrence of the Spaniard Limestone is in the NW¼NE¼NE¼NE¼ sec. 24, T. 27 N. (Fig. 2[Oᴬ]), where it was encountered in a core hole at a depth of 122 ft (Hemish, 1990b, p. 51). It was described as a grayish-black, very impure, shaly limestone 0.8 ft thick, containing abundant fossil shells.

The previously known southernmost exposure of the Spaniard Limestone was mapped by Oakes (1977, pl. 1) in the NW¼ sec. 34, T. 10 N., R. 19 E., Muskogee County, just north of the Canadian River (Fig. 2[X⁸]). He stated that the Spaniard is

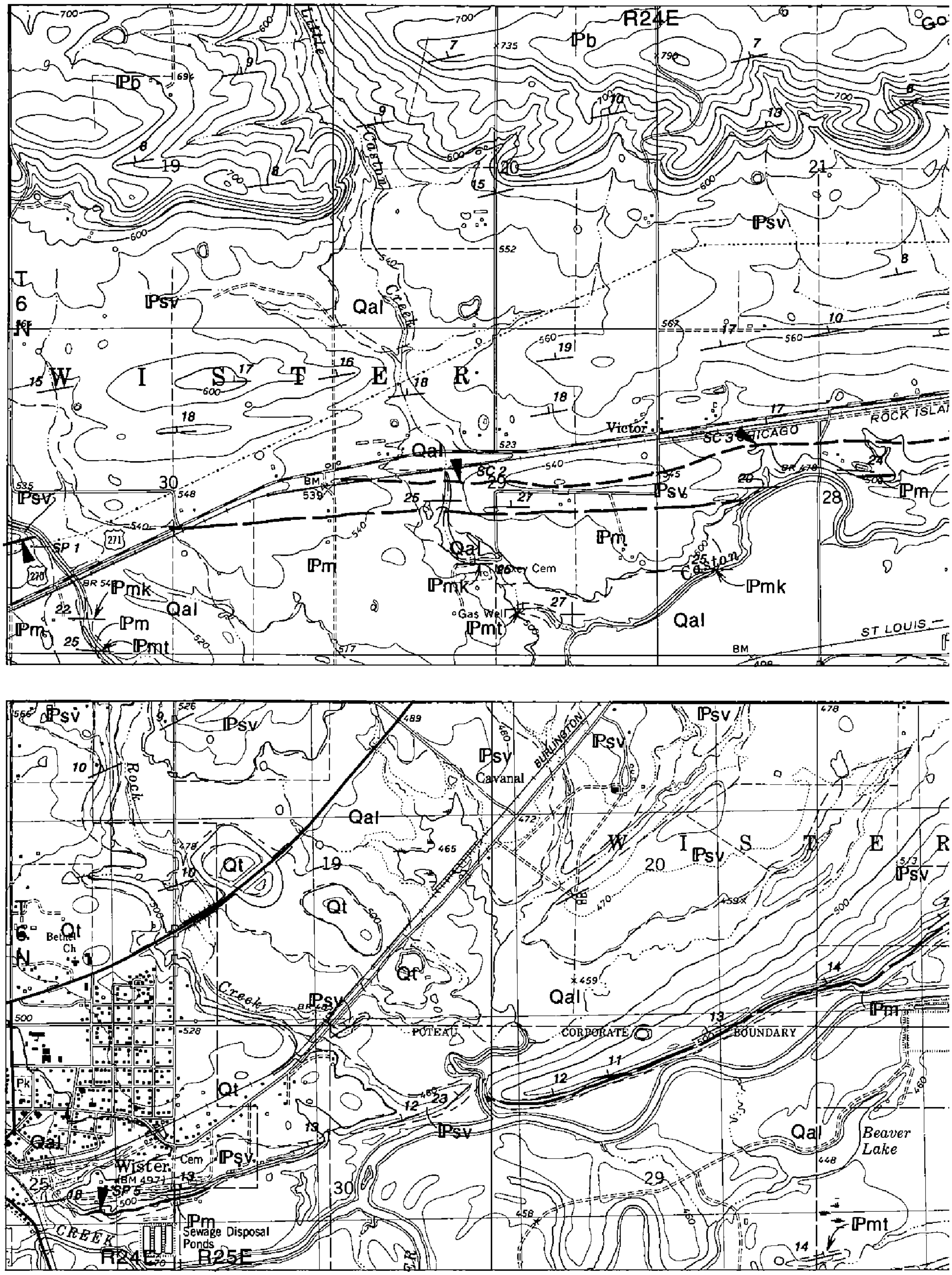
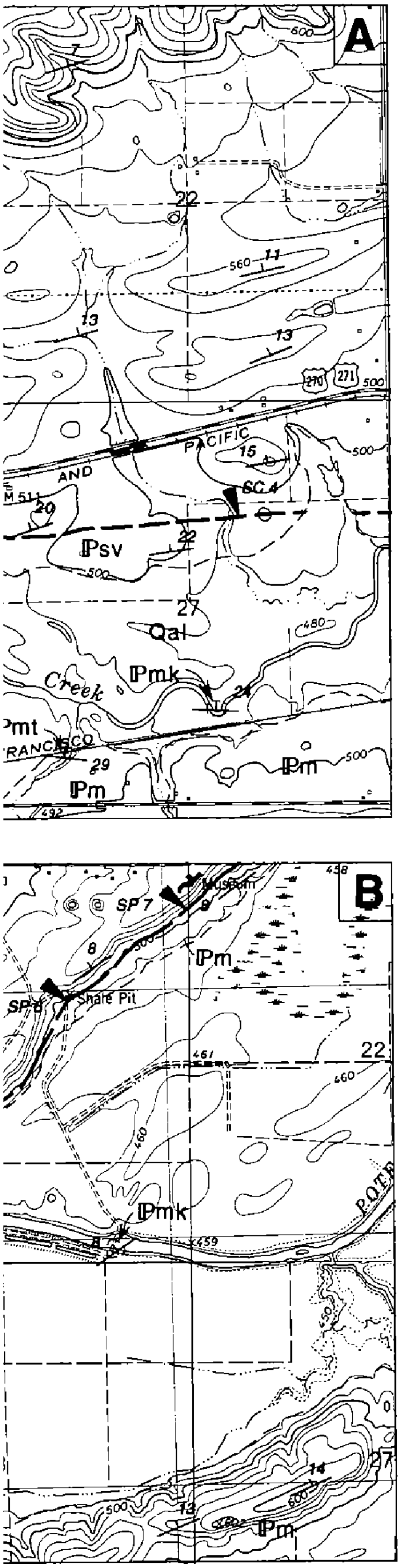
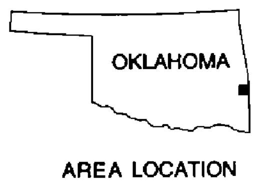


Figure 1. Geologic maps showing stratigraphic units present in study area and their relationship to exposures of the Spaniard(?) and Sam Creek(?) Limestones (outcrop lines in color).

(continued on next page)





EXPLANATION

Qal	Quaternary alluvium
Qt	Quaternary terrace deposits
Pb	Boggy Formation
Psv	Savanna Formation
Pm	McAlester Formation

PENNSYLVANIAN (Boggy, Savanna and McAlester Formations)

Contact–Dashed where approximately located

Spaniard Limestone (?) approximately located

Sam Creek Limestone (?) approximately located

25

Strike and dip of beds, facing direction know

SP 1

Exposure of Spaniard (?) Limestone; number corresponds to measured section, appendix

SC 2

Exposure of Sam Creek (?) Limestone; number corresponds to measured section, appendix

Pmk

Exposure of Keota Sandstone Member of McAlester Formation

Pmt

Exposure of Tamaha Sandstone Member of McAlester Formation

0 — 1 MILE

0 — 1 KM

Modified excerpts from (*A*) Hemish and Mazengarb (1992) and (*B*) Hemish and Suneson (1993).

- X^1 Type section of Spaniard Limestone (Muskogee County)
- X^2 Type section of Sam Creek Limestone (Muskogee County)
- X^3 Location of photographed outcrop of Spaniard Limestone (Wagoner County)
- X^4 Typical outcrop of Spaniard Limestone in shelf area (Measured Section MM-105-82-H) (Muskogee County)
- X^5 Typical outcrop of Sam Creek Limestone in northern Arkoma Basin area (Measured Section MM-98-82-H) (Muskogee County)
- X^6 Northernmost known outcrop of Spaniard Limestone (Craig County)
- X^7 Norththernmost known outcrop of Sam Creek Limestone (Craig County)
- X^8 Southernmost known outcrop of Spaniard and Sam Creek Limestones prior to this report (Muskogee County)
- X^9 Southernmost known outcrop of Sam Creek (?) Limestone, this report (Le Flore County)
- X^{10} Southeasternmost known outcrop of Spaniard (?) Limestone, this report (Le Flore County)
- O^A Northernmost known occurrence of Sam Creek and Spaniard Limestones, core-hole (Craig County)
- O^B Southeasternmost known occurrence of Sam Creek and Spaniard Limestones, gas well (Haskell County)

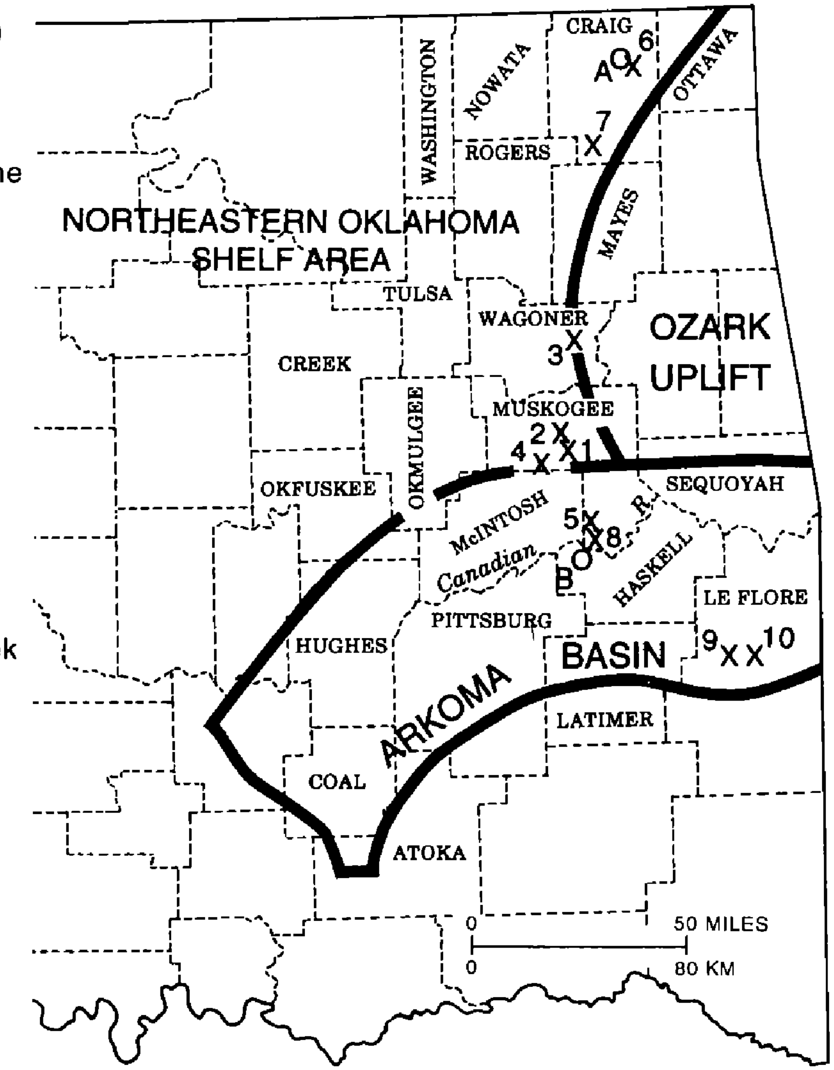


Figure 2. Eastern Oklahoma showing the northeastern Oklahoma shelf area, the Arkoma basin, and the Ozark uplift. Occurrences of Spaniard and Sam Creek Limestones discussed in text shown on map.

Photo by James R. Chaplin

Figure 3. Exposure of the Spaniard Limestone showing the McAlester–Savanna contact, NE¼NW¼SE¼NE¼ sec. 9, T. 17 N., R. 18 E., Wagoner County (Wagoner West 7.5′ Quadrangle). The limestone at this site is 3.1 ft thick, medium-gray, buff-weathering, thin-bedded and shaly in upper part, massive in lower part, and fossiliferous, with abundant horn corals.

2–9 in. thick in that vicinity. Oakes and Knechtel (1948) did not find the Spaniard Limestone south of the Canadian River in Haskell County. They did show (Fig. 4) that the Spaniard Limestone occupies approximately the same stratigraphic position as does the base of the lowest sandstone of the Savanna Formation in that county. The convention of mapping the contact between the McAlester Formation and the Savanna Formation at the base of the lowest Savanna sandstone, where the Spaniard Limestone is absent in quadrangles immediately west of the study area, was followed by Hemish and others (1990a,b,c) and Hemish (1991,1992).

Previous surface investigations by Morgan (1924) in the western Arkoma basin did not reveal the presence of the Spaniard Limestone or any likely equivalent in a similar stratigraphic position. A surface investigation of northern Latimer County (just west of the study area) by Russell (1960) did not reveal the presence of the Spaniard Limestone. He noted (p. 21) that the only limestone he observed "in the Savanna Formation occurs in a green shale approximately 920 feet above the base of the formation."

Neither Hendricks (1939), Knechtel (1949), nor Webb (1960) noted the presence of any limestones that might be equivalent to the Spaniard during their surface investigations of areas directly north from and/or including the area of present investigation.

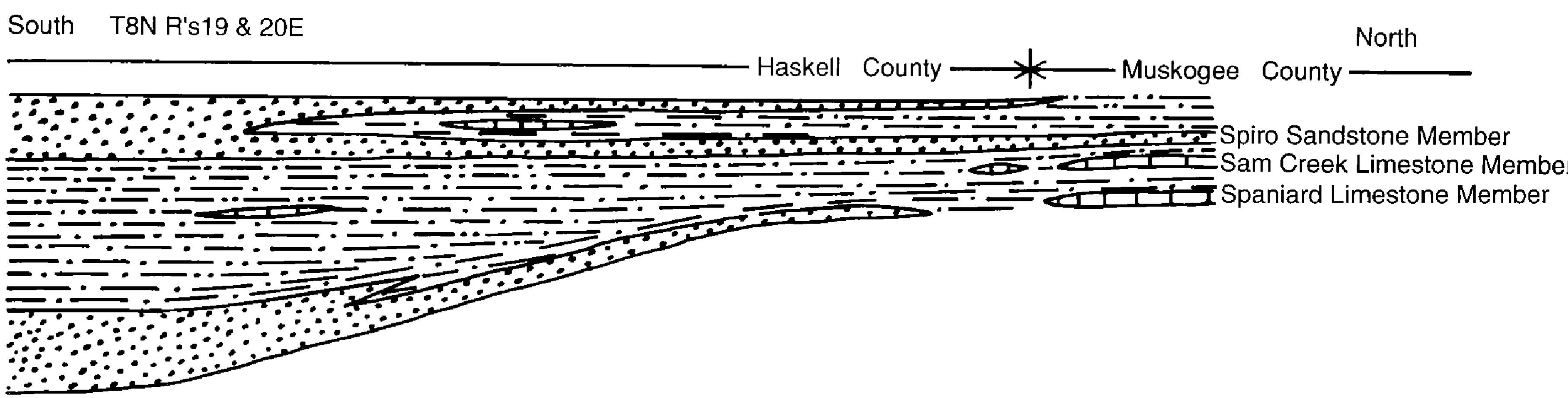


Figure 4. Diagram indicating the character of the Savanna Formation in Haskell County and its relation to representatives in Muskogee County. Not to scale. From Oakes and Knechtel (1948, fig. 7).

The Spaniard Limestone is of special interest because it is a well-known subsurface marker for mapping the McAlester–Savanna contact. The subsurface name for the Spaniard Limestone is "Brown lime." It was originally named "Little Brown lime" by Oscar Hatcher of Gypsy Oil Co., and R. C. Quiett of I.T.I.O. during development of Little River pool in T. 7 N., R. 6 E., Seminole County, ca. 1925. The name was shortened to "Brown lime," the bed that originally marked the base of the Savanna Formation (Jordan, 1957, p. 28). The name is descriptive of the normal color of sideritic limestone. In most places in the northern shelf area there are three Savanna Brown limes, probably physically correlatable to the surface analogs, Spaniard, Sam Creek, and Doneley Limestones.

The southeasternmost documented occurrence of the Brown lime is in a gas well drilled in 1981 in the center of the NW¼ sec. 12, T. 9 N., R. 18 E., Haskell County (Fig. 2[O^B]) (NRIS, 1993). The bottom depth of the Brown lime is listed at 775 ft. As the top is listed at 724 ft, and no single limestone bed that thick occurs in the area, it is assumed that all three of the Savanna Brown limes are present at this location, and that the lowest one is equivalent to the Spaniard Limestone.

Photographs of the Spaniard Limestone (Figs. 5,6) at two of the four outcrops observed in the Summerfield and Wister 7.5′ Quadrangles follow. Measured sections, with numbers corresponding to locations on the geologic map (Fig. 1) for each site are included in the appendix.

Sam Creek Limestone

The Sam Creek Limestone Member of the Savanna Formation was named from the type locality on Sam Creek in the eastern part of sec. 15, T. 14 N., R. 18 E., Muskogee County (Fig. 2[X^2]), by S. W. Lowman (1932) in an unpublished manuscript. Wilson (1935, p. 510) quoted the following measured section from the manuscript:

	Ft	In.
Gray limestone; weathers brown; contains so many *Marginifera muricata* that it is almost a coquina	0	6
Gray, fossiliferous shale	3	6
Alternation of gray limestone and gray, fossiliferous shale, the former essentially a reef composed of *Campophyllum torquium*	0	11
Gray limestone, with layers of gray shale	3	8
Total	8	7

Like the Spaniard Limestone, the Sam Creek is exposed sporadically throughout the northeastern Oklahoma shelf area (Fig. 2). Mappers found the lithology and thickness of the Sam Creek to be variable. In general, it consists of one or two impure dark-gray, dense, fine- to medium-crystalline, fossiliferous limestone beds that weather reddish-brown and total 0.5–2 ft thick (Wilson and Newell, 1937; Coleman, 1958; Gregware, 1958; Stine, 1958; Bell, 1959; Govett, 1959; Oakes, 1977; Hemish, 1990a). The following measured section from Hemish (in preparation) exemplifies the Sam Creek Limestone and associated strata in the northeastern Oklahoma shelf area and the northern part of the Arkoma basin (Fig. 2[X^5]):

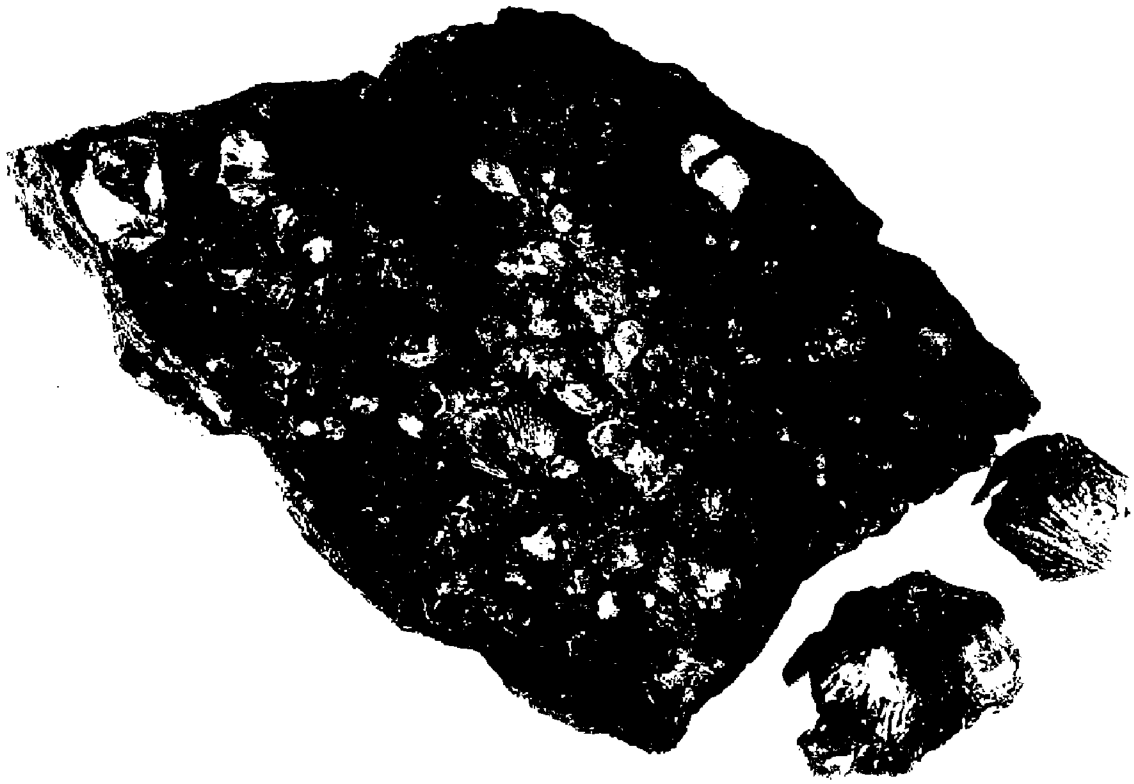


Figure 5. Outcrop sample from the Spaniard(?) Limestone at the location of Measured Section 1 (Appendix). Note the shelly nature of the rock at this site.

Figure 6. Outcrop photo of the Spaniard(?) Limestone at the location of Measured Section 6 (Appendix). Note similarity to limestone ~8.5 mi to the west, shown in Figure 5.

MM-98-82-H

SW¼SW¼NW¼NE¼ and SW¼NE¼NE¼SW¼ sec. 22, T. 10 N., R. 19 E., Muskogee County (Porum 7.5′ Quadrangle). Measured in gully adjacent to creek south of blacktop road and in creek bank downstream, by LeRoy A. Hemish. (Estimated elevation at top of section, 590 ft.)

	Thickness (ft)
KREBS GROUP	
Savanna Formation:	
Shale, grayish-brown, contains abundant stringers of moderate-brown and dark-yellowish-orange clay-ironstone	10.0
Limestone, grayish-brown, silty, sandy, impure; very fossiliferous, with brachiopods and crinoids abundant; flaggy (Sam Creek Limestone)	0.7
Shale, grayish-brown, soft	0.6
Shale, black with yellowish-gray and dark-yellowish-orange bands, highly carbonaceous, coaly in part	0.9
Coal, black with moderate-reddish-brown iron oxide deposits on cleat surfaces (Sam Creek coal)	0.2
Underclay, dark-gray with dark-yellowish-orange mottling, shaly; contains stringers of coal and carbonaceous shale	1.7
Shale, dark-gray with grayish-brown staining, silty, fissile; contains rounded ironstone concretions (to water level in creek)	5.0
Covered interval	19.0
Limestone, grayish-brown, impure, silty, very fossiliferous, thickness variable (Spaniard Limestone)	0.4
McAlester Formation:	
Coal, black, soft, weathered (Spaniard coal)	0.1
Underclay, medium-gray; contains black carbonized plant fragments	0.4
Total	39.0

The northernmost known exposure of the Sam Creek Limestone was mapped by Branson and others (1965, pl. 1) just northwest of the town of Big Cabin in the SW¼ sec. 15, T. 24 N., R. 19 E., Craig County (Fig. 2[X[7]]). The northernmost documented occurrence of the Sam Creek Limestone is in the NW¼NE¼NE¼NE¼ sec. 24, T. 27 N. (Fig. 2[O[A]]), where it was encountered in a core-hole at a depth of 82.5 ft (Hemish, 1990b, p. 51). It was described as a 0.75-in.-thick dark-gray lens of crinoidal limestone.

It is assumed that the Sam Creek is one of the Savanna Brown limes in the "Brown lime" interval listed in the log of the gas well in the center of the NW¼ sec. 12, T. 9 N., R. 18 E., Haskell County, discussed previously. If so, the southeasternmost known subsurface occurrence of the Sam Creek Limestone coincides with that of the Spaniard Limestone (Fig. 2[O[B]]).

The previously known southernmost outcrop of the Sam Creek Limestone was mapped by Stine (1958, p. 42) in secs. 33 and 34, T. 10 N., R. 19 E., Muskogee County, just north of the Canadian River (Fig. 2[X[8]]). Oakes and Knechtel (1948, p. 51) found limestone float northwest of Hoyt, to the south in Haskell County, that occupies about the same stratigraphic position as does the Sam Creek Limestone in Muskogee County. Previous surface investigations to the south by Morgan (1924), Hendricks (1939), Knechtel (1949), Russell (1960), and Webb (1960) did not reveal the presence of the Sam Creek Limestone or any likely equivalent in a similar stratigraphic position.

Figure 7. Sam Creek(?) Limestone at the location of Measured Section 2 (Appendix). The Sam Creek(?) is 1.2 ft thick at this outcrop, sandy, and contains few fossils.

Photographs of the Sam Creek(?) Limestone at each of three outcrops observed in the Summerfield 7.5′ Quadrangle follow (Figs. 7–9). Measured sections, with numbers corresponding to locations on the geologic map (Fig. 1A) for each site are included in the appendix.

Discussion of Spaniard(?) and Sam Creek(?) Limestones

Tentative correlation of the limestones found in Le Flore County with the Sam Creek and Spaniard Limestones of the northeastern Oklahoma shelf area is based on stratigraphic position, as well as similarity of lithologies, fossil types, and thicknesses.

Figure 10 is a generalized stratigraphic column from the northeastern Oklahoma shelf area showing the same sequence of rocks (Krebs Group) that crop out in the study area. Figure 11 is a generalized stratigraphic column showing rocks of the Krebs Group in the Summerfield and Wister 7.5′ Quadrangles. Note (except for thicknesses) the similarity between the stratigraphic units in the shelf area and those in the Arkoma basin.

The Hartshorne sandstone is present in both areas and is overlain by the dark-gray McCurtain Shale Member of the McAlester Formation. The ferruginous Warner Sandstone Member of the McAlester Formation has similar lithologic characteristics in both areas. The next sandstone stratigraphically above the Warner is the Cameron, identified in both areas by the occurrence of the McAlester (Stigler) coal just above the sandstone. The Tamaha Sandstone Member and the Keota Sandstone Member of the McAlester Formation are present in the overlying shale in both areas. Similarily, a fossiliferous limestone bed is present above the uppermost shale of the

Figure 8. Sam Creek(?) Limestone at the location of Measured Section 3 (Appendix). At 1.4 ft, this is the thickest occurrence of the limestone observed. Note the blocky nature of the rock at this site, as well as the sharp upper and lower contacts.

Figure 9. Sam Creek(?) Limestone exposed in the bed of a tributary of Caston Creek. This is the easternmost outcrop of this limestone observed to date in Le Flore County. The bed is 1.3 ft thick, and dips 14° to the northwest at this site (Measured Section 4, Appendix).

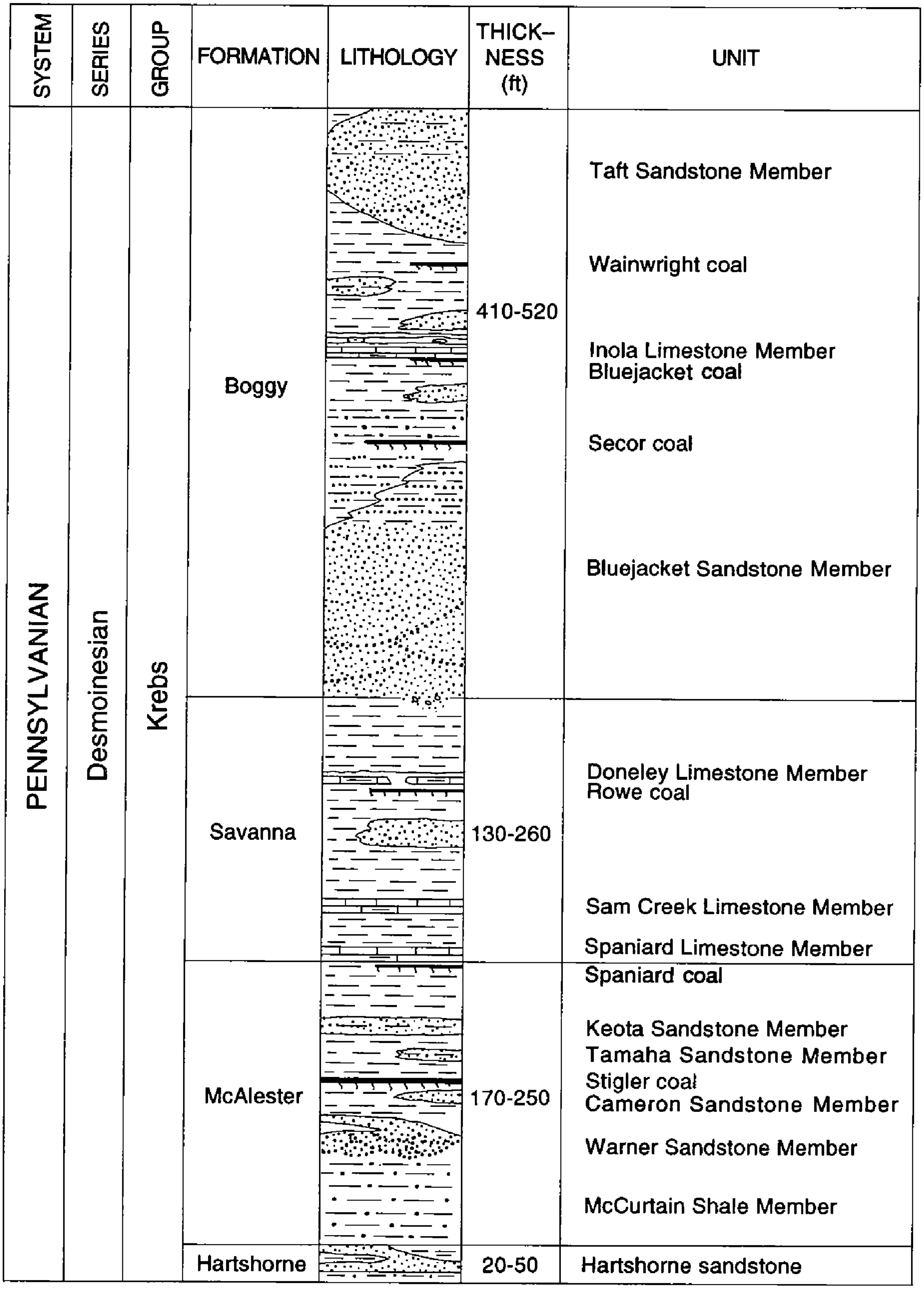


Figure 10. Generalized stratigraphic column, showing sequence of rocks in eastern Okmulgee County and western Muskogee County, near the type areas of the Spaniard and Sam Creek Limestones. Modified from Hemish (1988).

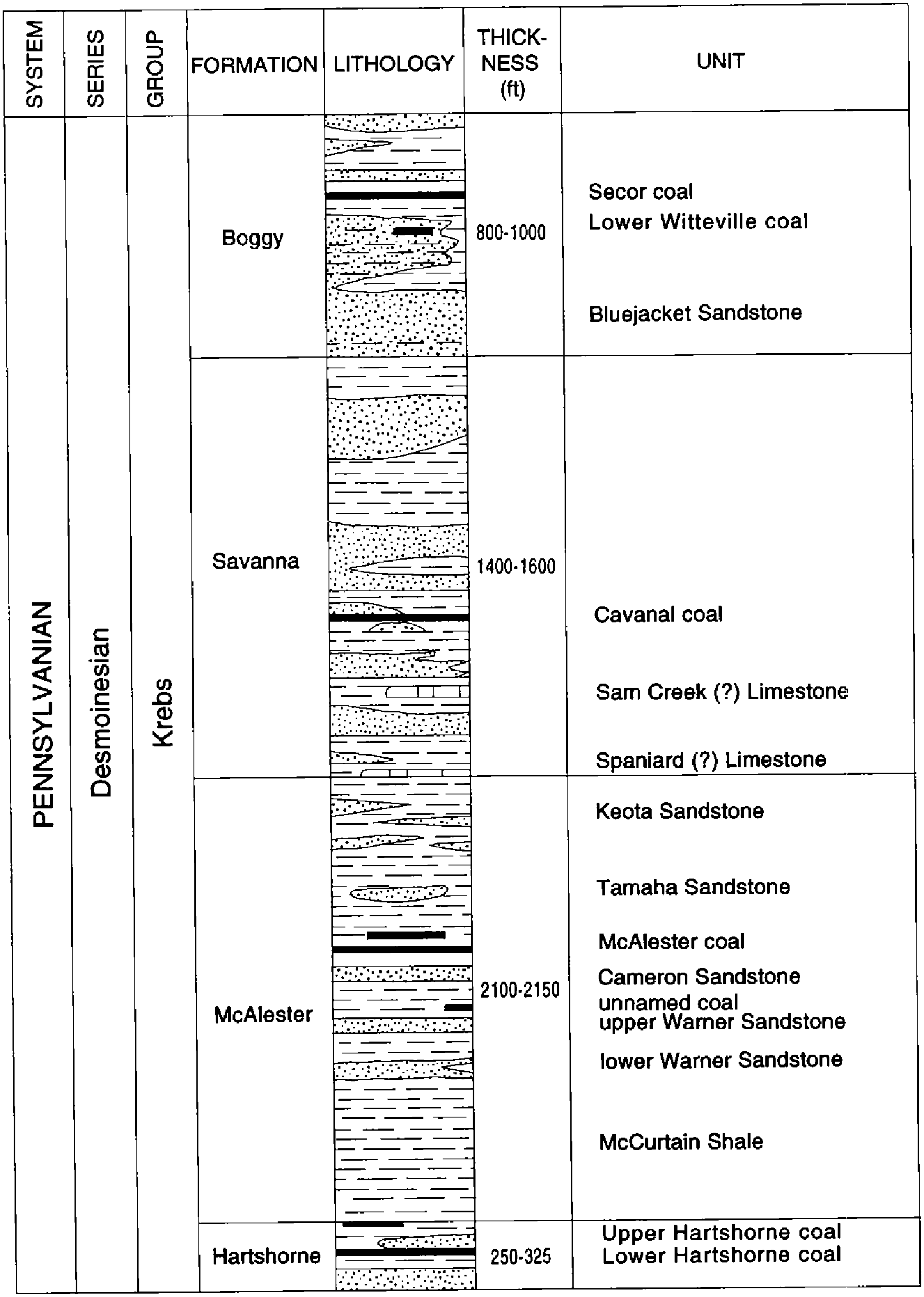


Figure 11. Generalized stratigraphic column, showing sequence of rocks in the study area (west-central Le Flore County). Compare with Figure 10.

McAlester Formation (Spaniard Limestone Member of the Savanna Formation in the shelf area, and the Spaniard[?] Limestone in the study area). A thin, discontinuous coal that occurs just below the Spaniard Limestone in the shelf area was not observed in the study area. Two well-developed, unnamed sandstone units occur between the Spaniard Limestone(?) and the Sam Creek(?) Limestone in the study area, but are not present in the shelf area. This dissimilarity can be expected, however, because the Savanna Formation is noted for having a much greater proportion of sandstone to shale in the Arkoma basin than it has in the shelf area. The Bluejacket Sandstone Member of the Boggy Formation overlies the Savanna Formation in both areas.

Figure 12 is an excerpt from a geophysical log cross section in Okmulgee County showing the log signatures of the various stratigraphic units discussed above. The Senora Formation, shown in the Okmulgee County cross section, is absent in the present study area, either because of erosion or nondeposition. Figure 13 is an excerpt from the log of a well drilled ~0.3 mi north of the north edge of the Summerfield 7.5′ Quadrangle, in the SE¼ sec. 7, T. 6 N., R. 24 E., <3 mi due north from the westernmost exposure of the Spaniard(?) Limestone (see Measured Section 1; Fig. 1A). A complete record of all the rocks of the Krebs Group exposed in the quadrangle is not shown because the upper part of the well (Boggy Formation) was not logged. The McAlester–Savanna contact was placed at the base of a minor, but sharp, leftward deflection on the gamma ray curve, which, as interpreted, marks the approximate position of the Spaniard(?) Limestone. The approximate position of the Sam Creek(?) Limestone is similarly shown, ~170 ft above the Spaniard(?) Limestone. Other Desmoinesian stratigraphic units below the contact are shown in Figure 13. All are present in the shelf area and most are shown in Figure 12.

The oldest exposed bedrock shown on the geologic maps of the study area (Fig. 1) consists of unnamed shales in the McAlester Formation. South of the map area (Fig. 1) in the Summerfield and Wister 7.5′ Quadrangles, the basal formation of the Krebs Group (Hartshorne Formation) crops out. It is about 250–325 ft thick. The Hartshorne Formation is overlain conformably by the basal member of the McAlester Formation, the McCurtain Shale Member, which is about 650–700 ft thick. Total thickness of the McAlester Formation is ~2,100 ft.

The Warner Sandstone Member overlies the McCurtain Shale. It consists of two ridge-forming sandstones separated by shale. Its thickness, which is variable, ranges from 250 to 290 ft.

An unnamed shale member ~350 ft thick separates the Warner Sandstone from the Cameron Sandstone Member. The Cameron (10–40 ft thick) forms a prominent ridge extending from west to east across the quadrangles, except where covered by alluvium. Above the Cameron Sandstone, and within the unnamed McAlester shale unit mapped in Fig. 1 (ℙm), two discontinuous sandstone members are present. The lower one is the Tamaha Sandstone, which is ~3 ft thick, thin-bedded, shaly, and not a ridge-former. It was observed in secs. 26–29, T. 6 N., R. 24 E. and secs. 28 and 29, T. 6 N., R. 25 E. Exposures are indicated in Figure 1.

The next higher sandstone is the Keota Sandstone Member. Like the Tamaha Sandstone, it is erratic in occurrence. It generally consists of two to four very fine-grained, thin- to medium-bedded, parallel-bedded, ripple-marked sandstone beds separated by silty shale intervals of varying thickness. It forms a discontinuous, low-lying ridge extending from ~2 mi west of Caston Creek eastward to just southwest of Wister. It is buried under the alluvium of Caston Creek and the Poteau River south and east of Wister except for an exposure in the SE¼ sec. 21, T. 6 N., R. 25 E. (Fig. 14).

Notwithstanding its variable thickness and heterogeneous nature, the Keota Sandstone has great lateral extent. It is identifiable in both the subsurface and on outcrops well northward and westward into the shelf area (Hemish, 1988,1990b). At places it is probably the "Third Booch" sand (Jordan, 1957, p. 21) of subsurface terminology. Oakes and Knechtel (1948, p. 44) earlier correlated the Keota Sandstone at its type area with units both to the south and north. They stated: "The Keota Sandstone Member in Haskell County is directly equivalent to the Keota Sandstone in northern Le Flore County, to the east, and in Muskogee County, to the north." Identification of the sequence of named sandstone members in the McAlester Formation, particularly the Keota Sandstone, is critical for correlation of the Spaniard(?) and Sam Creek(?) Limestones for purposes of this study.

A thick shale interval separates the top of the Keota Sandstone Member of the McAlester Formation from the base of the Spaniard(?) Limestone Member of the Savanna Formation in the study area. Oakes and Knechtel (1948, p. 48) defined the McAlester–Savanna contact in Haskell County and northern Le Flore County as "the top of the first shale unit above the Keota Sandstone Member of the McAlester Formation. Throughout most of the two counties it is equivalent to the actual McAlester–Savanna contact as originally mapped by Taff [1899] in the vicinity of McAlester, Pittsburg County and extended by Taff and Adams [1900] and later by Hendricks [1939] to the vicinity of Poteau."

Oakes and Knechtel (1948, p. 49) noted that, "A fossiliferous calcareous zone crops out along the road ¼ mile north of the SW cor. sec. 18, T. 10 N., R. 21 E., 1.25 mi north of Perry, and the base of this limy outcrop is provisionally regarded as marking the actual McAlester–Savanna contact. . ." In my opinion this fossiliferous limy zone is equivalent to the Spaniard(?) Limestone observed in the Summerfield and Wister 7.5′ Quadrangles.

The Savanna Formation in the map area consists of a succession of sandstone and shale beds in which shale predominates, but the sandstone is most conspicuous. It contains the Cavanal coal bed as well as other thin, lensing, noncommercial coals. It also contains minor amounts of fossiliferous limestone in thin lenses and beds which are not mappable. The sandstones of the Savanna Formation are generally brown or grayish-orange, very fine-grained, and compact (Fig. 15). They vary in thickness and tend to be thicker in quadrangles mapped west of the Summerfield Quadrangle (Hemish and others, 1990a,b,c; Hemish, 1991,1992). The Savanna Formation is about 1,400–1,600 ft thick in the study area.

The Boggy Formation overlies the Savanna Formation. Its base is marked by the base of the Bluejacket Sandstone Member, only part of which is shown in Figure 1. The Bluejacket is widely distributed in eastern Oklahoma, where it is known in the subsurface as the "Bartlesville" sand. The part of the Boggy exposed in the Summerfield 7.5′ Quadrangle is ~700 ft thick.

Summary

The limestones that crop out at several locations in the Summerfield and Wister 7.5′ Quadrangles in the Arkoma basin are probably physically correlatable with the Spaniard and Sam Creek Limestones of the northeastern Oklahoma shelf area. The

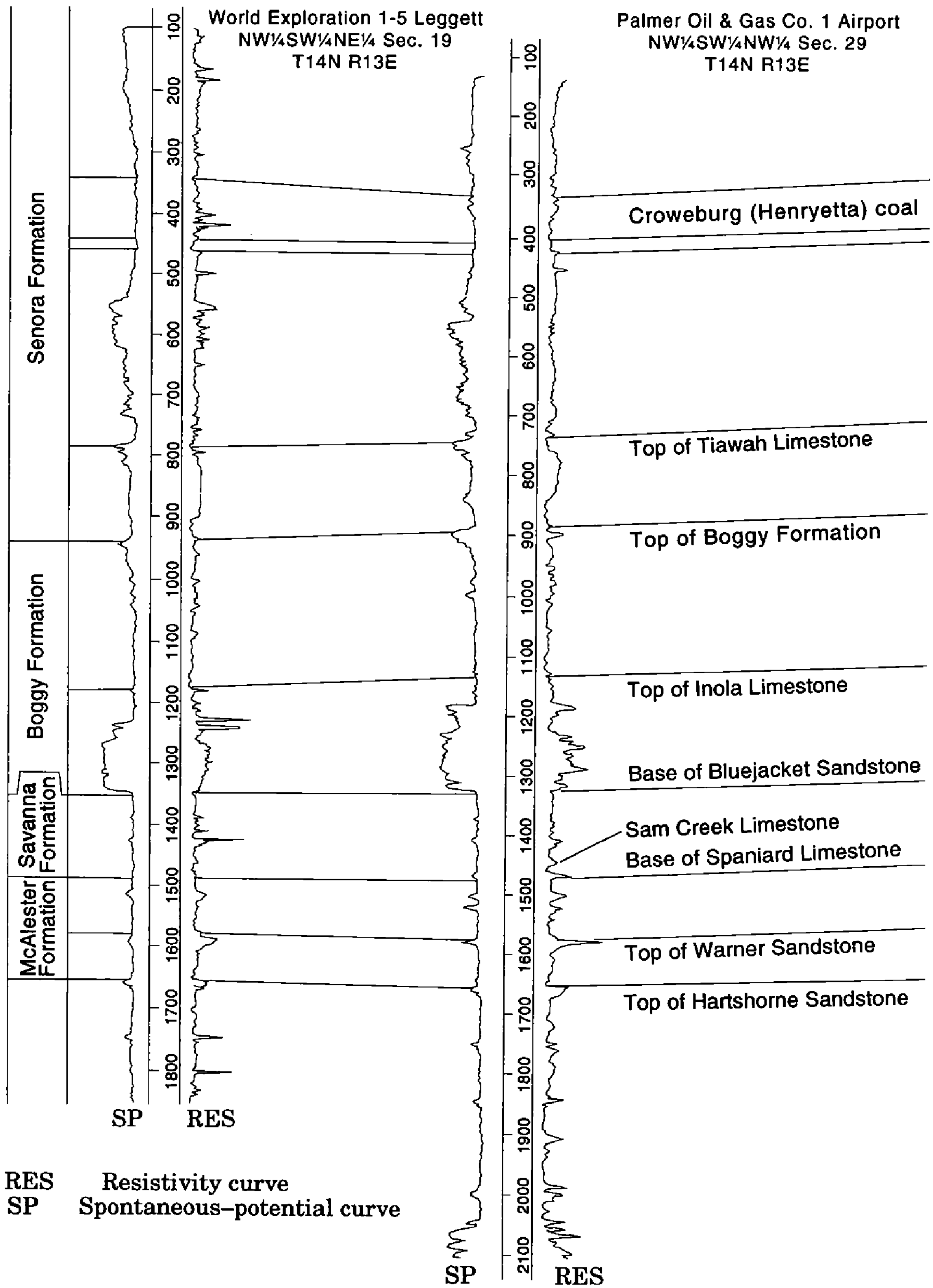


Figure 12. Excerpt from Hemish (1988, cross section B–B′) showing position of Spaniard and Sam Creek Limestones relative to overlying and underlying units on geophysical logs, northeastern Oklahoma shelf area, Okmulgee County.

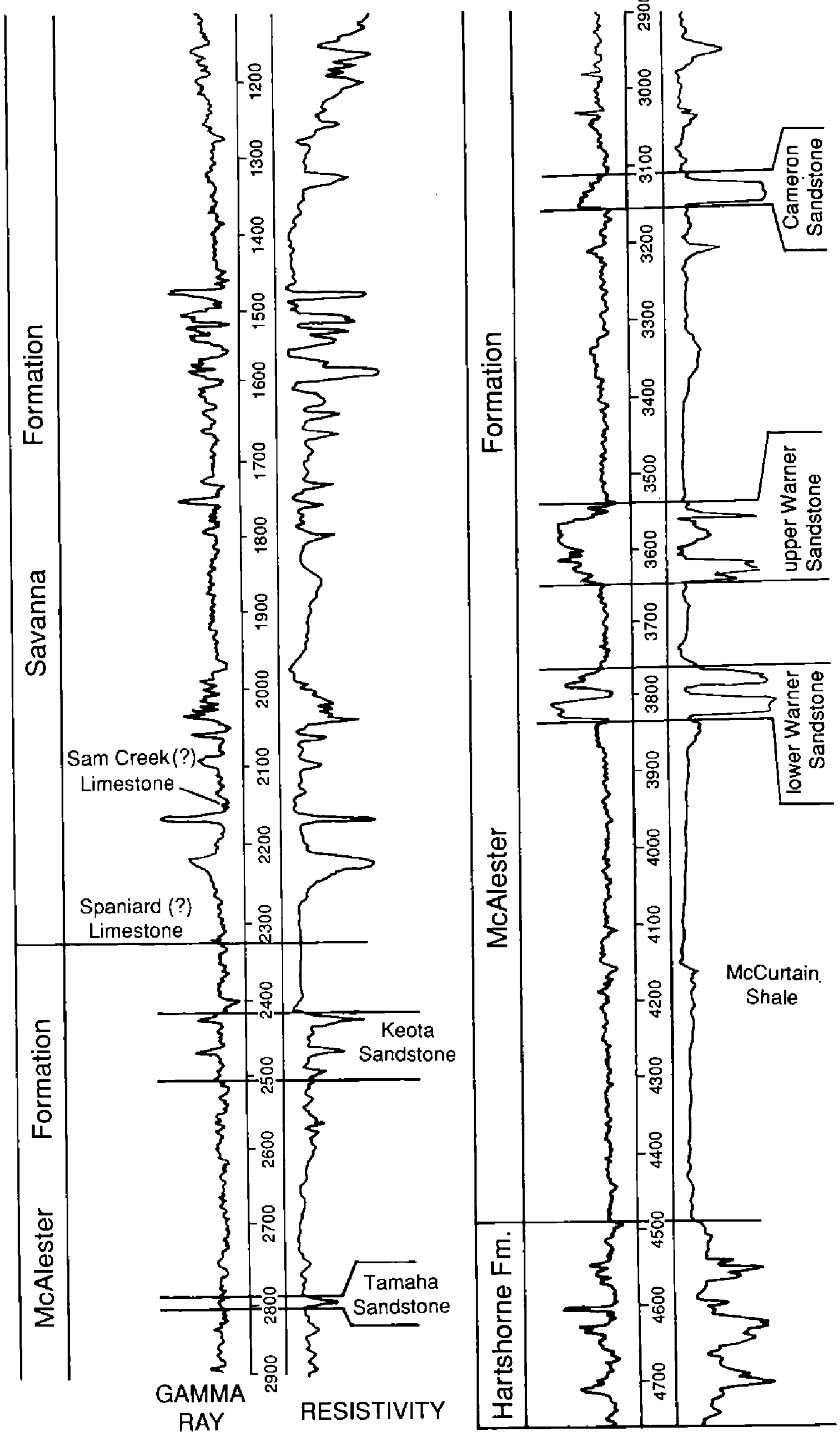


Figure 13. Excerpt from geophysical log (Eberly and Meade, Hawkins no. 2-7, center, NW¼SE¼ sec. 7, T. 6 N., R. 24 E., Le Flore County (<3 mi north of study area) showing sequence of rocks exposed in Summerfield 7.5′ Quadrangle. Compare with Figure 12.

Figure 14. Keota Sandstone exposed at Poteau River crossing, SW¼SW¼SE¼SE¼ sec. 21, T. 6 N., R. 25 E. Note the flaggy and shaly nature of the member.

bases for the correlation are similarity of stratigraphic position, as well as similarities in lithology, thickness, and fossil content.

The apparent absence of the Spaniard and Sam Creek Limestones throughout the Arkoma basin in Haskell, Latimer, and parts of Le Flore County perhaps can be attributed to a lack of detailed field mapping, but to some extent it is due to the enormous influx of clastics at the front of the "Savanna River" delta where it debouched into the subsiding trough. Field mapping to the west of the limestone outcrop area shows that sandstone beds within the Savanna Formation are thicker and better developed than in the study area. The sandstones tend to thin and pinch out in the same area where the limestones appear, probably in the delta-fringe area. The increasing prominence of the Savanna sandstone ridges ~6 mi west of the town of Wister (along U. S. Highway 270) is obvious to even the casual observer. The ridges stand topographically high and form the Sans Bois Mountains just north of the highway. Between the city of Poteau and Caston Creek, in the area where the Spaniard(?) and Sam Creek(?) Limestones are well developed, the Savanna Formation is manifested only by rolling ridges separated by broad shale valleys.

At the time of this writing the extent of the Spaniard(?) and Sam Creek(?) outcrops to the northeast, beyond the map area, is unknown. If present, they will provide definitive markers for mapping the McAlester–Savanna contact in both surface and subsurface investigations.

Figure 15. Basal sandstone bed of the Savanna Formation exposed in Little Caston Creek (Unit 1, Measured Section 2, Appendix). Units below the pictured sandstone bed (including the Spaniard[?] Limestone) are covered by alluvium for ~0.2 mi downstream. The Sam Creek(?) Limestone occurs stratigraphically ~155 ft higher in the section.

References Cited

Bell, Walton, 1959, Surface geology of the Muskogee area, Muskogee County, Oklahoma: University of Oklahoma unpublished M.S. thesis, 113 p.

Branson, C. C.; Huffman, G. G.; and Strong, D. M., 1965, Geology and oil and gas resources of Craig County, Oklahoma: Oklahoma Geological Survey Bulletin 99, 109 p.

Coleman, W. F., 1958, Surface geology of the Rentiesville area, Muskogee and McIntosh Counties, Oklahoma: University of Oklahoma unpublished M.S. thesis, 100 p.

Gregware, William, 1958, Surface geology of the McLain area, Muskogee County, Oklahoma: University of Oklahoma unpublished M.S. thesis, 10 p.

Govett, R. W., 1959, Geology of Wagoner County, Oklahoma: University of Oklahoma unpublished Ph.D. dissertation, 182 p.

Hemish, L. A., 1988, A stratigraphic and structural study of the Eram coal and associated strata in eastern Okmulgee County and western Muskogee County, Oklahoma: Oklahoma Geological Survey Map GM-30, 1 sheet, scale 1:31,680, accompanying text.

____1990a, Coal geology of Tulsa, Wagoner, Creek, and Washington Counties, Oklahoma: Oklahoma Geological Survey Map GM-33, 5 sheets, scale 1:63,360, accompanying text, with appendixes.

____1990b, Lithostratigraphy and core-drilling, upper Atoka Formation through lower Senora Formation (Pennsylvanian), northeastern Oklahoma shelf area: Oklahoma Geological Survey Special Publication 90-2, 54 p.

____1991, Geologic map of the Leflore Quadrangle, Latimer and Le Flore Counties, Oklahoma: COGEOMAP Geologic Quadrangle Maps, 1 sheet, scale 1:24,000.

____1992, Geologic map of the Gowen Quadrangle, Latimer County, Oklahoma: COGEOMAP Geologic Quadrangle Maps, 1 sheet, scale 1:24,000.

____ [in preparation], Coal geology of McIntosh and Muskogee Counties, Oklahoma: Oklahoma Geological Survey.

Hemish, L. A.; and Mazengarb, Colin, 1992, Geologic map of the Summerfield Quadrangle, Le Flore County, Oklahoma: COGEOMAP Geologic Quadrangle Maps, 1 sheet, scale 1:24,000.

Hemish, L. A.; and Suneson, N. H., 1993, Geologic map of the Wister Quadrangle, Le Flore County, Oklahoma: COGEOMAP Geologic Quadrangle Maps, 1 sheet, scale 1:24,000.

Hemish, L. A.; Suneson, N. H.; and Ferguson, C. A., 1990a, Geologic map of the Panola Quadrangle, Latimer County, Oklahoma: COGEOMAP Geologic Quadrangle Maps, 1 sheet, scale 1:24,000.

____1990b, Geologic map of the Red Oak Quadrangle, Latimer County, Oklahoma: COGEOMAP Geologic Quadrangle Maps, 1 sheet, scale 1:24,000.

____1990c, Geologic map of the Wilburton Quadrangle, Latimer County, Oklahoma: COGEOMAP Geologic Quadrangle Maps, 1 sheet, scale 1:24,000.

Hendricks, T. A., 1939, The Howe–Wilburton district, Latimer and Le Flore Counties, *pt. 4 of* Geology and fuel resources of the southern part of the Oklahoma coal field: U.S. Geological Survey Bulletin 874-D, p. 255–300.

Jordan, Louise, 1957, Subsurface stratigraphic names of Oklahoma: Oklahoma Geological Survey Guidebook 6, 220 p.

Knechtel, M. M., 1949, Geology and coal and natural gas resources of northern Le Flore County, Oklahoma: Oklahoma Geological Survey Bulletin 68, 76 p.

Lowman, S. W., 1932, Lower and middle Pennsylvanian stratigraphy of Oklahoma east of the meridian and north of the Arbuckle Mountains [abstract]: Tulsa Geological Society Summaries and Abstracts, Tulsa Daily World, December 19, 1932.

Morgan, G. D., 1924, Geology of the Stonewall Quadrangle, Oklahoma: Oklahoma Bureau of Geology Bulletin 2, 248 p.

Natural Resources Information System (NRIS), 1993, Data files: Oklahoma Geological Survey.

Oakes, M. C., 1977, Geology and mineral resources (exclusive of petroleum) of Muskogee County, Oklahoma: Oklahoma Geological Survey Bulletin 122, 78 p.

Oakes, M. C.; and Knechtel, M. M., 1948, Geology and mineral resources of Haskell County, Oklahoma: Oklahoma Geological Survey Bulletin 67, 134 p.

Russell, D. T., 1960, Geology of northern Latimer County, Oklahoma: Oklahoma Geological Survey Circular 50, 57 p.

Stine, J. G., 1958, Geology of southern Muskogee County, Oklahoma: University of Oklahoma unpublished M.S. thesis, 89 p.

Taff, J. A., 1899, Geology of the McAlester–Lehigh coal field, Indian Territory: U.S. Geological Survey 19th Annual Report, pt. 3, p. 437–438.

Taff, J. A.; and Adams, G. I., 1900, Geology of the eastern Choctaw coal field, Indian Territory: U.S. Geological Survey 21st Annual Report, pt. 2, p. 277–278.

Webb, P. K., 1960, Geology of the Cavanal Syncline, Le Flore County, Oklahoma: Oklahoma Geological Survey Circular 51, 65 p.

Wilson, C. W., Jr., 1935, Age and correlation of Pennsylvanian surface formations and of oil and gas sands of Muskogee County, Oklahoma: American Association of Petroleum Geologists Bulletin, v. 19, p. 503–520.

Wilson, C. W., Jr.; and Newell, N. D., 1937, Geology of the Muskogee–Porum district, Muskogee and McIntosh Counties, Oklahoma: Oklahoma Geological Survey Bulletin 57, 184 p.

Appendix

Measured Section 1

NW¼SW¼NW¼SW¼ sec. 30, T. 6 N., R. 24 E., Le Flore County (Summerfield 7.5′ Quadrangle). Measured from top of sandstone ridge south across gully to base of power-line pole on knoll.

	Thickness (ft)
KREBS GROUP	
Savanna Formation:	
7. Sandstone , light-olive-gray (5Y 5/2), weathers moderate-reddish-brown (10R 4/6), very fine-grained, noncalcareous, thin- to medium-bedded; generally planar, parallel-bedded, but irregular-bedded in places; rectangular jointing; trace fossils on sole in places; base sharp	3.0
6. Shale, light-olive-gray (5Y 6/1; 5Y 5/2), noncalcareous, fissile; includes some moderate-brown (5YR 3/4; 5YR 4/4), bioturbated siltstone stringers in bottom few feet; ironstone concretions scattered throughout; base gradational	35.1
5. Shale, dark-gray (N 3), noncalcareous, brittle, fissile; iron-stained on joint surfaces; base sharp	12.3
4. Ironstone, grayish-red (5R 4/2), dense, hard; forms continuous layer where exposed; base sharp	0.2
3. Shale (same description as Unit 5)	3.1
Spaniard(?) Limestone Member:	
2. Limestone (skeletal lime mudstone), dark-yellowish-brown (10YR 4/2), weathers light-brown (10YR 5/6) to moderate-brown (10YR 4/4), impure, shaly, silty, ferruginous, thin-bedded; contains abundant, well-preserved brachiopod valves; base gradational	0.2
McAlester Formation:	
1. Shale, dark-gray (N 3) to light-olive-gray (5Y 5/2) brittle, fissile; noncalcareous; contains scattered ironstone concretions; base covered	31.5
Total thickness of section	85.4

Measured Section 2

NW¼SW¼SE¼NW¼ sec. 29, T. 6 N., R. 24 E., Le Flore County (Summerfield 7.5′ Quadrangle). Measured from railroad bridge downstream along Little Caston Creek to covered area at base of sandstone in SW¼NW¼NE¼SW¼ sec. 29, T. 6 N., R. 24 E.

	Thickness (ft)
KREBS GROUP	
Savanna Formation:	
20. Covered from base of railroad bridge (assumed to be shale)	10.0
19. Sandstone, light-olive-gray (5Y 5/2), weathers moderate-brown (5YR 3/4) to dusky-brown (5YR 2/2), very fine-grained, noncalcareous, thick-bedded; contains some discontinuous, curved, nonparallel beds, and some low-angle cross-laminations; base sharp	3.0
18. Shale, grayish-black (N 2), noncalcareous; light-olive-gray (5Y 5/2) with	

some light-brown (5YR 5/6) sandy siltstone beds in lower part; noncalcareous; contains dark-yellowish-orange (10YR 6/6) to moderate-yellowish-brown (10YR 4/2) ironstone concretions	27.8
17. Sandstone, light-olive-gray (5Y 5/2), weathers moderate-brown (5YR 4/4), very fine-grained, noncalcareous, thin- to medium-bedded; planar to wavy, parallel-bedded; flaggy; ripple-drift cross-laminated in part; interference ripple-marked; shaly in lower half; base gradational	2.5
16. Shale, medium-gray (N 5) to light-olive-gray (5Y 5/2), clayey, noncalcareous, flaky	5.0
15. Sandstone, light-olive-gray (5Y 5/2) to moderate-yellowish-brown (10YR 5/4), very fine-grained, noncalcareous, medium-bedded; contains ripple-drift cross-laminations; ripple-marked; slabby; trace fossils on soles; interbedded with olive-gray (5Y 4/1), noncalcareous shale containing light-brown (5YR 5/6) ironstone stringers and concretions. Individual sandstone layers 0.75–7 in. thick; base gradational	3.5
14. Shale (same description as Unit 16); base sharp	20.4
Sam Creek(?) Limestone Member:	
13. Limestone (skeletal lime mudstone), light-brownish-gray (5YR 6/1) to brownish-gray (5Y 4/1), weathers moderate-brown (5YR 4/4), impure, silty, blocky, irregularly thin-bedded; contains sparsely distributed shell fragments and crinoid ossicles; surface and sole irregular and "lumpy" in appearance	1.2
12. Mudstone, dark-yellowish-brown (10YR 4/2) to medium-gray (N 5), noncalcareous, nodular	2.0
11. Sandstone, medium-gray (N 5), very fine-grained, thin-bedded, hackly, bioturbated; noncalcareous to weakly calcareous, with some very calcareous layers that contain fossil debris composed of shell fragments and crinoid ossicles; base gradational	1.3
10. Siltstone, brownish-gray (5YR 4/1) to olive-gray (5Y 4/1), weathers dusky-brown (5YR 2/2), impure, shaly, noncalcareous, thin- to very thin-bedded; planar, parallel-bedded; bioturbated; hackly; base gradational	7.9
9. Shale, dusky-yellowish-brown (10YR 2/2), silty, noncalcareous; weathers to low-relief, "lumpy" surface	33.7
8. Covered interval	40.8
7. Sandstone, moderate-yellowish-brown (10YR 5/4), weathers moderate-brown (5YR 3/4), very fine-grained, noncalcareous, medium-bedded, blocky; base sharp	1.3
6. Shale, light-olive-gray (5Y 5/2) to dark-gray (N 3), noncalcareous, flaky, (mostly covered)	60.7
5. Sandstone, light-olive-gray (5Y 5/2), weathers light-brown (5YR 5/6) to dusky-brown (5YR 2/2), very fine-grained, noncalcareous, cross-laminated, thin- to medium-bedded, parallel-bedded, flaggy, interference ripple-marked, abundant trace fossils on sole; base sharp	0.7
4. Covered interval	4.5
3. Sandstone (same description as Unit 5)	0.8
2. Covered interval	0.7
1. Sandstone (same description as Unit 5); basal sandstone bed of Savanna Formation	0.8
Total thickness of section	228.6

Measured Section 3

SW¼NW¼SE¼NW¼ sec. 28, T. 6 N., R. 24 E., Le Flore County (Summerfield 7.5′ Quadrangle). Measured at north edge of small creek about ⅓ mi southeast of Victor, from covered area near top of slope to creek bed.

	Thickness (ft)
KREBS GROUP	
Savanna Formation:	
5. Shale, olive-gray (5Y 4/1) to yellowish-gray (5Y 7/2), flaky, noncalcareous, weathered; contains light-brown (5YR 5/6), resistant ironstone concretions that weather out to flakes and nodules on the outcrop	6.5
Sam Creek(?) Limestone Member:	
4. Limestone (skeletal lime mudstone), light-gray (N 7) to yellowish-gray (5Y 7/2), weathers moderate-brown (5YR 4/4), impure; silty, thin-bedded; wavy, parallel-bedded; blocky; ferruginous in upper part; contains abundant fossil shell hash as well as small crinoid ossicles; base sharp	1.4
3. Mudstone, brownish-black (5YR 2/1), noncalcareous; contains hard siltstone lenses with light-brown (5YR 5/6) veinlets; blocky fracture; base gradational	2.1
2. Shale, dark-yellowish-brown (10YR 4/2), clayey, noncalcareous	1.0
1. Covered to water level in creek; assumed to be shale	2.0
Total thickness of section	13.0

Measured Section 4

NW¼SW¼NE¼ sec. 27, T. 6 N., R. 24 E., Le Flore County (Summerfield 7.5′ Quadrangle). Measured at south-flowing tributary of Caston Creek from sharp westward bend in stream down to covered area at base of sandstone.

	Thickness (ft)
KREBS GROUP	
Savanna Formation:	
8. Shale, olive-gray (5Y 3/2) to grayish-black (N 2), weathers grayish-brown (5YR 3/2) to grayish-orange (10YR 7/4), noncalcareous, brittle, fissile; contains abundant light-brown (5YR 5/6) ironstone concretions as much as 1 ft in diameter and 3 in. thick; base gradational	83.4
7. Shale, dark-yellowish-brown (10YR 4/2), silty, noncalcareous, hard, blocky fracture; base sharp	4.0
Sam Creek(?) Limestone Member:	
6. Limestone (skeletal lime mudstone), yellowish-gray (5Y 7/2) to pale-yellowish-brown (10YR 6/2), weathers light-brown (5YR 5/6) to moderate-brown (5YR 4/4), impure, silty; indistinctly nonparallel-wavy-bedded; blocky; fossiliferous, shell fragments and crinoid ossicles abundant; base sharp	1.3
5. Mudstone, olive-gray (5Y 4/1) to olive-black (5Y 2/1), iron-stained, hard, noncalcareous; contains fossil shells and egg-sized ironstone concretions	0.7

4. Covered interval 55.6
3. Sandstone, light-olive-gray (5Y 5/2), weathers moderate-brown (5YR 4/4) to dusky-brown (5YR 2/2), very fine-grained, noncalcareous, medium-bedded; surface irregular, ripple-marked; contains low-angle cross-stratification and well-formed climbing ripples; includes trace fossils and fossil plant impressions; upper and lower contacts sharp 1.0
2. Covered interval 30.1
1. Sandstone, dark-yellowish-brown (10YR 4/2), weathers moderate-brown (5YR 3/4) to dark-reddish-brown (10R 3/4), very fine-grained, noncalcareous, medium-bedded; planar to wavy, parallel-bedded; includes some low-angle cross-stratification; base sharp and irregular, with abundant trace fossils and fossil plant impressions; exposed in ridges east and west of stream, but not in creek bed; basal sandstone bed of Savanna Formation 0.8

Total thickness of section 176.9

Measured Section 5

NW¼NW¼NE¼SE¼ sec. 25, T. 6 N., R. 24 E., Le Flore County (Wister 7.5′ Quadrangle). Measured in hillside below satellite dishes ~700 ft northwest of sewage disposal ponds in Wister city limits.

Thickness (ft)

KREBS GROUP

Savanna Formation:

8. Sandstone, light-olive-gray (5Y 5/2), weathers moderate-reddish-brown (10R 4/6), very fine-grained, noncalcareous, thin- to medium-bedded; bedding is wavy to irrregular, mostly nonparallel; shaly in places, weakly bioturbated; contains rare, poorly preserved marine fossils in lower 0.5 ft of unit; base sharp 8.8
7. Shale, light-olive-gray (5Y 5/2), weathers grayish-orange (10YR 7/4), silty; weathers to small, blocky flakes on outcrop; contains sandy, ferruginous, clay-filled concretionary masses as much as 8 in. long and 2 in. thick; base gradational 13.7
6. Sandstone, dark-yellowish-brown (10YR 4/2), weathers moderate-brown (5YR 4/4), very fine-grained, siltstone in part, shaly, very thin-bedded, flaky; includes mica and black (N 1) carbonized plant fragments on bedding surfaces; weakly bioturbated; base gradational 3.0
5. Shale, olive-gray (5Y 4/1) to medium-light-gray (N 6), stained moderate-brown (5YR 4/4), silty, brittle, fissile, moderately bioturbated, trace fossils on bedding planes; includes two thin stringers of dark-yellowish-orange (10YR 6/6) and dark-red (5R 3/4) ironstone near base of unit; base sharp 10.4
4. Sandstone, grayish-brown (5YR 3/2) to dark-yellowish-brown (10YR 4/2), very fine-grained, impure, silty, noncalcareous, thin, wavy-bedded, moderately to strongly bioturbated; occurs as lens that pinches out laterally; contains rare, poorly preserved fossil shells; base sharp 0.4
3. Shale, dusky-yellowish-brown (10YR 2/2) to olive-gray (5Y 4/1), noncalcareous, brittle, flaky; contains abundant discontinuous stringers of dark-yellowish-orange (10YR 6/6) to light-brown (5YR 5/6) clay-ironstone concretions, weakly bioturbated; base sharp 8.4

Spaniard(?) Limestone Member:

2. Limestone (skeletal lime mudstone), dark-yellowish-brown (10YR 4/2) to dark-yellowish-orange (10YR 6/6), impure, shaly, very fossiliferous; contains predominantly brachiopod valves; occurs as discontinuous pods and lenses 0.5–1.0 in. thick; base sharp 0.1

McAlester Formation:

1. Shale, medium-dark-gray (N 4), noncalcareous, weathers to small flakes on the outcrop; contains abundant flaky, dark-yellowish-orange (10YR 6/6) clay-ironstone stringers, as well as some black (N 1), carbonaceous shale laminae; base covered 5.0

Total thickness of section 49.8

Measured Section 6

SW¼NE¼SW¼NE¼ sec. 21, T. 6 N., R. 25 E., Le Flore County (Wister 7.5′ Quadrangle). Measured in shale pit and in road ditch.

Thickness (ft)

KREBS GROUP

Savanna Formation:

9. Sandstone, light-olive-gray (5Y 5/2) to moderate-yellowish-brown (10YR 5/4) to light-brown (5YR 5/6), with some moderate-reddish-brown (10R 4/6) staining, very fine-grained, micaceous, noncalcareous, thin- to medium-bedded; bedding irregular, to parallel and nodular in places; blocky fracture; bioturbation features abundant; interbedded with light-olive-gray (5Y 5/2), silty, flaky shale; base sharp, with trace fossils on sole 16.0
8. Shale, grayish-orange (10YR 7/4) to moderate-yellowish-brown (10YR 5/4), to light-olive-gray (5Y 5/2), weathers to small flakes on outcrop; includes a 2-in.-thick layer of thin-bedded, bioturbated, light-olive-gray (5Y 5/2), sandy siltstone 2 ft below top of unit; also contains dark-reddish-brown (10R 3/4), sandy, ferruginous concretions 1–8 in. in diameter in upper 4 ft of unit; weakly to moderately bioturbated; base gradational 15.2
7. Shale, olive-gray (5Y 4/1) to medium-dark-gray (N 4), flaky, moderately bioturbated, carbonaceous in some thin layers; base sharp 2.5
6. Sandstone, light-olive-gray (5Y 5/2) to moderate-yellowish-brown (10YR 5/4), stained light-brown (5YR 5/6) in part, very fine-grained, noncalcareous, shaly, indistinctly parallel-wavy-bedded, thin-bedded, moderately bioturbated, base gradational 5.2
5. Shale, olive-gray (5Y 4/1) with light-olive-gray (5Y 6/1) tint in part; stained grayish-brown (5YR 3/2) in places, silty, brittle, fissile, contains rare dark-yellowish-orange (10YR 6/6) and grayish-red-purple (5RP 4/2) clay-ironstone concretions in lower part, includes concretionary shale structures several feet in diameter; base gradational 14.8
4. Shale, dark-gray (N 3), weathers light-brown (5YR 5/6) along joints, silty, brittle, fissile, contains concretionary shale structures continuous with overlying unit; also contains abundant dark-yellowish-orange (10YR 6/6) and blackish-red (5R 2/2) clay-ironstone concretions occurring in irregular, rounded discoidal shapes that form ledges 0.5–1.0 ft apart; moderately bioturbated; base sharp 8.6

Spaniard(?) Limestone Member:

3. Limestone (skeletal lime mudstone), brownish-gray (5YR 4/1) to grayish-black (N 2), weathers moderate-brown (5YR 4/4), to light-brown (5YR 5/6), impure, shaly, abundantly fossiliferous, contains numerous well-preserved brachiopod valves and crinoid ossicles; base sharp 0.1

McAlester Formation:

2. Shale, grayish-black (N 2), very calcareous, crumbly, contains abundant well-preserved brachiopod fossils, carbonaceous; contact between fossiliferous shale and underlying nonfossiliferous shale sharp 0.2
1. Shale, medium-dark-gray (N 4), weathers moderate-reddish-brown (10R 4/6), noncalcareous, soft, clayey; contains rare, dark-gray (N 3), irregular-shaped, 1-in.-diameter nodules; base covered 2.4

Total thickness of section 65.0

Measured Section 7

SE¼NE¼NE¼NE¼ sec. 21, T. 6 N., R. 25 E., Le Flore County (Wister 7.5′ Quadrangle). Measured from top of bluff down steep slope ~150 yards southwest from Kerr Museum.

Thickness (ft)

KREBS GROUP

Savanna Formation:

8. Sandstone, light-olive-gray (5Y 5/2) to moderate-brown (5YR 4/4) and dark-reddish-brown (10R 3/4), very fine-grained, noncalcareous, medium- to thick-bedded; irregular, nonparallel- to nodular-bedded; indistinctly cross-laminated; blocky; micaceous; contains small fragments of black (N 1) carbonized plant material; trace fossils on sole; top eroded; base sharp 3.0
7. Shale, light-olive-gray (5Y 5/2), weathers grayish-orange (10YR 7/4) and light-brown (5YR 5/6); includes some shaly siltstone stringers; moderately bioturbated; weathers to small, blocky flakes on outcrop; base gradational (poorly exposed) 17.4
6. Sandstone, light-olive-gray (5Y 5/2), weathers grayish-orange (10YR 7/4) and moderate-brown (5YR 4/4), very fine-grained, noncalcareous, very thin-bedded, shaly, weathers to flakes on the outcrop, moderately to strongly bioturbated; base gradational 2.3
5. Shale, olive-gray (5Y 4/1) to light-olive-gray (5Y 6/1), stained light-brown (5YR 5/6) in part, silty, fissile, flaky, moderately bioturbated; includes rare dark-reddish-brown (10R 3/4) and moderate-reddish-brown ironstone concretions as well as rare, 4-in.-thick, dusky-brown (5YR 2/2), ferruginous concretions containing poorly preserved fossil shells; base sharp 18.4
4. Sandstone, grayish-brown (5YR 3/2) to moderate-reddish-brown (10R 4/6), very fine-grained, noncalcareous, medium-bedded, strongly bioturbated; contains rare, poorly preserved fossil marine shells; thickness variable laterally; base sharp 1.1
3. Shale, medium-dark-gray (N 4) to olive-gray (5Y 4/1), fissile, flaky, noncalcareous; contains abundant, dark-yellowish-orange (10YR 6/6) and moderate-brown (5YR 4/4) clay-ironstone concretions occurring in 0.5-in.-thick, discontinuous layers; weakly bioturbated; base sharp 12.9

Spaniard(?) Limestone Member:

2. Limestone (skeletal lime mudstone), medium-gray (N 5), weathers moderate-yellowish-brown (10YR 5/4), impure, shaly, contains abundant broken and well-preserved marine fossils—predominantly brachiopods; thins laterally; base gradational 0.6

McAlester Formation:

1. Shale, medium-dark-gray (N 4), weathers moderate-reddish-brown (10R 4/6), brittle, flaky, noncalcareous; contains scattered moderate-brown (5YR 3/4; 5YR 4/4) ironstone concretions of varying sizes—generally 1–2 in. in diameter; includes concretionary shale structures; base covered 27.5

Total thickness of section 83.2

MINERAL INDUSTRY OF OKLAHOMA, 1992

The value of nonfuel mineral production in Oklahoma was estimated at $284.3 million by the U.S. Bureau of Mines. This was an almost $8.8 million increase over the $275.5 million reported in 1991. Sales increased in 1992 for most mineral commodities produced in the State. Increases in masonry cement, salt, and construction sand and gravel production were the most substantial, followed by crude gypsum, feldspar, and lime. There were also increases in the production of iodine, crushed stone, and portland cement. Crushed stone continued as the State's leading mineral commodity, accounting for more than 35% of the total nonfuel mineral value. Combined values of crushed stone, portland cement, crude iodine, and construction sand and gravel accounted for nearly 76% of the estimated total mineral value reported in 1992. Oklahoma ranked 34th nationally in nonfuel mineral value and continued as the nation's leading producer of iodine and crude gypsum.

Employment

Oklahoma's mineral-industry employment in October 1992, the latest month with available data, totaled 35,600, a 14.6% decline from the 42,000 employed in October 1991. Approximately 1,900 workers were employed in the nonfuel sector of the industry, a decrease of 200 from October 1991. Employment in the oil and gas extraction sector was down 14.9%, from 39,600 in October 1991 to 33,700 in 1992. Workers in the stone, clay, and glass products sectors increased a total of 3.1% to 10,000 in 1992. The 5,100 persons employed in the primary metals sector were 100 fewer than in 1992. Employment in the construction industry remained stable at 39,100 workers.

Legislation and Government Programs

House bill 1662 required the Oklahoma Department of Mines to accept written comments from local soil conservation districts and other public entities on the environmental effects of proposed mining operations. In addition, any person who may be adversely affected by any permitted mining activity may request the Department of Mines to hold an informal conference on the matter.

Enacted Senate bill 663 establishes seasonal restrictions on production from natural gas wells and grants the Oklahoma Corporation Commission the authority to increase or decrease the amount of gas that may be produced, for the purpose of preventing waste and more closely following market demand. The legislation is expected to help stabilize natural gas prices and to increase the number of nationally competitive Oklahoma producers.

Senate Joint Resolution 42 extended the existence of the Commission on Natural Gas Policy through February 15, 1997, so that the Commission may continue to address issues of importance to the State's oil and gas industry.

House bill 2278 established the Oklahoma Independent Energy Education and Marketing Act to educate the general public on the importance of independent oil exploration and production, encourage efficient energy usage, promote environmentally sound production methods, develop oil resources, and support research and education benefiting independent petroleum producers. The Oklahoma Independent Energy Resources Board was created to coordinate the program.

NONFUEL MINERAL PRODUCTION IN OKLAHOMA

Mineral	1991 Quantity[b]	1991 Value (thousands)	1992[a] Quantity[b]	1992[a] Value (thousands)
Cement:				
Portland (thousand short tons)	1,620[c]	$63,180[c]	1,627	$63,180
Clays (metric tons)	824,176[c]	4,178[c]	786,230	5,135
Gem stones	—	—	—	711
Gypsum (crude) (thousand short tons)	2,356	12,925	2,485	13,642
Iodine (crude) (kilograms)	1,998,914	31,389	2,041,500	26,619
Sand and gravel:				
Construction (thousand short tons)	9,000[c]	22,300[c]	10,200	25,800
Industrial (thousand short tons)	1,241	20,918	1,225	21,637
Stone:				
Crushed[d] (thousand short tons)	25,678	95,509	26,100	100,000
Dimension (short tons)	3,836[d]	596[d]	5,182	706
Tripoli (metric tons)	15,885	141	—	—
Combined value of cement (masonry), feldspar, lime, salt, stone (crushed dolomite [1990–91], crushed unidentified [1992], dimension sandstone [1991])	—	24,389	—	26,833
Total	—	275,525	—	284,263

Source: USBM Denver Regional Office of State Activities in cooperation with the Oklahoma Geological Survey.
Dashes indicate data not available, withheld to avoid disclosing company proprietary data, or not applicable.
[a]Preliminary figures.
[b]Production as measured by mine shipments, sales, or marketable production (including consumption by producers).
[c]Estimated.
[d]Excludes certain stones; kind and value included with "Combined value" data.

House bill 2227 (Oklahoma Environmental Quality Act) provided a framework for reorganizing the State's environmental agency structure. Provisions of the bill address agency overlap and duplication of effort, public confusion about agency regulatory responsibilities, lack of timeliness and definitive response to questions and complaints, and the elimination of dual water discharge permits from both the State and federal governments.

Enactment of House bill 2445 sets fees for dumping hazardous waste in the State and contains a provision capping Health Department fees charged to Zinc Corp. of America in Bartlesville. Without the cap, the company anticipated closure or layoffs. Zinc Corp. produces about 60,000 tons of zinc per year.

The U.S. Bureau of Land Management reduced royalty rates for coal on federal leases in nine eastern Oklahoma counties to encourage development of the coal. The rate for underground coal was reduced from 8% to 2% and that for surface-mined coal was reduced from 12.5% to 4%. The new rates are expected to make mining costs for federal coal more competitive with those for State and private coal, and are retroactive to December 17, 1990.

The U.S. Environmental Protection Agency (EPA) issued two regulations to implement air pollution controls required by the Clean Air Act. These included regulation of a number of mineral-products industries for toxic air pollutants and the implementation of permitting requirements for all major sources of air pollution. New standards also were set for visibility and particulate matter that apply to calciners and dryers at plants processing or producing construction products, including lightweight aggregate. EPA anticipates that product price increases resulting from the new standards probably would be less than 0.5%, but could be as much as 1.75% for the lightweight aggregate industry. EPA also studied the process of using wastes as fuel in cement kilns, in an effort to reduce regulatory burdens on industry and to redefine what is considered a waste. EPA determined that there were no data to indicate that emissions from burning wastes in cement kilns threaten human health or the environment, and that there was no measurable increase in the level of toxic metals in the cement product.

Scientists with the Oklahoma Geological Survey studied the mineral resource potential of Permian and Triassic redbed deposits in the western part of the State.

A workshop on Industrial-Minerals Development in Oklahoma was held in December at the University of Oklahoma in Norman. Co-sponsored by the Oklahoma Geological Survey, the Oklahoma Department of Mines, and the U.S. Bureau of Mines, the purpose of the workshop was to improve the development and use of Oklahoma's industrial-mineral resources.

Review by Nonfuel Mineral Commodities

Crushed stone continued as Oklahoma's leading mineral commodity, accounting for more than 35% of the total nonfuel mineral value in 1992. Oklahoma remained the only state producing crude iodine, which constituted almost 9.5% of the State's total nonfuel mineral value. The State remained first of 20 states producing crude gypsum, with an increase of about 5.5% over the production and value in 1991.

The largest increases in 1992 were for masonry cement, salt, and construction sand and gravel. Estimated production and value of masonry cement increased nearly 18% over reported 1991 totals. Salt production increased about 17%, while the value increased more than 32% from amounts reported in 1991. Production and value increases of about 13% and almost 16%, respectively, were reported for construction sand and gravel.

After reopening in April, the Sequoyah Fuels Corp. uranium processing plant at Gore, Sequoyah County, experienced two more incidents of chemical leaks, resulting in further investigation by the Nuclear Regulatory Commission and increased controversy. The plant was shut down in November. In late December, the company received permission to operate on a limited basis, to fulfill current contracts for uranium tetrafluoride. The contracts expire during the summer of 1993, at which time uranium tetrafluoride production also will cease. At yearend, controversy arose as to who will pay for the cleanup, anticipated to cost as much as $20 million and take up to 12 years to complete. Sequoyah is a subsidiary of General Atomics of San Diego.

Ball-InCon Glass Packaging Corp. closed its glass plant in Sand Springs, Tulsa County, and another plant it owns in southern California, primarily because of the excessive cost to upgrade equipment and bring the plants up to industry standards. The company's other plants in 10 states, including one in Okmulgee, will take over production from the closed plants. Ball leads the nation in the production of glass containers for the food industry and is third in the production of commercial glass bottles and jars.

Conoco developed a reclamation process for fluorinated alumina waste generated at its Ponco City refinery. Kaiser Aluminum & Chemical Corp. will use the waste as a high quality additive in manufacturing aluminum. Conoco expects to reclaim about 260,000 pounds of alumina from this plant each year. Activated alumina is used in the production of high octane gasoline. The alumina draws out unwanted fluorides from propane and butane products. The first shipments of waste were sent to Kaiser's Mead, Washington, plant in December.

Soil, contaminated by lead, zinc, and cadmium from the former Blackwell Zinc smelter, was removed from the Washington School and Beatty-Rodgers Park in Blackwell, Kay County. The soil contained bound lead, not considered a danger, and was removed from the sites under the direction of EPA.

In Bartlesville, EPA removed soil from schools and day-care facilities that was contaminated by lead and cadmium. In 1991 and 1992, the Health Department took blood samples from residents and the soil was tested by EPA. About 10% of those tested contained high levels of lead in their blood.

Muskogee Bridge Co., Inc. obtained a court order allowing the company to temporarily continue operating, despite an order to shut down issued by the Oklahoma Department of Mines. Two workers were killed when lightening set off an explosion of dynamite in October. The company was operating the limestone quarry for its own construction use, but was mining without a permit.

NEW OGS PUBLICATION

SPECIAL PUBLICATION 93-1. *DIRECTORY OF OKLAHOMA MINING INDUSTRY, 1993,* Robert H. Arndt and Robert Springer (project coordinators). 153 pages. Price: $4.

Cooperatively compiled by the Oklahoma Geological Survey (OGS) and the Oklahoma Department of Mines (ODM), this volume is the only comprehensive directory of Oklahoma's mining industry published since 1970. Firms listed in this directory are those that held mining permits from the ODM during the period 1988 to the present, or reported production in the years 1991 through June 1992, or both. Basic information includes firm name, address, name of permittee, telephone number, county of operation, legal description of permitted property, and commodity mined. Supplementary information includes mine name, local address of mine, responsible manager, specific mining information, employment, products, and transportation. Data is listed alphabetically by headquarters, mine, commodity, and county.

SP 93-1 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. Add 10% to the cost of publication(s) for mail orders, with a minimum of 50¢ per order.

NOTES ON NEW PUBLICATIONS

Paleokarst, Karst-Related Diagenesis, Reservoir Development, and Exploration Concepts: Examples from the Paleozoic Section of the Southern Mid-Continent

This guidebook was prepared for the 1993 PBS–SEPM Field Trip Conference, a two-day trip concentrating on the stratigraphy and post-depositional history of the classical Arbuckle Group exposures along Interstate 35 where it crosses the Arbuckle Mountains in southern Oklahoma. Edited by David R. Keller and Christy L. Reed, the 109-page book contains road logs and technical papers.

Order PBS–SEPM Publication No. 93-34 from: Permian Basin Section–SEPM, P.O. Box 1595, Midland, TX 79702; phone (915) 683-1573, fax 915-686-7827. The price is $30 for non-members ($25 for members); for orders $49.99 or less, add $4 for shipping in North America (orders more than $50, add $6). In Texas add 7.75% sales tax.

Water-Level Changes in the High Plains Aquifer—Predevelopment to 1990

Jack T. Dugan and Donald E. Schild wrote this 55-page USGS water-resources investigations report, which describes the High Plains aquifer, the factors that affect water levels in the aquifer, the history of development of the aquifer, and water-level changes from predevelopment through 1990. Individually authored state sections provide more detailed local analyses of water-level changes. The Oklahoma section, "Increased Precipitation and Decreased Irrigation Lands Have Slowed Water-Level Declines," was written by J. S. Havens.

Order WRI 91-4165 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 $25.75 for a paper copy; add 25% to the price for foreign shipment.

GSA Journals on Compact Disc

The Geological Society of America is offering an IBM-compatible PC diskette with a 20-minute, interactive demonstration of the new *GSA Journals on Compact Disc.* The demonstration shows features of the search-and-retrieval software, with samples from the *GSA Bulletin, Geology, GSA Today,* and the *GSA Data Repository.* In addition, a 20-year *Retrospective Index* includes bibliographic data and GeoRef™ keywords for back issues of those publications.

GSA Journals on Compact Disc is an annual publication, containing the complete ASCII text and graphical page-images of all articles for each year starting with 1992. The two-disc introductory package, to be shipped at the end of 1993, will contain complete journal data for 1992 and 1993; three years of data from *GSA Today,* two years of the *GSA Data Repository,* and the 20-year *Retrospective Index.*

Order GSA Demo from: Geological Society of America, P.O. Box 9140, Boulder, CO 80301; phone (303) 447-2020. The price is $4 for the 3½" high-density demonstration diskette, refundable on any new CD order or on any order for GSA publications totaling $50 or more.

GSA ANNUAL MEETING
Boston, Massachusetts ▪ October 25–28, 1993

New England geologists are preparing a broad-based, enthusiastic welcome for GSA's Annual Meeting in Boston. The Annual Meeting Committee, from eight universities, several consulting firms, and secondary schools, has planned a meeting that is something like a Millennial Celebration. Its central focus, Geology and Health (or, as some say, "Rocks and Docs") underscores the centrality of geological knowledge and education to discussions of human interactions with global and local environments.

Symposia, and notably the half-day Keynote Symposium, include several focused on the central theme. The rest of the program is GSA's largest ever: theme sessions, field trips of great geological variety and significance (with at least two volumes of field guides), and short courses (with text) on the cutting edge of many fields. The former Science Theater has evolved into a Computer Technology Program with its own space in the Exhibit area. A new feature, the Science Classroom of the Future *will feature a recurring program of lectures and workshops on computer hardware and software in the service of geology, as well as a similar hands-on program. Education programs for K–12 teachers have a full range of offerings including field trips, short courses, and free one-day admission. Special events and guest activities of great variety and interest will have the special flavor of Boston.*

Boston at any season is a highly stimulating scientific, academic, cultural, historic, business, gastronomic, and tourist paradise. The end of October, moreover, is the height of the foliage season, a magnificent time in New England for any outdoor interest, but especially for field trips and guest tours. The Hynes Convention Center is at the hub of the "Hub of the Universe" (as Bostonians say) near Quincy Market, the waterfront, and many of the above attractions, within walking distance or a short ride on the MBTA (the public transport). On behalf of the Annual Meeting Committee and the geologists of New England's IGC, I am pleased to invite you to Boston and look forward to welcoming you to what we hope and expect will be one of the most significant and most enjoyable meetings of GSA in this millennium.

— Jim Skehan, S.J.
General Chairman

BOSTON

GSA Annual Meeting Agenda

Technical Program

Symposia

Keynote Symposium—Geology and Health
Fractal Geometry and Chaos Theory and Their Use in the Earth Sciences
Geological Insight and Ground-Water Modeling
The Permian–Triassic Mass Extinction: Causes and Consequences
Fluids and Fluid Flow in the Crust
Inferring Paleoearthquakes from Fault-Rock Fabrics: Experimental and Field Evidence
Coalification: Metamorphic Parameters and Interpretation of Maturation Histories
Sedimentological and Stratigraphic Framework of Ground-Water Resources
Neogene and Quaternary Sea-Level Change and Coastal Plain Evolution: U.S. East Coast
Organics and Ore Deposits
Geochemical Aspects of Minerals in Physiological Fluids
Sedimentary Diagenesis of Nitrogen and Sulfur in Organic Matter
Evolution and Global Consequences of the Himalayan Orogenic System
Deep Seismic Imaging across Continental Margins: From the Ocean–Continent Boundary to the Beach and Beyond
Human Problems, Foraminiferal Solutions
The First Half-Billion Years in the Inner Solar System
Chlorine and Fluorine as Monitors of Fluid-Rock Interaction: New Developments
Historical Research as a Function of Exploration Methodology
Analytical Methods in Archaeological Geology
Beyond Student Literacy: How to Create an Earth-Literate Public
Successfully Funded Laboratory and Field Technique Programs in the Geosciences
Finding and Communicating Geoscience Information
Metamorphic and Metamorphosed Ore Deposits

Theme Sessions

Fractal Geometry, Self-Organized Criticality, Chaos Theory, and Their Application in the Earth Sciences
Tectono-Metamorphic Evolution of North and Central America
Teaching Mineralogy
Coalification: Metamorphic Parameters and Interpretation of Maturation Histories
Geochemistry of Large Rivers
Geologic Impacts of the Gulf War
Hydrogeochemistry Related to Health and Disease
The Urban Ocean Environment: Geological Perspectives
Processes of Supradetachment Basins
Environmental Geology: The Voice of Warning
Environmental Geology: The Voice of Reason
Interpreting Stromatolites: Biological vs. Sedimentological Information
Mineral Resources in Developing Nations: Economic Impact and Environmental Concerns

Evolution and Global Consequences of the Himalayan Orogenic System
Evolution and Biogeography of Marine Microplankton During the Paleocene Epoch
Health Implications of Metals in Soils
Constraints on the Evolution of the Early Earth
Paleogeography of Silurian Taconica
The Cretaceous–Tertiary Boundary Event: Biotic and Environmental Changes
The New England–Acadian Shoreline Revisited
Deep Seismic Imaging across Continental Margins: From the Ocean–Continent Boundary to the Beach and Beyond
Fate and Transport of Contaminants in Boston Harbor and Massachusetts Bay
Advances in Tectonic Models of Precambrian Orogens from Structural Geology and Geochronology
The Geology of Natural Gas Resources: Challenges and Opportunities
Structure and Geophysics of the Appalachian Orogen
High-Resolution Paleozoic Isochrons
Paleoenvironments in Oxygen-Deficient Basins: The Carbon–Sulfur–Iron System and Related Geochemical and Ecological Constraints
First Transition Series Metals and Health: Fact and Fiction
Applications of Modern Geodetic Techniques to the Solution of Geological Problems
Isotope Paleobiology
New Perspectives on the Evolution of Atlantic Continental Rises
Geochemistry and Chronology of Appalachian Mylonites and Shear Zones
Environmental Issues in Urban Settings
Metamorphism, Fluid Flow, and Ore Deposits
Flow and Transport in Variable-Density Ground Water
Geologic Disposal of Nuclear Waste and the Risks to Public Health and Safety
Advances in Dating Young Ground Water
Thermobarometric Studies and P–T Path Determinations in Mountain Belts
Paleoecology of Pre-Carboniferous Terrestrial Ecosystems
Pluton Interiors: Structure and Dynamics
New Developments in Quaternary Geology: Implications for Geoscience Education and Research

Field Trips

Premeeting

Layered Gabbro–Diorite Intrusions of Coastal Maine: Basaltic Infusions into Silicic Magma Chambers, *Oct. 21–24*
Sequence and Correlation of Tectonic and Metamorphic Events in Southeastern Vermont, *Oct. 21–24*
A Tectonic-Stratigraphic Transect across the New England Caledonides of Massachusetts, *Oct. 21–24*
Petrologic and Isotopic Studies in Metamorphic Rocks of Eastern Vermont and Western New Hampshire, *Oct. 21–24*
Age and Petrogenetic Relationships in the Adirondack Highlands, New York, *Oct. 21–24*
A Transect through the Taconide Zone of Central Vermont, *Oct. 21–24*
Granite Pegmatites in Northern New England, *Oct. 22–24*
Sea-Level Change, Coastal Processes, and Shoreline Development in Northern New England, *Oct. 22–24*

Evidence from Thermochronology, Geochronology, and Petrology for Late Paleozoic Assembling of Lithotectonic Terranes in South-Central New England, *Oct. 21–24*
The Late Glacial Marine Invasion of Coastal Central New England (Northeastern Massachusetts–Southwestern Maine): Its Ups and Downs, *Oct. 22–24*
Carboniferous Geology of the Anthracite Fields of Eastern Pennsylvania and New England, *Oct. 21–24*
Geology of the Coastal Lithotectonic Belt, Southwestern Maine and Southeastern New Hampshire, *Oct. 22–24*
Petrology and Field Relations of Successive Metamorphic Events in Pelites of West-Central Maine, *Oct. 22–24*
Migmatites of Southern New England: Melting, Metamorphism, and Tectonics, *Oct. 21–24*
Ring Dikes and Plutons: The Deeper View of Calderas, *Oct. 21–24*
High-Pressure Taconian and Subsequent Polymetamorphism of Southern Quebec and Northern Vermont, *Oct. 22–24*
Paleoenvironmental Traverse across the Early Mesozoic Hartford Rift Basin, Connecticut, *Oct. 22–24*
Field Evidence and Petrogenesis of the A-Type and I-Type Paleozoic Plutonic Complexes of Eastern Massachusetts, *Oct. 22–24*
Methods of Characterizing Fluid Movement and Chemical Transport in Fractured Rock, *Oct. 23–24*
Highlights of Proterozoic Geology of Boston, *Oct. 24*
Archaeological Geology of Long Island, Boston Harbor, *Oct. 24*
Pleistocene Geology of the Boston Basin and Its Adjacent Surroundings, *Oct. 24*
Dimension Stone Quarries: A New England Resource in Transition, *Oct. 24*

Half-Day Trips (held during the meeting)

Boat Tour of Boston Inner and Outer Harbor and Islands, *Oct. 26*
Petrologic and Age Relationships of Igneous Rocks in the Pine Hill Area, Medford, Massachusetts, *Oct. 26*
Geology of East Point, a Rocky New England Coastline, *Oct. 27*
Engineering Geology and the Geology in Active Tunnel Projects in the Boston Area, *Date to be determined*

Postmeeting

Coastal Geologic Hazards and Management Strategies along a Complex Microtidal Coastline, *Oct. 28–31*
Alleghanian and Avalonian Tectonism in Southeastern New England, *Oct. 28–31*
Geology and Geomorphology of the Acadian Orogen, Central Maine, *Oct. 28–31*
Highlights of Metamorphic Stratigraphy and Tectonics in Western Maine to Northeastern Vermont, *Oct. 28–31*
Building Blocks of Boston, *Oct. 29*
Multiple Glaciations and Deglaciation of a Transect from Boston, Massachusetts, to the White Mountains, New Hampshire, *Oct. 29–30*
The Avalon and Nashoba Terranes (Eastern Margin of the Appalachian Orogen in Southeastern New England), *Oct. 29–31*
Ground-Water Contamination and Solute-Transport Research at the U.S. Geological Survey's Cape Cod Field Site, *Oct. 29*

Other Field Trips

Mineral Deposits of the Adirondack Mountains, *Oct. 19–22*
Besshi-Type Massive Sulfide Deposits of the Vermont Copper Belt, *Oct. 21–23*
Boston Harbor Explorations, *Oct. 24*
Coastal Geology North of Boston, *Oct. 24*
Geology of the Boston Basin, *Oct. 24*
Geosecrets of Downtown Boston: City Geology with a City Geologist, *Oct. 24*
Evolution of Cape Cod Landscapes: Marine and Glacial Field Techniques Applied to Cape Cod, *Oct. 30*

Short Courses/Workshops/Forums

GIS and the Geosciences, *Oct. 23*
Urban Geology: Foundation for Inner City Health, *Oct. 23*
Asia: A Continent Built and Assembled Over the Last 500 Million Years, *Oct. 23–24*
Contaminant Hydrogeology: Practical Monitoring, Protection, and Cleanup, *Oct. 23–24*
Fracture Mechanics of Rock, *Oct. 23–24*
Alternative Pedagogies in Geological Sciences: A Workshop, *Oct. 24*
Application of Sedimentological Information to Hydrogeological Problems, *Oct. 24*
Computer Mapping at Your Desk That Really Works, *Oct. 24*
Environmental/Engineering Geology and Land-Use Planning—An Interface between Science and Regulations, *Oct. 24*
Geochemistry and Stable Isotopes of Paleosols, *Oct. 24*
Isotope Hydrology, *Oct. 24*
Fractals and Their Use in Earth Sciences, *Oct. 29–30*
Geoscience Legislation in Congress, *Oct. 26*
Health Effects of Mineral Dusts, *Oct. 22–24*
Teaching Topics in Earth Science and Geology with Video as a Partner: For Secondary School Teachers, *Oct. 23*
Taphanomic Approaches to Time Resolution in Fossil Assemblages, *Oct. 24*
Teaching Introductory Geology with Video as a Partner: For College Teachers, *Oct. 24*
DataBase Forum, *Oct. 24*
GeoRef Intermediate/Advanced Workshop, *Oct. 26*
Preparing Successful Grant Proposals to Fund Curriculum Innovation in the Geosciences, *Oct. 26*

For further information about the annual meeting, contact GSA, Meetings Dept., P.O. Box 9140, Boulder, CO 80301; (303) 447-2020 or 1-800-472-1988. The preregistration deadline is September 24.

UPCOMING MEETINGS

Geochemistry of the Earth Surface, 3rd International Symposium, August 1–6, 1993, University Park, Pennsylvania. Information: Lee Kump, Dept. of Geosciences, Pennsylvania State University, University Park, PA 16802; (814) 863-1274, fax 814-865-3191.

SEPM Annual Meeting, "Stratigraphic Record of Global Change: Climate, Eustasy, and Life," August 8–12, 1993, University Park, Pennsylvania. Information: Michael Arthur, Dept. of Geosciences, Pennsylvania State University, University Park, PA 16802; (814) 865-6711, fax 814-865-3191.

American Water Resources Association, Annual Meeting, August 29–September 3, 1993, Tucson, Arizona. Information: Herbert B. Osborn, 2341 S. Lazy A Place, Tucson, AZ 85713; (602) 883-4517.

Friends of the Pleistocene, Field Trip, September 10–12, 1993, Mission Valley/Flathead Lake, Montana. Information: Dan Levish, Bureau of Reclamation, D-3611, Box 25007, Denver, CO 80225; (303) 236-8532.

Coal Science, 7th International Conference, September 12–17, 1993, Banff, Alberta, Canada. Information: David Brown, P.O. Bag 1280, Devon, Alberta T0C 1E0, Canada; (403) 450-5200, fax 403-987-3430.

WORLDTech I, International Congress on Mining Development, September 15–17, 1993, Philadelphia, Pennsylvania. Information: Meetings Dept., Society for Mining, Metallurgy, and Exploration, P.O. Box 625002, Littleton, CO 80162; (303) 973-9550, fax 303-979-3461.

Society for Organic Petrology, 10th Annual Meeting, October 9–13, 1993, Norman, Oklahoma. Information: Brian Cardott, Oklahoma Geological Survey, 100 E. Boyd, Room N-131, Norman, OK 73019; (405) 325-3031, fax 405-325-7069.

Society of Vertebrate Paleontology, Annual Meeting, October 13–16, 1993, Albuquerque, New Mexico. Information: Spencer G. Lucas, New Mexico Museum of Natural History and Science, 1801 Mountain Road N.W., Albuquerque, NM 87104; (505) 841-8837, fax 505-841-8866.

American Association of Petroleum Geologists, International Meeting, October 17–20, 1993, The Hague, Netherlands. Information: Convention Dept., AAPG, Box 979, Tulsa, OK 74101; (918) 584-2555, fax 918-584-0469.

National Ground Water Association, 45th Annual Convention and Exposition, October 17–20, 1993, Kansas City, Missouri. Information: NGWA, 6375 Riverside Dr., Dublin, OH 43017; (614) 761-1711, fax 614-761-3446.

Hunton Group Core Workshop and Field Trip, November 2–3, 1993, 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.

American Geophysical Union, Fall Meeting, December 6–10, 1993, San Francisco, California. *Abstracts due September 9.* Information: Meetings Dept., AGU, 2000 Florida Ave. N.W., Washington, DC 20009; (202) 462-6900, fax 202-328-0566.

OKLAHOMA ABSTRACTS

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

Regional Depositional Relationships and Fracturing of the Wapanucka Limestone, Frontal Ouachita Mountains

DARRELL L. MAULDIN, Phillips Petroleum Co., Houston, TX 77253

Although gas production in the Ouachita Mountains has been primarily from the Spiro (Atokan), the Wapanucka (Morrowan) is locally a gas reservoir and thus is a secondary objective. Outcrop study of imbricate thrust sheets forms a basis for predicting the character of rocks in the subsurface. Thick successions of repetitive subtidal carbonate cycles of platform, platform margin, and basinal facies characterize the Wapanucka in outcrop, except for most of the basinal outcrops, in which cyclicity is not evident. Each cyclic sequence records aggradation and southward progradation of the ramp-like shelf margin. Shoaling marine environments are represented by bryozoan crinoid shallow shelf bars capped by oolites that developed on local and regional topographic highs. These repetitive subtidal cycles are occasionally capped by localized beach deposits (limestone pebble conglomerates with abundant oolites and carbonaceous wood fragments).

Demosponges were the most abundant biota at times when the shallow shelf waters were muddied by fine clastic influx. Sponges commonly grew with the tubular algae, Donezella and were occasionally encrusted with Archaeolithophyllum a phylloid algae. These two algaes form boundstones that dominate the basinward facies with associated encrusting forams. In the eastern portion of the study area, phylloid algae is often the dominant bioclast in arenaceous grainstone shoal deposits. They are also found as the major constituent of algal-mud mounds.

The top of the Wapanucka can be correlated throughout the outcrop region as a stratigraphic sequence boundary. A fine clastic influx, probably from the terrestrial Foster channels to the north, choked out the carbonate production of the Wapanucka. This shaly facies conformably overlies the Wapanucka and is either termed the middle shale or sub-Spiro shale. In this interval, cross-bedded sandy calcarenites within the shale probably represent shelf bars. These local buildups, make it difficult to separate the Wapanucka and Spiro. Several of these discontinuous bars occur in outcrop within a few miles laterally, and were also observed in subsurface core. The Spiro Formation conformably overlies the middle shale and represents a return to shallow shelf carbonate deposition similar to the Wapanucka. However, significant amounts of sand were transported to form sand dominated shallow marine bars, in contrast to the bioclastic and oolite shoals of the Wapanucka.

Several facies of the Wapanucka are potential hydrocarbon reservoir rocks. These include limestone pebble conglomerate, oolitic grainstone, algal boundstone

and spiculitic limestone. Spiculitic limestones (often sponge boundstones) often develop fracture porosity. Numerous fractures in the frontal Ouachitas cut through bedding, and most of these are oriented perpendicular or parallel to strike. Fracturing is believed to be of major importance to reservoir potential of the Wapanucka, and probably the Spiro as well.

Reprinted as published in the American Association of Petroleum Geologists, *1993 Annual Convention Official Program*, p. 147–148.

Controls on Variability of Depositional Style in Carboniferous Submarine Fan Complexes of the Ouachita Basin of Oklahoma and Arkansas

JAMES L. COLEMAN, JR., Amoco Production Co., Houston, TX 77253

The Paleozoic stratigraphic succession of the Ouachita Basin is dominated by deep water siliciclastics, carbonates, and chert. Volumetrically, siliciclastics of the Carboniferous Stanley, Jackfork, Johns Valley, and Atoka Formations make up the preponderance of this interval. Well-documented, shelf biostratigraphy and paleoenvironmental indicators help constrain age and depositional environment interpretations of the basinal sedimentary rocks. This study illustrates the influence of eustacy, climate, and tectonics on the basinal sedimentation of four sequential stratigraphic units.

The Stanley fan complex was deposited during an overall sea level highstand, and is a thick shale interval with upper and lower sandstone sections. The overlying Jackfork is predominantly a sandstone section, with no shelf equivalent, and was deposited following a major eustatic fall. The Johns Valley represents highstand basinal sedimentation at the initiation of Ouachita Basin shelf collapse. The Atoka Formation is a complex of basinal, slope, and shelf margin siliciclastics deposited during a rising sea level as a result of overwhelming tectonic influence, abundant sediment supply, and increasing accommodation space.

Reprinted as published in the American Association of Petroleum Geologists, *1993 Annual Convention Official Program*, p. 86–87.

Clay Minerals in Atokan Deep-Water Sandstone Facies, Arkoma Basin: Origins and Influence on Diagenesis and Reservoir Quality

DAVID W. HOUSEKNECHT and LOUIS M. ROSS, JR., Dept. of Geological Sciences, University of Missouri, Columbia, MO 65211

Strata of the lower and middle Atoka Formation in the Arkoma Basin comprise submarine-fan and marine-slope facies that display a variety of primary and secondary sedimentary structures, formed by sediment gravity-flow depositional processes and dewatering, respectively. Primary sedimentary structures are most common in beds deposited by unconfined sediment gravity flows on submarine-fan lobes,

whereas secondary sedimentary structures are most common in beds deposited by channelized sediment gravity flows in fan channels and slope channels. Primary sedimentary structures display horizontal fabrics, whereas secondary sedimentary structures display deformed and vertical fabrics. Abundance and distribution of clay minerals in Atoka sandstones are related to sedimentary structures. Beds that display primary sedimentary structures contain little detrital clay that is sparsely disseminated through the sandstone. In contrast, beds that display secondary sedimentary structures contain more detrital clay that forms pervasive grain coatings, bridges between grains, and consolidation laminae. Other beds lack sedimentary structures and display abundant detrital clay that forms a matrix-supported fabric.

The abundance and distribution of detrital-clay minerals exerted significant influences on diagenesis and reservoir quality of Atoka sandstones. Among sandstones with grain-supported fabrics, those that display primary sedimentary structures and contain little detrital clay were pervasively cemented by quartz overgrowths and are characterized by poor reservoir quality. Those that display secondary sedimentary structures and contain more abundant detrital clay retained primary porosity because quartz-overgrowth nucleation was inhibited by clay coatings on detrital grains. Porosity was enhanced in these sandstones by dissolution of framework grains, and the sandstones are characterized by good reservoir quality. Sandstones with matrix-supported fabrics apparently had little original porosity, which was reduced by compaction of the pervasive matrix; they are characterized by poor reservoir quality. These observations suggest that channelized turbidite facies have greater potential to retain good reservoir quality than unconfined turbidite facies, because the former have detrital-clay minerals emplaced within sand during dewatering and those clay minerals inhibit destruction of porosity by quartz cementation.

Reprinted as published in *Origin, Diagenesis, and Petrophysics of Clay Minerals in Sandstones,* SEPM Special Publication No. 47, 1992, p. 227.

Trap Analysis: Case Study of Arbuckle Reservoir in Fault-Bounded Structure, Wilburton Field, Arkoma Basin, Oklahoma

CHARLES A. STERNBACH, Shell Western Exploration and Production, Inc., P.O. Box 991, Houston, TX 77001

Trap analysis has widespread application for prospect evaluation of fault-bounded closures in the Mid-Continent. Trap analysis involves detailed study of how the objective section is juxtaposed with the sealing section across a fault and can be used to predict prospect viability and potential hydrocarbon column heights for lower Ordovician dolomite objectives in faulted structures along the Marathon–Ouachita orogen.

In the Arkoma Basin, productive column height of the Arbuckle gas accumulation at Wilburton Field is substantially less than the mapped structural closure. Some gas in the upthrown Arbuckle Dolomite leaked into Simpson Sandstone on the downthrown side of the critical counter-regional fault and migrated away from the Arbuckle trap. Post-Simpson tight limestone and shale on the downthrown block sealed gas in Arbuckle Dolomite on the highest part of the upthrown block. A regional isopach map of the Simpson Sandstone indicates the minimum fault throw prospects need to juxtapose Arbuckle reservoir with the post-Simpson sealing section increases to the south. Not only can fault throws be too small, they can also be too large to seal. The Pennsylvanian Spiro Sandstone is a potential thief sandstone for prospects in the Arkoma Basin with large fault throws. Viable prospects are constrained by a stratigraphically controlled window of fault throws consistent with trap analysis.

The deeper pool Arbuckle discovery at Wilburton field in late 1987 set off a drilling boom in the Arkoma Basin. Before and after Wilburton, many Arbuckle dry holes have been drilled with little regard for trap analysis. Many dry holes outside of Wilburton did not have proper fault throw on the critical trapping fault to juxtapose Arbuckle reservoir section with downthrown seal section. Trap risks can be evaluated prior to drilling with a good understanding of the structure and the rock properties of local stratigraphy.

Reprinted as published in the American Association of Petroleum Geologists, *1993 Annual Convention Official Program*, p. 186.

Productive Thrust Sheets and the Surface Fault Traces Identified by Microbial Survey, Arkoma Basin, Oklahoma

JAMES D. TUCKER, DANIEL C. HITZMAN, and DONALD O. HITZMAN, Geo-Microbial Technologies, Ochelata, OK 74501

A large microbial survey was conducted over a portion of the Arkoma basin, Oklahoma, to identify microbial trends related to recently discovered productive areas. The microbial survey analyzed shallow soil samples for a specific suite of microorganisms associated with light hydrocarbons using the Microbial Oil Survey Technique (MOST) developed by Phillips Petroleum Company. Regions of high microbial activity indicate the presence of elevated hydrocarbon gases in the soils related to microseepage. The microbial samples were collected from the shallow soil environment every 0.1 mile along existing roads and right of ways. The Arkoma basin presents a particular problem for any surface geochemical technique due to the depth of the reservoirs and the highly faulted and thrusted nature of the region. Despite these obstacles, large clusters of elevated microbial activity were identified over specific thrust sheets where successful deep gas wells have recently been drilled. Likewise, several dry holes were accurately predicted in thrust sheets having only background values indicating little hydrocarbon microseepage present. Often measured microbial activity changed rapidly after crossing into different thrust sheets, thus indicating a microbial signature able to identify sheet boundaries. In some areas, clusters of elevated microbial activity dropped rapidly with no mapped fault boundary, possibly indicating the presence of unmapped fault blocks. Mapped surface faults were identified by isolated microbial highs wherever the surface trace was crossed. In these deep, highly faulted environments, microbial surveys appear to be a powerful exploration tool for identification of productive thrust sheets and surface fault traces.

Reprinted as published in the American Association of Petroleum Geologists, *1993 Annual Convention Official Program*, p. 192.

Arkoma Basin (Oklahoma) Coal-Bed Methane Resource Base and Development

J. M. FORGOTSON, School of Geology and Geophysics, University of Oklahoma, Norman, OK 73019; and SAMUEL A. FRIEDMAN, Oklahoma Geological Survey, 100 E. Boyd, Norman, OK 73019

Seventy percent of the 4 TCF coal bed methane resource estimated for the Arkoma Basin is in the basal Desmoinesian (Pennsylvanian) Hartshorne coals that are a total of 3 to 12 ft thick. The Lower Hartshorne coal is a maximum of 10 ft thick and is 4 to 5 ft thick in most of the basin. Distribution and thickness of Hartshorne coals have been determined from outcrops, surface and underground mines, core holes, and logs of wells drilled for gas in deeper formations. From the western to the eastern part of the Oklahoma Arkoma basin the rank of Hartshorne coals increases from high-volatile C bituminous to low-volatile bituminous, and the gas content increased from 300 cu ft/ton to 600 cu ft/ton at depths of 800 to 2,000 feet.

Approximately 40 wells in the Kinta area of Haskell County are producing gas commercially from the Hartshorne coal reservoir. In Pittsburg County a few wells previously producing from the Hartshorne sandstone have been recompleted in the overlying Hartshorne coal. Approximately 20 test wells, drilled in Le Flore County, are waiting on pipeline connections, are in various stages of completion, or have been abandoned. Coal-bed methane production rates in the basin range from 25 MCF/D to 250 MCF/D with little or no water production.

Preliminary economic evaluation suggests that because of the good infrastructure of roads, pipelines and gas field services, and low drilling and operating costs development of coal-bed methane production from Hartshorne coals totaling 5–10 ft thick, at depths of 500 to 2,000 feet underlying relatively flat, easily accessible grazing land, should provide internal rates of return of 30% or more if the wellhead price is at least $2.00 MCF.

Reprinted as published in the American Association of Petroleum Geologists, *1993 Annual Convention Official Program*, p. 103.

Growth of Silt-Size Quartz During Diagenesis/Low-Grade Metamorphism of Pelitic Rocks

MATTHEW W. TOTTEN, Dept. of Geology and Geophysics, University of New Orleans, New Orleans, LA 70148; and HARVEY BLATT, School of Geology and Geophysics, University of Oklahoma, Norman, OK 73019

The smectite-illite transformation has been cited by many authors as a source of silica during diagenesis of mudrocks. However, illites themselves undergo chemical changes as they recrystallize into micas during high-grade diagenesis/low-grade metamorphism. Average compositions of phyllosilicates from the literature suggest that an equivalent amount of silica is available from transformation of illite to muscovite as from illitization of smectites. The fate of silica released by this process has not

been reported, but could be a major contributor to the silt-size quartz population.

The quartz and feldspar fraction of pelites from the Stanley Shale (Mississippian) in the Ouachita Mountains of Oklahoma and Arkansas was analyzed using standard petrographic techniques. The data obtained were related to illite crystallinity and vitrinite reflectance as reported by Guthrie et al. (1986) and Houseknecht and Matthews (1985).

Both the percentage of quartz and the mean grain size of the quartz and feldspar fraction increase with increasing illite crystallinity. The growth in quartz is especially apparent in the finest size fractions. A corresponding decrease in the silica content of the clay-mineral fraction is also observed. Development of quartz polycrystallinity occurs across the same interval.

The results of this study are consistent with reported differences between quartz in schists and their shale precursors, and suggest that release of silica during diagenesis of phyllosilicates continues after the smectite-illite transformation. This silica precipitates as quartz within the pelite, consistent with the suggestion by Blatt (1987) that metapelites are the source of abundant silt-size quartz.

Reprinted as published in the American Association of Petroleum Geologists, *1993 Annual Convention Official Program*, p. 191–192.

The Record of Ordovician Sea Level Changes in Outer Continental Margin Settings of North America

STANLEY C. FINNEY, Dept. of Geological Sciences, California State University, Long Beach, CA 90840; and CLAUDIO BARTOLINI, Dept. of Geological Sciences, University of Texas, El Paso, TX 77986

Ordovician rocks exposed in the Ouachita Mountains of Arkansas and Oklahoma and the Marathon region of Texas and Ordovician strata in the Roberts Mountains allochthon of Nevada were deposited in deep-marine basins peripheral to the North America continent. Ordovician rocks in Sonora, Mexico, accumulated in a similar setting. Deposition in all three areas, which were to some extent continuous, was very similar and included black shale, bedded chert, sandstone, and limestone. The sandstone is turbiditic and composed of quartz and/or carbonate grains derived from the North American craton and shelf. The introduction of turbidites into the peripheral basins occurred twice, in the latest Ibexian to middle Whiterockian and in the latest Whiterockian to Mohawkian. Both times are recorded in all three areas where the sandstones are separated by black shale of middle to late Whiterockian age. The nearly simultaneous, widespread deposition of turbiditic sandstone indicates that the deposition events were initiated by eustatic sea level changes. In some areas, the turbiditic events are recorded by thick (hundreds of meters) sequences of coarse-grained, thick-bedded quartzite, quartz arenite, and quartz wacke with interbedded siltstone, shale, limestone, and conglomerate; in others areas, by 1–2 massive 5–10 m thick beds of quartzite; and in still other areas, by thin-bedded siltstone and fine-grained sandstone. Although Ordovician sea level changes may have been simultaneous along the western and southern margins of North America, sandstone deposition was uneven in the peripheral basins because turbidites originated from point sources.

Reprinted as published in the American Association of Petroleum Geologists *Bulletin*, v. 77, p. 696, April 1993.

Ouachita–Appalachian Juncture: A Paleozoic Transpressional Zone in the Southeastern U.S.A.

W. S. HALE-ERLICH and J. L. COLEMAN, JR., Amoco Production Co. International, P.O. Box 3092, Houston, TX 77253

The northern margin of Gondwana collided with the southern margin of the North American craton in the late Paleozoic (330–265 Ma). Near-normal compressional stresses, generated where the trend of the North American margin was nearly perpendicular to Gondwana's plate-motion vector (closure direction), caused extensive crustal shortening and décollement thrusting within the sedimentary section. The Appalachian and Ouachita fold belts are the erosional remnants of this collision on the North American margin. Transecting the Ouachita fold belt are several zones of late Paleozoic transcurrent faulting: the Val Verde, Ardmore–Anadarko, and Reelfoot zones. They occur where the precollision margin of the North American craton was oriented oblique or parallel to the closure direction with Gondwana. Stresses generated within these zones during the collision were transpressional rather than simply compressional, and gave rise to high-angle faulting, high-amplitude vertical displacements, and the emplacement of positive flower structures. In the Val Verde and Ardmore–Anadarko basins, these features have proven to be major structural traps for oil and gas. On the basis of seismic and well data, this study identifies a zone of complex structures, including positive flower structures, in the subsurface Paleozoic section of Kemper County in east-central Mississippi. The region is considered to be another transpressional zone analogous to the Val Verde, Ardmore–Anadarko, and Reelfoot zones. The Kemper County zone separates and truncates the Appalachian Valley and Ridge fold belt in the subsurface from the Mississippi Ouachita deformed belt to the west and is, therefore, also identified as the juncture between the Ouachita and Appalachian fold-belt systems in the southeastern U.S.A.

Reprinted as published in the American Association of Petroleum Geologists *Bulletin*, v. 77, p. 552, April 1993.

Southeastern Extent of the North American Craton in Texas and Northern Chihuahua as Revealed by Pb Isotopes

ERIC WILLIAM JAMES and CHRISTOPHER D. HENRY, Bureau of Economic Geology, University of Texas, Austin, TX 78713

The geographic patterns of Pb isotopic compositions of Eocene to Miocene igneous rocks appear to delineate the southeastern edge of the North American Precambrian craton in Trans-Pecos Texas and northern Chihuahua, Mexico. The boundary parallels and lies southeast of the buried fault contact between Ouachita

facies thrust sheets and Paleozoic cratonic sedimentary rocks. Lead isotopic data for basalts and granulite xenoliths suggest that the basalts contain a mixture of Pb from mantle and lower-crustal sources. On the northwest side of the boundary, this mixing involves 1.35 to 1.1 Ga cratonic lithosphere and yields linear arrays of $^{206}Pb/^{204}Pb$ versus $^{207}Pb/^{204}Pb$ and $^{208}Pb/^{204}Pb$. Basaltic magmas on the southeast side of the boundary apparently interacted with more-radiogenic lithosphere accreted during the Ouachita orogeny. Basalts in a 50-km-wide central zone between the northwestern and southeastern provinces have Pb isotopic compositions that are intermediate between those of the northwestern and southeastern sources. In the northwestern province lead isotopic compositions of intermediate to felsic rocks are less radiogenic than those of associated basalts, whereas in the southeast province they have more radiogenic compositions than the basalts. This isotopic divergence reflects assimilation of contrasting crust of each province.

Most felsic Tertiary rocks of the northwestern province have lower $^{207}Pb/^{204}Pb$ versus $^{206}Pb/^{204}Pb$ and somewhat elevated $^{208}Pb/^{204}Pb$ versus $^{206}Pb/^{204}Pb$, suggesting assimilation of relatively high Th/U Precambrian crust. The central province also contains low $^{206}Pb/^{204}Pb$ and $^{207}Pb/^{204}Pb$ Precambrian components, but few igneous rocks have elevated $^{208}Pb/^{204}Pb$. Southeastern-province crust appears dominantly Phanerozoic, although Precambrian basement with Pb isotopic compositions near model average crust may be present. The Pb isotopic zonation observed in West Texas is similar to that found in the Appalachians of the northern United States and Canada and in the Caledonides of Europe: that is, a progression from more-radiogenic outboard terranes to less-radiogenic inboard terranes.

Lead isotopic ratios from Tertiary igneous rocks of the northwestern part of Trans-Pecos Texas are similar to those of adjacent New Mexico and southeastern Arizona, although regional basement ages and isotopic characteristics differ. Extending the West Texas isotopic terranes to the southwest holds promise for testing and improving the understanding of the Sonora–Mojave megashear; Precambrian assembly of Gondwana; and correlation of Grenville–Caledonian terranes between the Appalachians, Texas, and eastern to southern Mexico.

Reprinted as published in the Geological Society of America *Bulletin*, v. 105, p. 116, January 1993.

Paleoceanographic and Tectonic Implications of a Regionally Extensive Early Mississippian Hiatus in the Ouachita System, Southern Mid-Continental United States

PAULA J. NOBLE, Dept. of Geological Sciences, University of Texas, Austin, TX 78712

A regionally extensive Early Mississippian hiatus is recognized at the transition from preflysch to flysch rocks in the Ouachita system of the southern mid-continental United States. It is recognized only in sections where detailed biostratigraphic control exists, and it is coeval with a regional unconformity in the Ouachita foreland throughout parts of Texas, New Mexico, and Oklahoma. Widespread Early Mississippian erosion and nondeposition is attributed to a reconfiguration in basin geometry caused by the onset of Ouachita orogenic activity. Crustal flexure resulting from

the impending collision would have initiated erosional processes throughout the foreland, while simultaneously altering bottom-current pathways in the basin and allowing for a prolonged period of sedimentary bypass. In the Late Mississippian, increased constriction may have eventually cut off transequatorial bottom-water circulation, allowing deposition to resume on the shelf and in the basin. An important tectonic implication of this study is that Ouachita deformation started in the Late Devonian to earliest Mississippian, at least 10 m.y. before the onset of flysch deposition.

Reprinted as published in *Geology*, v. 21, p. 315, April 1993.

Rotation of Fold Axes during Southerly Directed Thrusting, Broken Bow Uplift, Ouachita Mountains of Oklahoma

QINGMING YANG and KENT C. NIELSEN, Programs in Geosciences, University of Texas at Dallas, Richardson, TX 75083

The Broken Bow Uplift has been subdivided into four large structures: Hochatown dome, Carter Mountain anticlinorium, Linson Creek synclinorium, and Cross Mountain anticlinorium. Detailed geological mapping of lower Paleozoic units in the western portion of Carter Mountain anticlinorium has revealed three fault zones from north to south: North Bee Creek fault zone (NBCFZ), South Carter Creek fault zone (SCCFZ), and Dyer Mountain fault zone (DMFZ). These fault zones separate two anticlines: Carter Mountain anticline and Brigham anticline. DMFZ is the tectonic contact between the Carter Mountain Anticlinorium and Hochatown dome to the south. The earliest folds in Hochatown dome are overturned, tight to isoclinal, subhorizontal with planar limbs and sharp hinges that trend east–west. The Carter Mountain and Brigham anticlines are interpreted to be associated with these earliest folds. As DMFZ is approached from Hochatown dome, fold axes plunge 15–20° to W. N. W. The folds within the fault zones have been significantly rotated and plunge at 30–55° to northwest or north. Within the South Carter Creek fault zone, a horse block is developed around a thick folded sequence of Arkansas Novaculite with fold hinge trending 350°/50°. Pencil structures which are believed to be younger fabrics than this set of fold axes also appear to be rotated to 310°/30–40° in the DMFZ. The fold axes data clearly show concentration trending in northwest direction. However there is a scatter of data with orientations trending due north as well as to northeast. A model of earlier fold axes rotation as a result of simple shear associated with inferred southerly directed thrusting has been proposed to explain the geometric relationship described above. The best fit great circle for the rotated fold axis data has an orientation of 95°/55° N. This calculated plane represents the plane of flattening associated with the southerly directed thrusting.

Reprinted as published in the Geological Society of America *Abstracts with Programs, 1993,* v. 25, no. 1, p. 46–47.