OKLAHOMA GEOLOGY

October 1996
Vol. 56, No. 5

On The Cover —

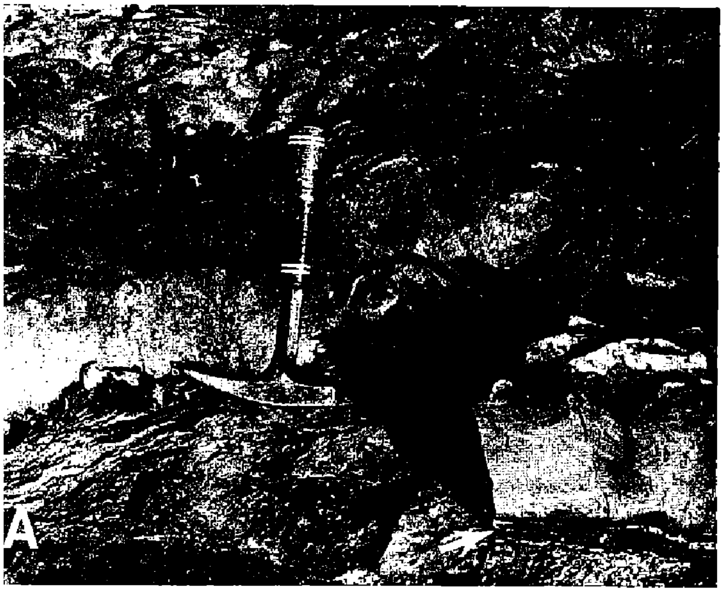
Stromatolites in the Savanna Formation

The cover photograph shows well-developed stromatolites exposed on the surface of a 10- to 14-in.-thick carbonate bed in the Savanna Formation (Pennsylvanian), Pittsburg County, Oklahoma. Stromatolites are laminated structures that occur as bulbous heads or stacks. Occurrences of beds such as these are uncommon in the Arkoma basin; none has been documented previously.

Stromatolites are considered to be organic forms, although only laminated carbonate sediment can be seen when they are examined. They contain no evidence of preserved organic skeleton. However, modern analogues observed on tidal flats in carbonate settings indicate that sediment is trapped on a sticky organic surface formed by a complex of blue-green algal mats. Following deposition, the organic mats decompose and only the laminated sediment remains (Blatt and others, 1980, p. 471–472).

The close-spaced hemispherical growth forms of the pictured stromatolites (inset photograph A [geologic pick is 1.1 ft

(continued on p. 236)



OKLAHOMA GEOLOGICAL SURVEY

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Christie Cooper

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T. Wayne Furr, *Manager*
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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.

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OKLAHOMA GEOLOGY
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October 1996
VOL. 56, NO. 5

SAVANNA FORMATION—BASIN-TO-SHELF TRANSITION

LeRoy A. Hemish[1]

Abstract

The Savanna Formation (Pennsylvanian) thins northward across the northeastern Oklahoma shelf area, from ~1,450 ft within the Arkoma basin of eastern Oklahoma (its type area) to ~70 ft just south of the Oklahoma-Kansas border. The Savanna Formation consists primarily of clastics in both areas, but the percentage of sandstone decreases from ~16% in the basin to about 2–3% in the shelf area. The balance of the formation is shale and some thin beds of coal and impure marine limestone.

The lower, sand-rich part of the Savanna Formation pinches out northward from the type area, necessitating a change in the definition of its basal boundary. The basal contact in the southern and central Arkoma basin is the base of the lowest mappable sandstone overlying shale of the McAlester Formation. It changes to the base of the Spaniard Limestone Member in the area from the Canadian River north to the Oklahoma-Kansas line. The upper contact of the Savanna Formation is marked by the base of the Bluejacket Sandstone Member of the overlying Boggy Formation throughout both the basin and shelf areas.

A supplementary reference section is established in the Arkoma basin area. Additionally, a new reference well is established in the northeastern Oklahoma shelf area.

Introduction

This paper shows the changes in lithology of the Savanna Formation from the stratotype area in the Arkoma basin to the northeastern Oklahoma shelf area, demonstrates the thinning of the formation northward out of the Arkoma basin, and discusses the different definitions for the basal contact of the Savanna Formation in the Arkoma basin and in the shelf area. It establishes a supplementary reference section for the Savanna in the southeastern part of the Arkoma basin (Appendix 1) and a reference well in the northeastern Oklahoma shelf area (Appendix 2). The reference well illustrates how the Savanna Formation rock types in the shelf area differ from those in the basin area.

This paper supplements an earlier paper by Hemish (1995), in which a principal reference section (Adamson section) was established for the Savanna Formation in its type area in central Pittsburg County, Oklahoma (Fig. 1). A complete discussion of the history of usage and previous investigations regarding the Savanna Formation is presented in that paper and will not be repeated here.

Briefly, the Savanna Formation (Savanna sandstone as originally defined) was named and first described by Taff (1899, p. 437–438) in central Pittsburg County. Subsequent usage of the term, as well as placement of boundary positions by various writers, differed from that of Taff, as shown by Hemish (1994, fig. 7). Currently, the contact between the underlying McAlester Formation and the Savanna is defined as the base of the Spaniard Limestone, or in its absence, as the base of the first mappable sandstone above the Keota Sandstone Member of the McAlester Formation. The current placement of the contact between the overlying Boggy

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[1] Oklahoma Geological Survey.

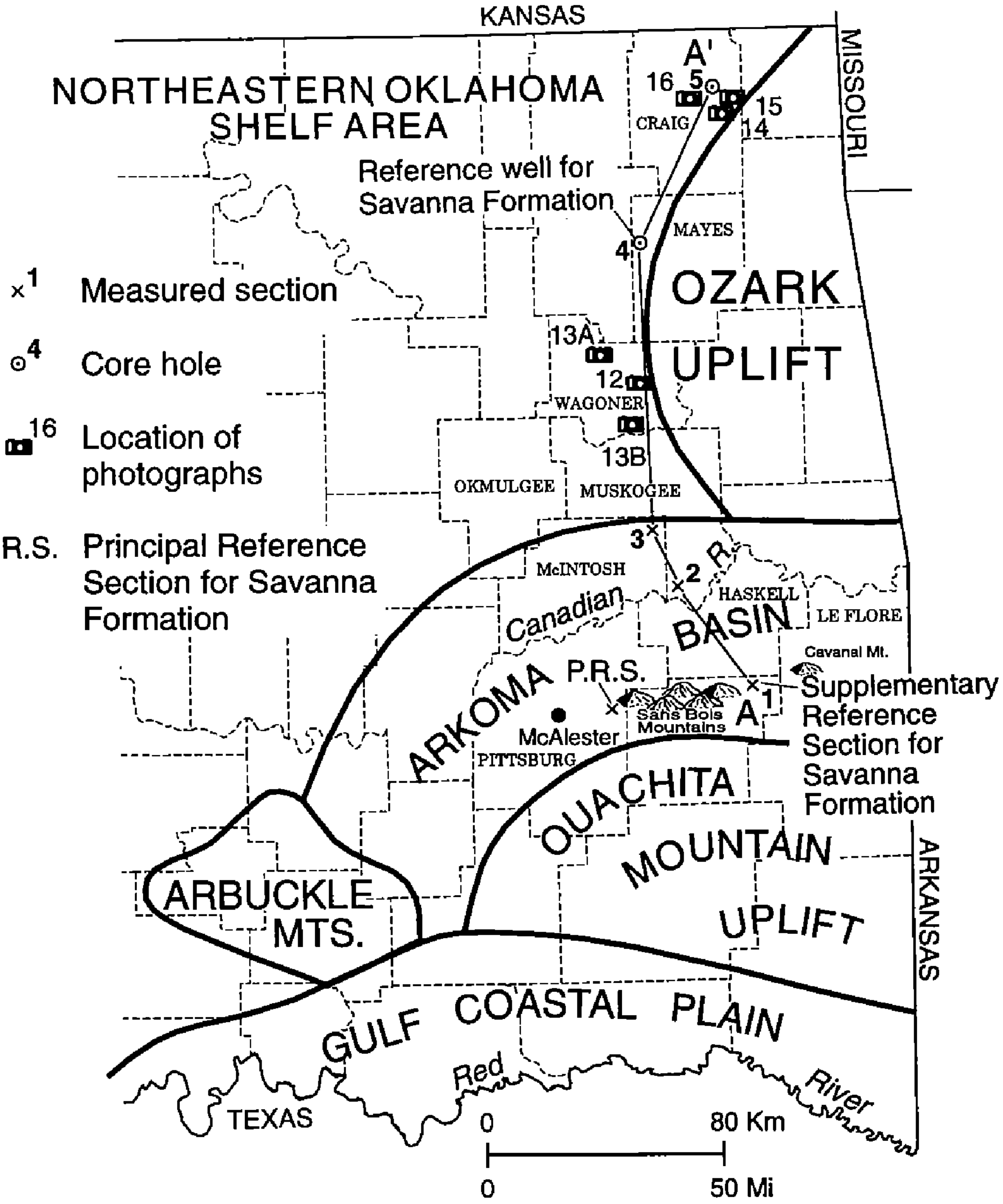


Figure 1. Map of eastern Oklahoma showing the major geologic provinces; the location of the principal reference section for the Savanna Formation (P.R.S.) (Hemish, 1995); the locations of the supplementary reference section and the reference well, both new; the line of stratigraphic correlation diagram A–A′ (shown in Figure 2); and the locations of photographs in Figures 12–16. (See Figure 4 for locations of photographs in Figures 5–11.)

Formation and the Savanna is at the base of the Bluejacket Sandstone Member of the Boggy. It was defined by Miser (1954) because it was the longest continuously mappable boundary available, and suitable for both the Arkoma basin and the northeastern Oklahoma shelf area (Fig. 1). In Oklahoma, the outcrop belt of the Savanna Formation extends from the Arkansas-Oklahoma line westward in the Arkoma basin to the northern flank of the Arbuckle Mountains and northward to the Kansas-Oklahoma line (Miser, 1954).

The Savanna Formation is not recognized in Kansas; its stratigraphic equivalents become part of the Krebs Formation (Brady and others, 1994, sheet 1). The Savanna Formation in Arkansas is believed to be equivalent to the Savanna Formation in Oklahoma (Haley, 1961, p. 8). Haley states that the formation in Arkansas is lithologically similar to the Savanna Formation in Oklahoma and that at least six coal beds are present in the unit in Arkansas. The Savanna is thicker in Arkansas, where its maximum thickness is ~2,200 ft (Haley, 1961, p. 8). In the Arkoma basin of Oklahoma, the Savanna Formation generally is about 1,100–1,450 ft thick. The thickest reported occurrence of the Savanna in Oklahoma is in the vicinity of Wister, Le Flore County, where it is ~1,750 ft thick (Hendricks, 1939, p. 272).

Stratigraphic Correlations

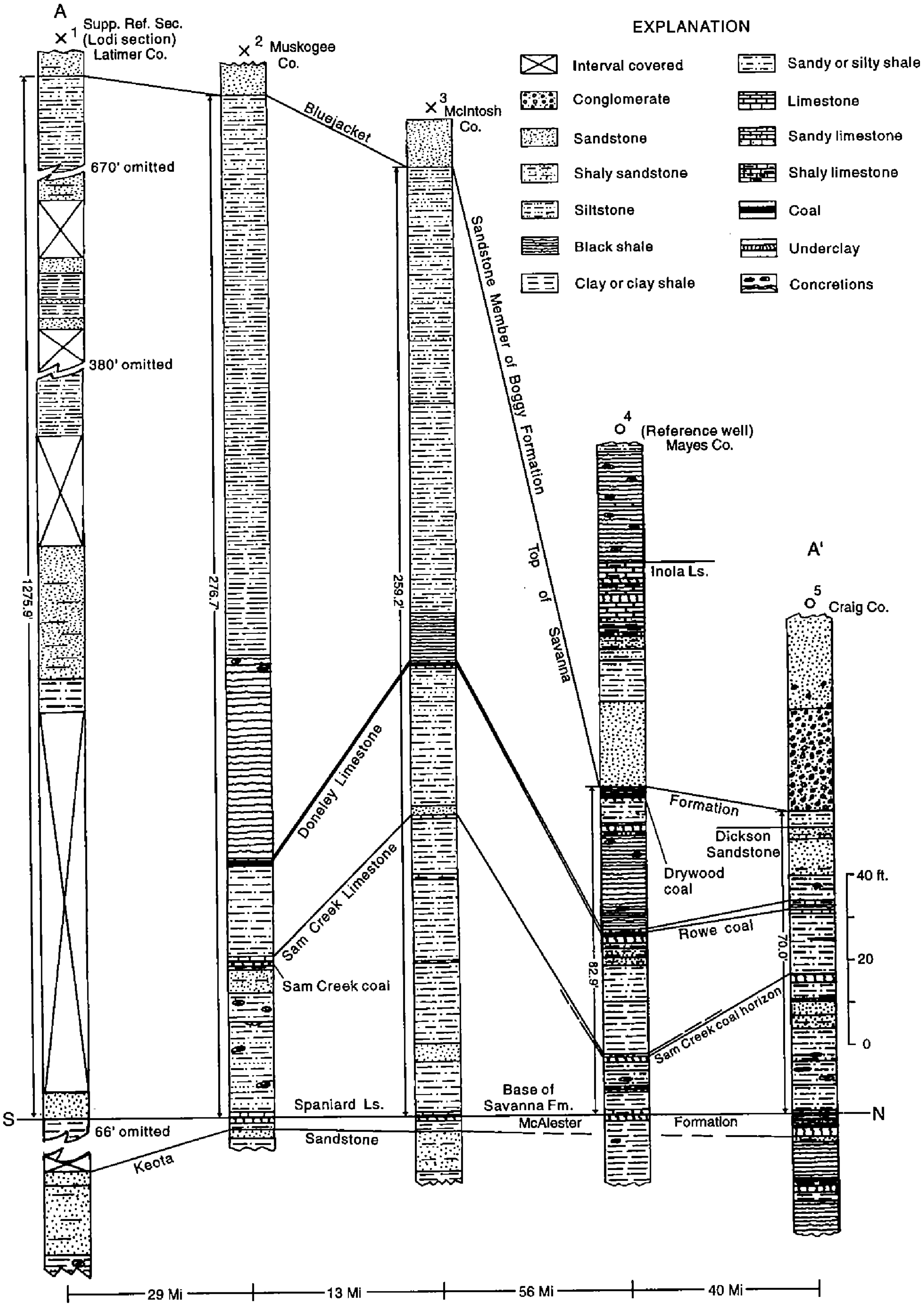
Three measured sections and two core holes (Fig. 1, A–A′) were used to construct a stratigraphic correlation diagram of the Savanna Formation from the Arkoma basin to just south of the Kansas-Oklahoma line (Fig. 2). The diagram shows not only a marked thinning of the Savanna Formation northward, but also a change in lithology.

Figure 3A is a generalized stratigraphic column showing the lithology of the Savanna Formation and the adjacent formations in the central part of the Arkoma basin. Figure 3B shows the same formations in the northern part of the Arkoma basin and the northeastern Oklahoma shelf area.

In the Arkoma basin, the Savanna Formation consists mostly of sandstone and shale; it includes a few discontinuous thin limestone beds, as well as several thin coals (of which the Cavanal is the only one named). The sandstones in the Savanna form prominent ridges throughout most of the Arkoma basin; because of their resistance to weathering, these sandstones account for much of the relief in the region (notably, in the Sans Bois Mountains) (Fig. 1). However, the combined thickness of the shale beds in the Savanna is much greater than that of the sandstones. Hemish (1995, p. 222) noted that the combined thickness of the sandstone units in the principal reference section (Fig. 1) accounts for only 16% of the formation (232.9 ft of sandstone out of 1,449.1 ft total thickness).

A section (Lodi section) measured in Latimer County (Fig. 2, x^1; Fig. 4; Appendix 1) shows marked lithologic similarities to the principal reference section for the Savanna ~30 mi west in Pittsburg County (Fig. 1). The basal unit of the Savanna Formation at both locations is a 5- to 8-ft-thick, blocky, very fine grained sandstone (Fig. 5A). The contact with the underlying gray shale unit (McAlester Formation) is sharp, irregular, and disconformable (Fig. 5B). The top of the Keota Sandstone Member of the McAlester Formation is present at both locations ~70 ft below the contact (Fig. 6). The seven ridge-forming Savanna sandstone "groups" (comprising both sandstone and shale units) described by Hemish (1995, p. 210) and informally called the Savanna 1–7 sandstones, are present in the Lodi section (Appendix 1).

Figure 2 (*opposite page*). Stratigraphic correlation diagram showing changes in lithology and thinning of the Savanna Formation northward from the Arkoma basin. Line of A–A′ is shown in Figure 1. The location of measured section x^1 (Lodi section) is shown in Figure 4, and it is described in Appendix 1; measured sections x^2 and x^3 are described in Wilson and Newell (1937, appendix, measured sections 5,20); core-hole logs for $\bigcirc^4$ and $\bigcirc^5$ are given in Hemish (1990b, appendix, core holes 7,10).


A
X 1 Supp. Ref. Sec. (Lodi section) Latimer Co.
X 2 Muskogee Co.
X 3 McIntosh Co.
O 4 (Reference well) Mayes Co.
A'
O 5 Craig Co.
EXPLANATION
Interval covered
Conglomerate
Sandstone
Shaly sandstone
Siltstone
Black shale
Clay or clay shale
Sandy or silty shale
Limestone
Sandy limestone
Shaly limestone
Coal
Underclay
Concretions
670' omitted
380' omitted
66' omitted
1275.9'
276.7'
259.2'
82.9'
70.0'
Bluejacket
Sandstone Member of Boggy Formation
Top of Savanna
Inola Ls.
Formation
Dickson Sandstone
Drywood coal
Rowe coal
Sam Creek coal horizon
Doneley Limestone
Sam Creek Limestone
Sam Creek coal
Spaniard Ls.
Base of Savanna Fm.
McAlester
Formation
Sandstone
Keota
S
N
40 ft.
20
0
29 Mi
13 Mi
56 Mi
40 Mi

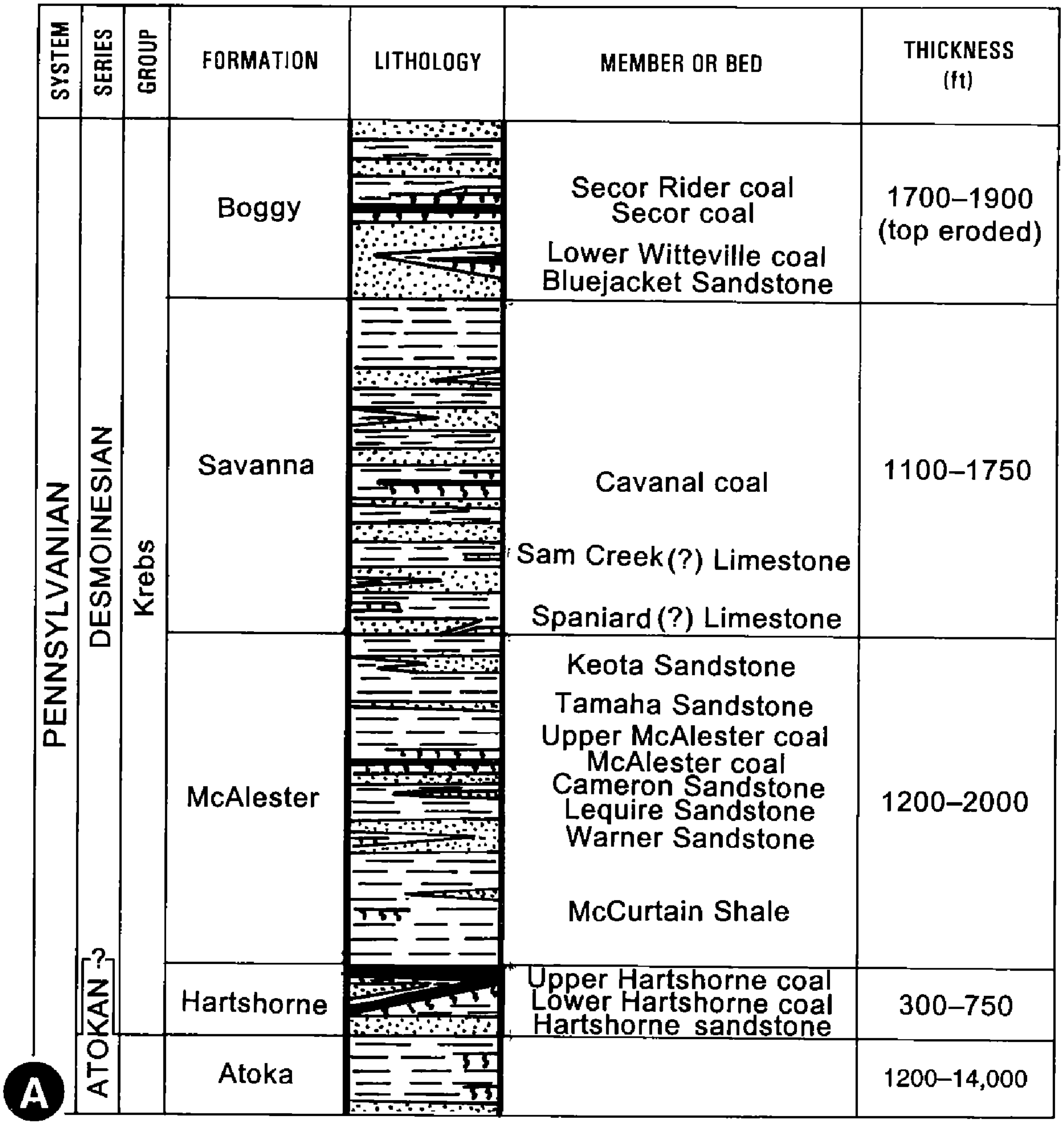
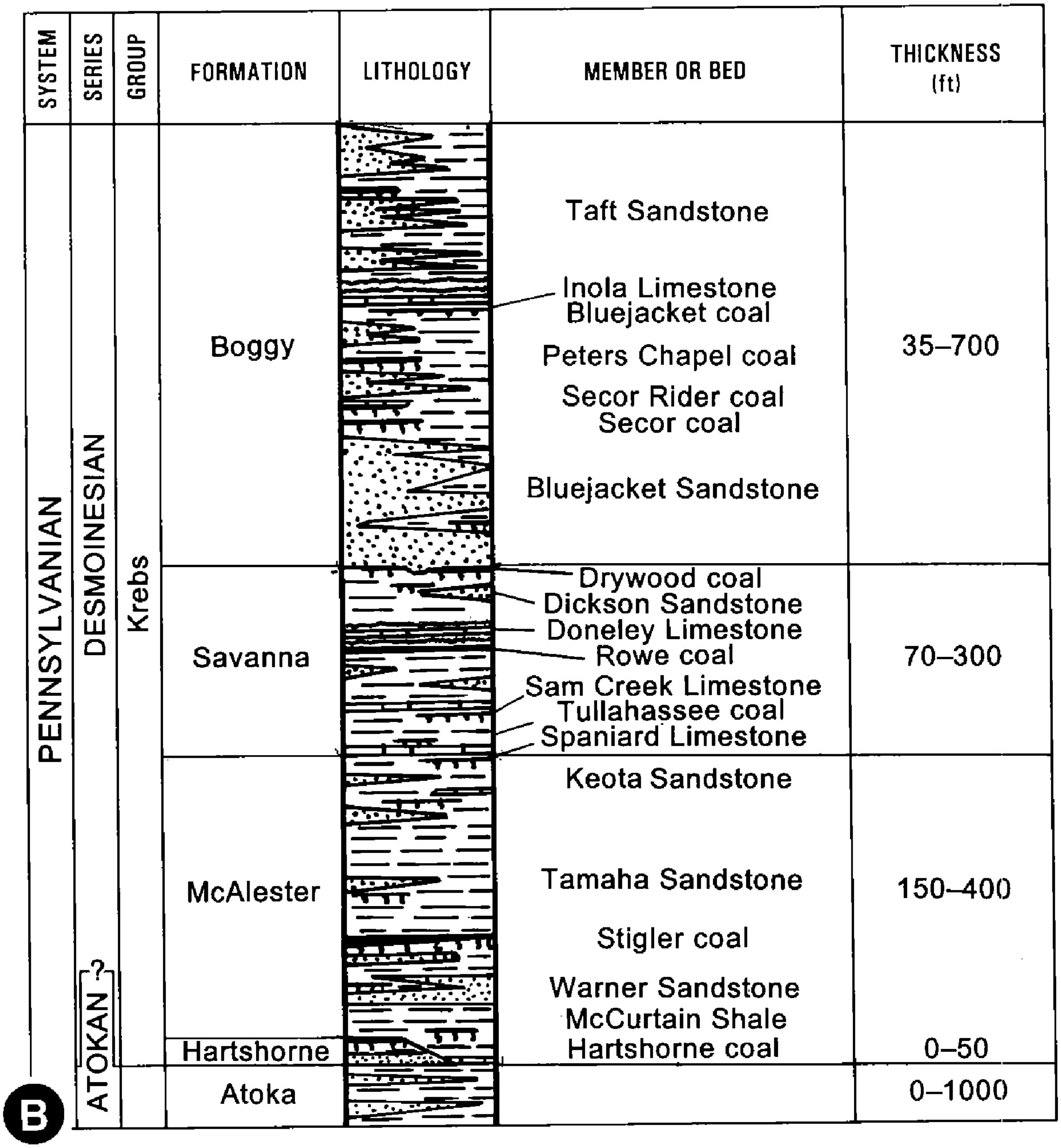


Figure 3. (A) Generalized stratigraphic column showing the Krebs Group and the upper part of the Atoka Formation in the central Arkoma basin. (B) (*opposite page*) Generalized stratigraphic column showing the same units in the northern part of the Arkoma basin and the northeastern Oklahoma shelf area. (See Figure 2 for explanation of symbols.)

Although the sandstones within the Savanna "groups" locally split and merge, pinch out and reappear, they persist across Latimer and Le Flore Counties to the Arkansas-Oklahoma line. The thick silty shale unit at the top of the Savanna is also persistent. It is ~240 ft thick in the Adamson section, and ~270 ft thick in the Lodi section, where it is better exposed. Figures 7–9 are selected representative lithologic units from the Savanna Formation in the Lodi section, where the Savanna is ~1,276 ft thick. Conformably overlying the Savanna Formation is the Bluejacket Sandstone Member of the Boggy Formation.



Along its outcrop belt in the eastern and south-central Arkoma basin, from Cavanal Mountain westward to the vicinity of the city of McAlester, the Bluejacket Sandstone comprises three informal units—a lower sandstone unit, a middle shale unit, and an upper sandstone unit. Figure 10A,B shows the lower unit of the Bluejacket Sandstone Member of the Boggy Formation. Figure 11A,B shows the thick, cross-bedded upper unit of the Bluejacket Sandstone, which caps Ryan Peak and marks the top of the 1,666.2-ft Lodi section (Fig. 4; Appendix 1).

Hemish (1996) found that ~6 mi north of Lodi in southern Haskell County, the Savanna Formation consists of only two mappable ridge-forming sandstone groups (an upper group and a lower group, separated by a valley-forming shale) and an overlying thick shale below the Bluejacket Sandstone. Oakes (1977, p. 25), using the term "zone" in the same sense as Hemish's "group," states that "the upper sandstone zone of the Savanna is about 200 feet thick and contains 50 feet of shale near the middle. It has this tripartite character northward to the Canadian

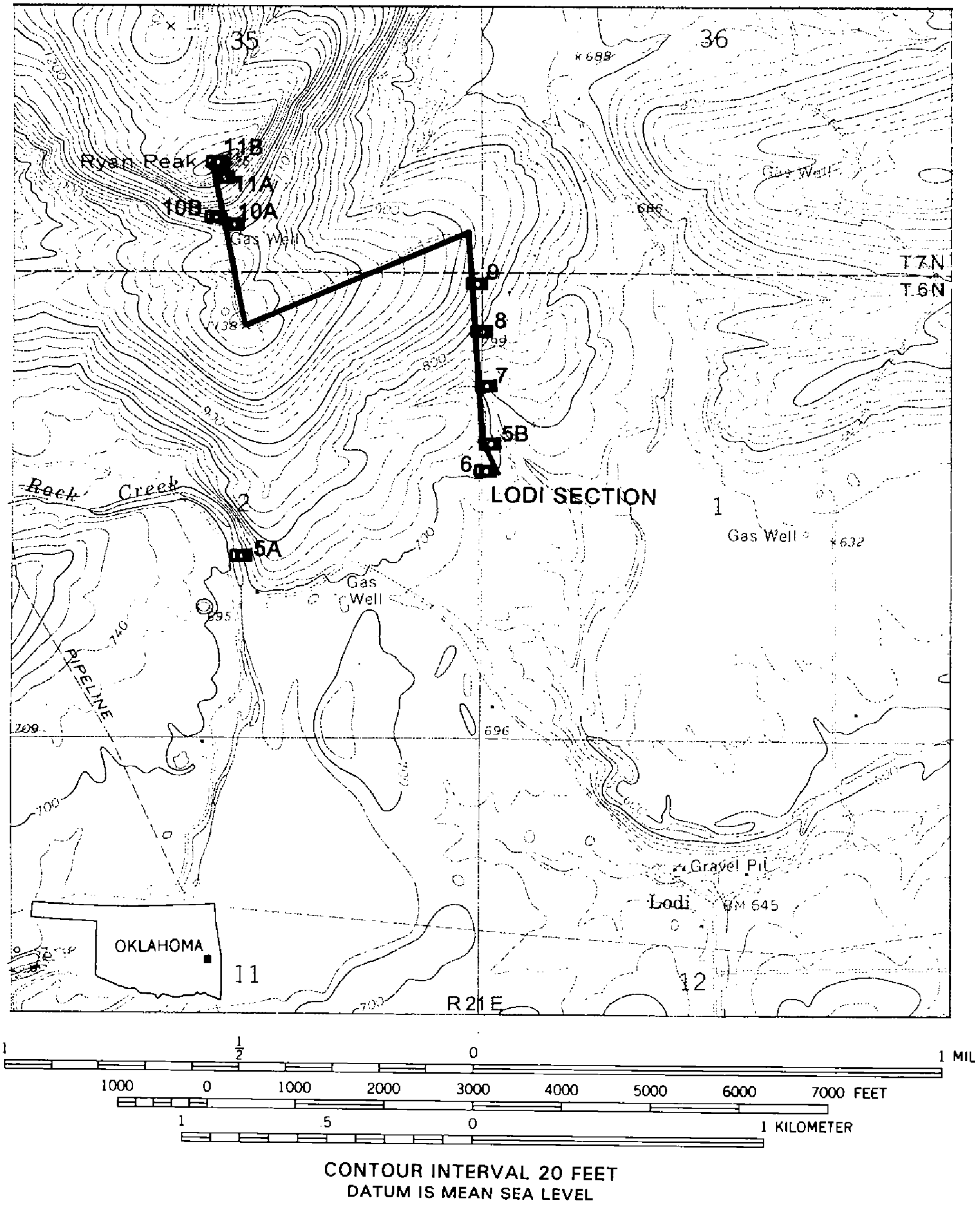


Figure 4. Map showing the location of measured section La-1-94-H (Lodi section, Latimer County), designated as a new supplementary reference section for the Savanna Formation (Appendix 1). Also shown are the locations of photographs in Figures 5–11. Map is from the Lequire 7.5′ quadrangle.

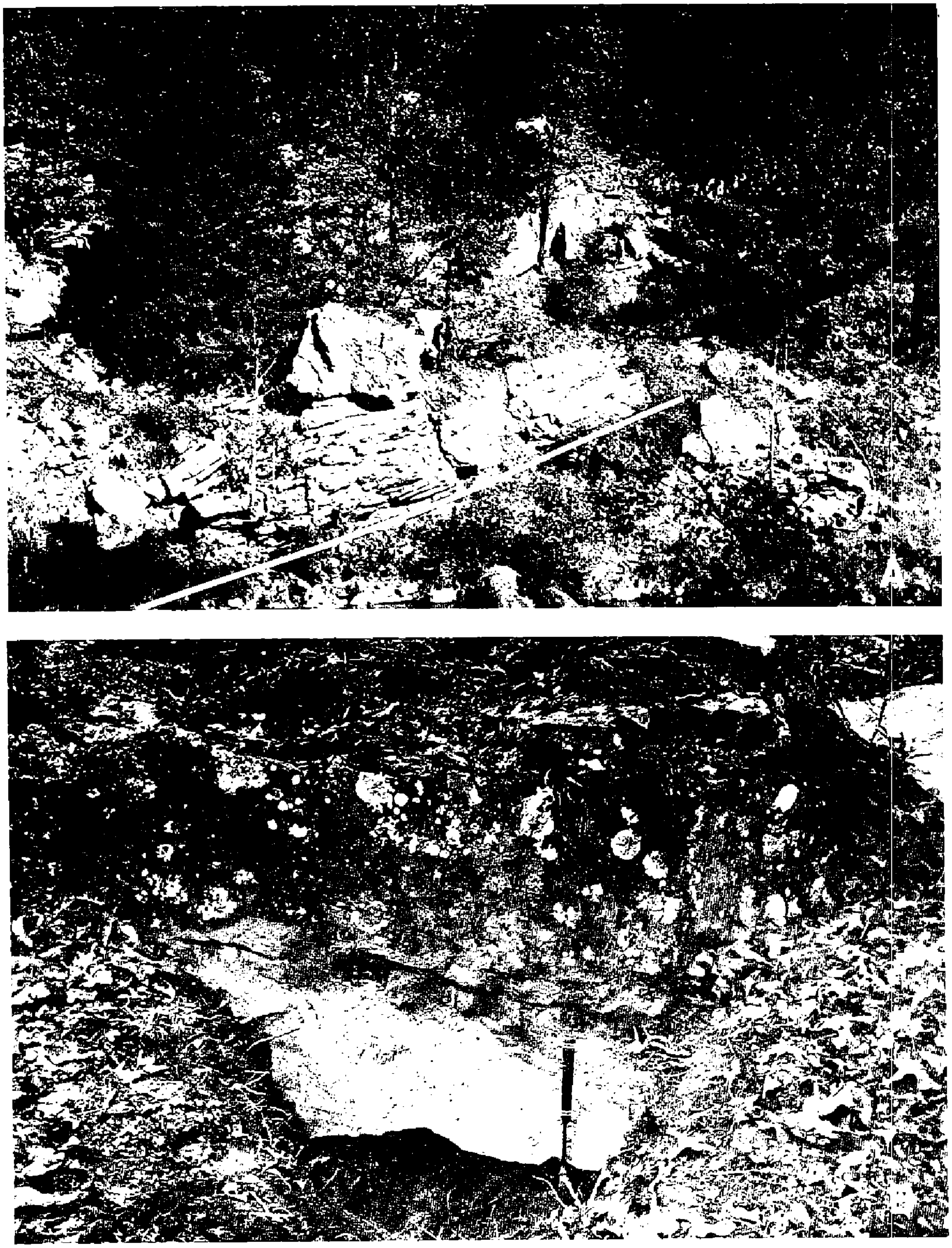


Figure 5. (A) Basal sandstone unit of the Savanna Formation, shown in outcrop at the east edge of Rock Creek, SW¼NW¼NW¼SE¼ sec. 2, T. 6 N., R. 21 E., Latimer County. Contact with the underlying McAlester Formation shown by white line. (B) Irregular contact between the McAlester Formation and the Savanna Formation (marked by head of pick). Psv1 (Unit 6, Appendix 1) is exposed in wooded area east of section-line road, SW¼NW¼SW¼NW¼ sec. 1, T. 6 N., R. 21 E., Latimer County. Geologic pick is 1.1 ft long. Figure 4 shows location of photographs.

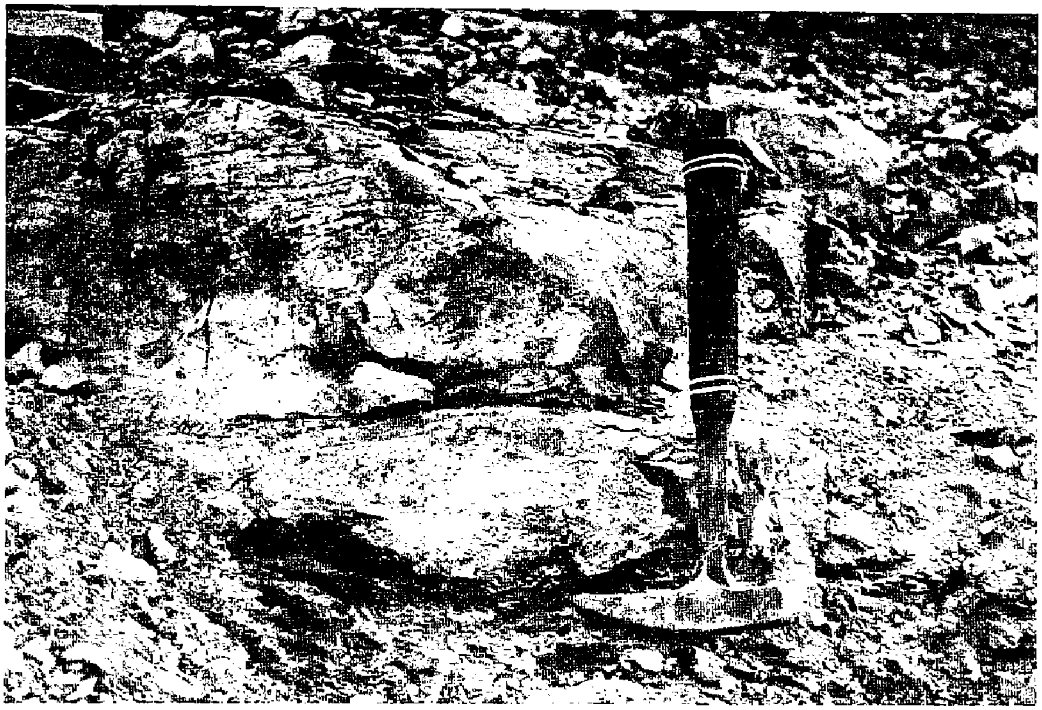


Figure 6. Keota Sandstone Member of the McAlester Formation (Unit 2, Appendix 1) exposed in edge of newly excavated stock pond, SW¼SW¼SW¼NW¼ sec. 1, T. 6 N., R. 21 E., Latimer County. Geologic pick (1.1 ft long) marks the Keota. Unit 1 (Appendix 1) is below the pick head. Figure 4 shows location of photograph.

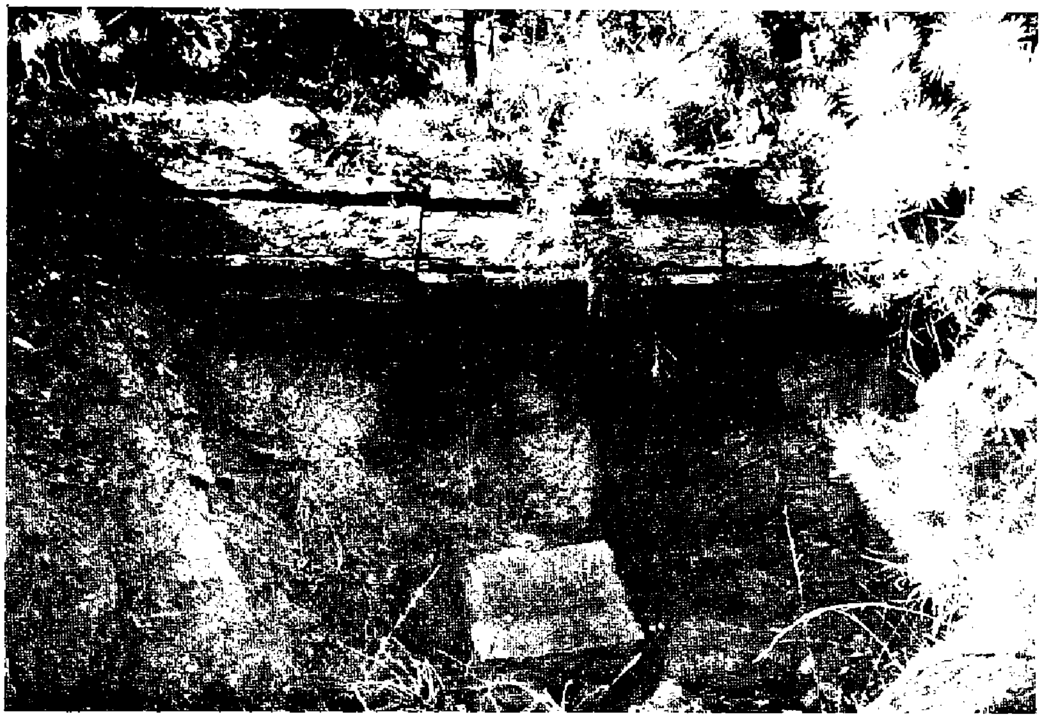


Figure 7. Wavy-, parallel-bedded sandstone (Psv3a, Unit 12, Appendix 1) and underlying shale (Unit 11, Appendix 1) in eroded road ditch, NE¼SE¼NE¼NE¼ sec. 2, T. 6 N., R. 21 E., Latimer County. Sandstone is 3.2 ft thick. Figure 4 shows location of photograph.

Figure 8. Stromatolitic limestone in Psv3 shale (Unit 16, Appendix 1), SE¼NE¼NE¼NE¼ sec. 2, T. 6 N., R. 21 E., Latimer County. Height of acid bottle is 2 in. Figure 4 shows location of photograph.

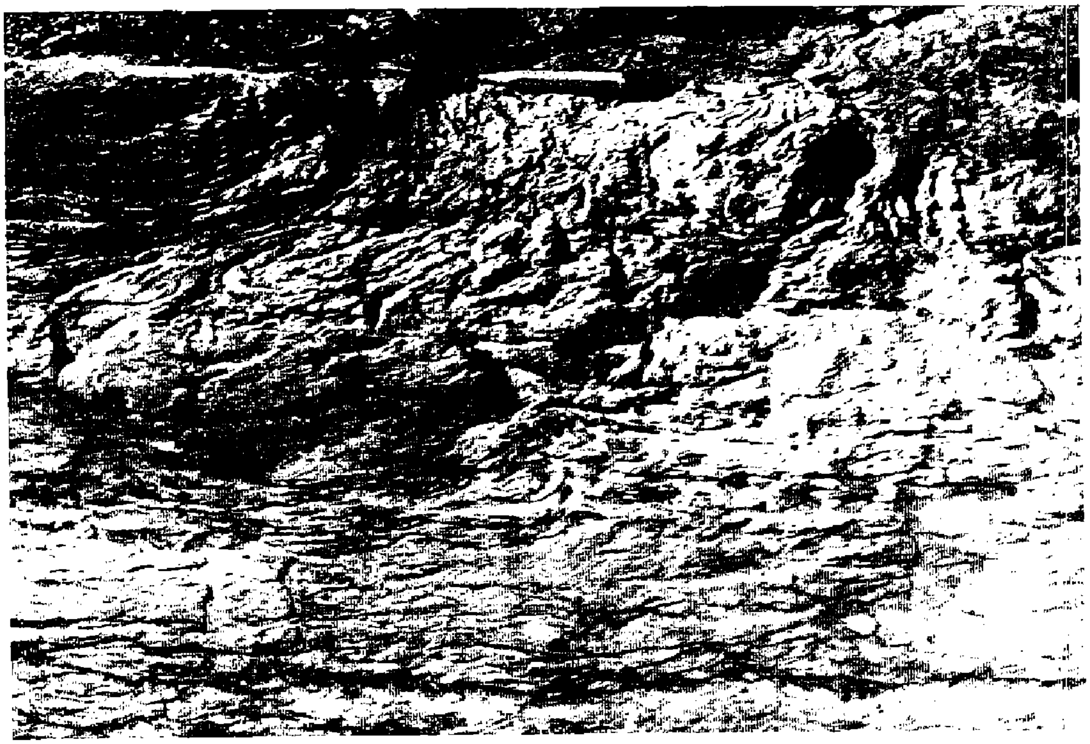


Figure 9. Convolute bedding in Psv4f (Unit 34, Appendix 1) exposed in road ditch on west side of road, NE¼NE¼NE¼NE¼ sec. 2, T. 6 N., R. 21 E., Latimer County. Pencil is 5 in. long. Figure 4 shows location of photograph.

River. . .northwest of Hoyt, Haskell County, where the upper unit is 15 feet thick, and the lower is 20 feet thick, and the intervening shale is 25 feet thick. . . . Sandstone assignable to the lower zone of the Savanna has not been found farther north than sec. 18, T. 9 N., R. 19 E." The lower, 20-ft-thick sandstone of the upper zone of the Savanna Formation described by Oakes (1977, p. 25) apparently is the only sandstone unit that persists northward into Muskogee County, where (for purposes of his report) he used the obsolete term "Spiro Sandstone" to identify it.

Oakes and Knechtel (1948, p. 51, fig. 7) showed that the Spaniard Limestone Member of the Savanna Formation in the vicinity of the Canadian River occupies approximately the same stratigraphic position as does the base of the lowest sandstone of the Savanna Formation in the Arkoma basin. Hemish (1993) reported the occurrence of a limestone bed in Le Flore County, Oklahoma, which he tentatively correlated with the Spaniard Limestone of the northeastern Oklahoma shelf area. In that report, he presented a detailed discussion of the naming of the Spaniard Limestone (in Muskogee County, by S. W. Lowman [1932]), as well as the history of usage and previous investigations.

Figure 12 shows the Spaniard Limestone, the lowermost of three persistent, thin, marine limestones that are key beds in the Savanna Formation throughout the northeastern Oklahoma shelf area. The other two persistent limestones are the Sam Creek Limestone and the Doneley Limestone. The three limestones are stratigraphically equivalent to the subsurface "Brown limes" (Jordan, 1957, p. 28). Hemish (1988) showed that the Savanna Formation thins westward from Muskogee County into west-central Okmulgee County,

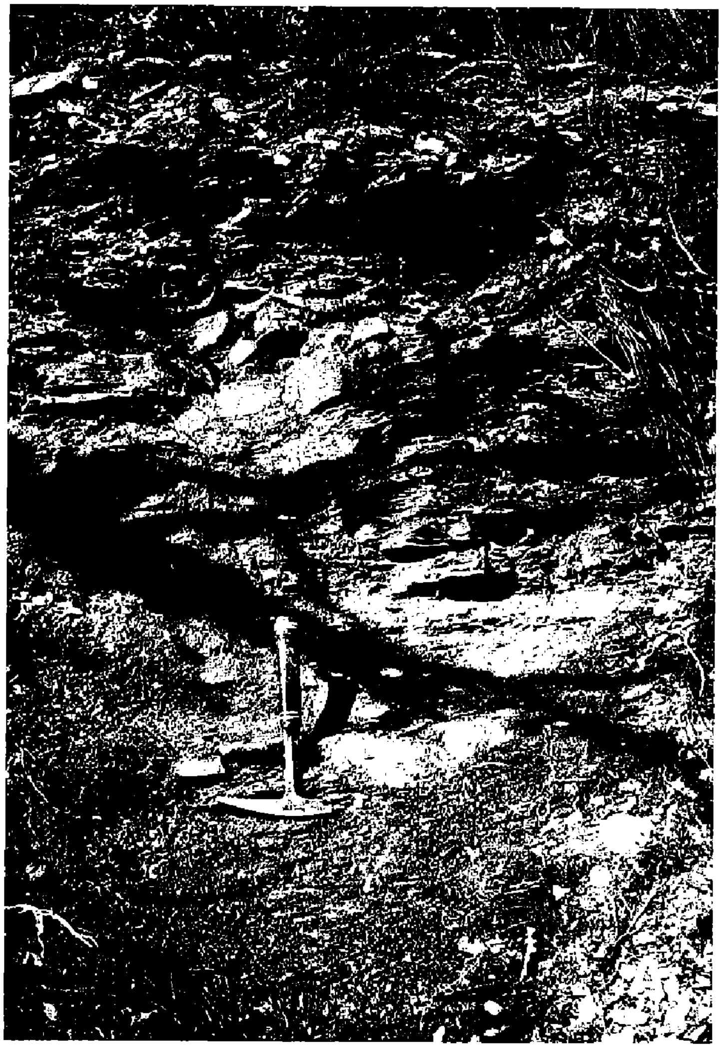
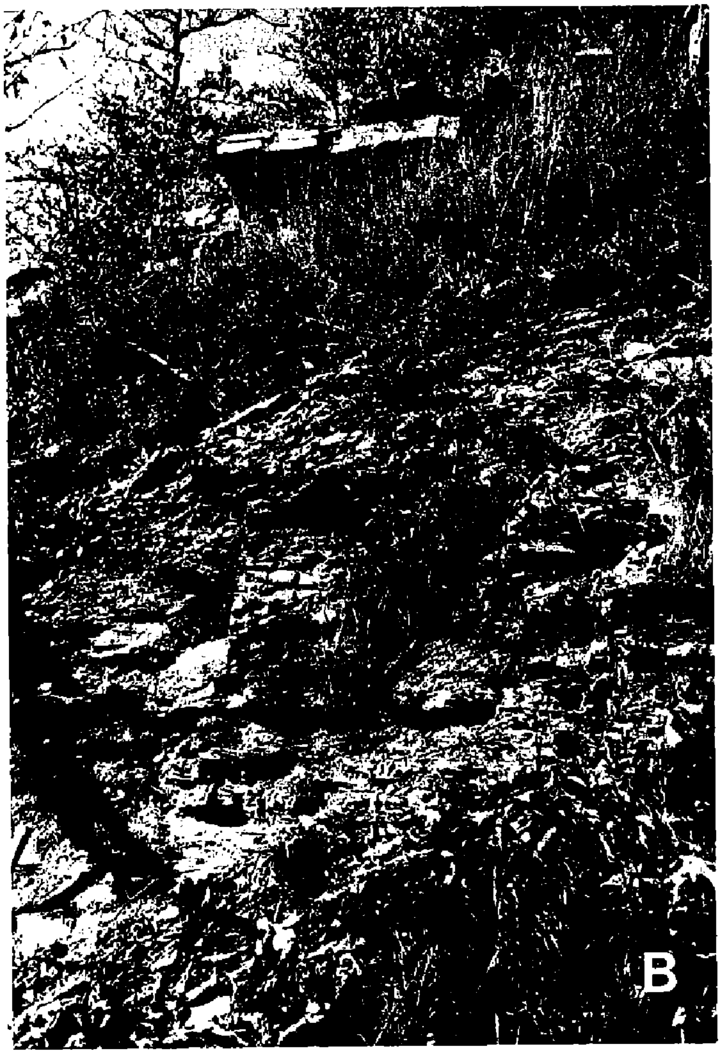


Figure 10. South slope of Ryan Peak, SW¼NE¼ SE¼SW¼ sec. 35, T. 7 N., R. 21 E., Latimer County. (A) Contact (at pick head) between Savanna Formation (below) and Boggy Formation (above). Top beds of the Savanna (Unit 45, Appendix 1) comprise silty, sandy shale, and abundant lenses and stringers of very fine grained sandstone. The overlying lower unit of the Bluejacket Sandstone (Unit 46, Appendix 1) contains thin-bedded, shaly, wavy-bedded, ripple-marked sandstone. (B) (*opposite page*) Lower unit of Bluejacket Sandstone. Beds dip 20° NW in this area. Figure 4 shows location of photographs.



where it is only ~130 ft thick. In this area, as it is throughout the shelf area and northern part of the Arkoma basin, the Savanna is marked by the base of the Spaniard Limestone, below, and the base of the Bluejacket Sandstone, above.

In T. 10 N., R. 19 E. (Fig. 1, $\times^2$), just north of the Canadian River in Muskogee County, the Savanna Formation is only ~277 ft thick (Fig. 2, $\times^2$). The base is marked by the well-developed Spaniard Limestone. Other key beds, such as the Sam Creek Limestone (Fig. 13A,B), the Doneley Limestone, and the Rowe coal (Fig. 14), are present. Other named coals in the Savanna Formation in the northern part of the Arkoma basin and in the northeastern Oklahoma shelf area include the thin, noneconomic Sam Creek coal, and, near the top of the formation, the Drywood coal (Fig. 3B). A locally developed coal named the Tullahassee coal by Hemish (1990a) is present just above the Spaniard Limestone in northern Muskogee and southern Wagoner Counties (Fig. 3B).

From the Canadian River northward to the vicinity of northern Craig County, no continuous sandstone beds are present in the Savanna Formation. Sandstone lenses, generally 4–6 ft thick, occur in that part of the formation below the Rowe coal (Fig. 2, $\times^2$, $\times^3$, $\bigcirc^4$; Fig. 3B). A sandstone, generally about 12 ft thick, is present in Craig County near the top of the Savanna Formation. Branson and others (1965, p. 27–28) named the sandstone the "Dickson," and traced it almost continuously from T. 25 N., R. 20 E. to the Kansas line. The Dickson Sandstone probably is included with the "Bartlesville sands" (equivalent to the Bluejacket Sandstone) of subsurface terminology in northeastern Oklahoma and southeastern Kansas. One of the best continuous exposures of that part of the Savanna Formation between the Sam Creek Limestone and the Bluejacket Sandstone is in shale pits and along a small creek in secs. 25 and 26, T. 11 N., R. 17 E., McIntosh County, Oklahoma. Exposed is 102.5 ft of section. The interval between the top of the Doneley Limestone and the base of the Bluejacket Sandstone is 82.7 ft thick, and includes near its base a black shale that commonly is associated with the Rowe coal and Doneley Limestone. For a detailed description, see measured section 26 in Hemish (in press).

It is noteworthy that the silty shale interval between the Doneley Limestone and the base of the Bluejacket Sandstone thins markedly northward from $\times^2$ to $\bigcirc^5$ (Fig.

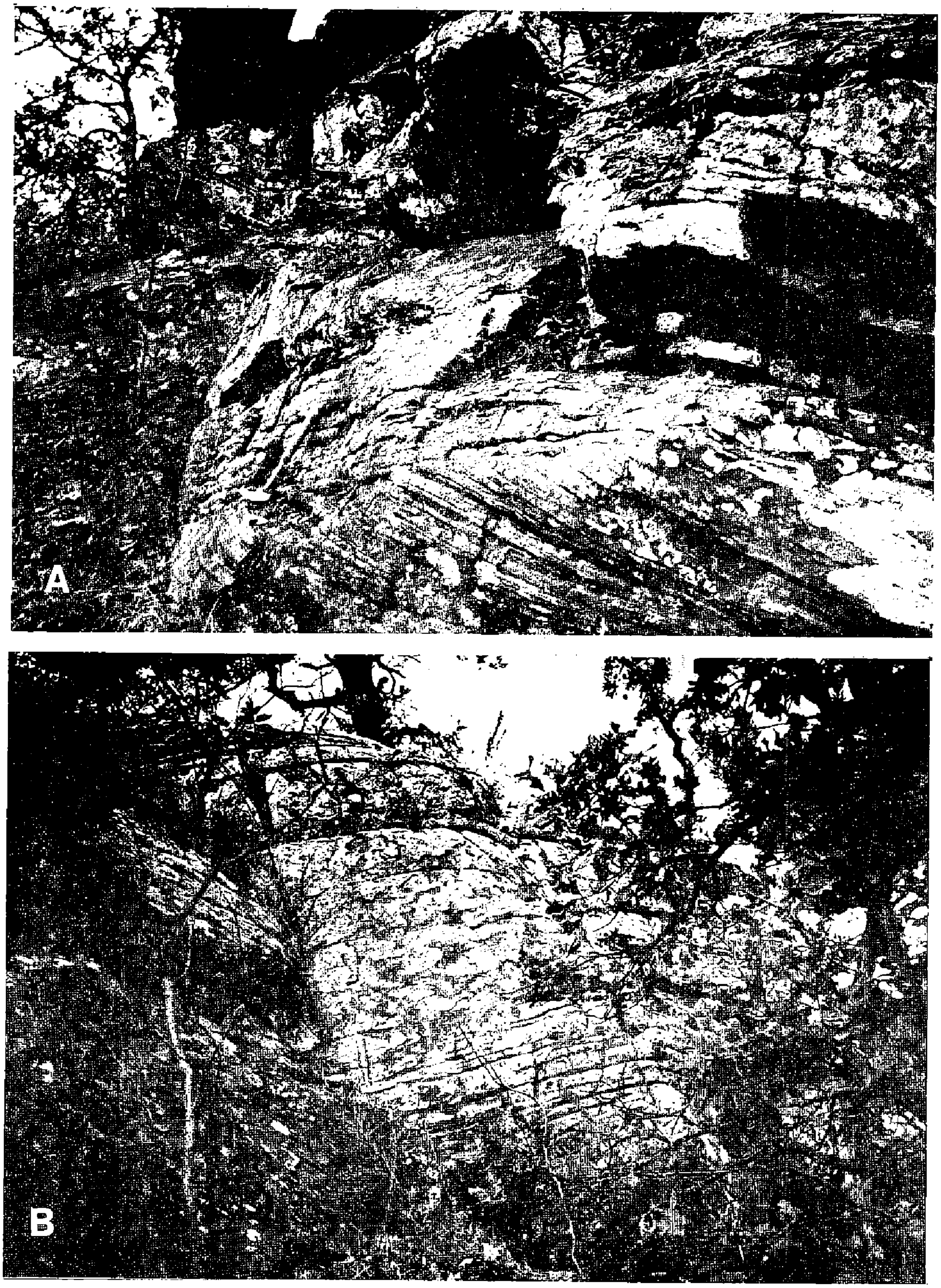


Figure 11. Ryan Peak, NW¼NE¼SE¼ sec. 35, T. 7 N., R. 21 E., Latimer County. (A) Cross-bedded upper unit of Bluejacket Sandstone Member of Boggy Formation (Unit 48, Appendix 1) exposed on south slope. Pick is 1.1 ft long. (B) Upper part of 125.8-ft-thick upper unit of Bluejacket Sandstone at top of Ryan Peak. Figure 4 shows location of photographs.

Figure 12. Exposure of the Spaniard Limestone in the shelf area of northeastern Oklahoma, 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. The McAlester-Savanna contact is at the base of the limestone. Figure 1 shows location of photograph.

2), whereas, the shale in the interval from the Spaniard Limestone to the Doneley Limestone thins by only about 8 ft in the same distance. It is also noteworthy that the black shale overlying the Rowe coal and/or the Doneley Limestone is a persistent unit and an excellent subsurface marker on geophysical logs.

Figure 15 shows the northernmost known exposure of the Spaniard Limestone (and the McAlester-Savanna contact). The photograph was taken ~2.5 mi southeast from O^5 (Fig. 1).

In places in Craig County the Bluejacket Sandstone contains a basal conglomerate (Fig. 2, O^5) that fills channels cut into the top of the Savanna Formation (Fig. 16). The streams which channeled into pre-Bluejacket beds have removed the Drywood coal locally (Hemish, 1989, p. 77).

The thickness of the Savanna Formation decreases progressively across the northeastern Oklahoma shelf area. In T. 27 N., R. 20 E., Craig County, the total thickness of the Savanna Formation is only 70 ft (Fig. 2, O^5), a decrease of more than 1,200 ft from its thickness of ~1,276 ft in the Lodi section, Latimer County (Fig. 2, x^1). In Kansas, ~12 mi north of T. 27 N., R. 20 E., where the strata of the Savanna Formation are included in the Krebs Formation, the only recognizable markers are the Rowe coal, the Doneley Limestone, and the Drywood coal (Brady and others, 1994).

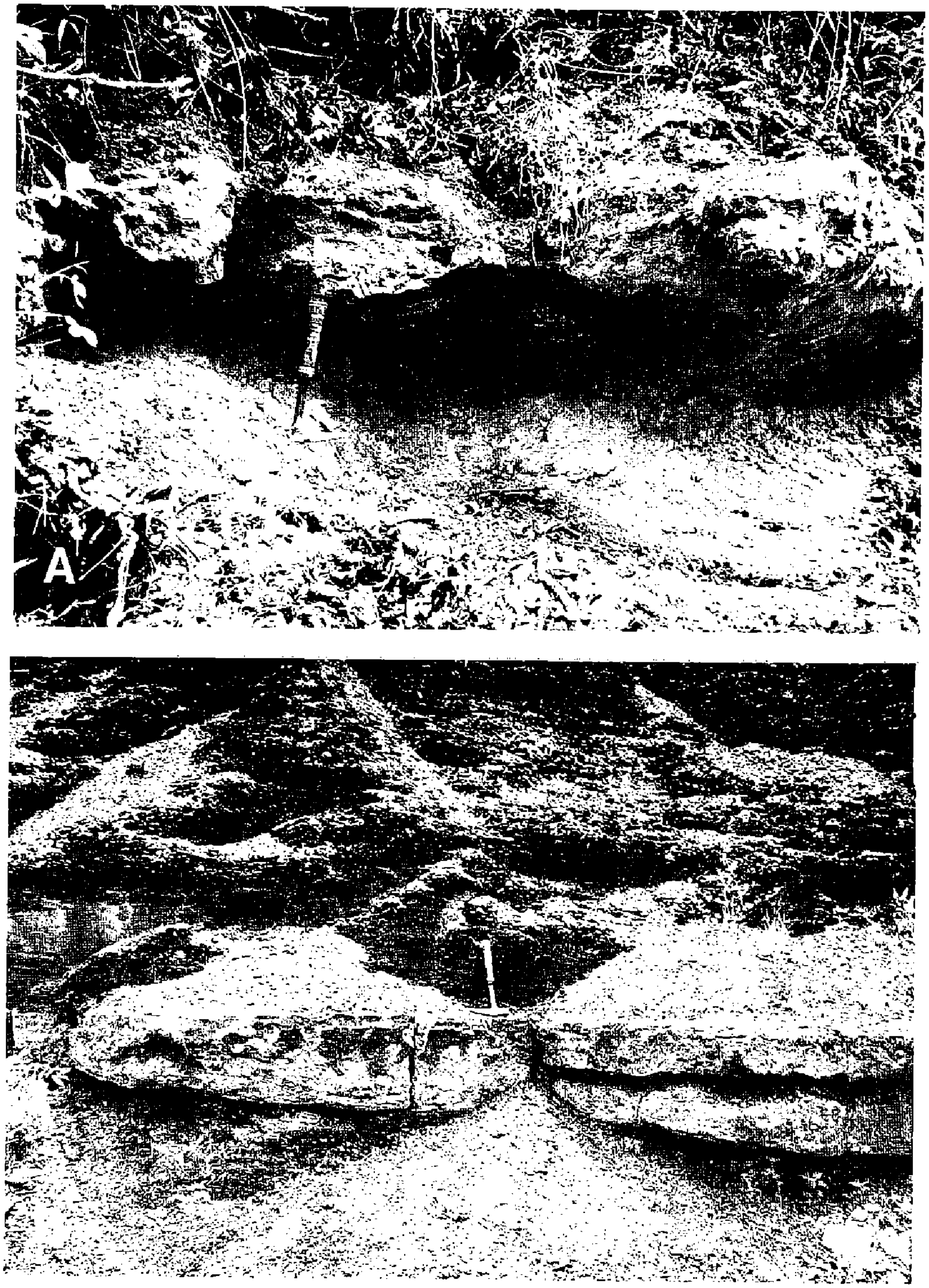


Figure 13. (A) Exposure of the Sam Creek Limestone in a gully, SW¼SE¼NW¼SE¼ sec. 9, T. 18 N., R. 17 E., Wagoner County (Neodesha 7.5′ quadrangle). The bed is moderate brown, 1.0–1.4 ft thick, has irregular upper and lower contacts, shows deformation features, and contains poorly preserved fossil fragments. (B) Sam Creek Limestone exposed in a shale pit NE¼NE¼NE¼NE¼ sec. 1, T. 15 N., R. 17 E., Wagoner County (Muskogee Northwest 7.5′ quadrangle). Limestone is reddish brown, impure and silty, iron stained, highly fossiliferous; it occurs as lenses that thicken to 2.5 ft or pinch out laterally along the outcrop. Geologic pick is 1.1 ft long. Figure 1 shows location of photographs.

Figure 14. Doneley Limestone (0.4 ft thick), 1-ft-thick shale, and underlying Rowe coal (0.3 ft thick) exposed in road ditch, NE¼NE¼NW¼NE¼ sec. 31, T. 27 N., R. 21 E., Craig County (Welch South 7.5′ quadrangle). Limestone is very dusky purple, fossiliferous, impure, silty, thin-bedded, and weathers moderate brown. Figure 1 shows location of photograph.

The Arkoma basin and the northeastern Oklahoma shelf area had different subsidence rates during the time the clastics of the Savanna Formation were being deposited. Yeakel (1964) showed diagrammatically that the source of the Savanna clastics was to the east and in part to the south of the subsiding basin. Thickening of the Savanna Formation to the east of Oklahoma, in Arkansas, suggests westward transport of sediments along the axis of the Arkoma basin. Apparently, only the finer-grained clastics were transported into the shelf area. The clastics of the Dickson Sandstone Member of the Savanna Formation probably came from the continental interior to the west and north of the Ozark dome.

Establishment of Supplementary Reference Section

In accordance with procedures recommended by the North American Commission on Stratigraphic Nomenclature (1983, p. 853) for establishing supplementary reference sections, the Lodi section is designated herein a supplementary reference section for the Savanna Formation of the Krebs Group. It is described and defined as follows. The Lodi section, La-1-94-H, (Fig. 1; $\times^1$; Fig. 4; Appendix 1) is located in secs. 1 and 2, T. 6 N., R. 21 E., and sec. 35, T. 7 N., R. 21 E., Latimer County, Oklahoma (Lequire 7.5′ quadrangle). The section was measured by LeRoy A. Hemish, October 11–12, 1994, from the top of Ryan Peak in the NE¼SE¼SW¼ sec. 35, T. 7

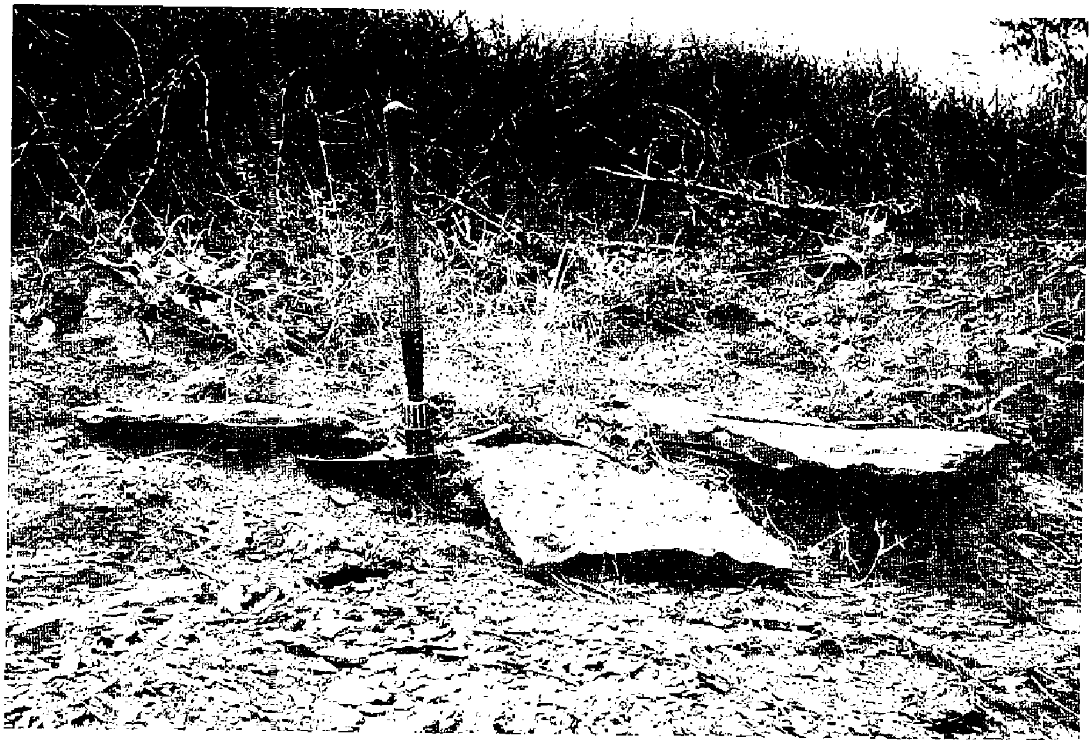


Figure 15. Northernmost known exposure of the contact between the McAlester Formation and the Savanna Formation, in a creek bank, SE¼SE¼SE¼SW¼ sec. 21, T. 27 N., R. 21 E., Craig County (Welch South 7.5′ quadrangle). Contact marked by trenching-tool blade at base of brown-weathering, fossiliferous, 0.3-ft-thick Spaniard Limestone. The upper beds of the McAlester Formation are flaky, light gray shale. Trenching tool is 1.7 ft long. Figure 1 shows location of photograph.

N., R. 21 E., in a southerly direction to the top of the second ridge south of an abandoned gas well site (note elevation 1,138 ft on topographic map [Fig. 4]); then offset along the gas well road ~0.5 mi to the northeast to a curve in road in the NE¼ SE¼SE¼SE¼ sec. 35, T. 7 N., R. 21 E.; then downslope to the south in the ditch paralleling section-line road, to a small shale pit south of creek; then in wooded area, ditches, creek bed, and in the side of a newly dug stock pond, all in the NE¼ sec. 2 and the NW¼ sec. 1, T. 6 N., R. 21 E.

A lithologic column of the supplementary reference section for the Savanna Formation, accompanied by a description of each lithologic unit, is presented in Appendix 1. Rock-color terms are those shown in the rock-color chart (Rock-Color Chart Committee, 1991). Included in the 1,666.2-ft measured section are 103.3 ft of the upper part of the McAlester Formation; 1,275.9 ft of the Savanna Formation; and 287.0 ft of the lower part of the Boggy Formation.

In the diagrammatic column (Appendix 1), the youngest units are listed first (p. 201). These have the highest unit numbers. For example, the upper unit of the Bluejacket Sandstone (the youngest of 48 lithologic units measured) is assigned Unit No. 48. The oldest lithologic unit measured is a shale in the upper part of the McAlester Formation. It appears on the last page of Appendix 1, extends from 0 to 15 ft, and has been assigned Unit No. 1 in the column. Lithologic symbols and sedimentary features are shown in the fourth and fifth columns from the left, respectively. Descriptions of each unit, as well as stratigraphic divisions, are shown

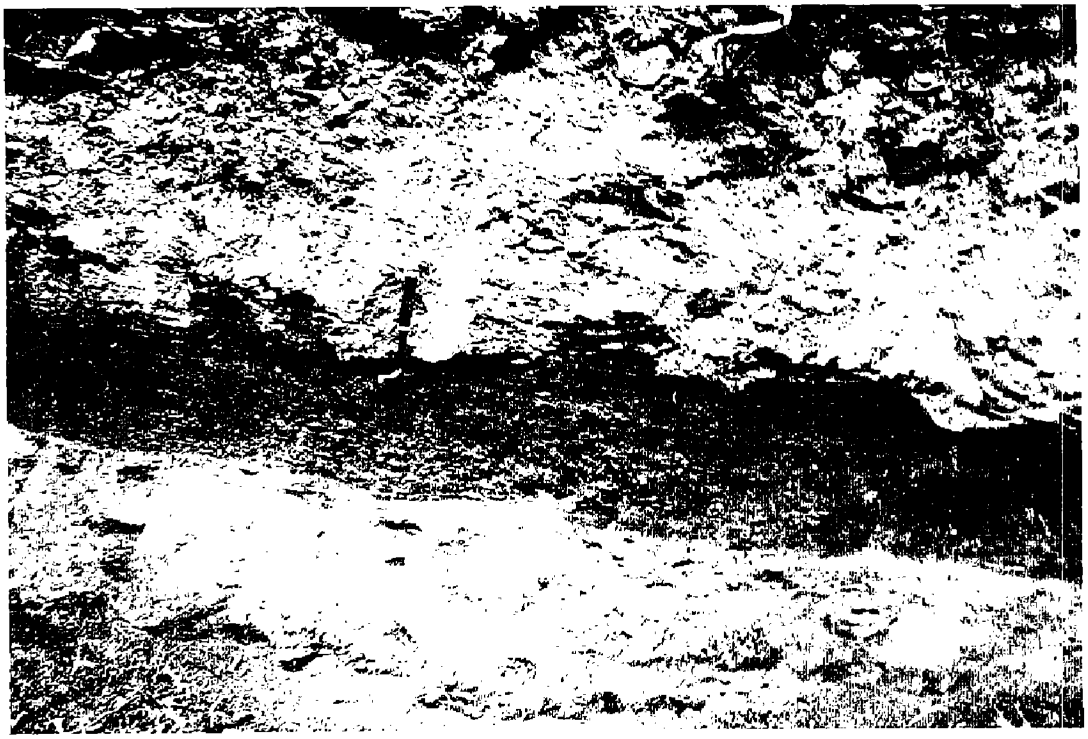


Figure 16. Contact between the Savanna Formation and overlying Bluejacket Sandstone Member of the Boggy Formation, SW¼NE¼NW¼SW¼ sec. 35, T. 27 N., R. 20 E., Craig County (Pyramid Corners 7.5′ quadrangle). The contact (marked by pick head) is disconformable. The Bluejacket is a conglomeratic sandstone containing coal spars, ironstone pebbles, weathered chert clasts, and fossil plant impressions. Channels have been cut into the top of the Drywood coal, which varies from 0.4 to 1.5 ft thick in this exposure. The coal is underlain by a very pale orange sandy underclay. Pick is 1.1 ft long. Figure 1 shows location of photograph.

in the right-hand column. The mappable sandstones of the Savanna Formation are designated Psv1–7, from lowest (oldest) to highest (youngest); lower-case letters (beginning with "a") identify individual sandstone units in the Savanna sandstones. For example, Psv3a is the lowest sandstone unit in Savanna sandstone 3; Psv3b is the next highest sandstone unit in Savanna sandstone 3. Individual shales in the Savanna Formation are not given numbers other than their unit numbers.

Establishment of Reference Well

In accordance with procedures recommended by the North American Commission on Stratigraphic Nomenclature (1983, p. 853–854) for establishing reference wells, a reference well for the Savanna Formation of the Krebs Group is here described and defined. The reference well (Fig. 1, O^4; Appendix 2) is located in the SE¼SE¼SW¼NW¼ sec. 18, T. 21 N., R. 18 E., Mayes County, Oklahoma, on the George Moore farm. Continuous 2-in. core was cut from below an 8.5-ft surface casing to a total depth of 441 ft. Samples of cuttings were collected and bagged from the upper 8.5 ft. Core-drilling was completed on August 16, 1988. Surface elevation estimated from a topographic map is 815 ft above sea level.

All the core drilling was done by the Oklahoma Geological Survey. Cores and cuttings from the reference well have been boxed and labeled, and they are available for study by the public at the Oklahoma Geological Survey Core and Sample Library, Norman, Oklahoma.

For purposes of this paper only, part of the log (surface to a depth of 203.8 ft) of the newly established reference well is presented in Appendix 2. The upper and lower boundaries of the Savanna Formation and parts of the underlying and overlying formations are included. For a log of the entire well, see Hemish (1990b, core-hole log 7 [C-RM-1], p. 37–43).

Summary

In Oklahoma, the thickness of the Savanna Formation decreases progressively northward across the northeastern Oklahoma shelf area, from ~1276 ft in its supplementary reference section (Lodi section, Latimer County) in the Arkoma basin to 70 ft in core hole 5 (Figs. 1,2) just south of the Oklahoma-Kansas border in the northeastern Oklahoma shelf area. The combined thickness of all of the sandstone units measured in the Savanna Formation in the Lodi section is 205.6 ft, while the total thickness of the formation itself is 1,275.9 ft (Fig. 2, $\times^{1}$; Fig. 4; Appendix 1). Thus, in the Lodi section, as in the principal reference section (Hemish, 1995, p. 222), only ~16% of the formation is sandstone. The percentage of sandstone in the Savanna Formation in the new reference well in Mayes County (Fig. 2, $\bigcirc^{4}$; Appendix 2), in the northeastern Oklahoma shelf area, is only 2.4%.

The lower sand-rich part of the Savanna Formation pinches out northward across Haskell County, making it necessary to change the definition of its basal boundary. From southern Muskogee County northward, the Spaniard Limestone occupies about the same stratigraphic position as does the lowest sandstone unit of the Savanna Formation in the southern and central Arkoma basin; therefore, the base of the Spaniard Limestone marks the McAlester-Savanna contact throughout the northeastern Oklahoma shelf area.

The Spaniard Limestone is the lowermost of the three limestone markers in the Savanna Formation, known collectively in subsurface terminology as the "Brown limes." The other two are the Sam Creek Limestone and the Doneley Limestone. The Rowe coal bed and an overlying black shale are associated with the Doneley Limestone. The three limestone markers are persistent, but thin northward. The black shale unit also thins northward.

The thick shale unit in the upper part of the Savanna Formation also decreases in thickness northward. In Craig County, the shale interval includes a 12-ft-thick sandstone (Dickson), as well as a coal bed (Drywood) which, where uneroded, is present at or just below the Savanna-Boggy contact. The base of the Bluejacket Sandstone Member of the Boggy Formation marks the top of the Savanna Formation both in the Arkoma basin and in the northeastern Oklahoma shelf area.

During the time that the clastics of the Savanna Formation were being deposited, the Arkoma basin and the northeastern Oklahoma shelf area had different rates of subsidence. Those differing subsidence rates at the time of deposition account for the thinning of the Savanna Formation from its type area in the Arkoma basin northward across the shelf area.

References Cited

Brady, L. L.; Nuelle, L. M.; Haug, D. B.; Smith, D. C.; Bostic, J. L.; and Jaquess, J. C., 1994, Coal resources of the Joplin 1° by 2° Quadrangle, Kansas and Missouri: U.S. Geological Survey

Miscellaneous Investigations Series, 2 sheets.

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.

Haley, B. R., 1961, Geology of the Paris Quadrangle, Logan County, Arkansas: Arkansas Geological Commission Information Circular 20-B, 40 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 with text, scale 1:31,680.

_____1989, Bluejacket (Bartlesville) Sandstone Member of the Boggy Formation (Pennsylvanian) in its type area: Oklahoma Geology Notes, v. 49, p. 72–89.

_____1990a, Coal geology of Tulsa, Wagoner, Creek, and Washington Counties, Oklahoma: Oklahoma Geological Survey Map GM-33, 3 sheets (pls. 1–5), scale 1:63,360, accompanying text.

_____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.

_____1993, Spaniard(?) and Sam Creek(?) Limestones in Le Flore County, Oklahoma: Oklahoma Geology Notes, v. 53, p. 84–111.

_____1994, Correlation of the Lower Witteville coal bed in the Arkoma basin, eastern Oklahoma: Oklahoma Geology Notes, v. 54, p. 4–28.

_____1995, Principal reference section (neostratotype) for the Savanna Formation, Pittsburg County, Oklahoma: Oklahoma Geology Notes, v. 55, p. 204–243.

_____1996, Geology of the Sans Bois syncline along the proposed route of State Highway 82, Haskell and Latimer Counties, Oklahoma: Oklahoma Geological Survey Open File Report 4-96, 1 sheet.

_____[in press] Coal geology of McIntosh County, Oklahoma: Oklahoma Geological Survey.

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 coalfield: 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.

Lowman, S. W., 1932, Lower and Middle Pennsylvanian stratigraphy of Oklahoma east of the meridian and north of the Arbuckle Mountains: Tulsa Geological Society Digest, v. 1, p. 4.

Miser, H. D., 1954, Geologic map of Oklahoma: Oklahoma Geological Survey and U.S. Geological Survey, 2 sheets, scale 1:500,000.

North American Commission on Stratigraphic Nomenclature, 1983, North American Stratigraphic Code: American Association of Petroleum Geologists Bulletin, v. 67, p. 841–875.

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.

Rock-Color Chart Committee, 1991, Rock-color chart: Distributed by the Geological Society of America, Boulder, Colorado.

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

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.

Yeakel, L. S., 1964, Deltaic sandstones in the Desmoinesian, Arkoma basin, and northeast Oklahoma platform: Unpublished manuscript and illustrations in files of Geology Research Department, Shell Development Company, E&P Research, Houston, Texas.

APPENDIX 1: Supplementary Reference Section for Savanna Formation
Measured Section La-1-94-H (Lodi section) Lequire 7.5′ Quadrangle

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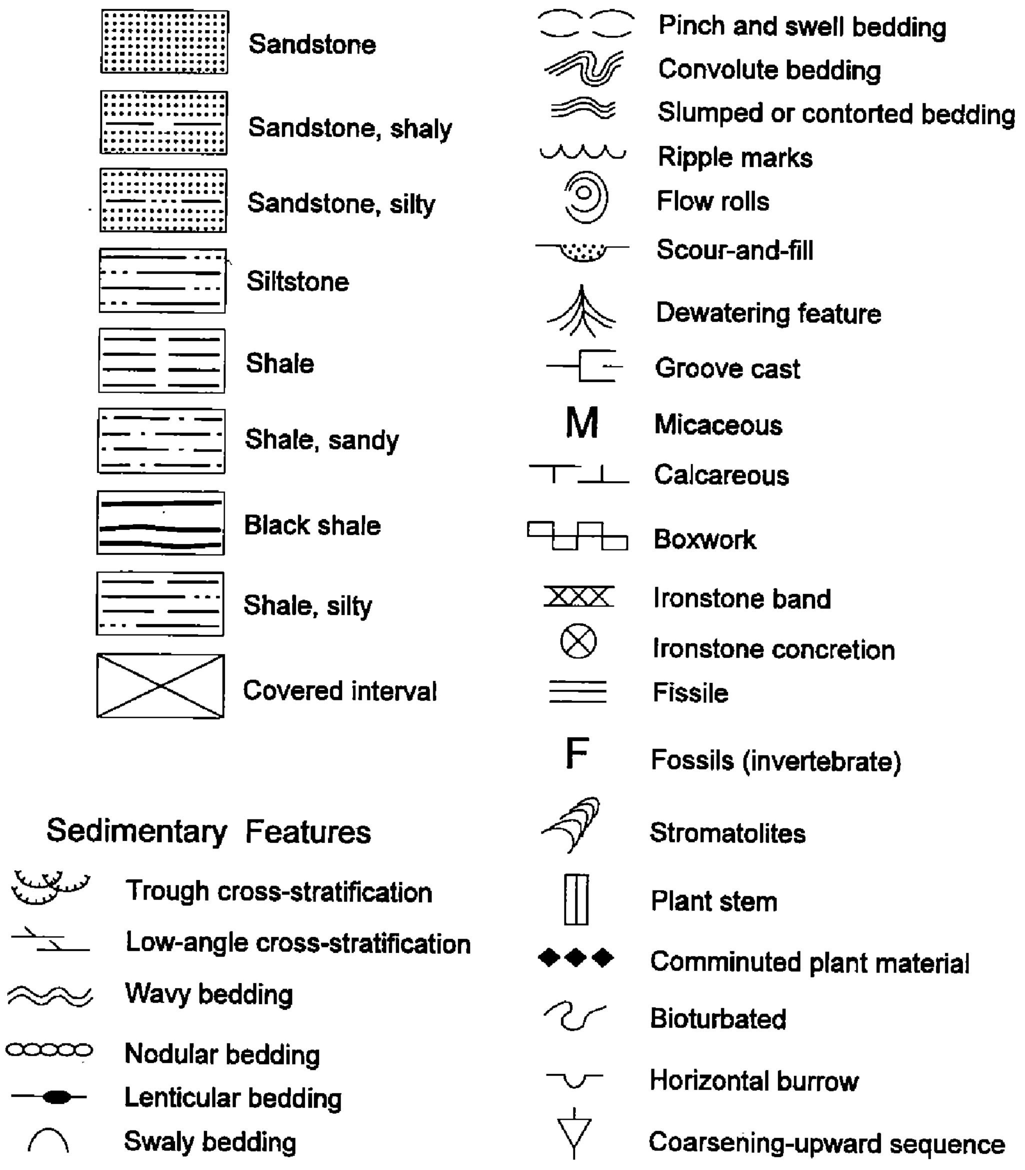
Measured from top of Ryan Peak in the NE¼SE¼SW¼ sec. 35, T. 7 N., R. 21 E., Latimer County, Oklahoma, in a southerly direction to top of second ridge south of abandoned gas well site (note elevation 1,138 ft on topographic map); then offset along gas well road ~0.5 mi to the northeast to curve in road in the NE¼SE¼SE¼ sec. 35, T. 7 N., R. 21 E.; measurements continued downslope to the south in ditch paralleling section-line road, to small shale pit south of creek; then in wooded area, ditches, creek bed, and in side of newly dug stock pond, all in the NE¼ sec. 2 and the NW¼ sec. 1, T. 6 N., R. 21 E. Section measured perpendicular to east-west strike of beds by LeRoy A. Hemish, October 11–12, 1994.

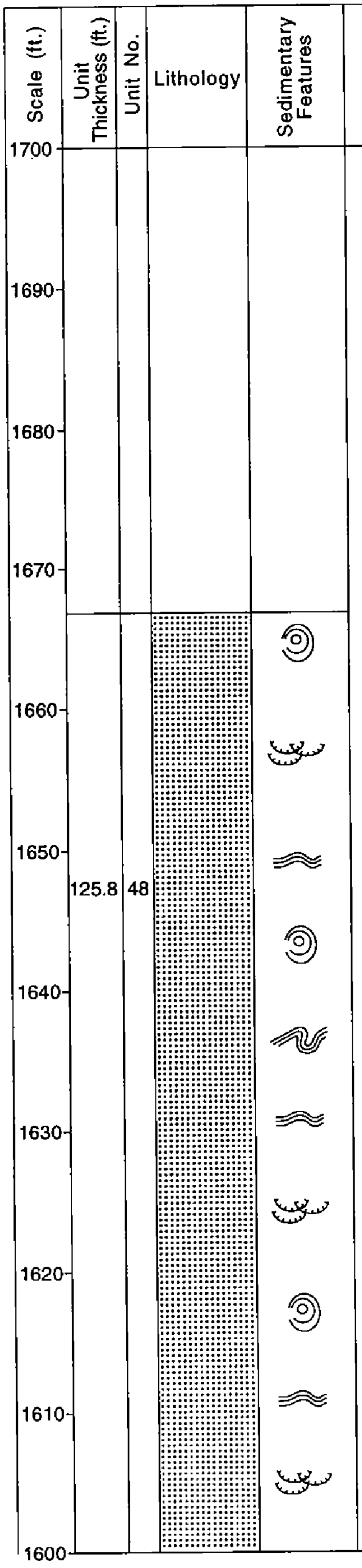
EXPLANATION



NOTES: (1) Rock-color terms are those shown in the rock-color chart (Rock-Color Chart Committee, 1991). (2) The mappable sandstones of the Savanna Formation are designated Psv1–7, from lowest (oldest) to highest (youngest); lower-case letters (beginning with "a") identify individual sandstone units in the Savanna sandstones. For example, Psv3a is the lowest sandstone unit in Savanna sandstone 3, Psv3b is the next highest sandstone unit in Savanna sandstone 3. Individual shales in the Savanna Formation are not given numbers other than their unit numbers.

APPENDIX 1: Supplementary Reference Section for Savanna Formation

Measured Section La-1-94-H (Lodi section) Lequire 7.5′ Quadrangle



Description of Units

KREBS GROUP

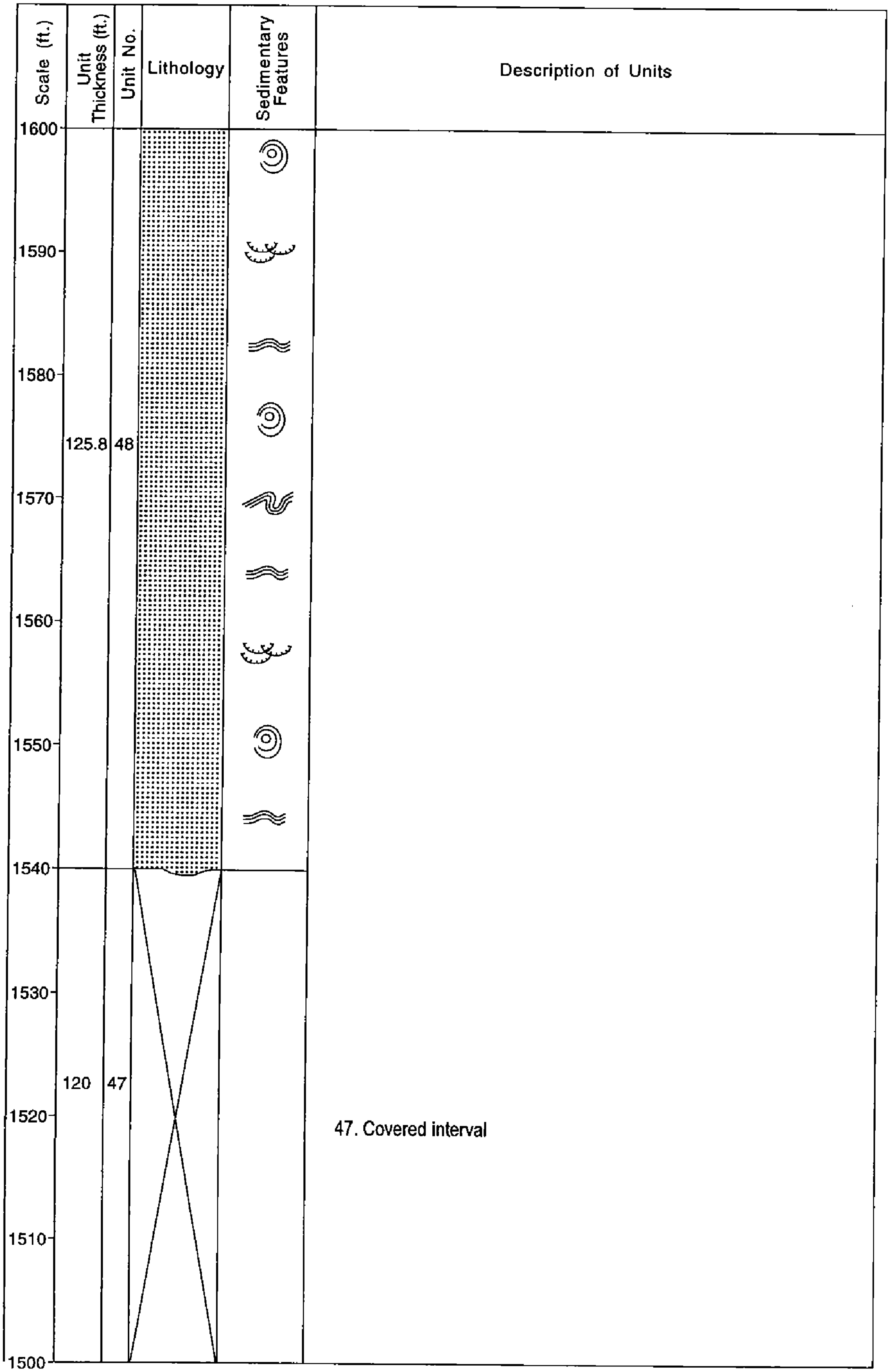
Boggy Formation

Bluejacket Sandstone Member:

48. Sandstone, dark yellowish orange (10YR6/6), weathers moderate yellowish brown (10YR5/4) to grayish pink (5R8/2) to light brown (5YR5/6), very fine to fine-grained, mostly medium- to thick-bedded, massive in lower part; base fills channels in underlying unit; contains extensive large-scale cross-bedding; flow rolls and other soft-sediment deformation features common; outcrop displays stacked-channel sequence; base sharp (upper unit, Bluejacket Sandstone)

APPENDIX 1: Supplementary Reference Section for Savanna Formation

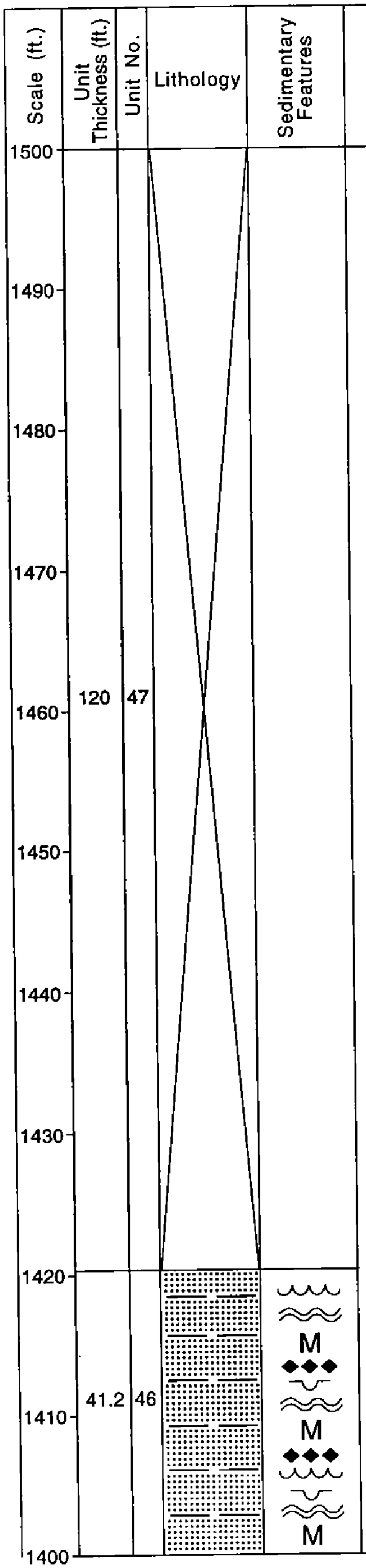
(continued)



47. Covered interval

APPENDIX 1: Supplementary Reference Section for Savanna Formation

(continued)

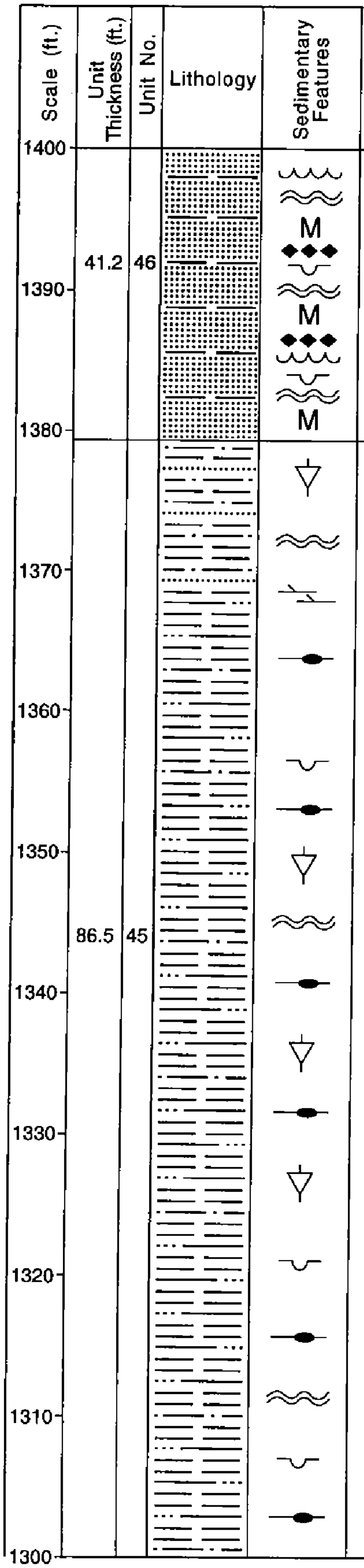


Description of Units

Bluejacket Sandstone Member:

46. Sandstone, pale yellowish brown (10YR6/2), weathers pale brown (5YR5/2) to moderate brown (5YR4/4, 5YR3/4), very fine grained, shaly, thin- to very thin bedded, wavy-bedded, ripple-marked, micaceous; black, carbonaceous, comminuted plant material on bedding surfaces; trace fossils on soles of beds; interbedded with shale in lower part; basal contact gradational (lower unit, Bluejacket Sandstone)

APPENDIX 1: Supplementary Reference Section for Savanna Formation
(continued)



Description of Units

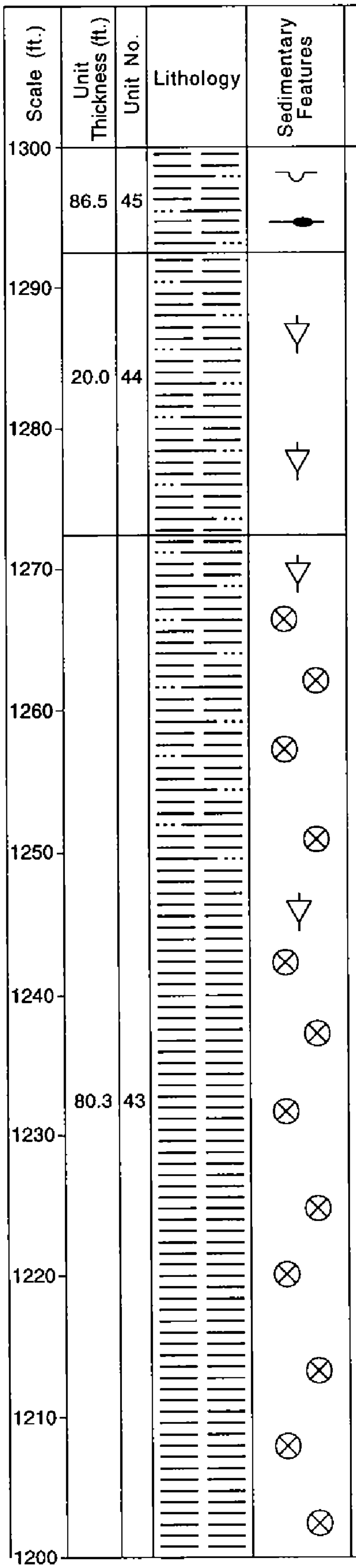
Boggy Formation

Savanna Formation

45. Shale, grayish orange (10YR7/4) to moderate yellowish brown (10YR5/4), very silty and sandy, lenticular to wavy-bedded; contains abundant lenses and stringers of very fine grained silty sandstone that are laminated in a cross-sectional view; trace fossils common; sandstone content increases upwards, and a few feet below contact with overlying unit, wavy-bedded, dark yellowish brown (10YR4/2), cross-laminated sandstone layers as much as 2 in. thick are present; base gradational; contact with overlying unit gradational and picked where sandstone crops out to form a resistant ledge in hill slope

APPENDIX 1: Supplementary Reference Section for Savanna Formation

(continued)

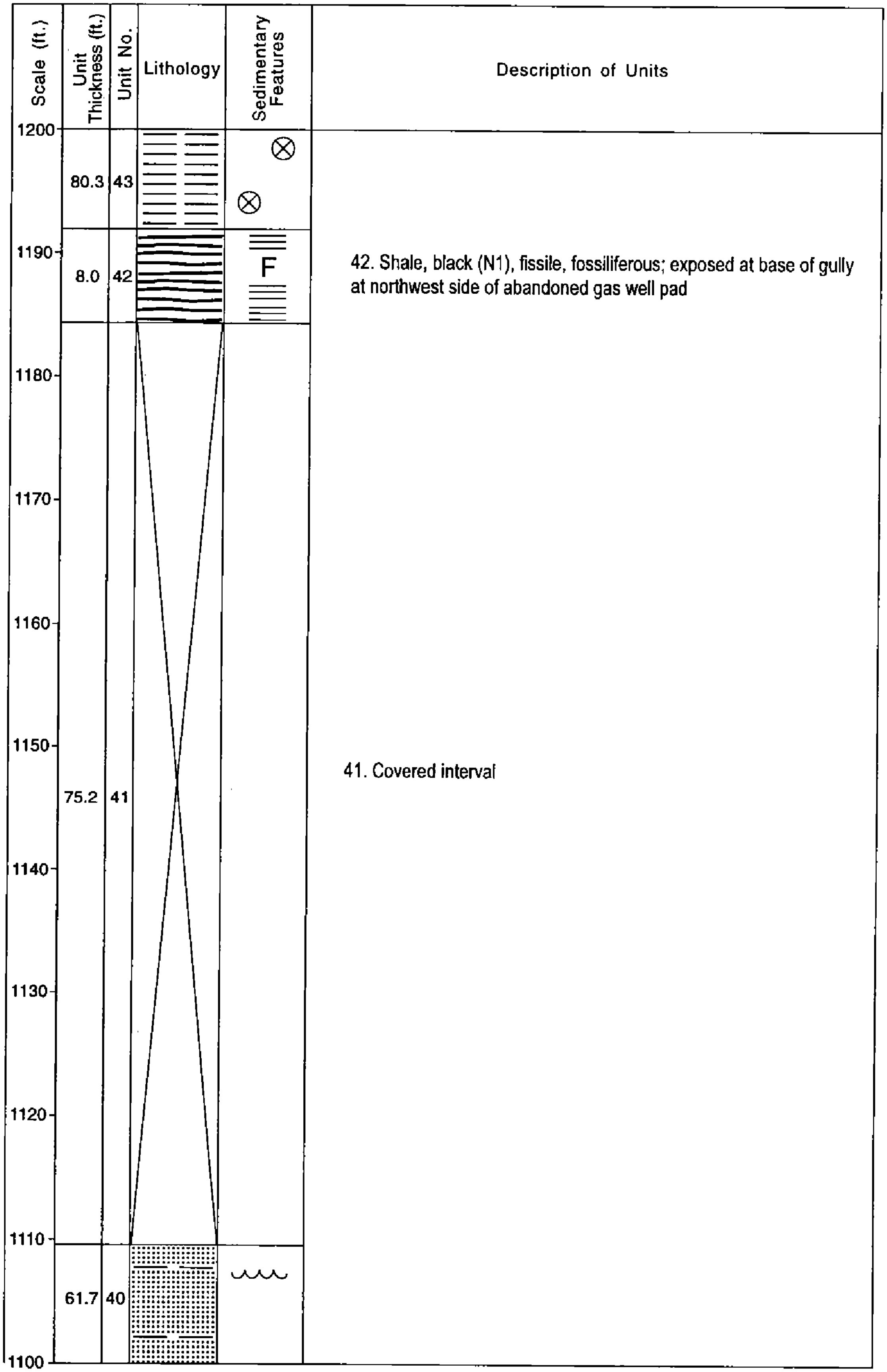


Description of Units

44. Shale, dark yellowish brown (10YR4/2), silty; contains well-indurated, light brown (5YR5/6) to moderate brown (5YR4/4) siltstone stringers that occur rhythmically about 1–2 ft apart and give the outcrop a ribbed appearance; base gradational

43. Shale, olive gray (5Y4/1), weathers moderate yellowish brown (10YR5/4); contains moderate reddish brown (10R4/6) iron-oxide crusts on some bedding surfaces as well as scattered ironstone concretions of the same color; becomes silty in upper 25 ft of unit

APPENDIX 1: Supplementary Reference Section for Savanna Formation *(continued)*

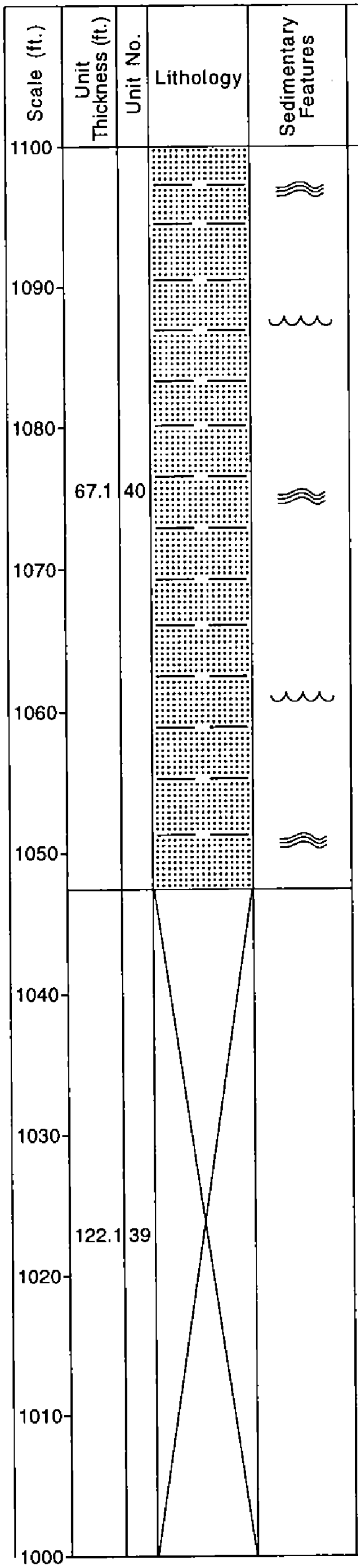


42. Shale, black (N1), fissile, fossiliferous; exposed at base of gully at northwest side of abandoned gas well pad

41. Covered interval

APPENDIX 1: Supplementary Reference Section for Savanna Formation

(continued)

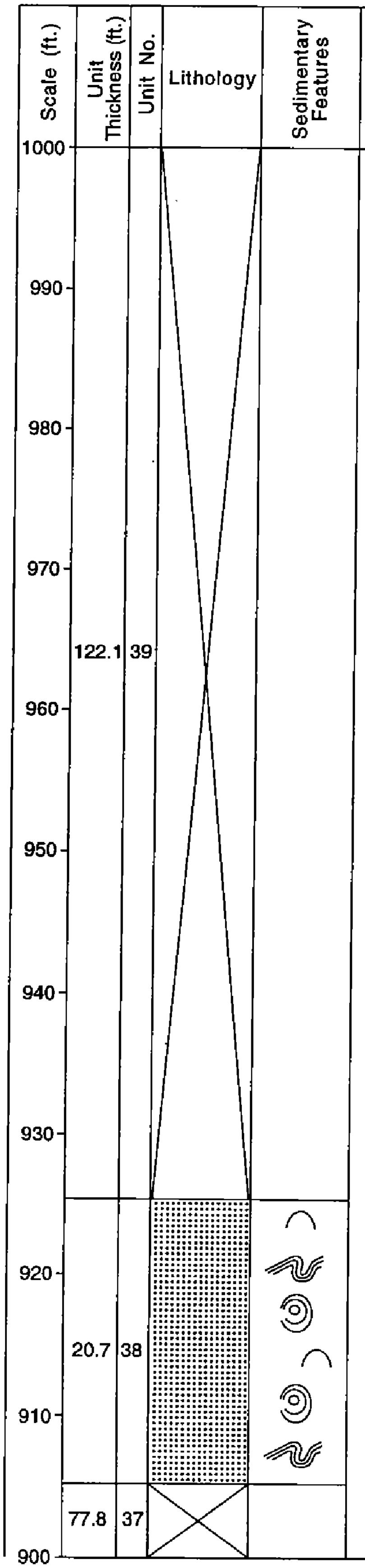


Description of Units

40. Sandstone, pale yellowish orange (10YR8/6), moderate reddish orange (10R6/6), grayish orange (10YR7/4), and moderate red (5R5/4), very fine grained, mostly irregular-bedded, thick- to medium-bedded; includes soft-sediment deformation features, rare current ripples, and asymmetric ripples on bed surfaces near top of unit; reentrant erosion of dip-slope exposures in road bed indicate interbedded shales (covered) are present in this interval (Psv7ss)

39. Covered interval

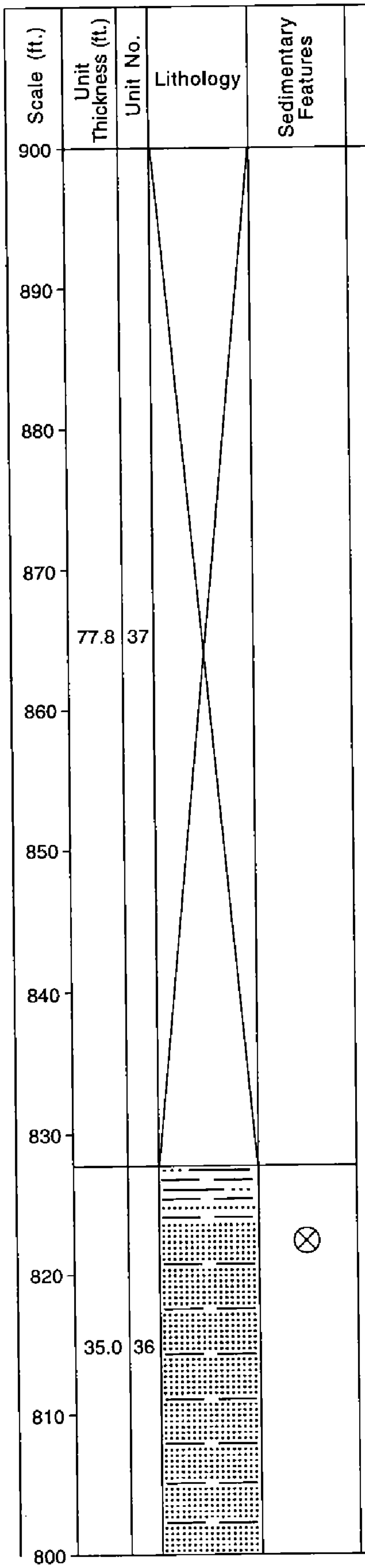
APPENDIX 1: Supplementary Reference Section for Savanna Formation
(continued)



Description of Units

38. Sandstone, dusky red (5R3/4) to moderate reddish orange (10R6/6), weathers grayish red (5R4/2), very fine to fine-grained; mostly thick-bedded and massive; contains abundant large-scale deformation features such as flow rolls and convolute beds; exhibits some swaly beds; weathers to large irregular-shaped blocks with "billowy" surfaces; poorly exposed in low ridge north of small pond (Psv6ss)

APPENDIX 1: Supplementary Reference Section for Savanna Formation
(continued)

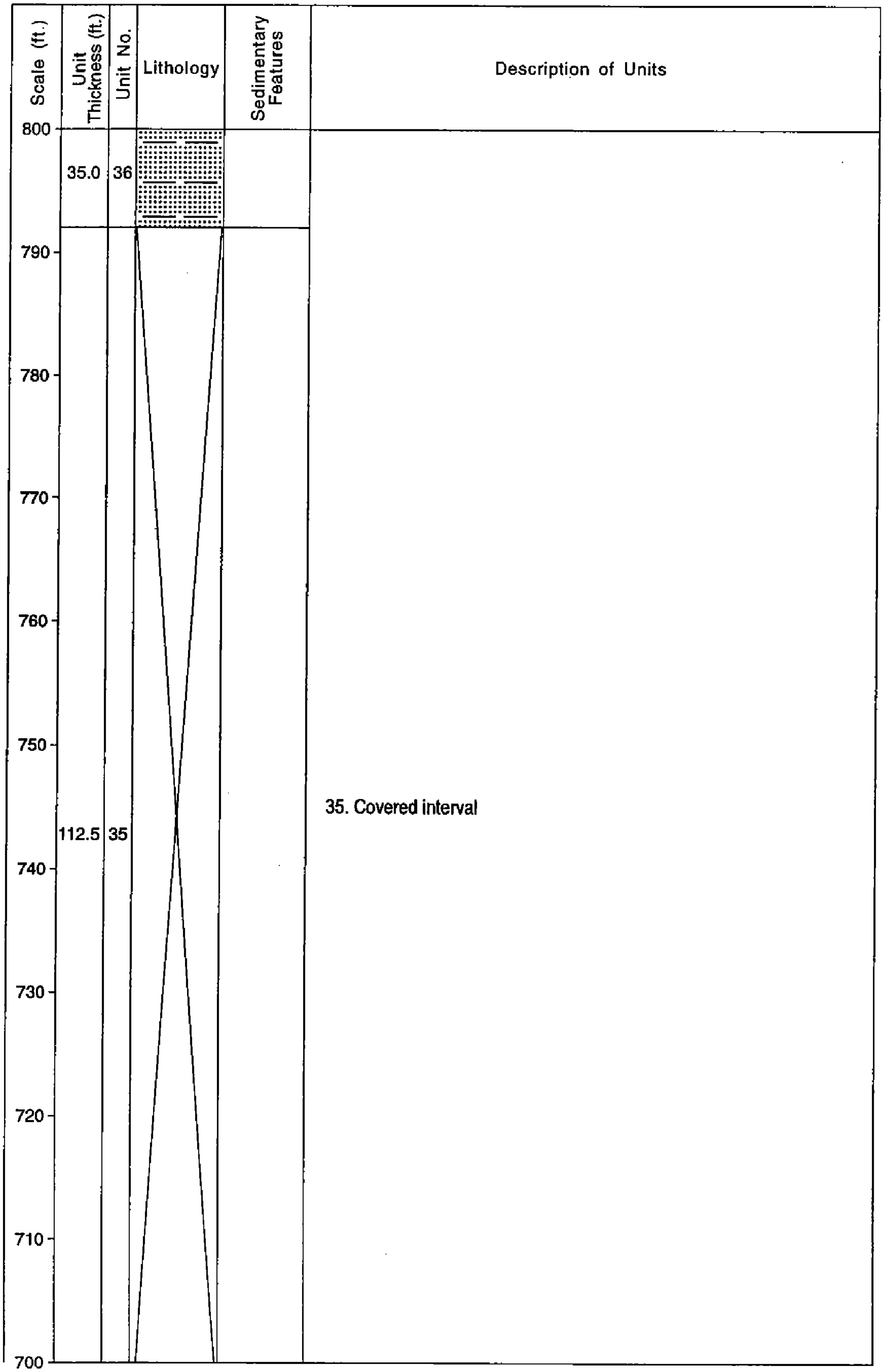


Description of Units

37. Covered interval

36. Sandstone interbedded with shale, grayish orange (10YR7/4) with light brown (5YR5/6) staining, very fine grained, medium-bedded, blocky, poorly exposed in road bed; at top is ~2 ft of mottled, moderate reddish brown (10R4/6) and grayish orange (10YR7/4) highly weathered silty shale; unit is covered where road forks, but is exposed in east fork of trail; here the sandstone is irregularly bedded and has a pitted surface from weathered-out shale and ironstone pebbles. Top is covered, but unit is at least 35 ft thick (Unit 36 is offset from top of ridge south of pond ~0.5 mile to the northeast along gas well road) (Psv5ss)

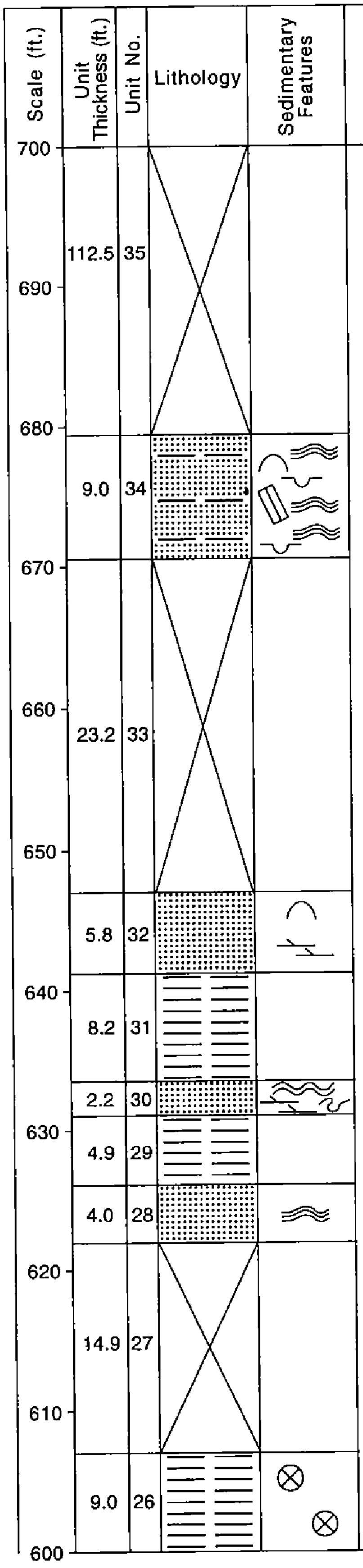
APPENDIX 1: Supplementary Reference Section for Savanna Formation
(continued)



35. Covered interval

APPENDIX 1: Supplementary Reference Section for Savanna Formation

(continued)



Description of Units

34. Sandstone interbedded with shale, olive gray (5Y4/1) to pale yellowish brown (10YR6/2) to dark yellowish brown (10YR4/2), thin- to medium-bedded, swaly bedded, trace fossils abundant on soles and bedding surfaces, pale reddish brown (10R5/4) plant fragment impressions abundant on some surfaces, soft-sediment deformation common in some sandstone beds (Psv4fss)

33. Covered interval

32. Sandstone, grayish orange (10YR7/4), weathers dark yellowish brown (10YR4/2), thick-bedded, very fine grained, includes some swaly beds and low-angle cross-stratification, blocky, base sharp (Psv4ess)

31. Shale, grayish orange (10YR7/4) to pale yellowish brown (10YR6/2), poorly exposed

30. Sandstone, dark yellowish brown (10YR4/2), weathers grayish red (10R4/2), medium-bedded, contains low-angle cross-stratification, wavy-laminated to flat, parallel-bedded in part; minor bioturbation features on some surfaces; base sharp (Psv4dss)

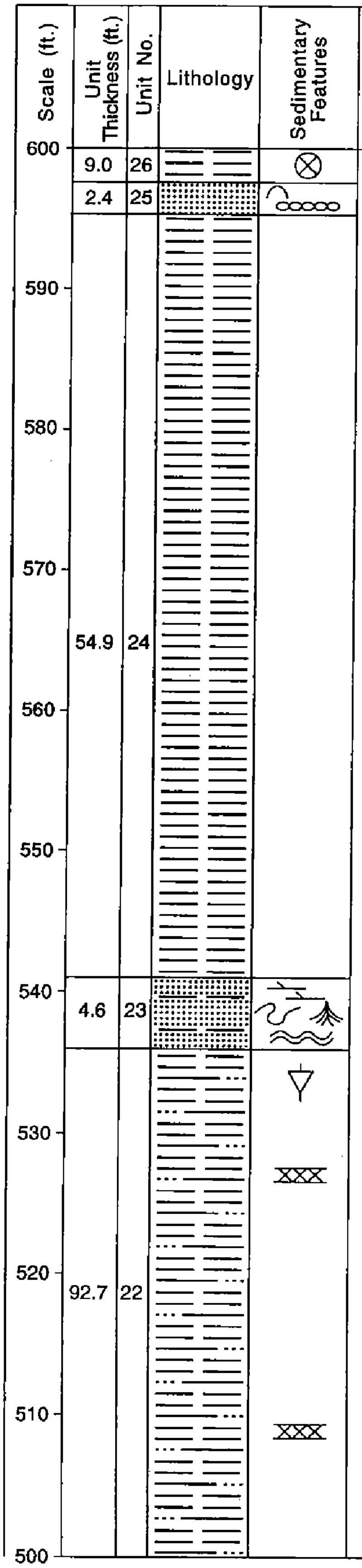
29. Shale, olive gray (5Y3/2), weathers yellowish gray (5Y7/2), poorly exposed

28. Sandstone, dark yellowish brown (10YR4/2), weathers blackish red (5R2/2), very fine grained, thick-bedded, massive; obscure evidence for soft-sediment deformation; breaks into irregular, small, blocky fragments at top of unit, base covered (Psv4css)

27. Covered interval

26. Shale, olive gray (5Y4/1), weathers grayish orange (10YR7/4) and yellowish gray (5Y7/2); contains scattered discoidal ironstone concretions ~3 in. in diameter and 0.3–1.0 in. thick; base sharp; top covered

APPENDIX 1: Supplementary Reference Section for Savanna Formation *(continued)*



Description of Units

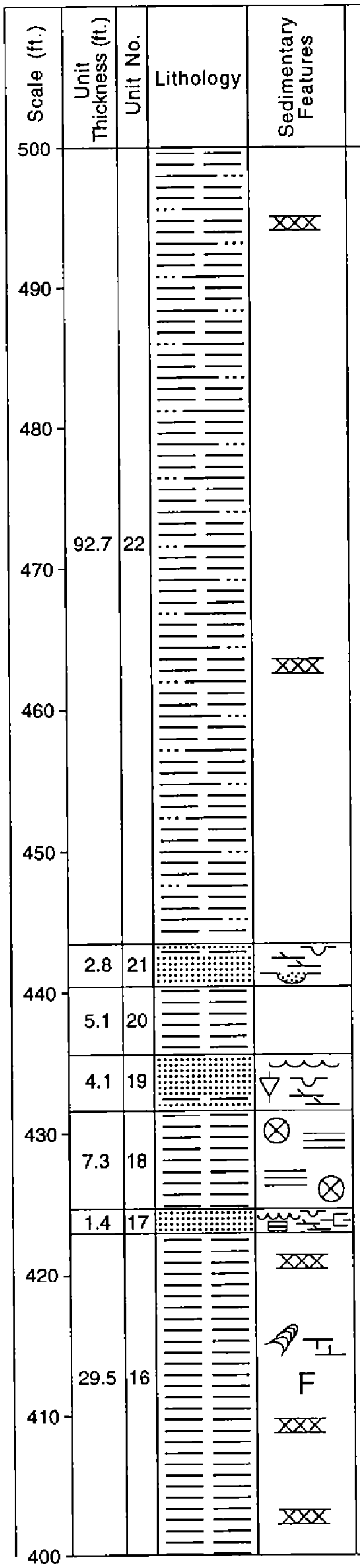
25. Sandstone, olive gray (5Y3/2), weathers moderate brown (5YR3/4) to dusky brown (5YR2/2), very fine grained, hard, medium-bedded, nodular-bedded in lower 0.7 ft; massive, with irregular, swaly parting surfaces in upper part (Psv4bss)

24. Shale, grayish red (10R4/2), very weathered, poorly exposed

23. Sandstone, dark yellowish brown (10YR4/2) to light olive gray (5Y5/2), very fine grained, shaly, very thin to thin-bedded; appears to be mostly flat, parallel-bedded, but contains low-amplitude wave laminae in lower part; moderately bioturbated; in upper 2 ft contains excellent dish-and-pillar dewatering structures; thin, wavy-bedded, with low-angle cross-stratification in upper 0.5 ft; base sharp (Psv4ass)

22. Shale, moderate yellowish brown (10YR5/4), silty, weathers dark yellowish orange (10YR6/6) and moderate brown (5YR4/4); includes rare layers of ironstone <0.5 in. thick, and rare sandstone stringers ~1.0 in. thick; becomes increasingly silty in upper 2.5 ft

APPENDIX 1: Supplementary Reference Section for Savanna Formation
(continued)



Description of Units

21. Sandstone, light olive gray (5Y5/2) to dark yellowish brown (10YR4/2), weathers moderate brown (5YR3/4), very fine grained, low-angle cross-stratification, scour-and-fill features common; thin- to medium-bedded, breaks into irregular blocks, trace fossils abundant on surface of some beds; interbedded with shale in upper part; base sharp (Psv3dss)

20. Shale, very light gray (N8) with dark yellowish orange (10YR6/6) and dusky brown (5YR2/2) staining; poorly exposed

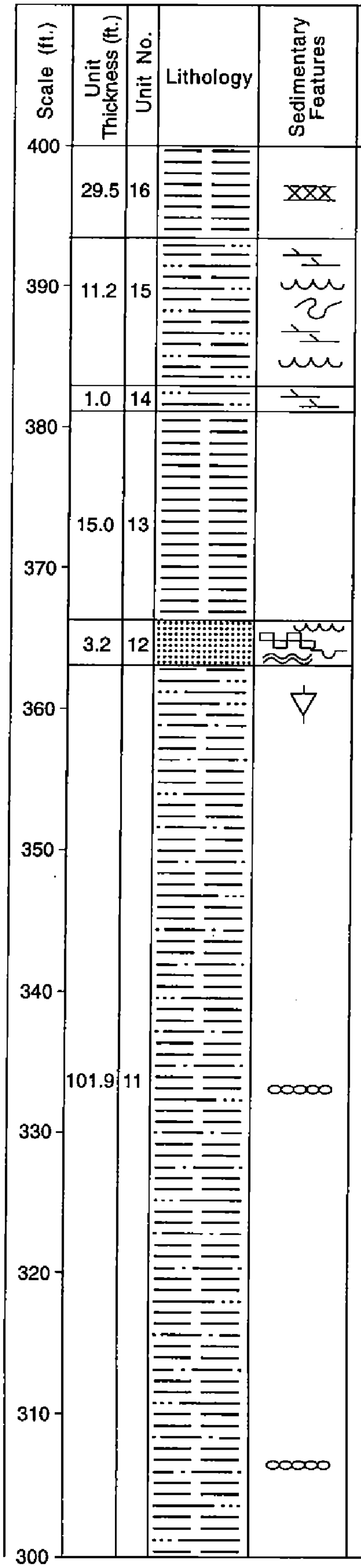
19. Sandstone, dusky yellow (5Y6/4) to light olive gray (5Y5/2); weathers light brown (5YR5/6) to moderate brown (5YR3/4), very fine grained, thin- to medium-bedded, thin-bedded and shaly in lower 1 ft, contains low-angle cross-stratification; trace fossils and indistinct ripples on some surfaces; base gradational (Psv3css)

18. Shale, medium gray (N5), weathers yellowish gray (5Y7/2), flaky; contains scattered, small, discoidal ironstone concretions, base sharp

17. Sandstone, light olive gray (5Y5/2) with light brown (5YR5/6) and dusky brown (5YR2/2) staining, very fine grained; forms a solid, resistant block that appears massive in lower 1 ft, but exhibits low-angle cross-lamination in upper 0.4 ft, surface ripple-marked and bioturbated; includes a 1.5-ft-long *Stigmaria* cast in upper 0.2 ft, trace fossils and grooves on sole; base sharp (Psv3bss)

16. Shale, medium dark gray (N4), weathers grayish orange (10YR7/4); includes a 0.2-ft-thick, dark reddish brown (10R3/4) ironstone layer containing carbonized plant fragments ~3.5 ft from base of unit; other ironstone layers scattered throughout; ~9 ft from top contains a 0.5-ft-thick layer of calcareous, grayish orange (10YR7/4), very fine grained, silty, concentric algal structures (stromatolites) with a thin-bedded, flat to irregular base in sharp contact with underlying shale—the surface has a bulbous or botryoidal appearance, with individual protrusions ranging from 1 to 8 in. across—internal laminae, in cross-section, more-or-less coincide with the surface structures; the surface is in sharp contact with the overlying shale; contains marine fossils below the stromatolite horizon

APPENDIX 1: Supplementary Reference Section for Savanna Formation
(continued)



Description of Units

15. Siltstone and shale, interbedded, dusky yellow (5Y6/4), dark reddish brown (10R3/4) and blackish red (5R2/2) staining on bedding planes, very thin bedded, low-angle cross-laminations, indistinctly ripple marked, rare bioturbation features, base gradational

14. Siltstone, very pale orange (10YR8/2), shaly, contains low-angle cross-laminations, forms minor ledge in gully, base gradational

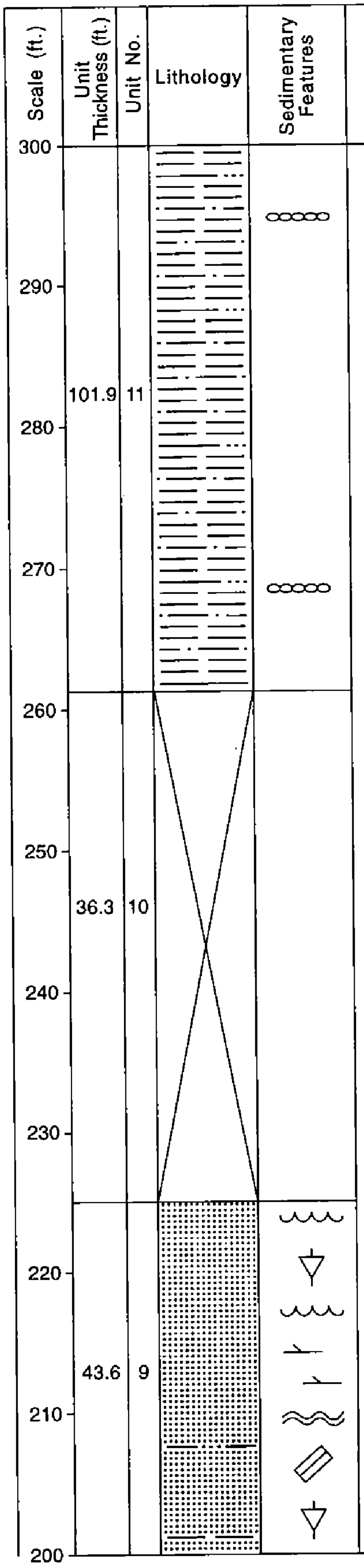
13. Shale, dark gray (N3), weathers yellowish gray (5Y7/2) and moderate yellowish brown (10YR5/4), base sharp

12. Sandstone, light olive gray (5Y5/2) to dark yellowish brown (10YR4/2), very fine grained, thin- to medium-bedded, parallel, wavy-bedded, ripple-marked, minor trace fossils on some soles; some boxwork structures on upper surface, well-indurated (Psv3ass)

11. Shale, light olive gray (5Y5/2) to moderate yellowish brown (10YR5/4) with dusky yellowish brown (10YR2/2) staining on joint surfaces where weathered, blocky; very silty and sandy in some intervals that form resistant ledges in gully; nodular bedded in places; some 0.5-in.-thick siltstone stringers in upper 3 ft

APPENDIX 1: Supplementary Reference Section for Savanna Formation

(continued)

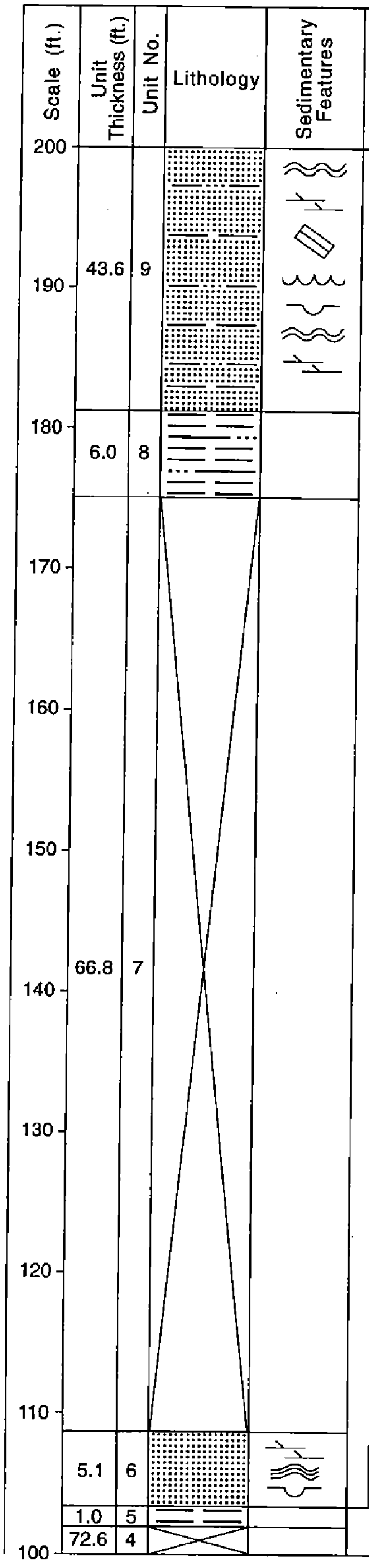


Description of Units

10. Covered interval

9. Sandstone, moderate yellowish brown (10YR5/4) to grayish orange (10YR7/4), very fine grained; silty, shaly, thin to very thin bedded, wavy-laminated; contains low-angle cross-stratification; includes scattered impressions of plant fragments; rare trace fossils on some soles; some surfaces ripple-marked; becoms medium- to thick-bedded and blocky in most places in upper 15 ft of unit, with shale interbeds decreasing upward; grain size increases to very fine and fine-grained; beds mostly parallel; base sharp; well-exposed in creek east of road (Psv2ss)

APPENDIX 1: Supplementary Reference Section for Savanna Formation *(continued)*



Description of Units

8. Shale, very pale orange (10YR8/2) with dark yellowish orange (10YR6/6) mottling, silty, weathered, base covered

7. Covered interval

6. Sandstone, grayish orange (10YR7/4) to light brown (5YR6/4), weathers grayish red (5R4/2), very fine grained, mostly irregularly medium-bedded; massive in part, but has abundant internal low-angle cross-laminations in cross-section; trace fossils on some top and bottom surfaces; contains some lenses with soft-sediment deformation features; base sharp and irregular (Psv1ss). (Contact with underlying McAlester Formation is exposed in woods ~100 ft east from N-S road, and ~200 ft N from E-W road; strike of beds is N. 66° E and dip is 15° NW.)

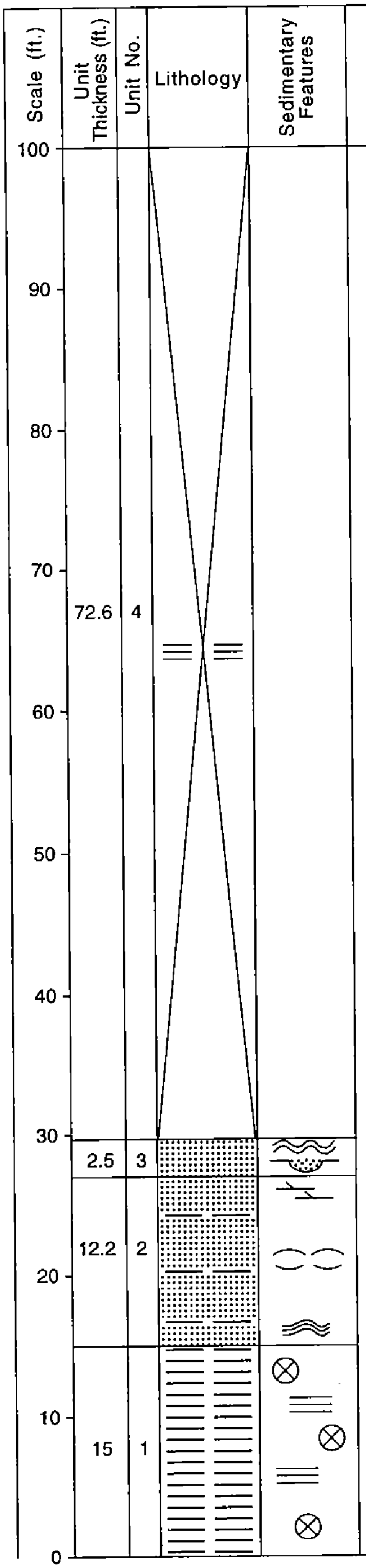
Savanna Formation

McAlester Formation

5. Shale, very pale orange (10YR8/2) to moderate reddish orange (10R6/6), highly weathered, base covered

APPENDIX 1: Supplementary Reference Section for Savanna Formation

(continued)



Description of Units

4. Covered interval with some poorly exposed shale; highly weathered, very pale orange (10YR8/2) shale with moderate reddish orange (10R6/6) mottling is exposed in road ditch east side of creek on north side of E-W road

Keota Sandstone Member:
(exposed in creek bed under fence S from E-W road)

3. Sandstone, grayish orange (10YR7/4), weathers moderate brown (5YR3/4), very fine grained, massive to obscurely wavy-bedded in upper part; occurs as solid, thick unit; includes small channel-fill unit at west end of exposure

Keota Sandstone Member:
(exposed at edge of stock pond)

2. Sandstone, dusky yellow (5Y6/4) to light olive brown (5Y5/6) to grayish orange (10YR7/4), very fine grained, shaly; contains low angle cross-stratification; thin- to medium-bedded; exhibits pinch-and-swell features, as well as soft-sediment deformation; some beds blocky and massive

1. Shale, olive gray (5Y3/2) to light olive gray (5Y5/2); contains dark reddish brown (10R3/4) ironstone concretions about 3–4 in. in diameter and 0.5–1.0 in. thick; weathers to small flakes

APPENDIX 2: Reference Well for Savanna Formation

Abbreviated from Hemish (1990b, core-hole log 7 [C-RM-1], p. 37–43).

SE¼SE¼SW¼NW¼ sec. 18, T. 21 N., R. 18 E., Mayes County, Oklahoma. Well cored by Oklahoma Geological Survey; lithologic descriptions by LeRoy A. Hemish. Drilled in pasture on hill south of pond. (Surface elevation, estimated from topographic map, 815 ft.)

	Depth to unit top (ft)	Thickness of unit (ft)
Pennsylvanian System		
Desmoinesian Series		
Krebs Group		
Boggy Formation		
Sandstone, moderate-reddish-brown, very fine-grained, noncalcareous, weathered	0.0	4.0
Sandstone, grayish-orange with dusky-brown flecks, very fine-grained, micaceous, noncalcareous, thin-bedded, weathered	4.0	4.5
Shale, dark-yellowish-orange to light-brown to pale-yellowish-brown, interlaminated with siltstone and very fine-grained sandstone, noncalcareous, weathered	8.5	2.0
Shale, grayish-black with dark-yellowish-orange bands, noncalcareous; contains some thin stringers of light-gray siltstone; fractured	10.5	2.5
Shale, grayish-black with medium-light-gray, sideritic bands, noncalcareous	13.0	7.8
Shale, grayish-black to black, noncalcareous; contains light-brownish-gray, sideritic concretions up to 2 in. thick	20.8	2.8
Limestone, light-brownish-gray, fine-grained, micritic, nonfossiliferous	23.6	0.5
Shale, grayish-black, noncalcareous; contains rare pyrite-filled burrows and light-brownish-gray, sideritic concretions up to 1.5 in. thick	24.1	14.4
Limestone, medium-dark-gray to light-gray, impure, shaly, fossiliferous; contains abundant broken shells and other fossil fragments; becomes darker gray in lower 1 ft, with better-preserved fossil shells; includes a 1/16-in.-thick coal stringer at contact with underlying unit (Inola Limestone)	38.5	3.7
Underclay, medium-dark-gray to medium-light-gray; blocky facture; carbonaceous in upper part	42.2	1.5
Shale, greenish-gray, clayey, noncalcareous; contains some bioturbation features in lower 8 in.	43.7	1.1
Limestone, light-gray with very light-gray mottling, fine-grained, hard; contains fossil shells and fossil fragments (Inola Limestone)	44.8	1.5
Underclay, light-gray with minor grayish-black streaks, blocky fracture, silty; grades into underlying unit	46.3	2.2
Limestone, very light-gray, fine-grained, calcarenitic; contains rare fossil shells and minor disseminated pyrite; cross-bedded (Inola Limestone)	48.5	5.4
Shale, medium-gray, noncalcareous, carbonaceous, pyritic; includes two coal layers totaling 0.75 in. thick at contact with overlying unit	53.9	0.1
Coal, black, bright, moderately friable; pyrite and calcite on cleats; includes a 4-in.-thick carbonaceous shale parting from 55.0 to 55.3 ft; 6 in. of coal below parting contains some thin shale laminae (Bluejacket coal)	54.0	1.8

APPENDIX 2: Reference Well for Savanna Formation
(continued)

Shale, medium-dark-gray, silty, sandy, coaly in upper part; contains abundant well-preserved, black, carbonized plant compressions	55.8	0.4
Sandstone, light-gray with medium-dark-gray shale streaks, micaceous, very fine-grained, noncalcareous, rippled; contains abundant black, carbonized and pyritized plant fragments (upper unit of Bluejacket Sandstone)	56.2	3.9
Siltstone, medium-light-gray, interbedded with medium-dark-gray shale, noncalcareous, wavy-bedded and cross-laminated in part, burrowed; contains black, carbonized plant fragments	60.1	2.9
Shale, dark-gray with medium-light-gray siltstone bands and streaks, noncalcareous; contains black, carbonized plant fragments and rare light-brownish-gray, sideritic concretions; contact with underlying unit sharp	63.0	10.7
Sandstone, medium-light-gray, fine-grained, noncalcareous, micaceous; contains scattered dark-gray shale streaks and pebbles, as well as numerous streaks of black, coalified plant material; shows flame structure and flaser bedding in places; includes some coal spars up to 1.5 in. thick in lower 8 in. of unit; contact with underlying unit sharp (basal unit of Bluejacket Sandstone)	73.7	21.4
Savanna Formation		
Ironstone, brownish-gray; contains a thin, diagonal streak of white gypsum	95.1	0.2
Shale, black, noncalcareous	95.3	0.7
Limestone, dark-gray, impure, silty, contains abundant fossil shells and fossil fragments	96.0	0.4
Shale, black, coaly, calcareous	96.4	0.1
Coal, black, moderately friable; contains pyrite in thin lenses and streaks (Drywood coal)	96.5	0.1
Shale, medium-gray, noncalcareous; silty, wavy-laminated; contains black, carbonized plant fragments; includes 2 in. of poorly developed underclay at top of unit; contains scattered pyrite-filled burrows and light-brownish-gray, sideritic concretions up to 1.25 in. thick	96.6	7.5
Shale, medium-dark-gray with grayish-black and black streaks, weakly calcareous; contains carbonaceous and pyritic layers, as well as streaks of coal	104.1	0.1
Underclay, medium-gray, blocky fracture, slickensided, burrowed, silty	104.2	2.1
Siltstone, medium-light-gray, noncalcareous, shaly	106.3	0.6
Shale, grayish-black with light-brownish-gray bands in upper 6 ft, noncalcareous, burrowed; contains pyrite masses and sideritic concretions up to 1.25 in. thick	106.9	8.1
Shale, grayish-black, noncalcareous; contains rare pyrite-filled burrows, small, calcareous fossil shells, and white calcite in veinlets and on bedding planes; contains some light-brownish-gray sideritic concretions up to 1 in. thick in lower 3.5 ft of unit	115.0	11.8
Limestone, grayish-black, impure, silty, fine-grained, fossiliferous; contains shell fragments and small crinoid ossicles	126.8	0.1
Shale, grayish-black, noncalcareous; includes thin, very light-gray streaks of calcareous siltstone and sandstone	126.9	1.6
Limestone, grayish-black, impure, silty, fossiliferous; contains fossil hash; grades into underlying unit	128.5	0.1

APPENDIX 2: Reference Well for Savanna Formation
(continued)

Shale, black, very calcareous; contains abundant white fossil shells and crinoid ossicles; grades into underlying unit..........	128.6	2.4
Limestone, grayish-black, very impure, silty, shaly, carbonaceous; fossiliferous; contains fossil hash (Doneley Limestone)................	131.0	0.8
Coal, black, bright, moderately friable, white calcite and pyrite on cleat surfaces (Rowe coal)..	131.8	0.7
Underclay, brownish-gray, silty; contains black, carbonized plant fragments..............	132.5	1.8
Shale, medium-light-gray, silty, noncalcareous...	134.3	1.5
Mudstone, medium-light-gray, noncalcareous.......	135.8	2.2
Sandstone and siltstone, medium-gray, shaly, very fine-grained, noncalcareous, laminated, burrowed......................................	138.0	2.0
Shale, medium-dark-gray with light-gray streaks of siltstone and very fine-grained sandstone, noncalcareous, extensively burrowed; includes rare, light-brownish-gray, sideritic concretions...	140.0	9.3
Shale, medium-dark-gray, noncalcareous; contains rare, thin streaks of light-gray siltstone.....	149.3	13.0
Limestone, brownish-gray, impure, shaly, fine-grained; contains abundant fossil hash; includes a 0.5-in.-thick band of black, carbonaceous shale at base (Sam Creek Limestone)..	162.3	0.2
Underclay, medium-dark-gray, churned, slickensided...	162.5	1.9
Shale, dark-gray, silty, sandy, noncalcareous; contains large bioturbation features filled with brownish-gray, very fine-grained sandstone.....................................	164.4	2.3
Shale, dark-gray with light-gray siltstone streaks and lenses, noncalcareous; contains rare, light-brownish-gray, sideritic concretions....................................	166.7	4.1
Coal, black, interbedded with dark-gray, noncalcareous, slickensided shale and layers of pyrite up to 1/16 in. thick...................	170.8	0.7
Coal, black, bright, moderately friable, pyrite and calcite on cleat surfaces (unnamed coal)...	171.5	0.3
Underclay, medium-gray, soft.....................	171.8	0.4
Shale, medium-light-gray, burrowed, noncalcareous; includes a 0.5-in.-thick layer of fossiliferous limestone 4 in. above base of unit..	172.2	4.8
Limestone, medium-dark-gray with light-brownish-gray sideritic bands about 1-in.-thick, impure, shaly, fossiliferous; contains abundant brachiopod shells and fossil hash (Spaniard Limestone)..........................	177.0	1.0
McAlester Formation		
Underclay, medium-gray, churned; contains a 2-in.-thick, calcarenitic limestone layer at 178.8 ft.....................................	178.0	1.7
Shale, medium-dark-gray to dark-gray, noncalcareous, brittle; includes rare, light-brownish-gray, sideritic concretions; extensively bioturbated in upper 15 in. of unit; contains rare burrows and streaks of pyrite in remainder of unit, with minor streaks of light-gray siltstone..........................	179.7	24.1
		203.8

NEW OGS *Publication*

CIRCULAR 98. ***Deltaic Reservoirs in the Southern Midcontinent, 1993 Symposium,*** edited by Kenneth S. Johnson. 295 pages, 32 contributions. Price: Paperbound, $10.

From the editor's preface:

The transfer of technical information will aid in the search for, and production of, our oil and gas resources. To facilitate this technology transfer, the Oklahoma Geological Survey (OGS) and the Bartlesville Project Office of the U.S. Department of Energy (BPO-DOE) co-sponsored a symposium dealing with the petroleum geology and reservoir characterization of fluvial-dominated deltaic (FDD) reservoirs in the southern Midcontinent. The symposium was held on March 23–24, 1993, at the Oklahoma Center for Continuing Education, The University of Oklahoma, Norman. This volume contains the proceedings of that symposium.

Research reported upon at the symposium focused on the following: types of FDD reservoirs, depositional settings, diagenetic history, reservoir characterization, and enhanced oil recovery. In describing the various FDD petroleum reservoirs in the southern Midcontinent, the researchers have increased our understanding of how the geologic history of a river/delta complex can affect reservoir heterogeneity and our ability to efficiently recover the hydrocarbons they contain. We hope that the symposium and these proceedings will bring such research to the attention of the geoscience and energy-research community, and will help foster exchange of information and increased research interest among industry, university, and government workers.

Nineteen papers were presented orally at the symposium, and they are presented here as full papers or abstracts. An additional 13 reports were given as posters, and they are presented here as short reports or abstracts. About 250 persons attended the symposium.

This is the sixth symposium in as many years dealing with topics of major interest to geologists and others involved in petroleum-resource development in Oklahoma and adjacent states. These symposia are intended to foster the exchange of information that will improve our ability to find and recover our nation's oil and gas resources. Earlier symposia subjects were: the Anadarko basin (published as OGS Circular 90); Late Cambrian–Ordovician geology of the southern Midcontinent (OGS Circular 92); Source rocks in the southern Midcontinent (OGS Circular 93); Petroleum-reservoir geology in the southern Midcontinent (OGS Circular 95); and Structural styles in the southern Midcontinent (OGS Circular 97).

Circular 98 can be purchased by mail from the Survey at 100 E. Boyd, Room N-131, Norman, OK 73019; fax 405-325-7069. Add 20% to the cost for mail orders.

All OGS publications can be purchased over the counter at the OGS Publication Sales Office's new location at 1218-B W. Rock Creek Road, Norman; phone (405) 360-2886; fax 405-366-2882. Parking is free and readily available.

UPCOMING *Meetings*

Mining and the Environment—New Directions, Annual Meeting, December 2–6, 1996, Spokane, Washington. Information: Northwest Mining Association, 10 N. Post St., Suite 414, Spokane, WA 99201; fax 509-623-1241.

International Symposium on Mine Simulation via the Internet, December 2–13, 1996, by the University of Idaho and National Technical University of Athens. Symposium site on WWW is http://www.metal.ntua.gr/msslab.

SEPM Foundation, Gulf Coast Section, Annual Research Conference, "Advanced Geophysical and Wireline Technology for Stratigraphic Analysis," December 8–11, 1996, Houston, Texas. Information: GCSSEPM Foundation, 165 Pinehurst Road, West Hartland, CT 06091; (860) 738-9302.

Tailings and Mine Waste '97, January 13–17, 1997, Fort Collins, Colorado. Information: Linda Hinshaw, Dept. of Civil Engineering, Colorado State University, Fort Collins, CO 80523; (970) 491-6081, fax 970-491-3584 *or* 970-491-7727.

Society for Mining, Metallurgy, and Exploration, Annual Meeting, February 24–27, 1997, Denver, Colorado. Information: SME, P.O. Box 625002, Littleton, CO 80162; (303) 973-9550, fax 303-973-3845; e-mail: smenet@aol.com. WWW site is http://www.smenet.org.

Erosion Control and the Environment Conference, February 25–28, 1997, Nashville, Tennessee. Information: International Erosion Control Association, P.O. Box 774904, Steamboat Springs, CO 80477.

Reservoir Characterization, International Conference, sponsored by U.S. Dept. of Energy and others, March 2–4, 1997, Houston, Texas. Information: Susan Hayden, BDM-Oklahoma, Inc., P.O. Box 2565, Bartlesville, OK 74005; (918) 337-4460, fax 918-337-4339; e-mail: shayden@bpo.gov.

Geological Society of America, South-Central and Rocky Mountain Sections Meeting, March 20–21, 1997, El Paso, Texas. *Abstracts due November 25, 1996.* Information: GSA Meetings Dept., Box 9140, Boulder, CO 80301; (800) 472-1988 *or* (303) 447-2020, ext. 133; e-mail: meetings@geosociety.org; WWW site is http://www.geosociety.org.

Environmental and Engineering Geophysical Society, Symposium on Application of Geophysics to Environmental and Engineering Problems, March 23–26, 1997, Reno, Nevada. Information: SAGEEP, 7632 E. Costilla Ave., Englewood, CO 80112; (303) 771-2000, fax 303-843-6232.

Marine Clastics in the Southern Midcontinent Conference, March 25–26, 1997, Oklahoma City, Oklahoma. Information: Kenneth S. Johnson, Oklahoma Geological Survey, 100 E. Boyd, Room N-131, Norman, OK 73019; (405) 325-3031, fax 405-325-7069.

Geological Society of America, Southeastern Section Meeting, March 27–28, 1997, Auburn, Alabama. *Abstracts due December 2, 1996.* Information: GSA Meetings Dept., Box 9140, Boulder, CO 80301; (800) 472-1988 *or* (303) 447-2020, ext. 133; e-mail: meetings@geosociety. org; WWW site is http://www.geosociety.org.

American Association of Petroleum Geologists, Annual Meeting, April 6–9, 1997, Dallas, Texas. Information: Convention Dept., AAPG, Box 979, Tulsa, OK 74101; (918) 584-2679, fax 918-584-0469.

SEPM (Society for Sedimentary Geology) Annual Meeting, April 6–9, 1997, Dallas, Texas. Information: SEPM, 1731 E. 71st St., Tulsa, OK 74136; (918) 493-3361.

Sixth Conference on Sinkholes—Engineering and Environmental Impacts of Karst, April 6–9, 1997, Springfield, Missouri. Information: B. F. Beck, P. E. LaMoreaux & Associates, Inc., P.O. Box 4578, Oak Ridge, TN 37831; (423) 483-7483; e-mail: pelaor@use.usit.net.

Seismological Society of America, Annual Meeting, April 9–11, 1997, Honolulu, Hawaii. Information: Susan Newman, SSA, 201 Plaza Professional Bldg., El Cerrito, CA 94530; (510) 525-5474; e-mail: snewman@seismosoc.org.

Geological Society of America Penrose Conference, "Paleocene/Eocene Boundary Events in Time and Space," April 24–29, 1997, Albuquerque, New Mexico. Information: Spencer Lucas, New Mexico Museum of Natural History, 1801 Mountain Road NW, Albuquerque, NM 87104; (505) 841-2873, fax 505-841-2866; e-mail: lucas@darwin.nmmnh-abq.mus.nm.us.

In Situ and On-Site Bioremediation, International Symposium, April 28–May 1, 1997, New Orleans, Louisiana. Information: The Conference Group, 1989 W. Fifth Ave., Suite 5, Columbus, OH 43212; (800) 783-6338, fax 614-488-5747.

Geological Society of America, North-Central Section Meeting, May 1–2, 1997, Madison, Wisconsin. Information: GSA Meetings Dept., Box 9140, Boulder, CO 80301; (800) 472-1988 *or* (303) 447-2020, ext. 133; e-mail: meetings@geosociety.org; WWW site is http://www.geosociety.org.

OKLAHOMA CITY GEOLOGICAL SOCIETY ELECTS NEW OFFICERS

Officers of the Oklahoma City Geological Society for the 1996–97 term are:

President: Steve Boone, Gulf Production Corp.
President Elect: George Troutman, Independent Geologist
Past President: Leonard Dionisio, Jr., Consulting Petroleum Geologist
Vice President: Gregory L. McMahan, Marathon Oil Co.
Treasurer: Debra Rutan, Southwestern Energy Production Co.
Secretary: Bryan Waller, Ramsey Property Management
Library Director: David Carman, Slawson Exploration
Shale Shaker Editor: William E. Jackson, Independent Petroleum Geologist
1st Presidential Appointee: Carroll Kinney, Consulting Petroleum Geologist
2nd Presidential Appointee: Jason Hamilton, Devon Energy Corp.

The offices of the Oklahoma City Geological Society are in the Park-Harvey Building at 227 W. Park Ave. in downtown Oklahoma City.

Oklahoma Areas of Oil and Gas Production

This three-page USGS open-file report was written by R. F. Mast, D. H. Root, L. Williams, and W. R. Beeman.

Order OF 94-0022-H from: U.S. Geological Survey, Information Services, Box 25286, Federal Center, Denver, CO 80225; phone (303) 236-7476. The price is $4 for microfiche and $1.50 for a paper copy; add 25% to the price for foreign shipment.

Estimated Freshwater Withdrawals in Oklahoma, 1990

In this U.S. Geological Survey water-resources investigations report, freshwater usage estimated with 1990 Oklahoma Water Resources Board data as the primary data source is shown by withdrawal source and category on two 35″ × 26″ sheets. Withdrawal source is either ground water or surface water; categories include irrigation, water supply, livestock, thermoelectric-power generation, domestic and commercial, and industrial and mining. Withdrawal data are aggregated by county, major aquifer, and principal river basin. The two types of illustrations that show withdrawal data in this report are maps and pie charts. A table lists the amount of estimated freshwater withdrawals by county use, and source for each county. Dee L. Lurry and Robert L. Totorelli are the authors of this report.

Order WRI 95-4276 from: U.S. Geological Survey, Water Resources Division, 202 N.W. 66th St., Bldg. 7, Oklahoma City, OK 73116; phone (405) 843-7570, fax 405-843-7712. A limited number of copies are available free of charge.

Geohydrology of Alluvium and Terrace Deposits of the Cimarron River from Freedom to Guthrie, Oklahoma

The study area for this USGS water-resources investigations report, by Gregory P. Adams and DeRoy L. Bergman, consists of 1,305 square miles underlain by Quaternary alluvium and terrace deposits associated with 115 miles of the Cimarron River from Freedom to Guthrie. Ground water in this area is used for irrigation, municipal, stock, and domestic supplies, and is the major source of water for the City of Enid, the largest single user of ground water in the State. The investigation, conducted from 1985 to 1988 in cooperation with the Oklahoma Geological Survey, was designed to provide State water managers with the quantitative knowledge necessary to manage the ground-water resources of this area effectively. The objectives of this 57-page report are: to describe the geologic setting and water quality of the alluvium and terrace deposits along the Cimarron River from Freedom to Guthrie; to estimate the quantity of water in storage, the annual recharge, and the annual discharge from these deposits to the Cimarron River; and to develop a mathematical model to test the conceptual model of the ground-water hydrology of these deposits.

Order WRI 95-4066 from: U.S. Geological Survey, Water Resources Division, 202 N.W. 66th St., Bldg. 7, Oklahoma City, OK 73116; phone (405) 843-7570, fax 405-843-7712. A limited number of copies are available free of charge.

Oklahoma ABSTRACTS

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

Cerium Anomalies in Paleozoic Strata of the Ouachita Allochthon, Oklahoma: Implications for Paleoredox Conditions and Paleotectonic Reconstructions

DOUGLAS R. REID, MICHAEL C. DIX, and *JOHN F. CASEY,* Dept. of Geosciences, University of Houston, Houston, TX 77204

The cerium anomaly in a sediment (Ce/Ce*, normalized to Post-Archean Average Australian Shale) is defined as the deviation of Ce abundance from that expected for a smooth rare-earth element (REE) pattern. This Ce fractionation can only be caused by redox processes, and is believed to be an indicator of water column anoxia in the sedimentary record (Berry et al., 1987; German and Elderfield, 1990). For siliciclastic sediments, positive anomalies (Ce/Ce* > 1) are taken to indicate oxygenated water conditions, while negative anomalies (Ce/Ce* < 1) indicate anoxic conditions.

Whole-rock geochemical analyses, including the determination of REE abundances and Ce/Ce*, were performed on 247 Paleozoic shales, sandstones, and cherts from within and around the Broken Bow uplift, Ouachita allochthon, Oklahoma. This sequence provides an uninterrupted early Ordovician through middle Pennsylvanian depositional history of the Ouachita basin. Three clear groupings are apparent in the data: (1) All Ordovician units, which are characterized by dark grey to black shales, show negative Ce/Ce*, low MnO, and elevated V, all indicative of anoxic conditions. (2) Beginning in the latest Ordovician, Ce/Ce* begins to increase, reaches positive values during the Silurian, and continues to increase to pronounced positive values during deposition of the Devonian to early Mississippian Arkansas Novaculite. MnO likewise increases, while V generally decreases. (3) During flysch deposition from the early Mississippian to the middle Pennsylvanian, Ce/Ce* returns to slightly negative values, although MnO and V concentrations remain essentially unchanged.

A number of oceanographic factors may be responsible for anoxia in the water column. One of the most straightforward, however, is the physical restriction of circulation within a basin due to the configuration of surrounding land masses. With this in mind, the temporal pattern of anoxia preserved in Paleozoic strata of the Broken Bow uplift is consistent with the tectonic reconstructions of Dalziel et al. (1994) and Dix et al. (1995) for the Ouachita basin. Following Cambrian rifting, the Ouachita basin evolved as a small, restricted ocean bordered on the north and west by the Laurentian continent, and on the southeast by the Occidentalia carbonate platform (now exposed in the Argentine Precordillera). Consistently anoxic conditions prevailed until the Occidentalia platform was attached to Gondwana in the Taconian-Famatinian orogeny and rifted away in the Late Ordovician. Increasingly oxygenated conditions developed during the Silurian and Devonian as Gondwana drifted away, opening the Ouachita embayment to unrestricted circulation. Slightly anoxic conditions were reestablished in the Mississippian as the basin narrowed and circulation was restricted before the terminal Ouachita orogeny.

Reprinted as published in the Geological Society of America *1996 Abstracts with Programs,* v. 28, no. 1, p. 60.

A Stratigraphic and Sedimentologic Analysis of a Lower Atoka Sandstone, Frontal Ouachita Thrustbelt, Western Arkansas

DEBRA E. VADER, Dept. of Geology, University of Arkansas,
Fayetteville, AR 72701

Prolific lower Atoka (Pennsylvanian) gas reservoirs have been exploited in the frontal Ouachita thrustbelt of eatern Oklahoma. Although the thrustbelt extends into western Arkansas, Pennsylvanian reservoirs have not been recognized. A lower Atoka sandstone unit, exposed behind the Ti Valley thrust fault, exhibits characteristics that indicate favorable reservoir quality. The outcrop is a succession of very fine to medium grained litharenite. Three zones are distinguished by grain size, mineral composition, and sedimentary structures. The stratigraphically lowest zone is very fine grained and is composed mostly of monocrystalline quarz with a clay matrix. Sedimentary structures include scours, horizontal burrows, and horizontal laminations. Porosity and permeability are nonexistent in this zone. Alternating sets of horizontally laminated fine to medium grained sandstone and bioclastic sandstone characterize the second zone. Secondary porosity has developed due to dissolution of skeletal grains. The stratigraphically highest zone exhibits porosity and permeability comparable to reservoirs within the Arkoma basin. Porosity values range from 6% to 24% with permeability as high as 248 millidarcies. The zone is a massively bedded, fine to medium grained sandstone. Monocrystalline and polycrystalline quartz are the dominant mineral components along with minor amounts of skeletal fragments. Porosity is secondary and has developed where pervasive chlorite grain coatings preclude silica cementation. The primary sedimentary structure is hummocky cross stratification implying deposition on a storm dominated shelf. The outcrop is significant in that it suggests: (1) the Arkoma "shelf" extended south of the present Ouachita thrustbelt trend and (2) reservoir quality rocks of Atokan age may be present in the subsurface behind the major thrust faults of the trend in western Arkansas.

Reprinted as published in the American Association of Petroleum Geologists *Bulletin*, v. 79, p. 1409, September 1995.

Intraplate Deformation During the Appalachian-Ouachita Orogeny as Recorded by Mesoscale Structures on the Ozark Plateau of North America

RANDEL TOM COX, Dept. of Geological Sciences, University of Memphis,
Memphis, TN 38152

Analysis of mesoscale fractures and folds in Paleozoic rocks across the Ozark plateau revealed four episodes of deformation in post-Mississippian time, and regional mesoscale structural trends suggest this deformation was controlled by far-field stresses resulting from Alleghenian-Ouachita collisions. Mesoscale structures are localized along fault zones and particularly at major bends in basement fault zones (suggesting restraining bend uplifts along strike-slip faults). In addition, geometries of conjugate extensional fault arrays associated with each of the four deformation events indicate localized areas of high vertical stress consistent with basement block uplift. High-angle faults reactivated in a reverse sense and bedding parallel veins suggest tensile minimum stresses and pore fluid pressures exceeding lithostatic stress. Brine pulses driven into the midcontinent from the Alleghenian-Ouachita orogen, as proposed by other authors, are consistent with these evidences of high pore fluid pressures.

The earliest three episodes of mesoscale deformation can be assigned to the progressive NW docking of the Ouachita block with the SE margin of North America. Event 1 NW in-plane compression records the approach of the Ouachita block after initial collision with North America. Systematic variation of Event 2 in-plane compression from N/NW in the south to NE in the north of the Ozark plateau suggests development of a slip-line deformation field in response to minor NE lateral escape of lithospheric blocks away from the leading edge of the NW-moving Ouachita block, which acted as a rigid indentor. Uniform NE in-plane compression recorded by Event 3 suggest minor NE movement of escape blocks during a more advanced stage of docking as the Ouachita block moved NW and the thrusting front moved into Oklahoma and central Texas. The dominant NW in-plane compression orientation of Event 4 is consistent with late stage convergence along the southeastern Alleghenian front.

Reprinted as published in the Geological Society of America *1996 Abstracts with Programs*, v. 28, no. 2, p. 8.

Gravity Constraints on the Deep Structure of the Ouachita Mountains

DENNIS L. HARRY, Dept. of Geology, University of Alabama, Tuscaloosa, AL 35487; and *KEVIN L. MICKUS*, Dept. of Geosciences, Southwest Missouri State University, Springfield, MO 65804

Nine bouguer gravity and topography profiles crossing the exposed Ouachita mountains and Arkoma basin constrain the subsurface structure of the Ouachita fold and thrust belt, the net strength of the crust along the pre-orogenic rifted margin of southern North America, and the thickness of material emplaced during thrusting. Gravity/topography coherence modeling indicates that the flexural rigidity of the crust in this region is $1 \pm 0.5 \times 10^{23}$ N-m. Analysis of the bouguer gravity admittance indicates that a combination of topographic and subsurface loads in the region of the Broken Bow and Benton uplifts is responsible for producing the Arkoma basin. The subsurface load is most pronounced on the western end of the Ouachita mountains and decreases eastward. The admittance data does not require a large subsurface load in the eastern Ouachita mountains—the emplaced load in this region can be mostly accounted for by the surface topography. An inverse method was developed to examine the spatial distribution of the subsurface load in the western and central Ouachitas. The inverse technique solves for the load required to produce a flexural style of subsidence in the Arkoma foreland basin which is consistent with the observed bouguer gravity. The inverse modeling suggests that the subsurface load follows the trend of the Broken Bow and Benton uplifts, but is displaced slightly further to the south. The load is greatest beneath the western Broken Bow uplift, where approximately 80% of the total load is estimated to lie in the subsurface, and decreases eastward. The inverse modeling combined with spectral analysis of the gravity data suggests that roughly equal amounts of crustal thickening occurs within the upper crust (interpreted as Ouachita facies strata) and in the middle to lower crust.

Reprinted as published in the Geological Society of America *1996 Abstracts with Programs*, v. 28, no. 2, p. 15.

Pennsylvanian Sequence Stratigraphy of the Arkoma Basin

ALLAN P. BENNISON, Geological Consultant, Tulsa, OK

Sequence stratigraphy for tectonically active foreland basins, such as the Arkoma Basin, differs appreciably from that now widely accepted for relatively passive marginal basins. Owing to its greater geographic confinement, sediments can be stacked above sea level, even in the trough area, until a loading threshold is reached and/or a rise in global sea level results in additional accommodation for sediments.

Another important difference is that an orogenic belt maintains its high relief and continues to contribute sediments during major flooding of the continental shelf, that diminishes sediment influx from that source. This results in a cratonward shift of the basinal axial deposits and a sediment stacking in the basinal area and orogenic border four or more times that on the cratonic shelf.

This foreland basin sequence is commonly unconformity bounded. Its initial deposits are usually those of the transgressive system tract, succeeded in turn by the highstand, lowstand and finally the forced regressive system tracts. This sequence is commonly interrupted by renewed tectonic and glacio-eustatic forced sea level changes.

The transgressive system tract is usually accomplished within one parasequence, owing to an accelerating rise in sea level. After a transgression, a highstand of sea level may continue throughout two or more eustatic fluctuations of sea level. In an idealized sequence, this phase is followed by basin filling, consisting of lowstand deposits of shallow marine to onshore regressive fluvial deposits.

Reprinted as published in the American Association of Petroleum Geologists *Bulletin*, v. 79, p. 1400, September 1995.

Stratigraphic Relations and Sedimentology of the Upper Part of the Atoka Formation (Pennsylvanian), Southeastern Arkoma Basin, Oklahoma

JAMES R. CHAPLIN, Oklahoma Geological Survey, 100 E. Boyd, Room N-131, Norman, OK 73019

Approximately 886 ft (270 m) of the upper part of the Atoka Formation (Pennsylvanian) is exposed in the southern part of the Arkoma Basin at Wister Lake Spillway, Le Flore County, Oklahoma. Many sandstones of uncertain stratigraphic position and continuity occur in the subsurface within the Atoka Formation. This is the first study to document that some of these sandstones, which are locally productive reservoirs, can be correlated to surface outcrops stratigraphically.

The upper part of the Atoka Formation is composed of two major depositional sequences: a lower 207-ft (63 m)-thick, less distal shelf, mud-dominated succession is more sand-rich, has higher sand/shale ratios, and shows more frequent evidence of wave-generated bed forms than the upper sequence; an upper 679-ft (207 m)-thick, more distal shelf, mud-dominated succession has lower sand/shale ratios, shows less frequent evidence of oscillatory flow-generated bed forms, and has a higher frequency of fine-grained sediments than the lower sequence.

The textures, vertical successions of facies, and sedimentary structures suggest variable energy conditions that produced a range of features: (1) suspension fallout features (mudstone/shales; laminated and rippled mudstone); (2) low-flow regime features (climbing ripples; straight-crested current ripples; ripples at top of planar crossbedded sets); (3) transitional-flow regime features (undulatory small-current ripples; trough cross-stratification); and (4) relatively high-flow regime features (linguoid current rippes; horizontal, parallel, continuous laminations; hummocky cross-stratification). Episodic rapid depositional events (e.g., storms) are indicated by sharp-based hummocks, syndepositionally deformed beds, laminated sandstone lenses in mud-rich intervals, and starved ripples. Wave-generated/influenced bed forms consist dominantly of symmetrical and asymmetrical wave ripples, hummocky cross-stratification, opposed ripple foreset directions within a single ripple horizon, and laminations out-of-phase with ripple forms.

All of the vertical stratigraphic trends of the successions, considered together, suggest that the upper pad of the Atoka Formation, at least at this stratigraphic level and geographic setting, is part of a thick, fining-upward transgressive shale sequence that contains thin, coarsening-upward regressive sandstone sequences deposited on a storm-influenced, mud-dominated shelf.

An understanding of these stratigraphic relations in the upper part of the Atoka Formation is of value in predicting the occurrence and quality of reservoirs in little explored areas of the Arkoma Basin.

Reprinted as published in the Geological Society of America *1996 Abstracts with Programs*, v. 28, no. 1, p. 8.

Depositional Systems Evolution of the Atokan Spiro Sandstone, Arkoma Basin, of Eastern Oklahoma

ARTHUR W. CLEAVES, FORREST B. HESS, and *MEMET KONT*, School of Geology, Oklahoma State University, Stillwater, OK 74078

The basal Atokan Spiro Sandstone Interval of Eastern Oklahoma was deposited in fluvial, deltaic, estuarine, and shallow marine depositional environments associated with an Atlantic-type trailing margin. Facies succession within the Spiro documents a single complete glacio-eustatic cycle that began and ended with highstand sea level conditions. This interval is disconformably underlain by shelf carbonates of the Wapanucka distally steepened ramp system and is overlain by deep water early Atokan submarine fans that accumulated beyond the newly collapsed shelf margin.

Spiro Interval sedimentation began with highstand accumulation of marine prodelta shale, probably sourced from a deltaic depocenter near Ft. Smith. Rapid marine regression gave rise to fluvial incision of this "pre-Spiro" shale unit and supplied coarse-grained terrigenous clastic sediment to lowstand wave-dominated deltaic systems perched on the outer margin of the ramp. The subsequent staggered marine transgression reworked the upper part of the deltaic sand bodies parallel to strike and brought about alluviation within the incised valleys (Foster Channels). Inasmuch as the northerly source area was still providing sediment during the sea level rise, temporary stillstands allowed for the "spillout" of local bayhead deltas along the trend of the channels. Complete inundation and wave reworking of these estuarine deltas generated the fossiliferous sheet sandstone facies present at the top of the Spiro Interval.

Reprinted as published in the Geological Society of America *1996 Abstracts with Programs*, v. 28, no. 1, p. 8.

Frontier Exploration Basin Modeling Technology Tested in the Mature Arkoma Basin, Oklahoma, USA

INDU D. MESHRI, Amoco Production Research, Tulsa, OK; *S. S. FOLAND*, Amoco Production Co., Denver, CO; *S. L. BOLTON*, Kansas Geological Survey, Lawrence, KS; and *J. M. WALKER*, Amoco Business Services, Tulsa, OK

Integrated Basin Chemical Modeling (IBCM) was developed as a predictive tool for frontier exploration and to date has been used in numerous basins worldwide. Amoco has utilized data from the mature Arkoma basin of eastern Oklahoma to verify the accuracy of this proprietary technique. The Arkoma basin was chosen as a test case due its complex tectonic history and the amount of subsurface data available.

Several dip and strike depth-converted seismic lines were used to model timing of critical events: Spiro deposition, thrusting, maximum paleotemperature, generation

and expulsion of hydrocarbons, genesis of pressure compartments and evolution of pressure seals within the basin.

Preliminary IBCM simulations of basin thermal history indicate that the time of maximum temperature occurred at 280 mya, post-dating thrusting of the Ouachitas. Therefore, it is not neccessary to palinspastically restore the traps within the thrusted terrain prior to identifying migration pathways. At the time of thrusting, 301 mya, the modeled pressures in the Atokan shales reached 7500 psi (500 atm) above normal hydrostatic pressures, creating effective pressure seals for the Pennsylvanian Spiro and Wapanucka reservoirs. Complex hydrologic flow thus became concentrated within these reservoir sections. The model also indicates that critical flow directions reversed several times during basin evolution.

Additional work is underway to confirm paleogeothermal gradients estimated from apatite fission track analysis and to define potential subtle traps using the diagenetic module of IBCM.

Reprinted as published in the American Association of Petroleum Geologists *Bulletin*, v. 79, p. 1405, September 1995.

Prediction and Analysis of Gas Composition in the Arkoma Basin

MAMOUD TABIBIAN, Occidental Petroleum, Bakersfield, CA; and
COLIN BARKER, Dept. of Geosciences, University of Tulsa, Tulsa, OK

The Arkoma Basin is an overmature, gas-dominated basin that straddles the Arkansas-Oklahoma border. It developed from an initial rifting phase, with subsequent continental collision and Ouachita thrusting on the southern margin. Burial histories were developed for locations in the Wilburton, Red Oak, and Bonanza Fields based on published well data. These were combined with thermal histories and used to calculate present day vitrinite reflectance values (R_o). The models were adjusted until calculated and observed R_o values agreed. With this information for the temperature at any time during basin evolution a thermodynamics program was used to calculate gas composition. This free energy-minimization program takes fluid composition, rock mineralogy (up to 25 phases), pressure, and temperature as input, and calculates the gas composition for the thermodynamically stable assemblage. The predicted gas composition for the Arbuckle Formation at Wilburton was dominantly methane, while at Bonanza (where temperatures have been higher) it was mainly carbon dioxide. Actual gas compositions were obtained by analyzing gas trapped in fluid inclusions in fracture-filling calcite cements in the Arbuckle. This was done using a pair of computer-controlled, high-speed mass spectrometers that analyzed the gas burst released as each individual inclusion was ruptured by heating in vacuum. Gas analysis takes 25 msec and up to several hundred inclusions can be analyzed using a 10 mg sample. Calcites from the Arbuckle dolomites at Wilburton were dominated by methane, while those from Bonanza contained mainly carbon dioxide. This study confirmed by analysis the gas compositions predicted by thermodynamic calculations.

Reprinted as published in the American Association of Petroleum Geologists *Bulletin*, v. 79, p. 1408, September 1995.

Geometry of Late Paleozoic Thrusting in the Wilburton-Hartshorne Area, Arkoma Basin, SE Oklahoma

ATA SAGNAK, *IBRAHIM CEMEN*, and *ZUHAIR AL-SHAIEB*, School of Geology, Oklahoma State University, Stillwater, OK 74078

The Arkoma Basin, located in southeastern Oklahoma and western Arkansas, has long been recognized as a foreland basin of Ouachita fold and thrust belt. This study mainly deals with the Late Paleozoic thrust system in the southwestern part of the Arkoma Basin in the Wilburton-Hartshorne area which contains the Wilburton gas field, producing from the overthrusted Pennsylvanian (Atokan) Spiro Sandstone as well as the Late Cambrian–Early Ordovician Arbuckle Group. Eight structural cross-sections are constructed to determine the geometry of the thrust system which is responsible for the overpressured gas reservoirs in the area. The cross-sections are based on the updated surface geological maps of the Oklahoma Geological Survey, wire-line well log data, and our interpretations of seismic profiles donated by Exxon. The structural cross-sections are restored by using the "key-bed" restoration method in order to find the percentage of shortening that was experienced in the area due to thrusting. The restored cross-sections suggest about 60% of shortening and are also used to determine the southern extend of the chamosite facies in the Spiro Sandstone.

The cross-sections suggest two different structural geometry on the hanging wall (upper) block and the footwall (lower) block of the Choctaw fault. The hanging wall block contains many south dipping imbricate thrusts which are mostly exposed at the surface. The Spiro Sandstone in the hanging wall block is displaced greatly by these faults. The footwall block shows well developed duplex structures. The duplexes are formed by several hinterland dipping imbricate thrust faults splaying from a main detachment surface, usually referred to as Springer Detachment. They join to a roof thrust in the Atoka Formation. The roof thrust is named as the Lower Atokan Detachment which continues in the Atoka Formation and displaces the Red Oak Sandstone before reaching a shallower depth and forming the Carbon fault as a north dipping backthrust in the northern part of the study area. The structure formed by the roof thrust and the back thrust defines a triangle zone similar to the ones well documented in the Alberta Foothills of the Canadian Rockies.

Reprinted as published in the Geological Society of America *1996 Abstracts with Programs*, v. 28, no. 1, p. 62.

Geometry of Thrusting in the Wilburton Gas Field and Surrounding Areas, Arkoma Basin, Oklahoma: Implications for Gas Exploration in the Spiro Sandstone Reservoirs

IBRAHIM CEMEN, ZUHAIR AL-SHAIEB, FORREST HESS, SALEEM AKTHAR, and *RODNEY FELLER*, School of Geology, Oklahoma State University, Stillwater, OK 74078

The Arkoma basin is an arcuate structural feature located in southern Oklahoma and western Arkansas. It is recognized as a foreland basin of the Ouachita fold and thrust belt and is one of the most prolific gas producing basins in North America. The Choctaw fault is the leading-edge thrust of the Ouachita frontal belt. Several south-dipping leading imbricate fan thrust faults are present in the hanging wall block of the Choctaw.

The Wilburton gas field is located in the central part of the basin and produces mostly from the Pennsylvanian (Atokan) Spiro Sandstone. We have constructed many balanced structural cross sections in the Wilburton gas field and adjacent areas to determine the detailed geometry and structural history of the thrusting. The cross sections are perpendicular to the tectonic transport direction and are based on updated surface geology by the Oklahoma Geological Survey, wire-line well log data, and our interpretation of several seismic profiles donated by the Exxon Oil Company. The restored cross sections suggest about 40% shortening in the Wilburton gas field area. There is a good correlation between the presence of Chamosite clay and the porosity and permeability in the Spiro Sandstone. The original distribution of the Chamosite bearing facies in the Spiro sandstone was plotted on the cross sections to determine the extent of potential reservoir rock.

In the Wilburton area, the cross sections suggest a shallow triangle zone floored by the Lower Atokan detachment and flanked by the south-dipping Choctaw thrust to the south and north-dipping Carbon fault to the north. The foot wall of the Choctaw contains duplexes that are located between Springer detachment (the lower detachment) and the Lower Atokan Detachment (the upper detachment). These duplexes contain overpressured Spiro sandstone gas reservoirs. There is a rough correlation between the pressure data in the Spiro reservoirs and the duplex structures. The highest pressure-depth gradients are found in the Spiro reservoirs that were brought to structurally higher positions by the thrust faults in the duplex structures. Structurally lower reservoirs exhibit lower pressure-depth gradients. Therefore, we suggest that the thrusting in the duplex structures may have formed seals that isolated the Spiro Sandstone gas reservoirs.

Reprinted as published in the American Association of Petroleum Geologists *Bulletin*, v. 79, p. 1401, September 1995.

The Importance of Applying "Intuition Factors" to Reservoir Volume Calculations: A Case Study in Wilburton Field, Arkoma Basin, Southeastern Oklahoma

LAURA L. WRAY, Amoco Production Company, Denver, CO

Calculating or extrapolating accurate reservoir parameters for recoverable reserve determinations is often difficult. Average porosities determined from logs can be incorrect due either to tool resolution in thin beds, wellbore rugosity, or faulty tool calibration. Water saturation estimates can vary depending upon the availability of measured or calculated Rw values. Reservoir thickness and aerial extent are only as accurate as the isopach maps from which they are derived. Measured reservoir pressures can be low in tight gas formations due to inadequate buildup times. Only formation temperature and abandonment pressure are more reliable numbers.

Characterization of the Spiro Sandstone reservoir in Wilburton Field, southeastern Oklahoma, requires the utilization of various "intuition factors." Extreme heterogeneity resulting from both depositional and diagenetic variability presents problems in accurately assessing pore volume calculations. By relying upon a systematic approach which allows scientific intuition to be merged with measured reservoir parameters, it is possible to predict economic and uneconomic results of proposed infill drilling locations.

Reprinted as published in the American Association of Petroleum Geologists *1996 Annual Convention Official Program*, v. 5, p. A153–A154.

Genetic Stratigraphy and Reservoir Characterization of the Spiro Sandstone, Red Oak Field, Arkoma Basin, Southeastern Oklahoma

BRIAN W. HORN, Colorado School of Mines, Dept. of Geology and Geological Engineering, Golden, CO

The Lower Atokan Spiro sandstone is a mixed carbonate-siliciclastic reservoir that produces hydrocarbons from three discrete stratigraphic intervals at the Red Oak Field. Reservoir-quality sandstones develop in the seaward stepping sub-Spiro sequence (highstand system tract), landward stepping Foster "channel," and upper Spiro depositional sequences (transgressive and highstand system tract). The sub-Spiro and Foster "channel" sequences are separated by regional unconformity interpreted as a sequence boundary. Regressive marine shoreface cycles, genetically related to the sub-Spiro shale, comprise the lowermost producing interval. Fluvial/estuarine valley-fill (Foster channel) sandstones progressively onlap the sequence boundary overlying the regressive shoreface cycles and juxtapose reservoir-quality sandstones of different sequences, creating a complex reservoir architecture. Upper Spiro reservoir sandstones are developed within marine shoreface cycles that are deposited in a landward-stepping succession (highstand systems tract) following the drowning of incised paleovalleys. These aggradational/retrogradational successions downlap onto the valley-fill and sub-Spiro sequences representing the final stages of Spiro deposition prior to the high stand of sea level during Middle Atokan time.

Regional stratigraphic correlations demonstrate progressive basinward truncation of the sub-Spiro regressive shoreface cycles by an erosional surface, creating a network of incised paleovalleys across the Pennsylvanian shelf. Based on core, well log, and outcrop interpretations, the magnitude of the facies offset across this sequence boundary indicates that a significant volume of reservoir-quality sediment has been partitioned basinward of the current producing areas. High-resolution correlations reveal that reservoir compartments are created by stratigraphic discontinuities resulting from the incisement of the sub-Spiro shoreface and deposition of the overlying Foster channel reservoir facies. This stratigraphic architecture explains reservoir geometry, compartmentalization, and reservoir heterogeneity of the Spiro sandstone at Red Oak Field. Further development of this regional correlation and detailed stratigraphic analysis will result in both a better understanding of other Spiro sandstone reservoirs and the identification potential Spiro reservoirs in untested geographic locations.

Reprinted as published in the American Association of Petroleum Geologists *1996 Annual Convention Official Program*, v. 5, p. A67.

Exploitation Strategies and Their Economic Applications in the Giant Red Oak Gas Field, Oklahoma, USA

JILL SCHLAEFER, JORDAN SMYTH, and *ANTONIO VIZURRAGA,*
Amoco Corp., Mid Continent Business Unit, Denver, CO

Red Oak field is a giant gas field located in the Arkoma basin of eastern Oklahoma, USA, with recoverable reserves of 73.6 BCM (2.6 TCF). Maximizing economic return from this field requires forward-looking strategic planning and continuous reassessment of economic and operational impacts.

Post-project economic and technical analyses confirm that this strategy for maturing fields effectively reduces technical and economic risk associated with infill drilling and field development. Accuracy of cost, reserve and financial performance predictions provided concrete measurement and feedback for continuous improvement of Amoco's Red Oak field strategy.

A strategy was formulated to maximize fieldwide productivity and define an economically prudent field development plan. Engineering field data and performance forecasts were integrated into the reservoir characterization model. This geotechnical model created the basis for the successful application for U.S. Federal Tight Gas Sandstone Designation in 1992 reducing net taxation on produced gas from low permeability (<0.1 md) reservoirs and resulting in substantial tax credit savings.

The multidisciplinary Red Oak team also targeted operational cost reduction. Integrated teams using process re-engineering eliminated or redesigned many costly steps. Strategic planning and post-drilling appraisals provided focus which allowed predictive scheduling of materials, optimization of compression and facilities capacity to trim costs 15% and boost production 0.5 MMCMd (20 MMcfd). The planning and forward-looking appraisals provide flexibility for uncertain future economic scenarios.

The multidisciplinary strategy proved robust enough to fund a 47 km^2 (18 mi^2) 3D seismic program to provide a detailed structural framework in which reservoir targeting could be accomplished with minimal economic risk.

Reprinted as published in the American Association of Petroleum Geologists *Bulletin*, v. 79, p. 1246, August 1995.

Exploitation Utilizing 3D Seismic in the Red Oak Gas Field of the Arkoma Basin, Oklahoma, USA

PATRICK RUTTY, JILL SCHLAEFER, and *ANTONIO VIZURRAGA*,
Amoco Corp., Mid Continent Business Unit, Denver, CO

Red Oak field, located in the Arkoma basin of eastern Oklahoma, produces 200 Mmcfd of gas under pressure depletion drive with 2.6 TCF of gas recoverable. Structurally, the field occupied a position along the northern flank of the southward collapsing shear-margin formed during the Ouachita Orogeny. The basin flank is characterized by rapid subsidence and deposition of over 20,000 feet (6,000 m) of shallow to deep marine shale and stacked sandstone in Atokan time (mid–late Carboniferous). This sequence culminates with a shoaling upward cycle and is structurally deformed by earliest Desmoinesian thrusting (280–265 Mya).

Interpretation from a 18 mi^2 (47 km^2) 3D seismic survey was integrated with available well control and lithofacies mapping defining detailed structural irregularities and providing new drill sites while reducing economic risk. Resolution of data from the 3D seismic survey varied greatly. The one failed aspect of the original 3D survey design was to precisely map Red Oak sandstone. However, the survey was robust enough to provide excellent shallow and deep data, leading to identification of additional reservoir targets and multiple drilling proposals.

Reprinted as published in the American Association of Petroleum Geologists *Bulletin*, v. 79, p. 1406–1407, September 1995.

Integrated Basin Chemical Modelling Redefines the Geothermal Evolution of the Arkoma Basin, Oklahoma, USA

SARA S. FOLAND, Amoco Corp., Denver, CO; *I. D. MESHRI, S. L. BOLTON*, and
J. M. WALKER, Amoco Production Research, Tulsa, OK; and *K. A. HEGARTY*,
Geotrack International Pty. Ltd., Melbourne, Australia

Amoco utilized a variety of exploration technologies to become the economic success leader (EPs >65%) in the thrusted Pennsylvanian Spiro sandstone play of the Arkoma basin, Oklahoma. It was found early in exploitation analysis that conventional thermal-history methodologies gave conflicting results about the overall geothermal evolution of the basin. Within the thrusted terrain, vitrinite reflectance and bottom-hole temperature data give abnormally low paleo-temperatures. Apatite fission track analysis was unusable for subsurface samples due to extremely high paleo-temperatures (>110°C at 450 m until 50 Mya).

Integrated Basin Chemical Modelling (IBCM) was used to determine timing of critical events (thrusting, timing of maximum paleo-temperature, generation, expulsion and diagenetic evolution). Preliminary modelling results indicate that maximum temperature post-dates thrusting of the Ouachitas—eliminating the necessity to palinspastically restore individual thrust sheets to determine spatial relationships of traps to migration pathways. Complex hydrologic flow is concentrated within the porous Spiro reservoir section and along thrust planes. IBCM modelling indicates the critical flow direction reverses several times during basin evolution.

The Arkoma basin is divided into two distinct thermal provinces, each experiencing a separate, complex thermal history. Fission track analysis of surface samples indicates two periods of regional cooling—Late Paleozoic and Late Cretaceous to Early Tertiary. Timing of these cooling events correlates to flow reversals indicated from IBCM modelling. Hydrologic flow reversals indicate multiple periods of migration/charge and the possibility of subtle stratigraphic traps formed from diagenetic changes within the prospective reservoir intervals.

Reprinted as published in the American Association of Petroleum Geologists *Bulletin*, v. 79, p. 1212, August 1995.

Effects of Depositional and Authigenic Clays on Porosity Development, White Oak Field, Arkoma Basin

DIANNE C. PHILLIPS, Dept. of Geology, University of Arkansas,
Fayetteville, AR 72701

Depositional and diagenetic processes have produced allogenic, infiltrated, and authigenic clay features that have contributed to the preservation of primary porosity in the early Pennsylvanian Sells Sandstone of the Arkoma Basin.

A core through a distributary mouth bar facies of the Sells contains well sorted, fine to medium grained sublitharenites and quartzarenites. Two clay rich zones within the medium grained quartzarenite act as permeability barriers and have contributed to the preservation of porosity within these zones. Clays within these zones are predominantly illite/mixed layer clays and authigenic chlorite (mostly chamosite). Allogenic features are present as inherited clay rinds or as soil cutans. Thin clay rinds oriented parallel to the surface of quartz grains are indicative of inherited clay features. Soil cutans are preferentially oriented parallel (concentric in appearance) to the surfaces of sedimentary grains. Cutans are generally indicative of well developed "B" soil horizons. Infiltrated clay features include disseminated intergranular clay matrix as well as clay coats and bridges between individual grains. Authigenic chlorite is present as radial crystals oriented tangential to grain surfaces and nucleating from grain coats, rinds, and cutans oriented parallel to the grain surfaces. Porosity in these clay rich zones is essentially absent and is in sharp contrast to intervals where porosity ranges from 10 to 15 percent. Clay rich zones reflect alternating sand and clay deposition within the Sells point bar. Shortly after deposition and during very early diagenesis, clay and sand layers were open to diffusive and advective exchanges. Clay minerals were readily translocated to grain surfaces and intergranular areas. Futher burial, compaction, and dissolution of framework grains served to further reduce porosity in the clay rich zones and produce partitions to fluid migration into the zones free of substantial clay matrix. Primary porosity was preserved in the clay free zones between clay barriers.

Reprinted as published in the American Association of Petroleum Geologists *Bulletin*, v. 79, p. 1405–1406, September 1995.

Stromatolites

(continued from p. 178)

long]) suggests deposition in relatively calm, shallow marine water. Close lateral linkage of hemispheroidal stromatolites is typical in modern environmental settings in protected intertidal mud flats, where wave action is slight (Blatt and others, 1980, p. 473).

A 1- to 3-in.-thick, grayish-black, sandy, silty, highly carbonaceous shale directly underlies the carbonate unit (indicated by arrow, lower right, inset photograph A). Below this shale is a strongly rippled, very fine grained, thin- to medium-bedded, parallel-bedded, light gray sandstone (inset photograph B). The sandstone has trace fossils on the ripples, contains macerated plant fragments, and includes several Stigmarian root systems. One such root system is indicated by the arrow on inset photograph B.

Outcrops such as this one are critical for interpreting depositional environments within the Savanna Formation in the Arkoma basin. The author recently discovered a second exposure of the same stromatolite horizon discussed here ~2 mi away in a road cut along State Highway 31 northeast of the city of McAlester. It has not been studied yet. Another stromatolite horizon was discovered by the author ~30 mi to the east in a different stratigraphic position within the Savanna Formation (see Figure 8 in "Savanna Formation—Basin-to-Shelf Transition," this issue, p. 189).

Reference Cited

Blatt, Harvey; Middleton, Gerard; and Murray, Raymond, 1980, Origin of sedimentary rocks: Prentice-Hall, Inc., Englewood Cliffs, New Jersey, 782 p.

LeRoy A. Hemish