OF 3-95

Stratigraphy and Sedimentation of Some Selected Pennsylvanian (Atokan–Desmoinesian) Strata in the Southeastern Part of the Arkoma Basin, Oklahoma

Guidebook for the Spring (1995) Field Excursion

Midcontinent Pennsylvanian Stratigraphic Working Group (Midcontinent SEPM)

LeRoy A. Hemish   Neil H. Suneson   James R. Chaplin

Oklahoma Geological Survey

Open-File Report

May 1995

Prepared as an unedited handout for the Midcontinent Pennsylvanian Stratigraphic Working Group Field Conference held in southeastern Oklahoma, May 20–21, 1995.

Oklahoma Geological Survey
100 E. Boyd, Room N-131
Norman, Oklahoma 73019

Itinerary for Midcontinent Pennsylvanian Stratigraphic Working Group Field Conference Southeastern Oklahoma (Arkoma Basin) May 20–21, 1995

Hosted by Oklahoma Geological Survey

The field trip will start in McAlester, Oklahoma, at 8:00 a.m., Saturday, May 20. Meeting place is in the parking lot of the Holiday Lodge, 615 S. George Nigh Expressway. Travel in caravan by personal vehicles.

Day 1

Stop 1—(Optional). Fossil-bearing shales in the Savanna Formation, exposed in a cut bank of a tributary of Miller Creek, NW¼ sec. 27, T. 5 N., R. 15 E., Pittsburg County, Oklahoma (Krebs 7.5' Quadrangle Map).

Stop 2—Fossil-bearing shales in the Savanna Formation, exposed in a cut bank on east side of small creek, NE¼ sec. 33, T. 5 N., R. 16 E., Pittsburg County, Oklahoma (Hartshorne 7.5' Quadrangle Map).

Stop 3—Calcareous sandstone in uppermost part of Atoka Formation, exposed along a small tributary of Blue Creek, SW¼ sec. 11, T. 4 N., R. 16 E., Pittsburg County, Oklahoma (Hartshorne 7.5' Quadrangle Map).

Stop 4—Calcareous sandstone in McAlester Formation, exceptionally well exposed on south side of small creek, SE¼ sec. 10, T. 4 N., R. 16 E., Pittsburg County, Oklahoma (Hartshorne 7.5' Quadrangle Map).

Stop 5—Road cut exposure of a black shale unit containing phosphatic nodules and marine fossils; creek-bank exposure of a 13 in. coal bed in a nearby stream—both in the middle part of the McCurtain Shale Member of the McAlester Formation (Desmoinesian), NW¼ sec. 30, T. 5 N., R. 17 E., Pittsburg County, Oklahoma (Adamson 7.5' Quadrangle Map).

Stop 6—Newly-described principal reference section (neostratotype) for the Savanna Formation, along a section-line road just northwest of the town of Adamson (parts of sec. 1, T. 5 N., R. 16 E.; sec. 6, T. 5 N., R. 17 E.; sec. 31, T. 6 N., R. 17 E.; and sec. 36, T. 6 N., R. 16 E., Pittsburg County, OK. [Adamson 7.5' Quadrangle Map]). Focus of the stop is a fossil-bearing, sandy limestone bed just above the lowermost sandstone unit of the Savanna Formation. Examination of a trace-fossil-rich unit just below the uppermost sandstone unit of the Savanna is optional.

Stop 7—Spillway exposure at northeast end of small lake, Adamson area, Pittsburg County, OK (Adamson 7.5' Quadrangle Map). Rippled, thin-bedded sandstones with plant fossils, and exposure of stromatolites in the middle part of the Savanna Formation (Desmoinesian).

Stop 8—(Optional). Calcareous turbidite sandstone in Atoka Formation south of Choctaw fault, on tributary of Buffalo Creek, NE¼ sec. 2, T. 3 N., R. 17 E., Latimer County, Oklahoma (Higgins 7.5' Quadrangle Map). Possibly uppermost Atokan (or Desmoinesian). Conodonts have been recovered from this unit.

Day 2

Leave A–OK Motel in Wilburton at 7:30 a.m., Sunday, May 21.

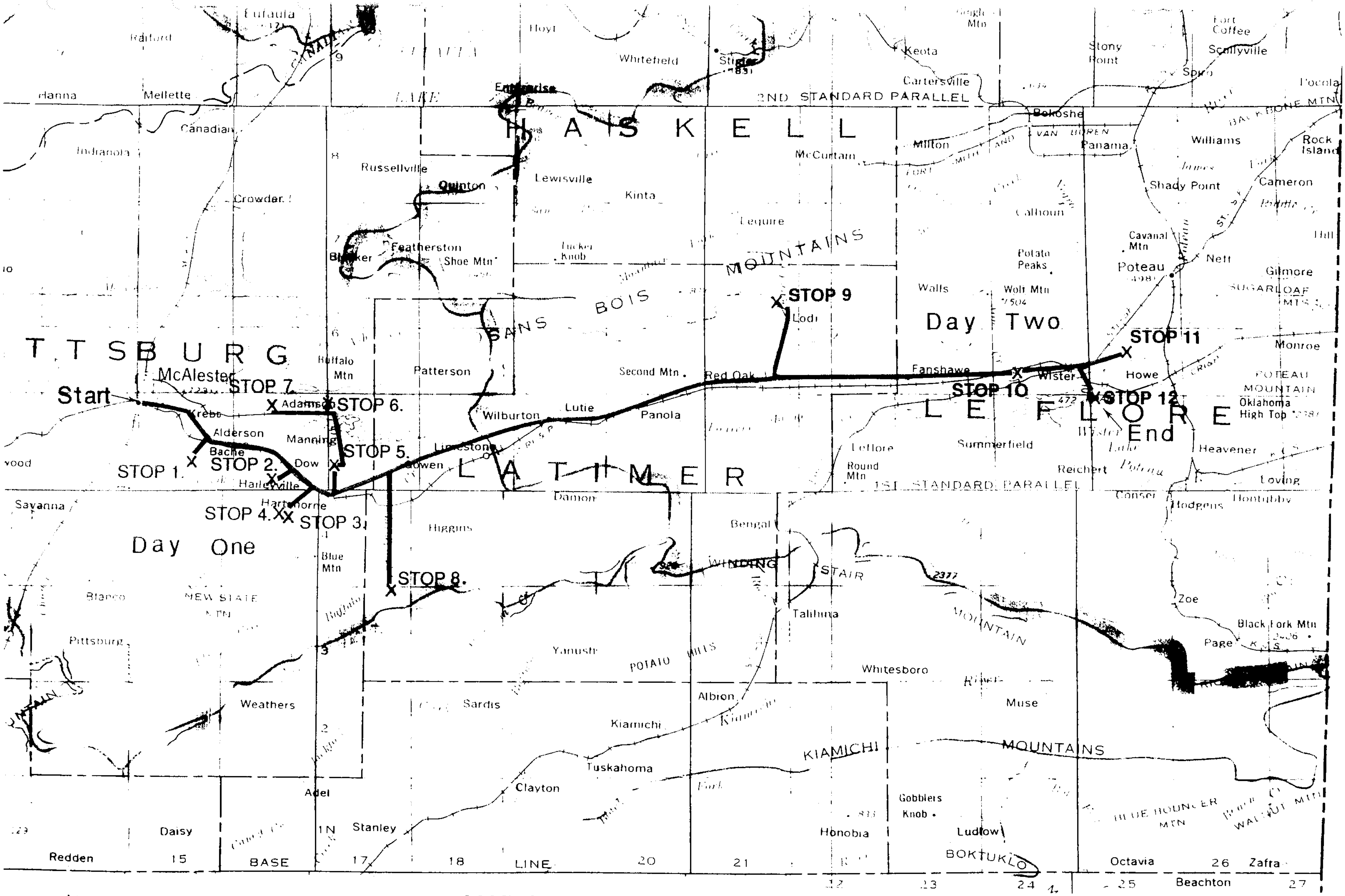
Stop 9—Reference section for the Savanna Formation (Lodi Section), measured mostly along a gas well road and to the top of Ryan Peak. Section includes lower part of McAlester Formation, entire Savanna Formation (excellent exposures of shale and sandstones in eroded ditches and gullies—including a stromatolite horizon and an 8-ft-thick black shale), as well as entire Bluejacket Member of Boggy Formation. NW¼ sec. 1, T. 6 N., R. 21 E., NE¼ sec. 2, T. 6 N., R. 21 E., and S½ of sec. 35, T. 7 N., R. 21 E., Latimer County, Oklahoma (Lequire 7.5' Quadrangle Map).

Stop 10—Sam Creek (?) Limestone Member of the Savanna Formation, NW¼ sec. 28, T. 6 N., R. 24 E., Le Flore County, Oklahoma (Summerfield 7.5' Quadrangle Map). (See Fig. 1, and Measured Section 3, Appendix, p. 107, Oklahoma Geology Notes, v. 53, no. 3, June, 1993. [Included in pocket]).

Stop 11—Spaniard (?) Limestone Member of the Savanna Formation, NE¼ sec. 21, T. 6 N., R. 25 E., Le Flore County, Oklahoma (Wister 7.5' Quadrangle Map). (See Fig. 1, and Measured Section 6, Appendix, p. 109, Oklahoma Geology Notes, v. 53, no. 3, June, 1993. [Included in pocket]).

Stop 12—Eroded Wister Lake Spillway, SW¼ sec. 6, T. 5 N., R. 25 E., Le Flore County, Oklahoma (Wister 7.5' Quadrangle Map). Outstanding exposures of the upper part of the Atoka Formation. Focus is on the diversity of sedimentary structures and fossiliferous horizons. For detailed sedimentology of spillway exposures, see Stop 3 (James R. Chaplin, OGS Guidebook 29, p. 14–38) included herein.

The field conference will end at the Wister Lake Spillway (about 10 miles southwest of Poteau, Oklahoma). Participants can depart at any time according to their personal scheduled needs. Some may wish to spend several hours at this remarkable exposure, or return at some future time for further work.



MAP OF FIELD-TRIP STOPS

Scale 1 inch ~8 miles

System	Series	Super-Group	Group	Formation	Member, Bed	
PENNSYLVANIAN	Desmoinesian	Des Moines	Marmaton (Part)	Mouse Creek	Blackjack Creek Limestone *OK*	
					Excello Shale *MO*	
			Cherokee *KS*	Swede Hollow	Mulky Coal *MO*	
					Shale and Sandstone	
					Limestone	
					Bevier Coal *MO*	
					Shale and Sandstone	
					Wheeler Coal	
					Ardmore Limestone *MO*	
					Oakley Shale	
					Whitebreast Coal	
				Floris	Carruthers Coal	
					Unnamed Coal	? "Spoon" ?
					Laddsdale Coal	
	? Atokan *OK*			Kalo	Cliffland Coal	
					Blackoak Coal	
				Kilbourn	Unnamed Coals	
	? Morrowan			Caseyville *IL*		
					Wyoming Hill Coal	
					Wildcat Den Coal	

Stratigraphic Nomenclature – Iowa.

System	Series	Group	Sub-Group	Formation	Member	Coal Bed
PENNSYLVANIAN	Desmoinesian (part)	Marmaton (part)		Fort Scott Ls. (part)	Excello Shale	
						Mulky
		Cherokee		Cabaniss	Breezy Hill Ls.	
						Bevier
					Verdigris Ls.	
						Croweburg
						Fleming
						Mineral
						Scammon
					Chelsea Ss.	
					Tiawah Ls.	
						Tebo
						Weir-Pittsburg
					Seville Ls.	
				Krebs		Bluejacket (?)
					Bluejacket Ss.	
						Drywood
						Rowe
						Neutral
					Warner Ss.	
						Riverton
	Atokan	"Gray"				
	Morrowan			Kearney		

Stratigraphic Nomenclature – Kansas.

System	Series	Group	Sub-Group	Formation	Member	Coal Bed
PENNSYLVANIAN	DESMOINESIAN (part)	MARMATON (part)	FORT SCOTT (part)	EXCELLO		
		CHEROKEE	CABANISS	MULKY		Mulky
					Breezy Hill Ls.	
				LAGONDA	"Squirrel" Ss.	
						Bevier
				BEVIER		
				VERDIGRIS	Ardmore Ls.	Wheeler
					Oakley Sh.	
				CROWEBURG		Croweburg
				FLEMING		Fleming
				ROBINSON BRANCH		Robinson Branch
				MINERAL		Mineral
				SCAMMON		
					Chelsea Ss.	Scammon
					Tiawah Ls.	
				TEBO		Tebo
				WEIR		Weir-Pittsburg
			KREBS	SEVILLE		
				BLUEJACKET		
				DRYWOOD		Drywood Coal
				ROWE		Rowe Coal
				WARNER		Warner Coal
	?			HARTSHORNE		
	Atokan			CHELTENHAM		
				RIVERTON		Riverton Coal
				BURGNER		
				McCLOUTH		
	Morrowan			"Prairie Grove Equivalent"		

Stratigraphic Nomenclature – Missouri

System	Series	Group	Formation	Member	Coal/Bed
PENNSYLVANIAN	DESMOINESIAN (part)	KREBS	BOGGY (part) (70–2850')		Sandstone 4
					Sandstone 3
					Sandstone 2
					Secor Coal
				Bluejacket Ss.	
			SAVANNA (70–1500')		Sandstone 7
					Sandstone 6
					Sandstone 5
					Cavanal Coal
					Sandstone 4
					Sandstone 3
				Sam Creek (?) Ls.	
					Sandstone 2
					Sandstone 1
				Spaniard (?) Ls.	
			McALESTER (100–2830')	Keota Ss.	
				Tamaha Ss.	
					Upper McAlester Coal
					McAlester Coal
				Cameron Ss.	
				Lequire Ss.	
				Warner Ss.	
				McCurtain Sh.	Unnamed Coal
			HARTSHORNE (30–350')		U. Hartshorne C.
					L. Hartshorne C.
	? Atokan		ATOKA (50–15,000')		
	Morrowan		WAPANUCKA LS.		

Stratigraphic Nomenclature – Oklahoma

System	Series	Group	Formation	Member	Coal Bed / Unit	Litho-facies	Field Trip Stop No.
PENNSYLVANIAN	DESMOINESIAN (part)	KREBS	McALESTER	Keota Ss.			
				Tamaha Ss.			
					Upper McAlester Coal		
					McAlester Coal		
				Cameron Ss.			
				Lequire Ss.			
							4
				Warner Ss.	Upper Warner Ss.		
					Lower Warner Ss.		
				McCurtain Sh.	Unnamed Coal		5
			HARTSHORNE		Upper Hartshorne Coal		
					Lower Hartshorne Coal		3
	-?- Atokan -?-		ATOKA	UPPER	Unnamed Coals		12
				MIDDLE			
				LOWER			8
	Morrowan		WAPANUCKA Ls.				

Stratigraphic Nomenclature – Oklahoma

System	Series	Group	Formation	Member	Coal Bed / Unit	Litho-facies	Field Trip Stop No.
PENNSYLVANIAN	DESMOINESIAN (part)	KREBS	BOGGY (part)				
					Sandstone 6		
					Sandstone 5		
					Sandstone 4		
					Sandstone 3		
					Sandstone 2		
					Secor Coal		
				Bluejacket Ss.			
					L. Witteville Coal		
			SAVANNA				
					Sandstone 7		1 - 2
					Sandstone 6		
					Sandstone 5		
					Cavanal Coal		
							7
					Sandstone 4		6
							9
					Sandstone 3		
				Sam Creek (?) Ls.			10
					Sandstone 2		
				Jolly (?) Ls.			
					Sandstone 1		
				Spaniard (?) Ls.			11

Stratigraphic Nomenclature – Oklahoma (Continued)

System	Series	Super-Group	Group	Formation	Member, Bed	
PENNSYLVANIAN	Desmoinesian	Des Moines	Marmaton (Part)	Mouse Creek	Blackjack Creek Limestone *OK*	
					Excello Shale *MO*	
			Cherokee *KS*	Swede Hollow	Mulky Coal *MO*	
					Shale and Sandstone	
					Limestone	
					Bevier Coal *MO*	
					Shale and Sandstone	
					Wheeler Coal	
					Ardmore Limestone *MO*	
					Oakley Shale	
					Whitebreast Coal	
				Floris	Carruthers Coal	
					Unnamed Coal	? "Spoon" ?
	? Atokan *OK* ?				Laddsdale Coal	
				Kalo	Cliffland Coal	
					Blackoak Coal	
				Kilbourn	Unnamed Coals	
	Morrowan			Caseyville *IL*	Wyoming Hill Coal	
					Wildcat Den Coal	

Stratigraphic Nomenclature – Iowa.

System / Series	Group	Sub-Group	Formation	Member	Coal Bed
PENNSYLVANIAN Desmoinesian (part)	Marmaton (part)		Fort Scott Ls. (part)	Excello Shale	
					Mulky
	Cherokee		Cabaniss	Breezy Hill Ls.	
					Bevier
				Verdigris Ls.	
					Croweburg
					Fleming
					Mineral
					Scammon
				Chelsea Ss.	
				Tiawah Ls.	
					Tebo
					Weir-Pittsburg
				Seville Ls.	
			Krebs		Bluejacket (?)
				Bluejacket Ss.	
					Drywood
					Rowe
					Neutral
				Warner Ss.	
					Riverton
Atokan	Gray				
Morrowan			Kearney		

Stratigraphic Nomenclature – Kansas.

System / Series	Group	Sub-Group	Formation	Member	Coal Bed
PENNSYLVANIAN DESMOINESIAN (part)	MARMATON (part)	FORT SCOTT (part)	EXCELLO		
					Mulky
	CHEROKEE	CABANISS	MULKY	Breezy Hill Ls.	
			LAGONDA	"Squirrel" Ss.	
					Bevier
			BEVIER		
			VERDIGRIS	Ardmore Ls.	Wheeler
				Oakley Sh.	
			CROWEBURG		Croweburg
			FLEMING		Fleming
			ROBINSON		Robinson Branch
			BRANCH		
			MINERAL		Mineral
			SCAMMON	Chelsea Ss.	Scammon
				Tiawah Ls.	
			TEBO		Tebo
			WEIR		Weir-Pittsburg
		KREBS	SEVILLE		
			BLUEJACKET		
			DRYWOOD		Drywood Coal
			ROWE		Rowe Coal
			WARNER		Warner Coal
? Atokan			HARTSHORNE		
			CHELTENHAM		
			RIVERTON		Riverton Coal
			BURGNER		
			McCLOUTH		
Morrowan			"Prairie Grove Equivalent"		

Stratigraphic Nomenclature – Missouri

System / Series / Group	Formation	Member	Coal/Bed
PENNSYLVANIAN DESMOINESIAN (part) KREBS	BOGGY (part) (70–2850')		Sandstone 4
			Sandstone 3
			Sandstone 2
			Secor Coal
		Bluejacket Ss.	
	SAVANNA (70–1500')		Sandstone 7
			Sandstone 6
			Sandstone 5
			Cavanal Coal
			Sandstone 4
			Sandstone 3
		Sam Creek (?) Ls.	
			Sandstone 2
			Sandstone 1
		Spaniard (?) Ls.	
	McALESTER (100–2830')	Keota Ss.	
		Tamaha Ss.	
			Upper McAlester Coal
			McAlester Coal
		Cameron Ss.	
		Lequire Ss.	
		Warner Ss.	
		McCurtain Sh.	Unnamed Coal
	HARTSHORNE (30–350')		U. Hartshorne C.
			L. Hartshorne C.
? Atokan	ATOKA 50–15,000')		
Morrowan	WAPANUCKA LS.		

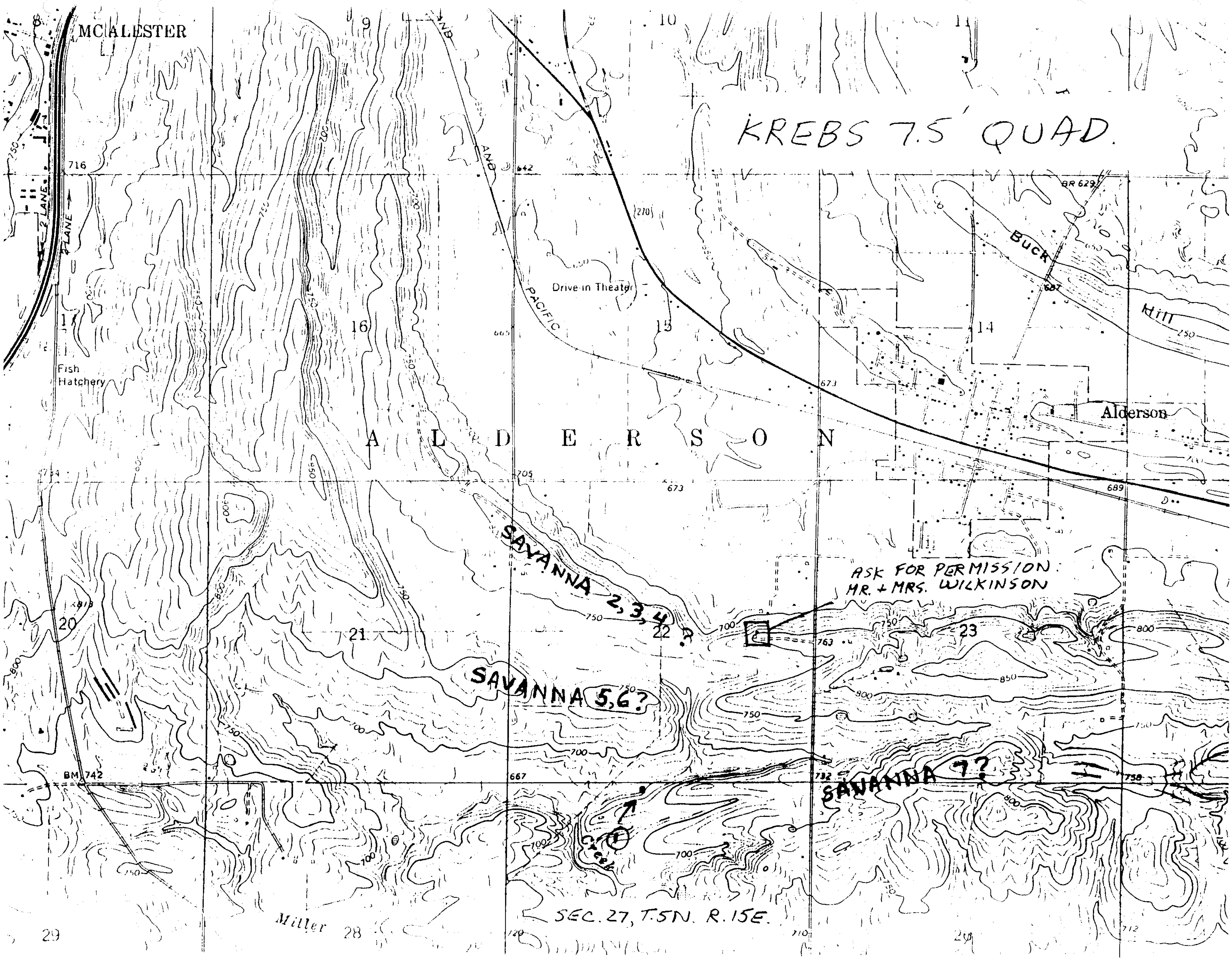
Stratigraphic Nomenclature – Oklahoma

STOP 1 (OPTIONAL). FOSSIL SHELLS IN SAVANNA FORMATION

Location: Along tributary to Miller Creek, NE/4 NE/4 NW/4 sec. 27, T5N R15E, Krebs 7.5' quadrangle, Pittsburg County, Oklahoma. Cut bank on south side of stream; about 3 feet of relatively soft (weathered?) very fine grained, stratified sandstone exposed above water level (unusually high) when visited on May 9.

Stratigraphic position: Probably between Savanna sandstones nos. 5,6 (undivided in this area) and Savanna sandstone no. 7. This area has not been mapped in detail, so the breakdown of the Savanna sandstones is uncertain. Similarly, the exact position of the fossil locality with respect to those sandstones is uncertain.

Note: For permission to visit this locality, please ask Mr. and Mrs. Wilkinson, who live at end of paved driveway near the center of the E/2 sec. 22.



KREBS 7.5' QUAD.
MCALESTER
ALDERSON
Alderson
Buck Hill
Drive-in Theater
PACIFIC
AND
Fish Hatchery
2 LANE
ASK FOR PERMISSION
MR. + MRS. WILKINSON
SAVANNA 2,3,4, ?
SAVANNA 5,6?
SAVANNA 7?
Creek
Miller
SEC. 27, T.5N. R.15E.

STOP 2. FOSSIL SHELLS IN SAVANNA FORMATION

Location: Near head of tributary to Peaceable Creek, SW/4 SE/4 NE/4 sec. 33, T5N R16E, Hartshorne 7.5' quadrangle, Pittsburg County, Oklahoma. Cut bank on east side of creek; about 8 feet of soft shale exposed.

Stratigraphic position: About 140 feet above the top of Savanna sandstones nos. 5,6 (undivided in this area) and about 100 feet below the base of Savanna sandstone no. 7.

Note: For permission to visit this locality, please ask Mr. and Mrs. Payne, who live at the end of the paved drive just west of the locality.

STOP 3. CALCAREOUS SANDSTONE IN UPPERMOST PART OF ATOKA FORMATION

Location: Just up small tributary to Blue Creek, NE/4 SW/4 SW/4 sec. 11, T4N R16E, Hartshorne 7.5' quadrangle, Pittsburg County, Oklahoma. Sandstone bed dipping 49^{o} on west side of creek.

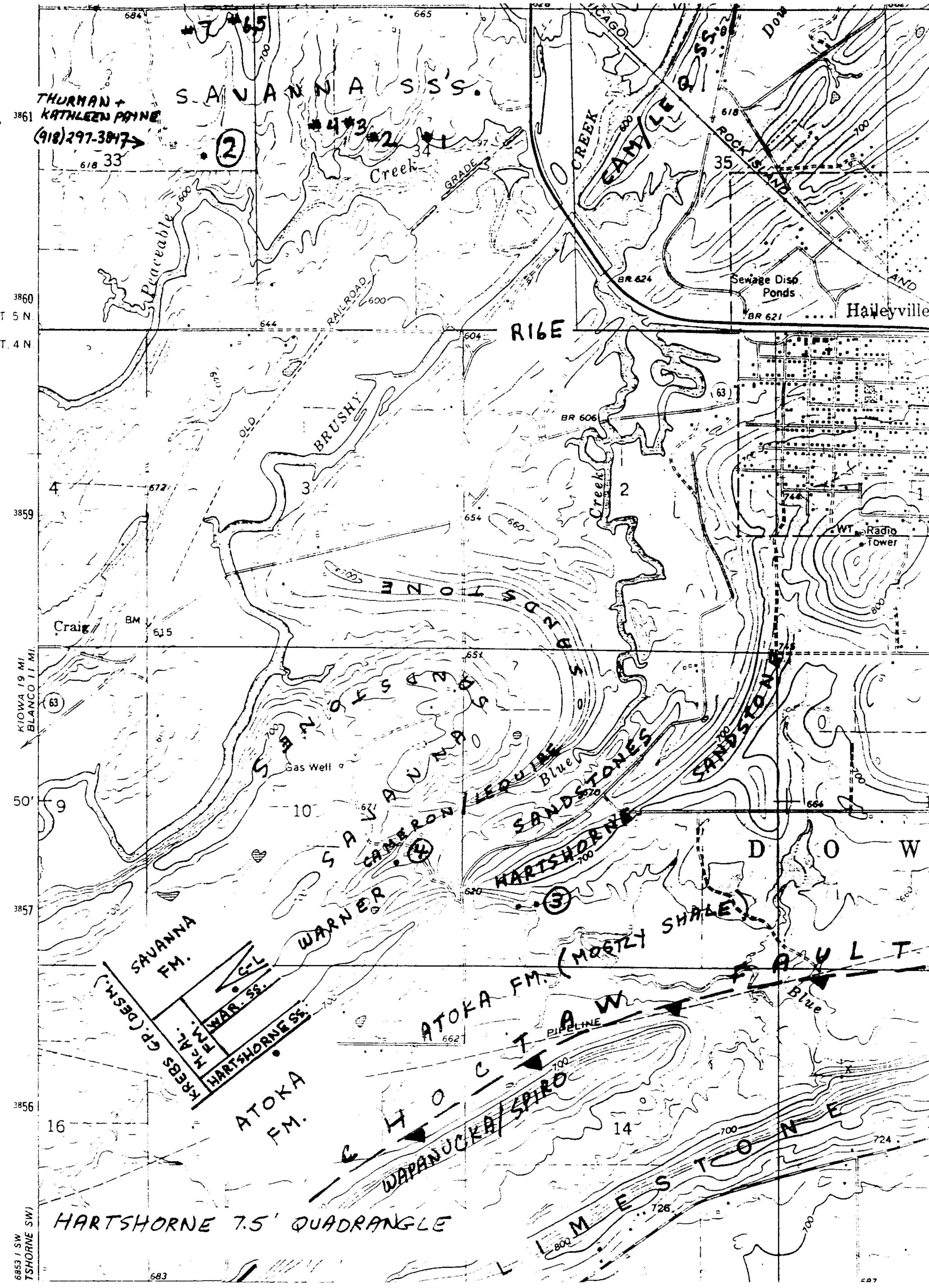
Stratigraphic position: In uppermost part of the Atoka Formation, about 450 feet below the base of the Hartshorne Formation. There are no outcrops between this and closely associated non-calcareous siliclastic sandstones and the Hartshorne near the top of the ridge to the north. The calcareous sandstone can be traced a couple hundred feet to the west.

STOP 4. CALCAREOUS SANDSTONE IN MCALESTER FORMATION

Location: On south side of small creek, SW/4 NE/4 SE/4 sec. 10, T4N R16E, Hartshorne 7.5' quadrangle, Pittsburg County, Oklahoma. Just SW of small abandoned house. The outcrop consists of a relatively thick sequence of shale, siltstone, and exceptionally well exposed thin, cross-stratified, fine-grained sandstone beds. Climbing ripples and mud drapes are common. The calcareous fine-grained sandstone is distinctly reddish in color, poorly stratified, and can be traced to the west end of the outcrop. The beds dip 81° north.

Stratigraphic position: In dominantly shale unit about 145 feet above the top of the upper Warner Sandstone and 240 feet below the base of the Cameron Sandstone, both in the McAlester Formation.

Note: The gas well immediately north of the outcrop is the Amoco 2 Smallwood. It spudded on Sept. 11, 1985, and was completed on April 3, 1986. T.D. is 11,027 feet. The producing formations are Wapanucka Limestone (perfs at 10,854-10,904 ft), Spiro sandstone (10,772-10,814 ft), and Smallwood (informal) sandstone (probably upper Atoka sandstone) (4596-4972).



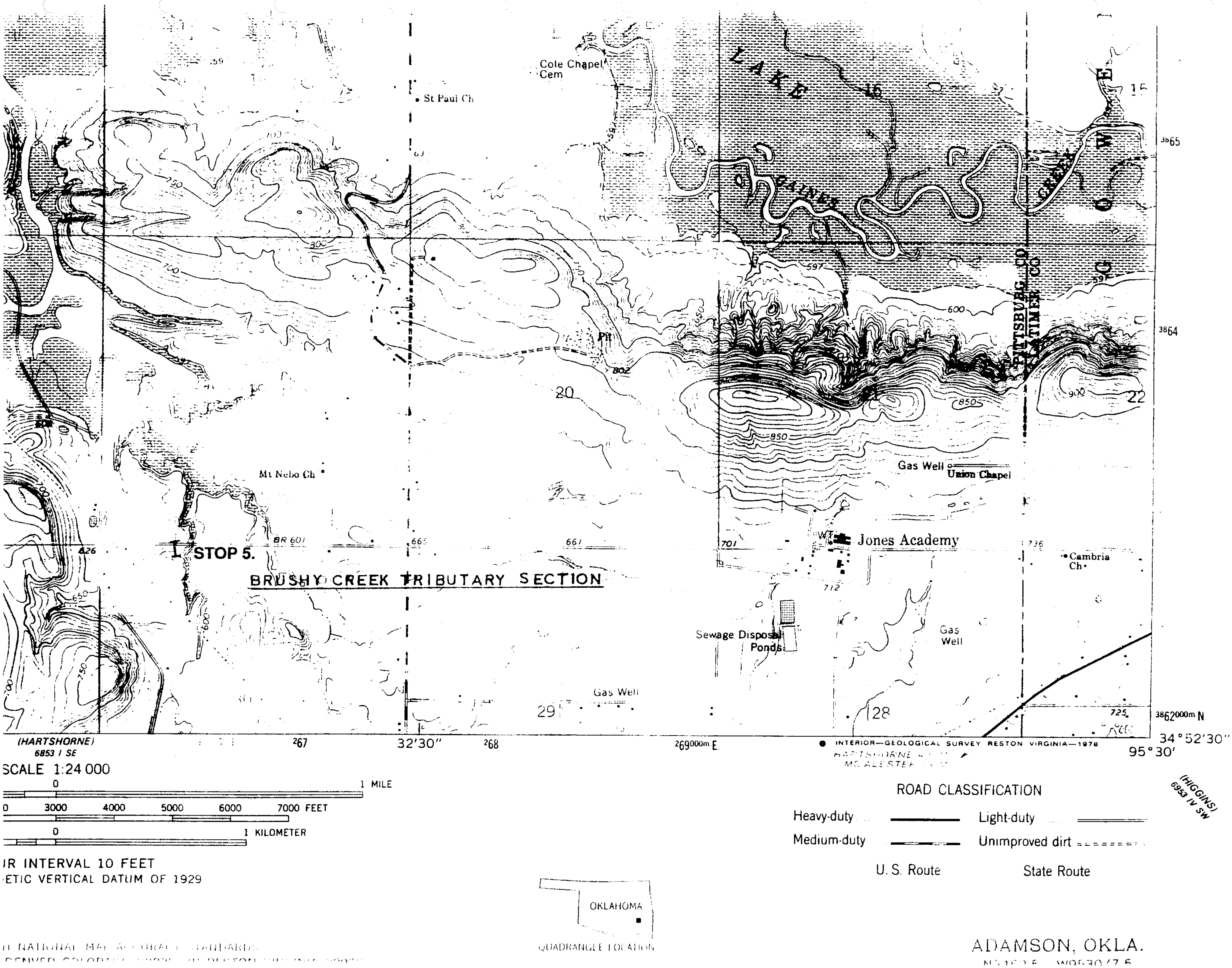
THURMAN + KATHLEEN PAYNE
(918)297-3847
SAVANNA SS'S.
CAMERON/LEQUIRE SS.
Creek
Peaceable
RAILROAD GRADE
OLD RAILROAD
ROCK ISLAND
Sewage Disp. Ponds
Haileyville
T 5 N.
T. 4 N.
R16E
BRUSHY
Creek
Craig
Gas Well
Radio Tower
SANDSTONE
SAVANNA SANDSTONES
CAMERON/LEQUIRE
WARNER
HARTSHORNE
SANDSTONES
SANDSTONE
Blue
DOW
SAVANNA FM.
C-L
WAR. SS.
MCAL. FM.
HARTSHORNE SS.
KREBS GP. (DESM.)
ATOKA FM.
ATOKA FM. (MOSTLY SHALE)
CHOCTAW FAULT
PIPELINE
WAPANUCKA/SPIRO
LIMESTONE
KIOWA 19 MI.
BLANCO 11 MI.
HARTSHORNE 7.5' QUADRANGLE

STOP 5

BRUSHY CREEK TRIBUTARY SECTION

SW¼SW¼SE¼SW¼ sec. 19, T. 5 N., R. 17 E. and NW¼NW¼NE¼NW¼ sec. 30, T. 5 N., R. 17 E., Pittsburg County, Oklahoma (Adamson 7.5′ Quadrangle map). Measured in cutbank of small stream, sec. 30, and in road cut just west of bridge in Sec. 19.

	Thickness (ft)
QUATERNARY	
Gerty Sand	
11. Gravel, moderate reddish brown (10R4/6); clasts are predominantly subrounded to subangular sandstone fragments ranging from granules to cobbles (~80%), and well-rounded, very light gray (N8) and moderate brown (5 YR4/4) chert and other forms of quartz (~15%), as well as ~5% other lithic types; matrix composed of sandy, silty clay; contact unconformable	1.5
PENNSYLVANIAN	
KREBS GROUP	
McAlester Formation	
McCurtain Shale Member:	
10. Shale, light brownish gray (5YR6/1) and light brown (5YR6/4); grayish black (N2) where unweathered; contains light brown (5Y5/6) clay-ironstone stringers; grades into underlying unit	3.5
9. Shale, grayish black (N2), flaky; contains scattered very small phosphatic nodules, clay-ironstone concretions about 3–4 in. in diameter, millimeter-thick, dark yellowish orange (10YR6/6), limonitic siltstone stringers, as well as scattered fossils (inarticulate brachiopods, gastropods, bivalves, and conodonts); cut by limonite-filled joints	5.0
8. Ironstone, grayish orange (10YR7/4), to dark gray (N3), calcareous in part, nodular bedded	0.1
7. Shale, brownish gray (5YR4/1), very fossiliferous (gastropods, brachiopods, bivalves), slightly calcareous	0.2
6. Ironstone, grayish orange (10YR7/4) to dark gray (N3), calcareous in part; appears to be laterally discontinuous	0.1
5. Shale, brownish gray (5YR4/1), very fossiliferous (gastropods, brachiopods, bivalves), slightly calcareous, base covered	0.5
4. Covered interval	16.2
3. Shale, light gray (N7), with moderate reddish brown (10R4/6) and grayish orange (10YR7/4) mottling, clayey, soft, weathered	2.5
2. Coal, black, iron oxide on cleat surfaces, weathered (unnamed coal)	1.1
1. Underclay, olive gray (5Y4/1) with pale yellowish orange (10YR8/6) mottling, plastic (to water in creek)	1.3
Total thickness of section	32.0


LAKE
EUFAULA
GAINES
CREEK
Cole Chapel Cem
St Paul Ch
Mt Nebo Ch
Pit
PITTSBURG CO
LATIMER CO
Gas Well
Union Chapel
Jones Academy
Cambria Ch
Sewage Disposal Ponds
Gas Well
STOP 5.
BRUSHY CREEK TRIBUTARY SECTION
BR 601
20
22
28
29
(HARTSHORNE)
6853 I SE
267
32'30"
268
269000m E.
3862000m N.
34°52'30"
95°30'
INTERIOR—GEOLOGICAL SURVEY RESTON VIRGINIA—1978
(HIGGINS)
6953 IV SW
SCALE 1:24 000
0
1 MILE
3000
4000
5000
6000
7000 FEET
1 KILOMETER
IR INTERVAL 10 FEET
ETIC VERTICAL DATUM OF 1929
ROAD CLASSIFICATION
Heavy-duty
Light-duty
Medium-duty
Unimproved dirt
U. S. Route
State Route
OKLAHOMA
QUADRANGLE LOCATION
ADAMSON, OKLA.

STOP 6

PRINCIPAL REFERENCE SECTION (NEOSTRATOTYPE) FOR THE SAVANNA FORMATION, PITTSBURG COUNTY, OKLAHOMA

LeRoy A. Hemish
Oklahoma Geological Survey

ABSTRACT.—A 1714.1-ft section measured and described in the south limb of the Sans Bois syncline just northwest of the town of Adamson (Adamson 7.5′ topographic quadrangle) is herein designated as the principal reference section for the Savanna Formation (Pennsylvanian). Although the Savanna Formation is a long- and well-established stratigraphic unit, a formal type section never was specified. The Adamson section has been selected as the neostratotype for the Savanna on the basis of (1) accessibility of rocks in place; (2) excellent exposures, including both the upper and lower contacts as well as exposures of lithologic units immediately above and below the contacts; (3) geographic location within the type area (central Pittsburg County); and (4) the fact that the neostratotype closely adheres to the original sense in which the Savanna Formation was defined by its nomenclator.

Introduction

The purpose of this paper is to formally present and describe a principal reference section for the Savanna Formation. A type section never was specified, nor was a type locality specifically stated. Presumably, it is in the vicinity of the town of Savanna, in central Pittsburg County (Fig. 1). Recognizing the need for a standard to serve for definition and recognition of the Savanna, I concluded that establishment of a principal reference section, in accordance with Article 8e, North American Stratigraphic Code (1983, p. 853), was in order.

As a first step in the procedure, I conducted a reconnaissance of the area around the town of Savanna to determine if an appropriate section could be measured there. Except for low ribs of sandstone protruding through extensive expanses of grassed-over, low-relief landscape, and an occasional road cut where a few feet of shale is exposed, virtually none of the Savanna Formation can be seen. Nor could I find exposures of either the lower or upper boundaries of the formation. Therefore, I shifted my focus to the north and east, to the synclinal Sans Bois Mountains where the Savanna Formation is well exposed in the flanks of the range. While working on an Oklahoma Geological Survey mapping project, I was fortunate to discover a nearly ideal area just northwest of the town of Adamson (Fig. 1) within the type area of the Savanna Formation in Pittsburg County, where both the upper and lower contacts of the Savanna are well exposed. Although some intervals (presumed to be predominantly shale) are covered in the Adamson section, it is unrealistic to expect to find a completely exposed unbroken and continuous sequence of strata in a formation ~1,450 ft thick.

The location of the neostratotype is sufficiently close to the type locality (Savanna, Oklahoma) so that this well-established name can be preserved, and stability of Oklahoma's stratigraphic nomenclature can be maintained.

Previous Investigations

The Savanna Formation (Savanna sandstone as originally defined) was named and first described by Taff (1899, p. 437–438). His original description is quoted below. Taff said:

> Next above the McAlester shale there is a series of sandstones and shales about 1,150 feet thick. The shaly beds combined are probably thicker than the sandstones, but since the sandstones are better exposed and their presence is so strongly impressed upon the observer in the prominent ridges which they make, sandstone seems the more appropriate term. There are five principal sandstone beds, which have different thicknesses, from nearly 50 to 200 feet, the one at the top and the one at the base being generally thicker than the intermediate ones. The sandstones may be distinguished only by their position in the section or their thickness of bedding. They are brown or grayish-brown, fine-grained and compact. Except in the uppermost beds, upon which the town of McAlester is built, the beds are generally thin and in part shaly. The uppermost sandstone occurs in two members, 75 to 100 feet thick, separated by variable blue clay shales. The uppermost beds of this sandstone are found in many places to be massive, and those in contact with the shale are often beautifully ripple-marked. No coal of any value has been found associated with these beds of sandstone in the McAlester district, though a thin bed has been reported to occur in the upper part of the series.

Taff and Adams (1900, p. 277–278) subsequently wrote about the Savanna Formation in the area from the east line of Pittsburg County to the Arkansas/Oklahoma line. They said that the formation "contains three prominent divisions or collections of sandstone beds ...separated by masses of shale and thin sandstone.... The shales of this formation are as a whole more sandy than shales of the formation below, though they are friable and disintegrate readily, forming valleys and level stretches of country. Estimates of the thickness of this formation vary from 1,200 feet to 1,500 feet."

Because the original description of the Savanna Formation was somewhat vague, because of the variable nature of its individual beds, and because of the lack of a precise measured section defining an upper and lower boundary, various writers included more or less than the equivalents of the original Savanna of Taff (1899). Figure 2 shows the changing concepts of the McAlester/Savanna and Savanna/Boggy boundary positions in Oklahoma through time. The neostratotype includes within the Savanna Formation the strata currently recognized by the Oklahoma Geological Survey as those comprising the formation.

In the Arkoma basin area the Savanna Formation subsequently was investigated and described by Snider (1914); Morgan (1924); Wilson (1935); Wilson and Newell (1937); Hendricks (1937, 1939); Knechtel (1937, 1949); Dane and others (1938); Oakes and Knechtel (1948); Russell (1960); Vanderpool (1960); Webb (1960); Hemish (1990a,b; 1991a,b; 1992; 1993; 1994; 1995; in preparation); Hemish and others (1990a,b,c); Hemish and Mazengarb (1992); Hemish and Suneson (1993, 1994).

Numerous stratigraphic sections have been measured by many of the early workers; however, the reader should keep in mind when referring to these sections, that reported thicknesses for the Savanna Formation are inaccurate by today's standards. Prior to 1954, changes in definitions of the upper and lower boundaries of the Savanna created the impression of a much thicker, or much thinner formation (Fig. 2). For many years the thick shale unit at the top of the Savanna Formation (as currently defined) was included in the overlying Boggy Formation. Miser (1954) established the contact between the Savanna Formation and the Boggy Formation at the base of the Bluejacket Sandstone Member of the Boggy in the course of preparation of the Geologic Map of Oklahoma. No further changes involving the thickness of the Savanna have been made since that time.

Stratigraphy

Figure 3 is an excerpt from the geologic map of the Adamson 7.5′ quadrangle (Hemish, 1995) showing the location of the neostratotype for the Savanna Formation. Bedrock units exposed in the map area (Fig. 3) include the Warner Sandstone Member of the McAlester Formation; the Cameron Sandstone Member of the McAlester Formation; the Keota Sandstone Member of the McAlester Formation; the Savanna Formation; and, on the north side of Buffalo Creek, the Bluejacket Sandstone Member of the Boggy Formation, along with some of the overlying, unnamed units in the Boggy. All of the strata are in the Krebs Group, middle Desmoinesian Series, Pennsylvanian System (see Explanation, Fig. 3).

The strata comprising the Savanna Formation have been characterized as extremely variable throughout the Arkoma basin, both lithologically and in thickness. Morgan (1924, p. 74–75) measured a section in T. 1 N., R. 7 E., and noted that "the formation consists of alternating shales and sandstones, with occasional thin, impure limestones." Its thickness is ~1,300 ft at that location. It includes near the bottom a thin limestone bed, "well exposed in the road in front of J. S. Jolly's house, 300 yards east of the northwest corner of sec. 8, T. 1 N., R. 7 E." Morgan (1924, p. 74) named the limestone the "Jolly Limestone Member" and said it occurs ~100 ft above the top of the McAlester Formation. In places it may be as much as 200 ft higher.

Writing about the McAlester district, Hendricks (1937, p. 17) said: "The Savanna sandstone is extremely variable in character throughout the district. It consists of 5 to 13 distinguishable sandstone beds separated by shale." He went on to say that "it was impossible to trace each individual sandstone bed, and for convenience in mapping several sandstones separated by thin shale beds were mapped together as sandstone groups." Hendricks (1937, p. 16) was of the opinion that "the Savanna rests unconformably on the McAlester shale" although only minor erosional contacts were observed in exposures in the McAlester district. In the McAlester area "the Savanna sandstone ranges from 1,120 to 1,325 feet in thickness in measured sections" (Hendricks, 1937, p. 19).

Dane and others (1938, p. 158) said that "the Savanna sandstone is extremely variable in character from place to place, owing to lenticularity and lack of continuity of many of the sandstone beds which it contains." At several localities in T. 7 N., R. 17 E., the northern part of T. 7 N., R. 18 E., and the southeast corner of T. 8 N., R. 18 E., Dane and others (1938, p. 159–160) reported "outcrops of thin fossiliferous limestone beds at horizons from 150 to 180 feet below the top of the Savanna sandstone." They also observed an 8-in.-thick bed of sandy limestone at several localities in secs. 9 and 10, T. 6 N., R. 17 E. at a horizon ~300 ft below the top of the Savanna.

Oakes and Knechtel (1948, p. 44) noted that the Savanna Formation "is a succession of sandstone and shale beds in which shale predominates but sandstone is most conspicuous in outcrops. It contains a minor amount of limestone in thin lenses and beds, and fossils of both marine animals and land plants are present locally." In southern Haskell County the formation is 500–1,150 ft thick, 80 ft thick in southern Muskogee County, and ~25 ft thick in the latitude of Muskogee (Oakes and Knechtel, 1948, p. 45). Although it is well known that the formations in the Krebs Group thin to the north out of the Arkoma basin, the thickness of 25 ft for the Savanna Formation at Muskogee seems erroneous. Hemish (1990a, p. 37–39, 50–51) described 82.9 ft of core from the Savanna in Mayes County (north of Muskogee), and 70.0 ft of core from the same formation in Craig County, <15 mi from the Oklahoma/Kansas line. Furthermore, in southern Haskell County, Oakes and Knechtel (1948, app., no. 5) describe strata in the Savanna Formation that total 1,390 ft, not in agreement with their statement that the formation is 500–1,150 ft thick in southern Haskell County.

Knechtel (1949, p. 27) said that the lower sandstone unit of the Savanna Formation (which marks the contact between the McAlester Formation and the Savanna Formation in the neostratotype [Appendix]) "cannot be traced farther north than sec. 18, T. 9 N., R. 19 E., northwestern Haskell County." He observed that this horizon "seems to occupy about the same stratigraphic position as the Spaniard Limestone." Throughout the northeastern Oklahoma shelf area, the base of the Spaniard Limestone marks the McAlester/Savanna contact. Hemish (1993) tentatively identified a limestone discovered in Le Flore County, in the eastern part of the Arkoma basin of Oklahoma, as the Spaniard Limestone, and used its base to define the McAlester/Savanna contact in that area.

Coal beds have been observed in the Savanna Formation throughout the Arkoma basin (Taff, 1899; Taff and Adams, 1900; Hendricks, 1937; Dane and others, 1937; Hendricks, 1939; Oakes and Knechtel, 1948; Knechtel, 1949; Russell, 1960; Webb, 1960; Hemish, in preparation), but most are thin and discontinuous. Knechtel (1949, p. 49) reported that "three and possibly four minable coal beds within the Savanna Formation crop out in...Cavanal Mountain." If minable coals are present elsewhere in the Arkoma basin within the Savanna Formation they have not been discovered to date.

The concept of mapping the sandstones of the Savanna Formation by "groups" or "divisions" based on topographic expression was originated by Taff (1899, p. 437) when he observed that "there are five principal sandstone beds, which have different thicknesses, from nearly 50 to 200 feet." Hendricks

(1937, p. 17) referred to "two large bands" of Savanna Sandstone in the McAlester area, but then later said that "for convenience in mapping several sandstones separated by thin shales were mapped together as sandstone groups. Over most of the district four such groups were traceable."

Russell (1960, p. 20), in Latimer County, observed that "the Savanna Formation consists predominantly of brown to grayish-green shales with 2 to 14 mappable sandstone units. Generally, the sandstone beds may be grouped into upper and lower groups. Each group contains several sandstone beds separated by shale."

It is apparent that the number of sandstone "groups" selected for mapping purposes depends in large part on (1) the topography in the area to be mapped and (2) the scale of mapping.

Hemish and others (1990c), mapping at a scale of 1:24,000, found that seven sandstone "groups" were mappable in the Wilburton 7.5′ quadrangle. These seven ridge-forming groups were mapped eastward in adjacent 7.5′ quadrangles to the Arkansas/Oklahoma line, and informally called the Savanna 1–7 sandstones. (Hemish and others, 1990a,b; Hemish, 1991b; Hemish and Mazengarb, 1992; and Hemish and Suneson, 1993, 1994). Although the units in places split into several beds separated by thin shales, or thin from several beds to just one (or even pinch out for some distance), they were sufficiently persistent and divisible to be mapped at the 1:24,000 scale. Hemish (1992, 1995) continued mapping the seven sandstone units westward from the Wilburton 7.5′ quadrangle, across the Gowen 7.5′ quadrangle, and into the Adamson 7.5′ quadrangle. Future mapping may necessitate modifications in this practice—Hemish (in preparation) was able to distinguish only two mappable ridge-forming units in the Savanna Formation in the north flank of the Sans Bois syncline in southern Haskell County just south of Lequire.

Principal Reference Section (Neostratotype) for the Savanna Formation

A diagram of the principal reference section for the Savanna Formation, accompanied by a description of each lithologic unit is presented in the Appendix. Rock-color terms are those shown in the rock-color chart (Rock-Color Chart Committee, 1991). Included are 122.5 ft of the upper part of the McAlester Formation, 1449.1 ft of the Savanna Formation, and 142.5 ft of the lower part of the Boggy Formation, for a total of 1714.1 ft of measured section.

The location of the measured section is shown in Figure 3. It covers a distance of slightly more than 1 mi, the base beginning in the road cut just east of the junction of the section-line road and the road extending ~0.7 mi northwest from Adamson. The lower part of the section was measured in the road cut east of the curving road, in the road, and in the road cut north of the road near the top of the escarpment. Measurements were then made on one side of the road or the other, in ditches or road cuts, to the knoll in the pasture just east of the road and just south of the iron pasture gate and east-trending trail. Other measurements were made in the road bed and ditch north to the low, covered area.

Further measurements were made in the ridge of resistant sandstones in the pasture east of the road in the SW¼SW¼NW¼ sec. 6, T. 5 N., R. 17 E. Measurements continued from the crest of the ridge northward along the road down to where the road bends sharply west. Measurements were made in the road cut north of the west-trending road to the base of the slope. Measurements were then continued northward from the curve in the road, along the section line between secs. 36, T. 6 N., R. 16 E., and sec. 31, T. 6 N., R. 17 E., down the bluff south of the Buffalo Creek valley, across the valley, and up to the top of the bluff on the north side of the valley. Beds in the area dip north, toward the axis of the Sans Bois syncline, from 33° at the community of Adamson, to 14° on the south flank of Buffalo Mountain, just north of the Buffalo Creek valley (Fig. 3).

In the diagrammatic column (Appendix), the youngest units are listed first (page 27). These have the highest unit numbers. For example: the upper unit of the Bluejacket Sandstone (the youngest of 64 lithologic units measured) is assigned unit No. 64. The oldest lithologic unit measured is a shale in the upper part of the McAlester Formation. It appears on the last page of the Appendix, extends from 0–46 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 in the right-hand column.

Of the 122.5 ft of the upper part of the McAlester Formation, all but 6.1 ft consists of shale and silty shale with abundant clay-ironstone concretions and layers (Fig. 4). Within the 122.5-ft-thick interval a 4.8-ft-thick shale unit interbedded with sandstone lenses, and an overlying 1.3-ft-thick, massive sandstone bed have been interpreted as the Keota Sandstone Member of the McAlester Formation. The top of this sandstone is 70.4 ft below the McAlester/Savanna contact.

Figure 5A,B shows the basal contact of the Savanna Formation. The exposure shows minor erosion at the top of the McAlester Formation with an irregular contact between Psv 1a and the underlying shale.

Figures 6, 7, 8, and 9A,B all show exposures of the other five sandstone units comprising Psvl. The total thickness of Psv 1 is 75.7 ft, including the interstratified shales.

Separating Psv 1 from Psv 2 is 44.8 ft of sandy, silty shale, including a 2.3-ft-thick, impure fossiliferous limestone bed (Jolly Limestone of Morgan [1924]?) (Fig. 10A,B). Psv 2 comprises four sandstone units and three shale units totaling 35.1 ft. Figure 11A,B shows outcrops of Psv 2a and Psv 2b, respectively. Note the irregular contact with underlying shale in both photographs.

Separating Psv 2 from Psv 3 is 155.1 ft of shale containing ironstone stringers. Psv 3 consists of six sandstone units, none of which exceeds 9 ft in thickness, separated by five shale units—most considerably thicker. The total thickness of Psv 3 is 128.3 ft. Figure 12 shows the flaggy, parallel-bedded character of Psv 3C as well as channeling at the base of the unit. Fossil plant casts are common in Psv 3d and Psv 3e.

Separating Psv 3 from Psv 4 is 135.3 ft of shale and siltstone. Psv 4 comprises three sandstone units separated by a shale unit (partly covered) and a sandy shale unit. Total thickness of Psv 4 is 40.3 ft. Figure 13 shows a large, rolled sandstone mass that is typical of the sedimentary structures found in Psv 4a.

One of two extensively covered areas (here 174.4 ft, and another in Buffalo Creek valley, 207 ft) obscures part of the Savanna Formation between Psv 4 and Psv 5. The covered area is topographically low, and is assumed to be underlain by shale.

Above the covered area, 105.1 ft of ironstone-bearing, silty shale is exposed in the east road ditch below Psv 5. Psv 5 is magnificently exposed on the high ridge in the pasture east of the section-line road. For permission to enter the pasture to examine the outcrops contact Thomas Irwin, Hartshorne, Oklahoma, phone (918) 297-2937. Figure 14 shows the parallel-bedded character of the lower part of Psv5, which is apparently a single 41.5-ft-thick unit in this area.

Approximately 30 ft stratigraphically above the top of Psv 5, the first sandstone bed in a series of poorly exposed, interbedded sandstones and shales crops out in the road bed downslope north from the ridge crest. This series includes Psv 6a and Psv 6b along with an intervening 34.9-ft-thick covered interval, and is 117.7 thick.

Part of the 97.1-ft-thick interval between Psv 6 and Psv 7 is covered, but the shales and siltstones that are exposed exhibit a variety of sedimentary structures. Figure 15 shows concentrically banded flow rolls at the base of Unit 53. Units 54 and 56 are thin wavy siltstone beds characterized by a proliferation of trace fossils on both the tops and bottoms of each bed. Unit 55 contains an abundance of spindle-shaped, pot casts (infillings of eroding vortex flows) (Myrow, 1992) that weather out of the shale and litter the outcrop (Fig. 16).

Psv 7 is at least 28.5 ft thick, and is exposed in the steep bluff on the south side of Buffalo Creek valley. It is a ferruginous, thick-bedded, blocky unit, well exposed only at the top of the bluff. The lowermost bed is exposed at the contact with alluvium at the edge of the flood plain of Buffalo Creek.

Buried under the alluvium in Buffalo Creek valley is 207 ft of the thick shale interval at the top of the Savanna Formation. Exposures of this part of the formation are rare because the shale is nonresistant to erosion, and streams typically follow the topographically low, strike-oriented valleys underlain by the shale. However, 33.3 ft of lenticular-bedded, silty, sandy shale in the upper part of the Savanna Formation is well exposed at the base of the Bluejacket Sandstone escarpment on the north side of Buffalo Creek valley (Appendix, Units 60, 61).

The contact between the Savanna Formation and the overlying Boggy Formation is at the base of Unit 62, the lower sandstone unit of the Bluejacket Sandstone Member. The contact is somewhat gradational, occurring in a coarsening-upward sequence where the lithology of the strata changes from predominantly shale to predominantly sandstone (Fig. 17).

Between the 24.0-ft-thick lower unit of the Bluejacket Sandstone and the 26.5-ft-thick upper unit of the Bluejacket Sandstone, 92.0 ft of strata are covered (Fig. 18). The Bluejacket exposed at the top of the bluff is coarser grained than the underlying sandstones of the Savanna Formation. It contains large-scale trough cross-bedding as well as numerous soft-sediment deformation features.

Summary

The name originally assigned to the Savanna Formation by Taff (1899, p. 437) was the "Savanna sandstone." He did note that in the series of sandstones and shales comprising the formation, "the shaly beds combined are probably thicker than the sandstones." He felt that because the sandstones are better exposed and because they form such prominent ridges, "sandstone" seemed a more appropriate term.

However, calculations made by combining the thicknesses of all the sandstone units measured in the Savanna in the Adamson section (neostratotype) show that their total thickness is only 232.9 ft. The total thickness of the Savanna Formation at this location is 1449.1 ft. Simple calculations reveal that only 16% of the formation is actually sandstone.

The percentage of sandstone in the Savanna probably increases eastward, but it definitely diminishes northward as the formation thins, and in places in the shelf area (in Mayes County [Hemish, 1990a, core-hole 7, app.]) the percentage of sandstone is only 2.4%.

Interpretations regarding the depositional environments of the various units in the Savanna Formation have not been presented in this paper. My overall impression is that the formation was deposited primarily in a nearshore and shelf environment. The abundance of flow rolls and other soft-sediment deformation features, which typify most of the Savanna sandstone units, suggests rapid, periodic sedimentation on oversteepened depositional slopes, with sediment failure occurring after deposition.

Establishment of this principal reference section creates a framework for future workers who may wish to expand the study, or to take the opportunity to collect samples and do petrographic work. Detailed studies would enhance the understanding of the sedimentology of the Savanna Formation.

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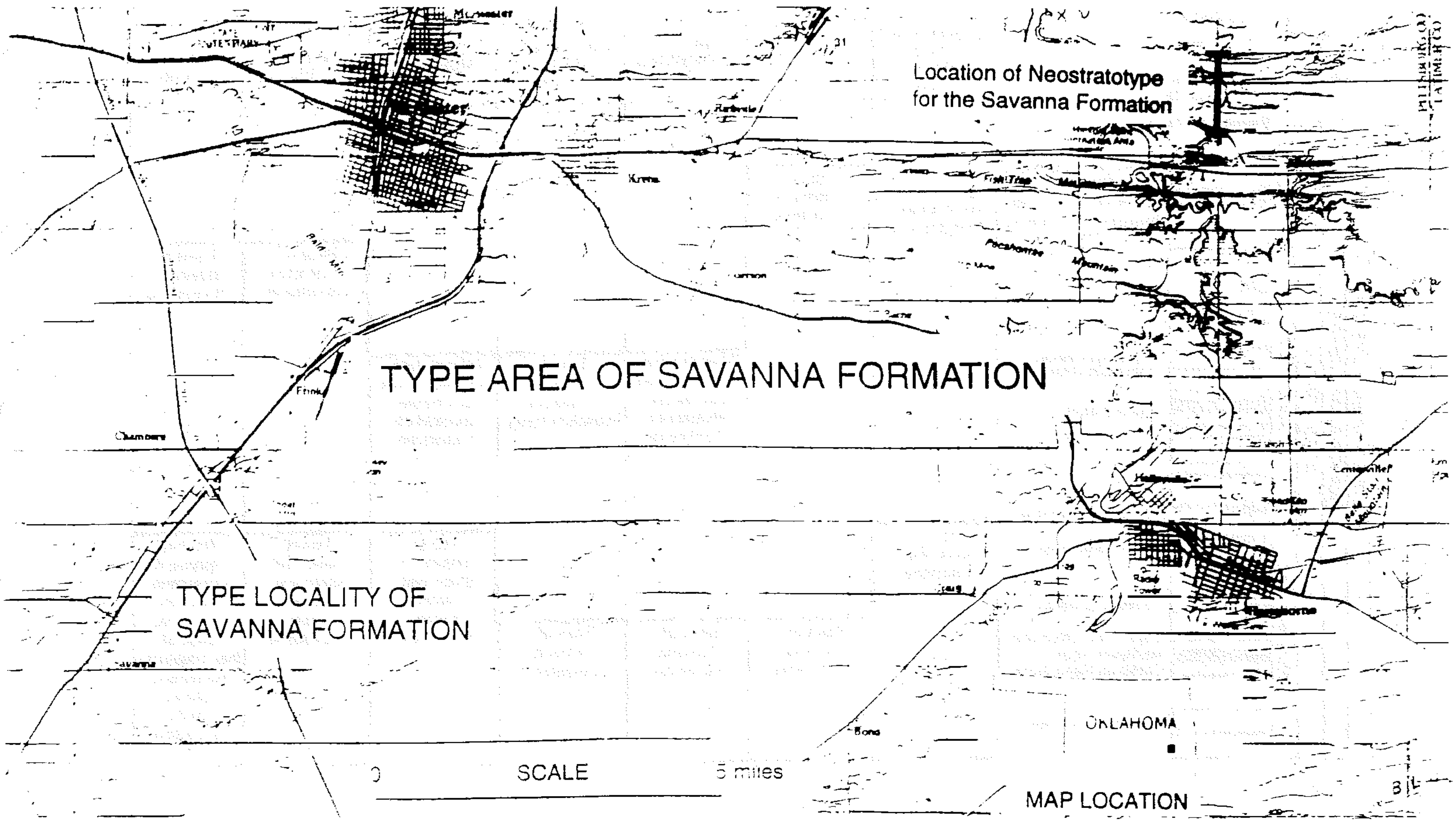


Figure 1. Map showing the type locality, type area, and location of the neostratotype for the Savanna Formation in central Pittsburg County, Oklahoma.

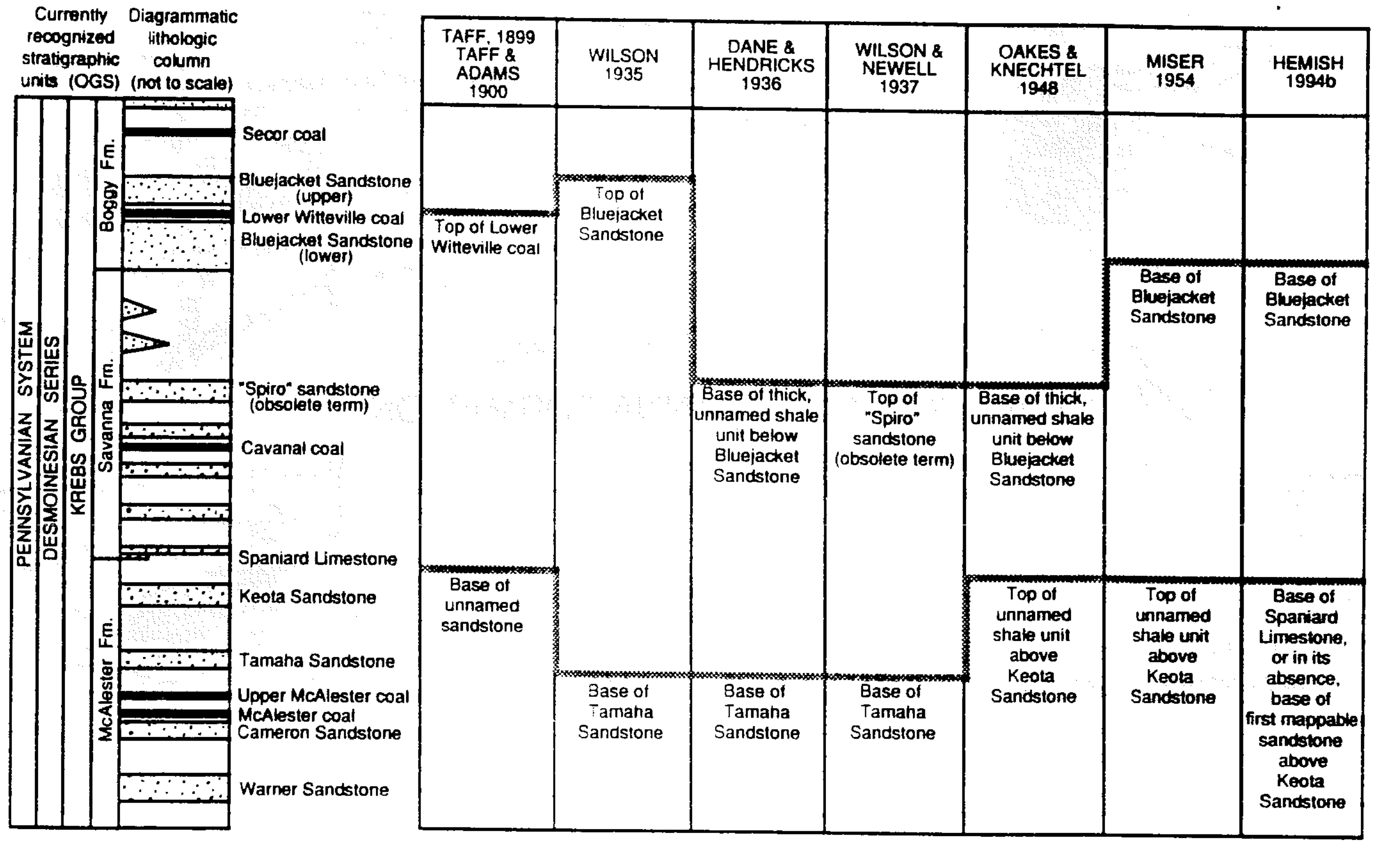


Figure 2. Concepts of the McAlester/Savanna and Savanna/Boggy boundary positions in Oklahoma (from Hemish, 1994, fig. 7).

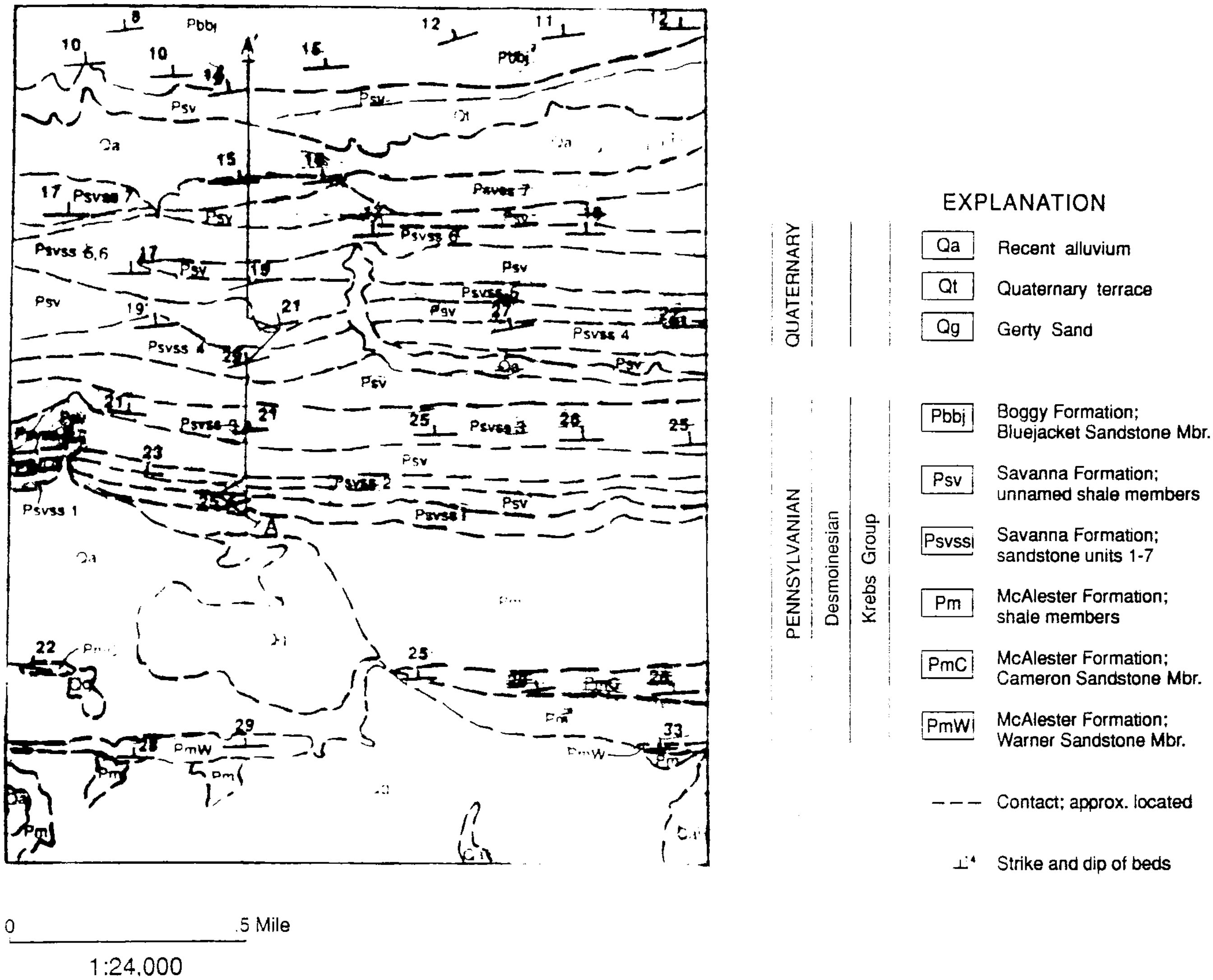


Figure 3. Geologic map of the northwest Adamson area showing the location of the neostratotype for the Savanna Formation (excerpt from Hemish, 1995). Line of measured section shown by A–A′.

Figure 4. Silty shale containing abundant clay-ironstone discoidal concretions and layers. Upper part of the McAlester Formation, Unit 1. Geologic pick is 1.1 ft long. Exposed in road cut near base of slope. (NW¼SW¼NW¼SW¼ sec. 6, T. 5 N., R. 17 E.)

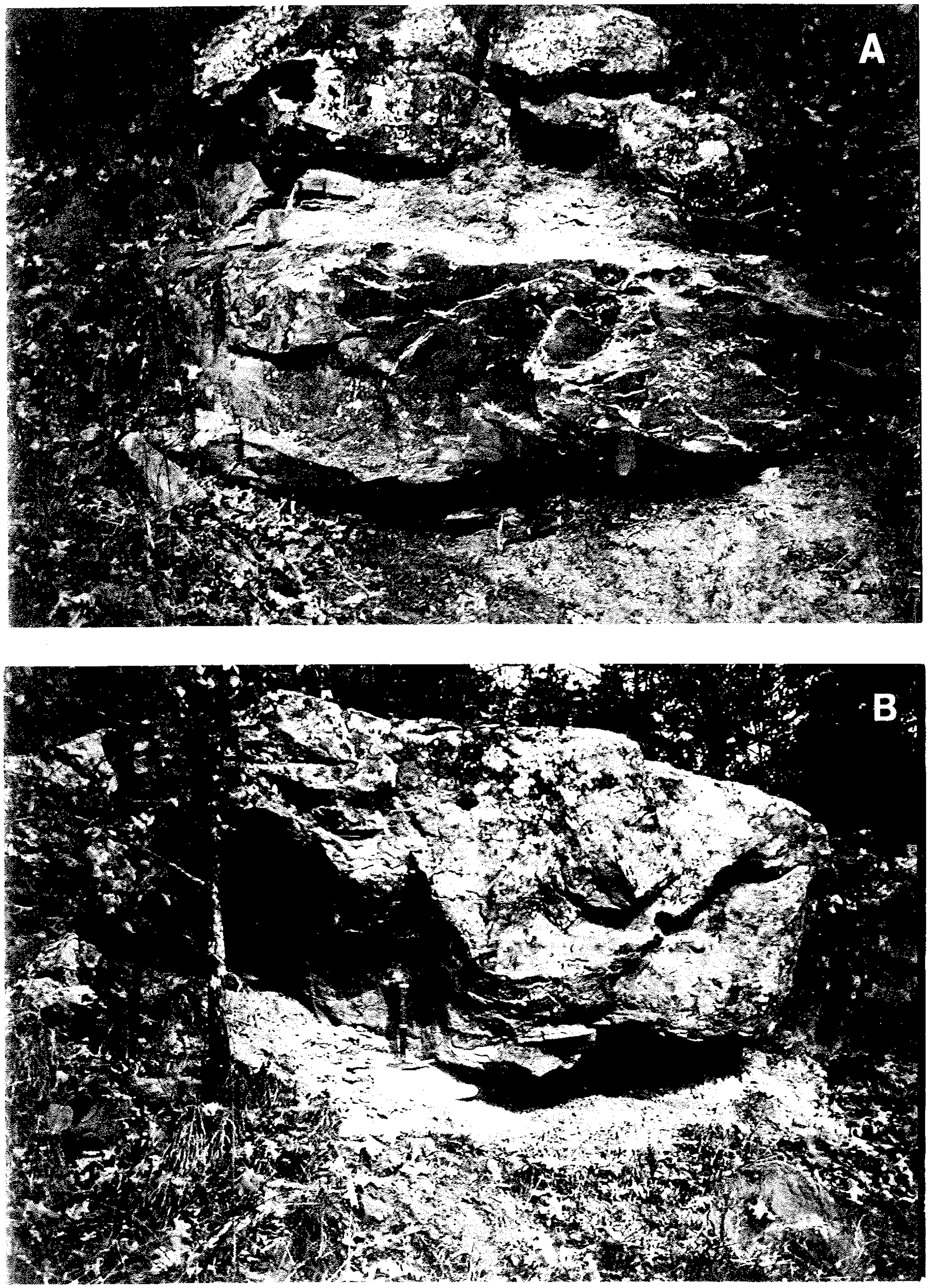


Figure 5. *A*—Contact between McAlester Formation and Savanna Formation. Geologic pick (1.1 ft long) marks a minor erosional channel in shale at the top of Unit 4. *B*—Irregular contact between the McAlester Formation and Savanna Formation (marked by pick). Note the soft-sediment deformation in Psv 1a (Unit 5). Geologic pick is 1.1 ft long. (NE¼SE¼NE¼SE¼ sec. 1, T. 5 N., R. 16 E.)

Figure 6. Psv 1b sandstone (Unit 7) showing parallel bedding, interbedded sandy shale, and sharp, irregular basal contact (marked by pick head). Geologic pick is 1.1 ft long. (SE¼NE¼NE¼SE¼ sec. 1, T. 5 N., R. 16 E.)

Figure 7. Psv 1c sandstone (Unit 9) showing massive, blocky character of the unit. Pick head marks the sharp, irregular basal contact. Geologic pick is 1.1 ft long. (SE¼NE¼NE¼SE¼ sec. 1, T. 5 N., R. 16 E.)

Figure 8. Psv 1d sandstone (Unit 11) and underlying silty, sandy shale with ironstone concretions (Unit 10) exposed in ditch where road curves sharply east. Pick marks a zone of flow rolls at the contact between Units 10 and 11. Geologic pick is 1.1 ft long. (SE¼NE¼NE¼SE¼ sec. 1, T. 5 N., R. 16 E.)

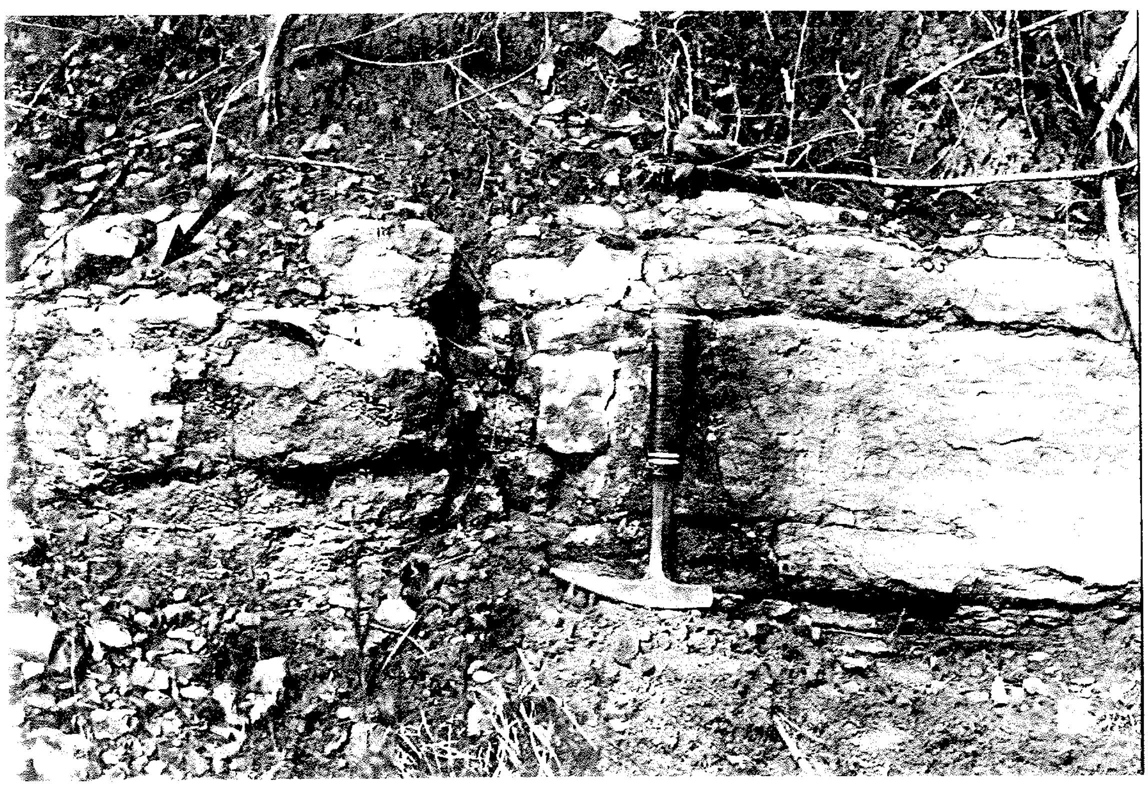


Figure 9. *A*—Psv 1e sandstone (Unit 13) exposed in road cut, north side of sharp bend in road. Sandstone is silty and parallel bedded. Geologic pick is 1.1 ft long. *B*—Close-up view of Unit 13 showing parallel bedding and bioturbation features (indicated by arrow, upper left of photograph). Geologic pick is 1.1 ft long. (SE¼NE¼NE¼SE¼ sec. 1, T. 5 N., R. 16 E.)

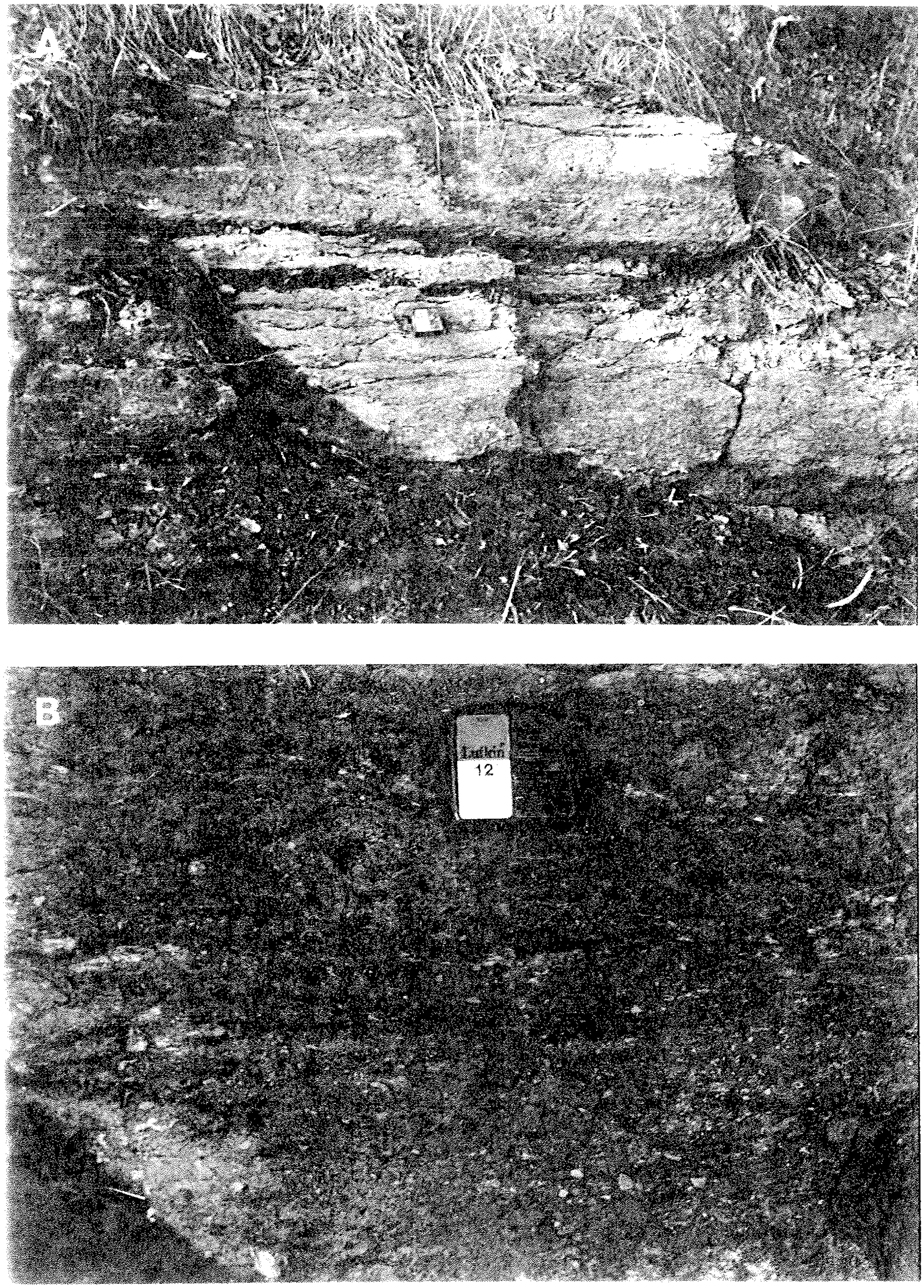


Figure 10. *A*—Impure, sandy and silty limestone (Unit 15) exposed in road cut, north side of road. *B*—Close-up view of Unit 15, showing the fossiliferous character of the limestone. Tape measure is 2 in. wide. (SE¼NE¼NE¼SE¼ sec. 1, T. 5 N., R. 16 E.)

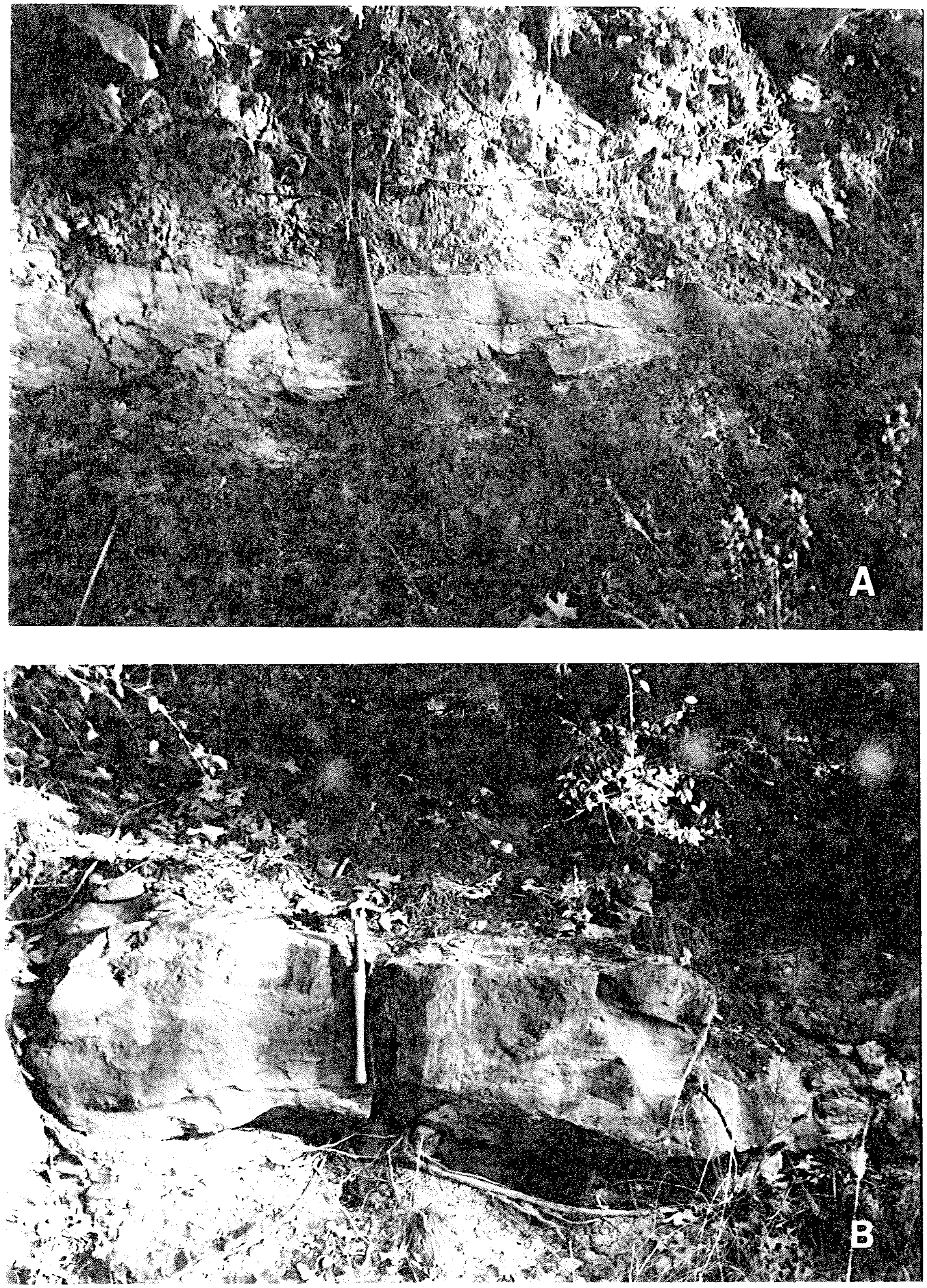


Figure 11. *A*—Psv 2a sandstone (Unit 17) enclosed in shale, showing sharp irregular upper and lower boundaries. Note swaly-bedded character. *B*—Psv 2b sandstone (Unit 19) showing blocky, thick-bedded character and sharp, irregular boundaries. Trenching tool is 1.75 ft long. Exposed in road cut north of road just before road bends to the north. (SE¼NE¼NE¼SE¼ sec. 1, T. 5 N., R. 16 E.)

Figure 12. Psv 3c sandstone (Unit 30), exposed in road cut at crest of first high ridge north of bend in road. Note thin to medium, parallel-bedding, and minor erosional channel (arrow) at top of underlying shale (Unit 29). Trenching tool is 1.75 ft long. (SE¼SE¼SE¼NE¼ sec. 1, T. 5 N., R. 16 E.)

Figure 13. Large, rolled sandstone mass (Psv 4a sandstone, Unit 39) exposed just east of road in pasture on low ridge. Soft-sediment deformation is common in this unit. Geologic pick is 1.1 ft long. (SW¼NW¼SW¼NW¼ sec. 6, T. 5 N., R. 17 E.)

Figure 14. Flat, parallel-bedded, lower part of Psv 5 sandstone (Unit 47) exposed in pasture near base of high ridge ~0.1 mi east of road. Strata shown are ~15 ft thick. (SE¼SW¼NW¼NW¼ sec. 6, T. 5 N., R. 17 E.)

Figure 15. Concentrically layered sandstone masses (flow rolls) in silty shale (Unit 53) exposed in road ditch ~0.1 mi west of right-angle bend in road. Tape measure is 2 in. wide. (SW¼SE¼SE¼SE¼ sec. 36, T. 6 N., R. 16 E.)

Figure 16. Spindle-shaped pot casts weathering out of shale (Unit 55) in road cut exposure north side of road ~0.05 mi west of right angle bend in road. Brunton compass is 2.75 × 3.0 in. wide. (SE¼SE¼SE¼SE¼ sec. 36, T. 6 N., R. 16 E.)

Figure 17. Contact between Savanna Formation and Boggy Formation (indicated by arrow in photograph). Top beds in the Savanna (Unit 61) comprise silty shale and lenses of very fine grained sandstone. The overlying lower unit of the Bluejacket Sandstone (Unit 62) contains flaggy, wavy-bedded, very fine grained sandstone. Contact is exposed in small gully part way up the bluff north of Buffalo Creek valley. (SE¼SE¼NE¼SE¼ sec. 36, T. 6 N., R. 16 E.)

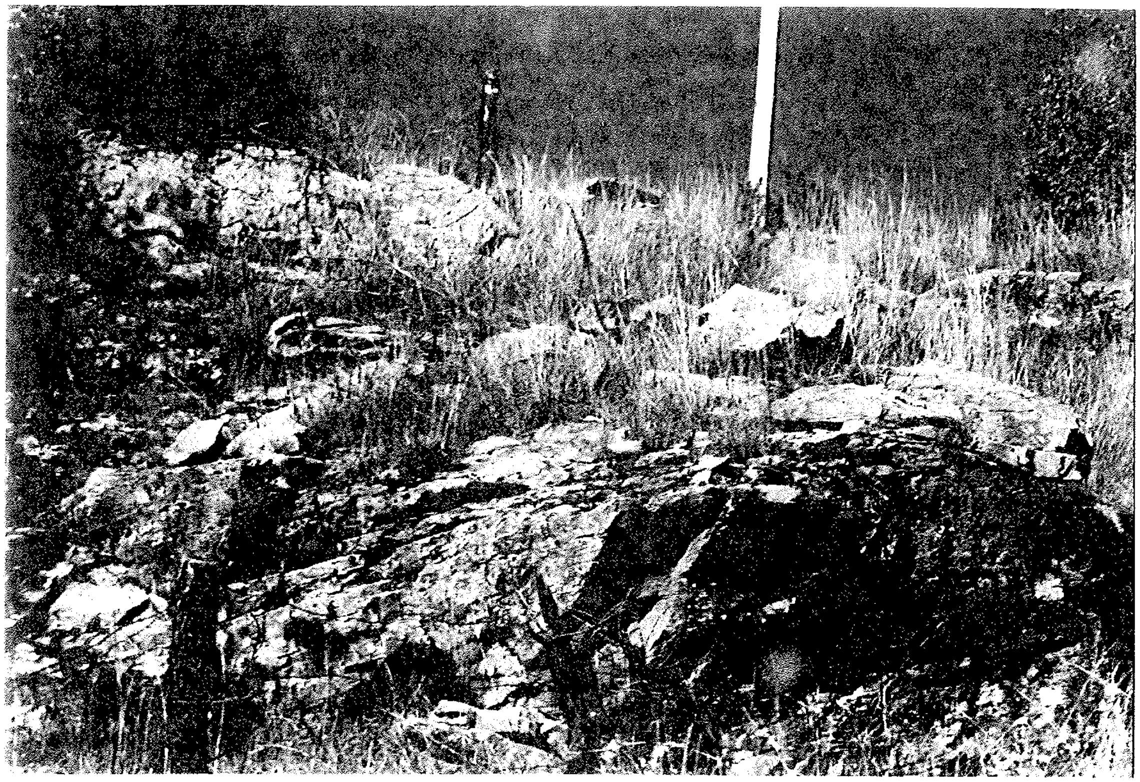


Figure 18. Cross-bedded, deformed upper unit of Bluejacket Sandstone Member of Boggy Formation (Unit 64) exposed at top of bluff north side of Buffalo Creek valley. (NW¼SW¼NW¼SW¼ sec. 31, T. 6 N., R. 17 E.)

APPENDIX

EXPLANATION

Sandstone

Sandstone, shaly

Sandstone, silty

Siltstone

Shale

Shale, sandy

Shale, silty

Limestone, sandy, silty

Covered interval

Sedimentary Features

Trough cross-stratification

Low-angle cross-stratification

Parallel stratification

Wavy bedding

Nodular bedding

Lenticular bedding

Climbing ripples

Current lineation

Swaly bedding

Convolute bedding

Slumped or contorted bedding

Ripple marks

Flow rolls

Load structures

Scour-and-fill

Dewatering feature

Groove cast

Pot cast

M Micaceous

Calcareous

Ironstone band

Ironstone concretion

Fissile

Plant stem

Comminuted plant material

F Fossils (invertebrate)

Brachiopod

Crinoid debris

Bivalve

Bioturbated

Vertical burrow

Horizontal burrow

Fining-upward sequence

Coarsening-upward sequence

Scale (ft.)	Unit Thickness (ft.)	Unit No.	Lithology	Sedimentary Features	Description of Units
1720					
1710					
1700	26.5	64			KREBS GROUP Boggy Formation: Bluejacket Sandstone Member: Sandstone, moderate orange pink (5YR8/4), weathers light brown (5YR6/4) to grayish orange pink (5YR7/2), fine-grained, medium- to thick-bedded, large-scale trough cross-bedded; includes some soft-sediment deformation features; base sharp; entire sequence shows a stacked-channel relationship (upper unit, Bluejacket Sandstone)
1690					
1680					
1670					
1660					
	92.0	63			63. Covered interval
1650					
1640					
1630					
1620					

Scale (ft.)	Unit Thickness (ft.)	Unit No.	Lithology	Sedimentary Features	Description of Units
1620, 1610, 1600	92.0	63			
1590, 1580	24.0	62		M M M M	Sandstone, grayish orange (10YR7/4) very fine grained, silty, shaly, micaceous, very thin to thin-bedded; wavy, parallel-bedded, ripple-marked; black, comminuted plant material on stratification surfaces; trace fossils on soles of beds; basal contact somewhat gradational, but readily defined by change in lithology from predominantly shale to predominantly sandstone (lower unit, Bluejacket Sandstone)
1570	7.5	61		M M	Savanna Formation: 61. Shale, moderate yellowish brown (10YR5/4), silty; contains small lenses of very fine grained, micaceous sandstone with black comminuted plant material on stratification surfaces; coarsens upward; base gradational
1560, 1550, 1540	25.8	60		M M	60. Shale, olive gray (5Y3/2), weathers yellowish gray (5Y7/2), silty; siltstone laminae are lenticular, micaceous, and have black, carbonized, comminuted plant material on bedding surfaces; unit contains burrows as much as 1 in. long and 0.3 in. in diameter; coarsens upward; base gradational
1530, 1520	207.0	59			

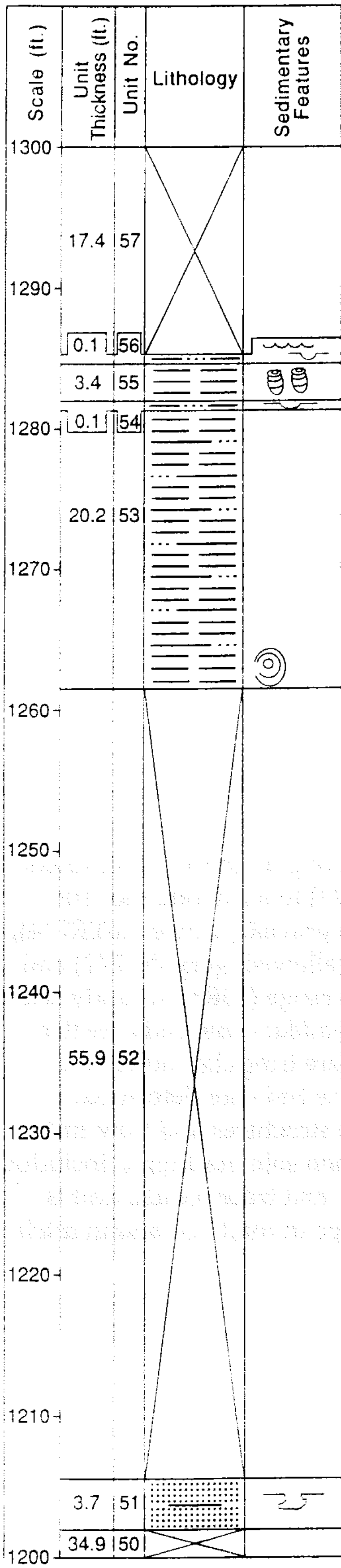
Scale (ft.)	Unit Thickness (ft.)	Unit No.	Lithology	Sedimentary Features	Description of Units
1520					
1510					
1500	207.0	59			Covered interval (alluvium in Buffalo Creek Valley)
1490					
1480					
1470					

30 feet of unit 59 omitted

Scale (ft.)	Unit Thickness (ft.)	Unit No.	Lithology	Sedimentary Features	Description of Units
1440					
1430					
1420	207.0	59			Covered interval (alluvium in Buffalo Creek Valley)
1410					
1400					

Scale (ft.)	Unit Thickness (ft.)	Unit No.	Lithology	Sedimentary Features	Description of Units
1400–1333	207.0	59			
1333–1303	28.6	58			58. Sandstone, grayish red (5R4/2), weathers very dusky red (10R2/2), ferruginous, very fine grained, thick-bedded, some swaly beds, blocky; many beds show soft-sediment deformation features; exposed mostly as float in steep dip slope south side of Buffalo Creek; some load casts and grooves on overturned float blocks; in situ exposure of sandstone exposed part way down slope is ripple marked; upper part (top?) of unit is exposed at contact with alluvium at edge of flood plain of Buffalo Creek (Psv7 ss)
1303–1300	17.4	57			

Scale (ft.): 1400, 1390, 1380, 1370, 1360, 1350, 1340, 1330, 1320, 1310, 1300



Description of Units

Covered interval (from top of bluff, south side of Buffalo Creek, to fence where road turns west)

56. Siltstone, light olive gray (5Y5/2) weathers light brown (5YR5/6), thin-bedded, ripple-marked; includes trace fossils in abundance on both top and bottom of bed; exposed on north side of bend-to-the-west in road and in road cut further west. This unit and three underlying units exposed in sloping road cut, north side of west-trending road

55. Shale, dark yellowish orange (10YR6/6), weathers grayish orange (10YR7/4); contains an abundance of spindle-shaped pot casts mostly ~3 in. long and 1-2 in. in diameter, but some much larger; base sharp

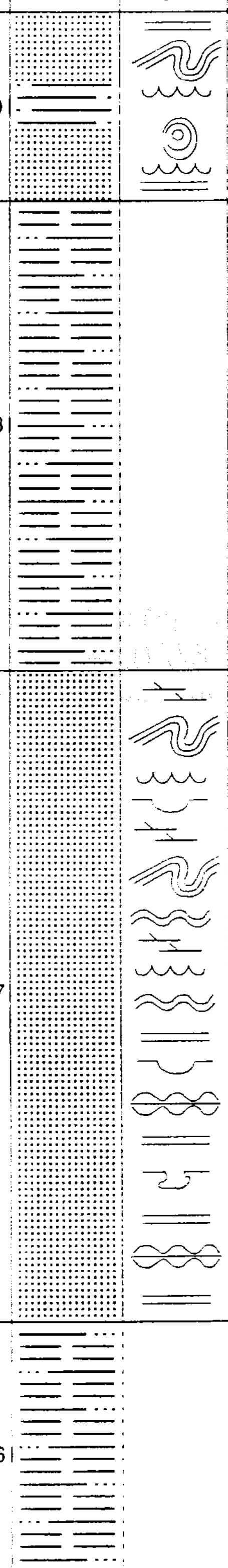
54. Siltstone, dark yellowish brown (10YR4/2) to light olive gray (5Y5/2), weathers dark yellowish orange (10YR6/6) and light brown (5YR5/6), thin-bedded, somewhat wavy-bedded; characterized by a proliferation of trace fossils of many kinds on both top and bottom of bed; base sharp

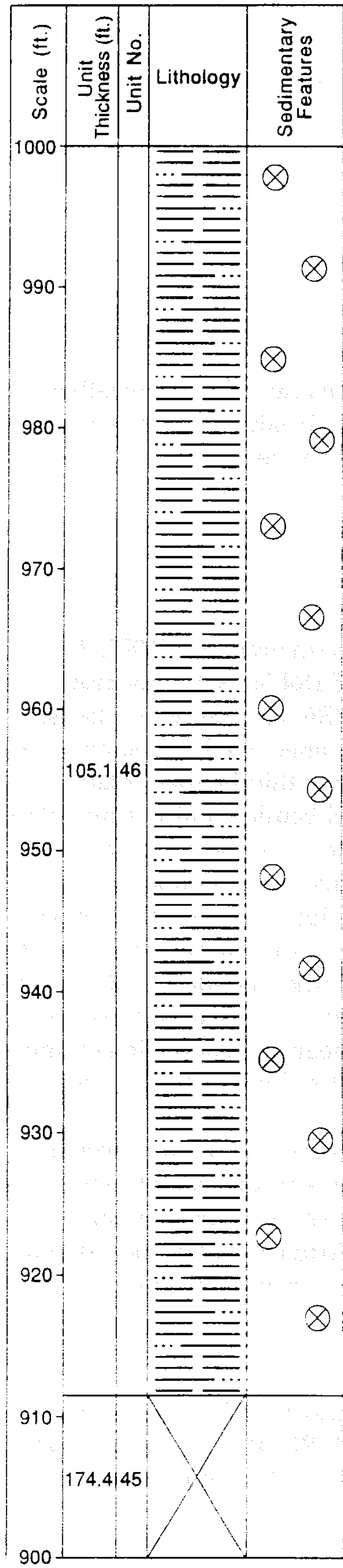
53. Shale, light olive gray (5Y5/2), weathers dark yellowish orange (10YR6/6) to yellowish gray (5Y7/2); contains siltstone stringers and sandstone lenses; near base of exposure, contains rounded, elongate, flattened, ellipsoidal, light brown (5YR5/6), very fine grained sandstone masses (flow rolls); unit has a banded appearance; base covered

51. Sandstone, light olive gray (5Y5/2), weathers moderate brown (5YR4/4), very fine grained, shaly, thin- to medium-bedded, irregularly bedded, load casts on some soles, poorly exposed in road bed (Psv 6b ss)

Scale (ft.)	Unit Thickness (ft.)	Unit No.	Lithology	Sedimentary Features	Description of Units
1200 1190 1180 1170	34.9	50			
1160 1150 1140 1130 1120 1110 1100	79.1	49			Sandstone, light olive gray (5Y5/2), weathers light brown (5YR6/4) to moderate reddish brown (10R4/6), to grayish orange (10YR7/4), interbedded with yellowish gray (5Y7/2) and moderate reddish orange (10R6/6) sandy shale; thin- to medium-bedded; some beds are flat and parallel, some are irregular, others are ripple marked; many beds are deformed, showing convolute structures and flow rolls; many beds have good sole markings, including load casts, grooves, and trace fossils; unit is exposed on dip slope in road bed and in ditch (Psv 6a ss)

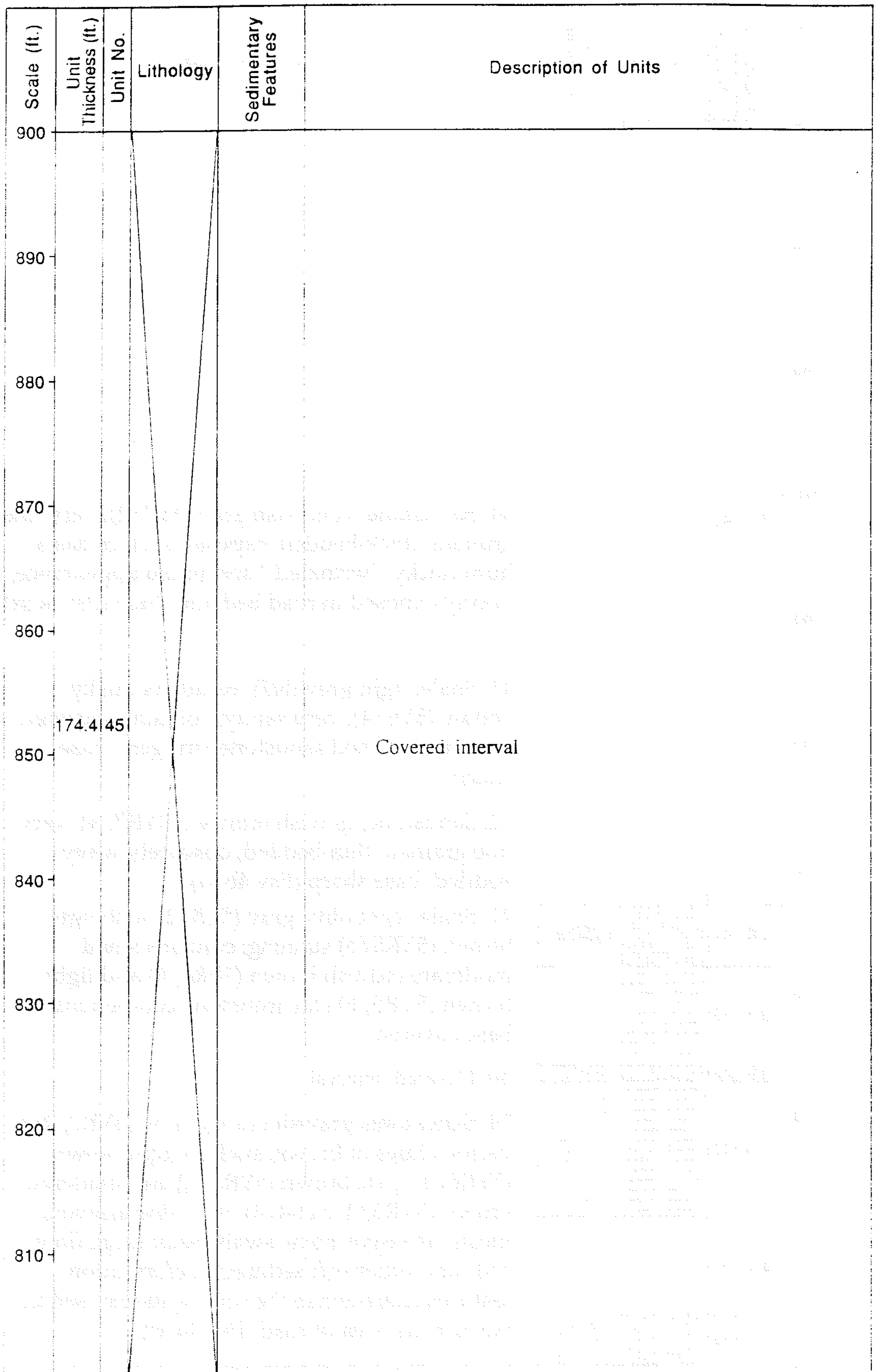
Scale (ft.)	Unit Thickness (ft.)	Unit No.	Lithology	Sedimentary Features	Description of Units
1100	79.1	49			
1090					
1080	29.8	48			48. Shale, light olive gray (5Y6/1), weathers dusky yellow (5Y6/4), silty; poorly exposed in road ditch, mostly covered
1070					
1060					
1050	41.5	47			47. Sandstone, grayish orange (10YR7/4) to moderate brown (5YR4/4) with moderate reddish orange (10R6/6) staining in places, very fine to fine-grained, well-sorted and well-rounded, very thin to thin-bedded, platy; mostly flat, parallel-bedded, but in some places contains large-scale, low-angle cross-bedding; some beds internally wavy-laminated, some have symmetrical ripple marks, others have parting lineation features; upper part is mostly pale red (5R6/2), thicker bedded, and displays more low-angle cross-bedding features; also shows some channeling relationships in upper part, as well as soft-sediment-deformation features. Note: Section was measured along excellent outcrops in pasture, east of road on high ridge. Overturned blocks show numerous sole markings such as load casts and trace fossils in this same area. Base sharp (Psv 5 ss)
1040					
1030					
1020					
1010	105.1	46			Shale, light olive gray (5Y5/2), weathers grayish orange (10YR7/4), silty; contains small, light brown (5YR5/6), discoidal clay-ironstone concretions
1000					

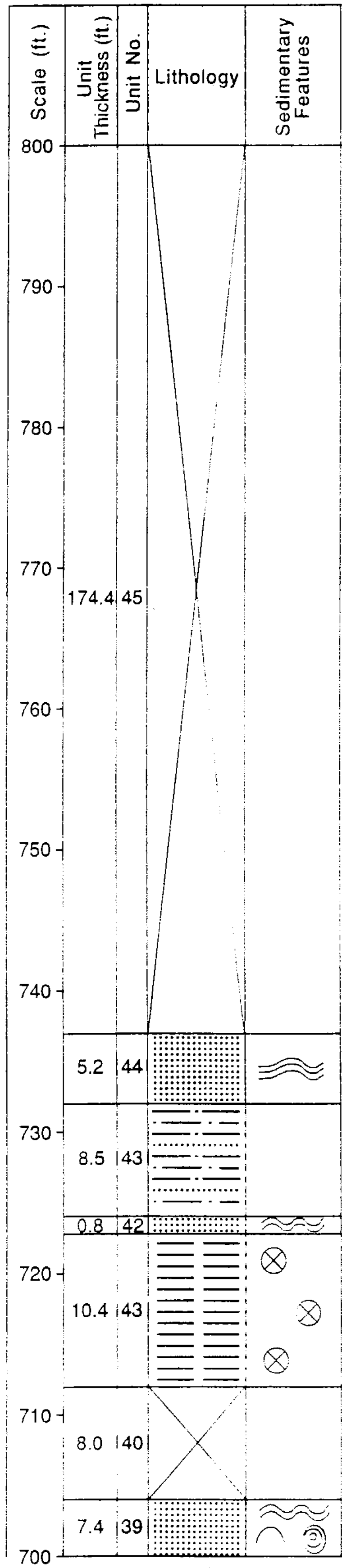




Description of Units

Shale, light olive gray (5Y5/2), weathers grayish orange (10YR7/4), silty; contains small, light brown (5YR5/6), discoidal clay-ironstone concretions


Scale (ft.)
Unit Thickness (ft.)
Unit No.
Lithology
Sedimentary Features
Description of Units
900
890
880
870
860
850
840
830
820
810
800
174.4
45
Covered interval



Description of Units

44. Sandstone, yellowish gray (5Y7/2), very fine grained, thick-bedded, exposed surface has a hummocky, "wrinkled," and pitted appearance, poorly exposed in road bed and ditch (Psv 4css)

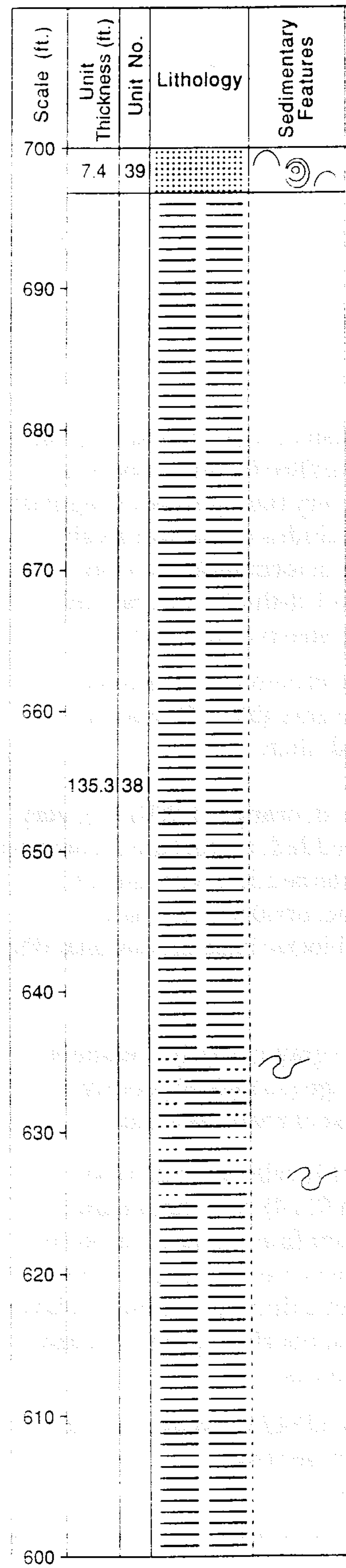
43. Shale, light gray (N7), weathers dusky yellow (5Y6/4), very sandy; contains scattered very fine grained sandstone stringers, base sharp

42. Sandstone, grayish orange (10YR7/4), very fine grained, thin-bedded, obscurely wavy-bedded, base sharp (Psv 4b ss)

41. Shale, light olive gray (5Y5/2) with light brown (5YR5/6) staining; contains small moderate reddish brown (10R4/6) and light brown (5YR5/6) clay ironstone concretions; base covered

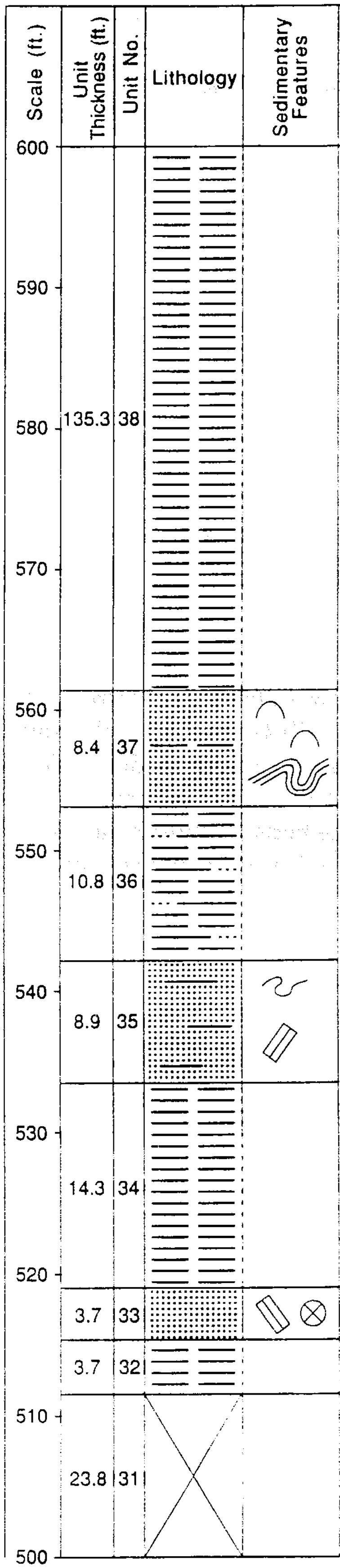
40. Covered interval

39. Sandstone, grayish orange pink (5YR7/2) to various hues of brown, such as light brown (5YR6/4), pale brown (5YR5/2) and moderate brown (5YR3/4, 5YR4/4); very fine grained; mostly massive; some swaly beds; large flow rolls and other soft-sediment deformation features characterize the unit; well-exposed in pasture just east of road (Psv 4a ss)



Description of Units

38. Shale, pale yellowish brown (10YR6/2) to grayish orange (10YR7/4) and very pale orange (10YR8/2); includes some thin-bedded, pale yellowish brown (10YR6/2), moderately bioturbated siltstone beds in middle part of unit; most of interval is poorly exposed or covered



Description of Units

37. Sandstone, grayish orange (10YR7/4), dark yellowish orange (10YR6/6), and very pale orange (10YR8/2), very fine grained, irregularly medium bedded; includes some thin swaly beds, soft-sediment deformation features common; includes a 1-ft-thick shale bed in middle of unit; base sharp (Psv 3f ss)

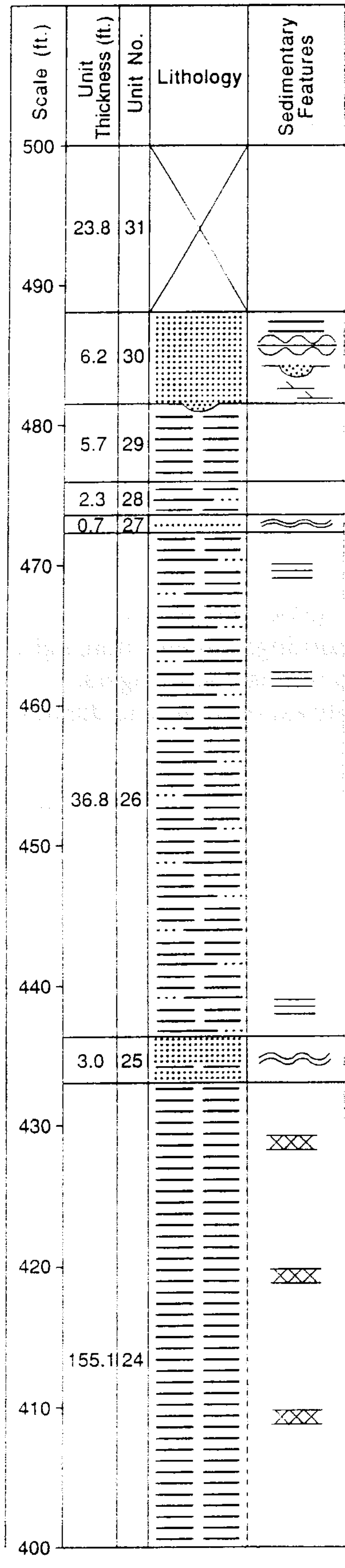
36. Shale, light olive brown (5Y5/6), silty, weathers light olive gray (5Y5/2), poorly exposed in east road ditch

35. Sandstone, grayish orange (10YR7/4), very fine grained, thin-bedded, bioturbated; contains fossil plant casts; interbedded with dusky yellow (5Y6/4) shale; breaks into small, irregularly shaped blocks; base gradational (Psv 3e ss)

34. Shale, light olive gray (5Y5/2), weathers dark yellowish orange (10YR6/6); poorly exposed in ditch east of road, base sharp

33. Sandstone, grayish yellow (5Y8/4) to grayish orange (10YR7/4), weathers light brown (5YR5/6), very fine grained, thick- to medium-bedded, beds are irregular; contains fossil plant casts and a thin discontinuous layer of ironstone pebbles; poorly exposed in road bed and ditch (Psv 3d ss)

32. Shale, olive gray (5Y4/1), weathers grayish orange (10YR7/4), base covered



Description of Units

30. Sandstone, grayish orange (10YR7/4), weathers moderate yellowish brown (10YR5/4), very fine grained, thin- to medium-bedded at top of unit; cut-and-fill near base, with low-angle cross-bedding; other beds flat and parallel with parting lineation features; well-exposed at crest of high ridge; base sharp—channels into underlying shale; (Psv 3c ss)

29. Shale, light gray (N7), weathers grayish orange (10YR7/4) and dark yellowish orange (10YR6/6), base gradational

28. Shale interbedded with siltstone, dark yellowish orange (10YR6/6), weathers grayish orange (10YR7/4), blocky, base gradational

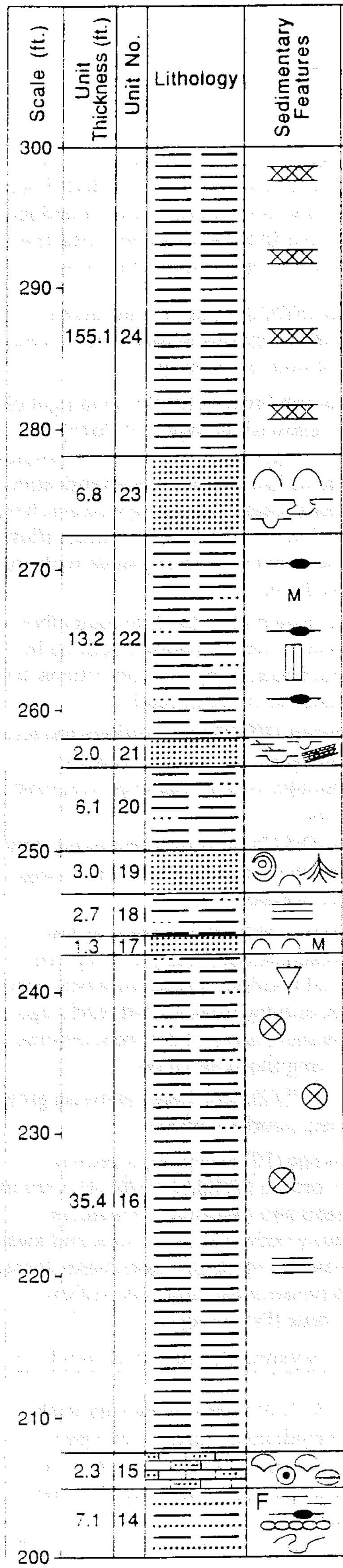
27. Sandstone, moderate yellowish brown (10YR5/4) to grayish orange (10YR7/4), very fine grained, silty, thin-bedded, obscurely wavy bedded, base sharp (Psv 3b ss)

26. Shale, olive gray (5Y4/1), weathers pale yellowish brown (10YR6/2), silty, breaks into small flakes on the outcrop; includes some light olive gray (5Y5/2) siltstone layers as much as 0.6 ft thick

25. Sandstone, moderate olive brown (5Y4/4), weathers light olive gray (5Y5/2), very fine grained, thin-bedded, interbedded with shale in lower part, obscurely wavy laminated; basal contact exposed in ditch, east side of road; top medium-bedded, blocky; base sharp (Psv 3a ss)

Scale (ft.)	Unit Thickness (ft.)	Unit No.	Lithology	Sedimentary Features	Description of Units
400–300	155.1	24			24. Shale, olive gray (5Y4/1) with dark yellowish orange mottling; contains thin, light brown (5YR5/6) clay-ironstone stringers; poorly, intermittently exposed in road ditches; mostly covered

Scale: 400, 390, 380, 370, 360, 350, 340, 330, 320, 310, 300



24. Shale, olive gray (5Y4/1) with dark yellowish orange mottling; contains thin, light brown (5YR5/6) clay-ironstone stringers; poorly, intermittently exposed in road ditches; mostly covered

23. Sandstone, dusky yellow (5Y6/4) with light brown (5YR5/6) and dark yellowish orange (10YR6/6) staining, very fine grained, irregularly thick to medium bedded, blocky, swaly-bedded in places; overturned beds in pasture have trace fossils and load casts on some soles; a 5-ft-thick, mottled, light olive gray (5Y5/2) and grayish orange (10YR7/4) clayey shale layer is present ~2.5 ft below top of unit; exposed where road turns north along section line (Psv 2d ss)

22. Shale, moderate olive brown (5Y4/4) interbedded with siltstone stringers and lenses of the same color, micaceous; siltstones include rare, finely ribbed plant casts in growth position

21. Sandstone, grayish orange (10YR7/4), weathers moderate yellowish brown (10YR5/4), very fine grained, shaly, micaceous, thin-bedded; contains low-angle cross-laminations, climbing ripples, and scour-and-fill features; trace fossils on bedding soles; top and base gradational (Psv 2c ss)

20. Shale, light olive brown (5Y5/6), weathers grayish orange (10YR7/4), silty, blocky, base sharp

19. Sandstone, yellowish gray (5Y7/2) to light olive gray (5Y5/2), weathers moderate brown (5YR3/4, 5YR4/4), very fine grained, thick-bedded, blocky; contains flow rolls, dewatering structures, and swaly beds, base sharp and irregular (Psv 2b ss)

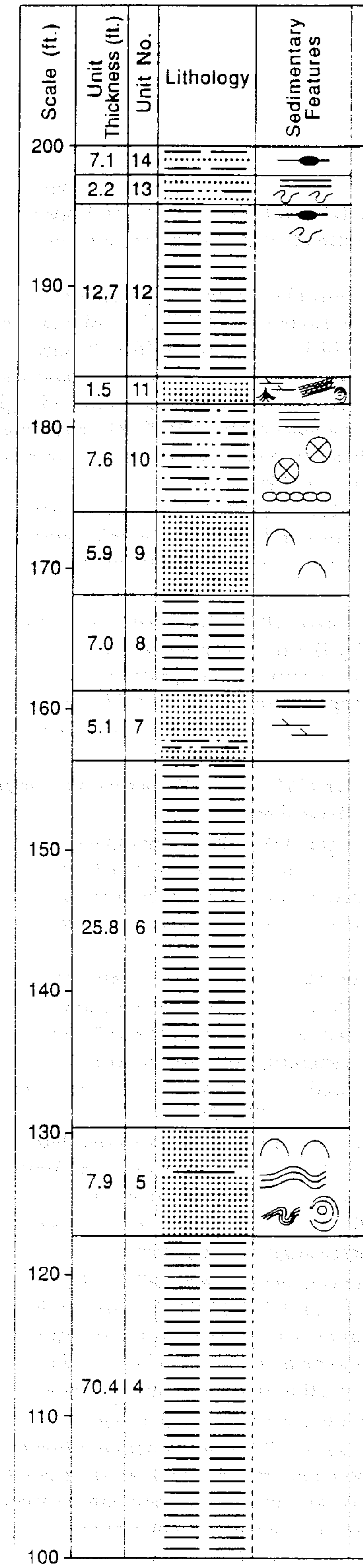
18. Shale, light olive gray (5Y5/2) silty, brittle, base sharp

17. Sandstone, dusky yellow (5Y6/4) to light olive gray (5Y5/2), weathers pale yellowish brown (10YR6/2) with grayish brown (5YR3/2) staining, very fine grained, micaceous, medium-bedded, contains low-amplitude swaly bedding, base sharp and curved (Psv 2a ss)

16. Shale, olive gray (5Y3/2), variegated grayish red (5R4/2) and yellowish gray (5Y5/2) in part; weathers to small brittle flakes; well-exposed in road cut, contains small, dark yellowish orange (10YR6/6) clay-ironstone concretions in upper part; becomes increasingly silty upwards

15. Limestone, moderate yellowish brown (10YR5/4), weathers moderate brown (5YR3/4; 5YR4/4); very impure, silty and sandy; abundantly fossiliferous—contains crinoid ossicles, brachiopods, and bivalves as much as 2 in. long and 1.5 in. wide; includes some thin shale partings, base sharp

14. Shale interbedded with nodular-bedded, lensing sandstone, grayish orange (10YR7/4) to moderate yellowish orange (10YR5/4) to moderate brown (5YR4/4); shale is silty and blocky; sandstone is very fine grained and noncalcareous in lower part of unit, but very calcareous and sparsely fossiliferous in upper part; bioturbated; base sharp



Description of Units

13. Sandstone, dusky yellow (5Y6/4) to light olive gray (5Y5/2), weathers moderate yellowish brown (10YR5/4), very fine grained, silty, thin- to medium-, parallel-bedded; strongly bioturbated; similar in appearance to limestone ~7 ft above, but is noncalcareous, base sharp (Psv 1e ss)

12. Shale, light olive gray (5Y5/2), weathers moderate yellowish brown (10YR5/4); contains lenses of bioturbated sandstone in upper 1 ft of unit; base sharp

11. Sandstone, pale yellowish brown (10YR6/2) to light olive gray (5Y5/2) with dark yellowish orange (10YR6/6) and light brown (5YR5/6) staining; very fine grained, medium-bedded, upper part contains low-angle cross-stratification, climbing ripples, and small-scale dewatering features; basal part consists of rolled, pillow-like, sandstone masses (flow rolls) extending downward into underlying shale with sharp but irregular contact (Psv 1d ss)

10. Shale, dark yellowish brown (10YR4/2) to light olive gray (5Y5/2), silty and sandy, fissile, nodular bedded in places; contains scattered, small, ironstone concretions, base sharp; well-exposed in ditch at curve in road

9. Sandstone, grayish orange (10YR7/4), weathers moderate brown (5YR4/4), very fine grained, massive, blocky; includes some low-amplitude, swaly beds in places; base sharp, irregular (Psv 1c ss)

8. Shale, light olive gray (5Y5/2), weathers yellowish gray (5Y7/2) with dark yellowish orange (10YR6/6) mottling, highly weathered, poorly exposed

7. Sandstone, grayish yellow (5Y8/4), to dusky yellow (5Y6/4), weathers moderate brown (5YR3/4), very fine grained; medium-, parallel-bedded; contains obscure, low-angle cross-stratification; unit includes a 1.5-ft-thick, light olive gray (5Y5/2) sandy shale layer ~1.3 ft from bottom; basal contact sharp and irregular (Psv 1b ss)

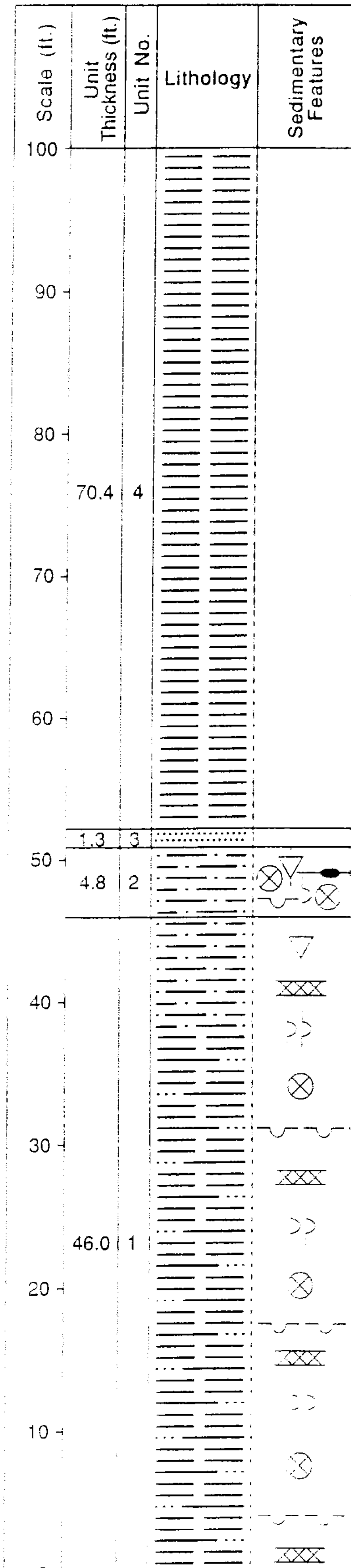
6. Shale, light olive gray (5Y5/2), weathers yellowish gray (5Y7/2), highly weathered, poorly exposed

5. Sandstone, grayish orange (10YR7/4), light brown (5YR5/6), and moderate brown (5YR3/4, 5YR4/4), very fine grained, massive; soft-sediment deformation features common, such as convolute beds, ball structures, and swaly beds; includes minor shale interbeds in places; basal contact sharp, irregular and disconformable, unit fills shallow channels in underlying shale (Psv 1a ss)

(Note: Total thickness of Savanna Formation is 1449.1 ft.)

McAlester Formation:

4. Shale, yellowish gray (5Y7/2) to moderate yellowish brown (10YR5/4), weathered, intermittently exposed—interval mostly covered except for upper 4 ft, which is mottled light brown (5YR5/6), moderate reddish brown (10R4/6), and yellowish gray (5Y7/2)

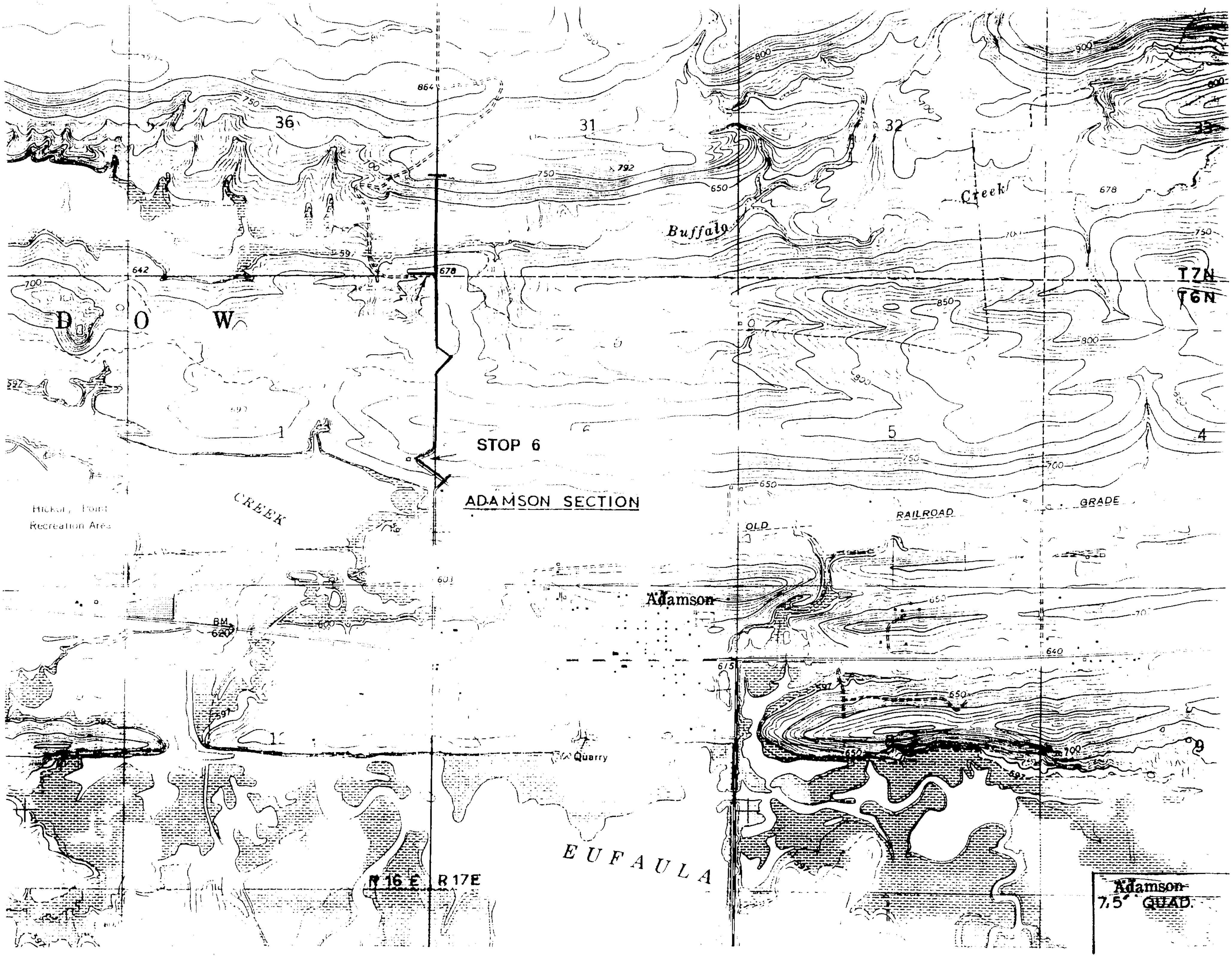


Description of Units

Keota Sandstone Member:
3. Sandstone, grayish orange (10YR7/4), very fine grained, thick-bedded, massive; poorly exposed in road bed and in ditch west of road; appears to be slumped in ditch, base sharp

Keota Sandstone Member:
2. Shale interbedded with very fine grained lenticular sandstone, light olive gray (5Y5/2), weathers moderate yellowish brown (10YR5/4) and moderate brown (5YR3/4), stained dusky yellowish brown (10YR2/2) by manganese oxide; moderately bioturbated, fossil burrows abundant; contains some dark reddish brown (10R3/4) ironstone concretions; becomes increasingly sandy upwards

1. Shale, olive gray (5Y4/1), weathers grayish orange (10YR7/4) to moderate yellowish brown (10YR5/4), silty; contains siltstone-filled burrows about 0.25-0.5 in. in diameter, generally on bedding planes, but also cutting across stratification; in upper part includes discoidal, dark reddish brown (10R3/4) to light brown (5YR5/6) clay-ironstone concretions ~0.6 in. in diameter and 1-2 in. thick, as well as clay-ironstone layers ~1 in. thick; becomes sandy upwards and grades into overlying unit; base of unit covered


STOP 6
ADAMSON SECTION
Buffalo
Creek
CREEK
OLD
RAILROAD
GRADE
Adamson
Quarry
EUFAULA
Hickory Point
Recreation Area
DOW
T7N
T6N
R 16 E
R 17E
36
31
32
33
1
5
4
6
9
864
792
678
642
620
BM
700
750
800
850
900
650
640
597
Adamson
7.5' QUAD.

STOP 7

SPILLWAY SECTION

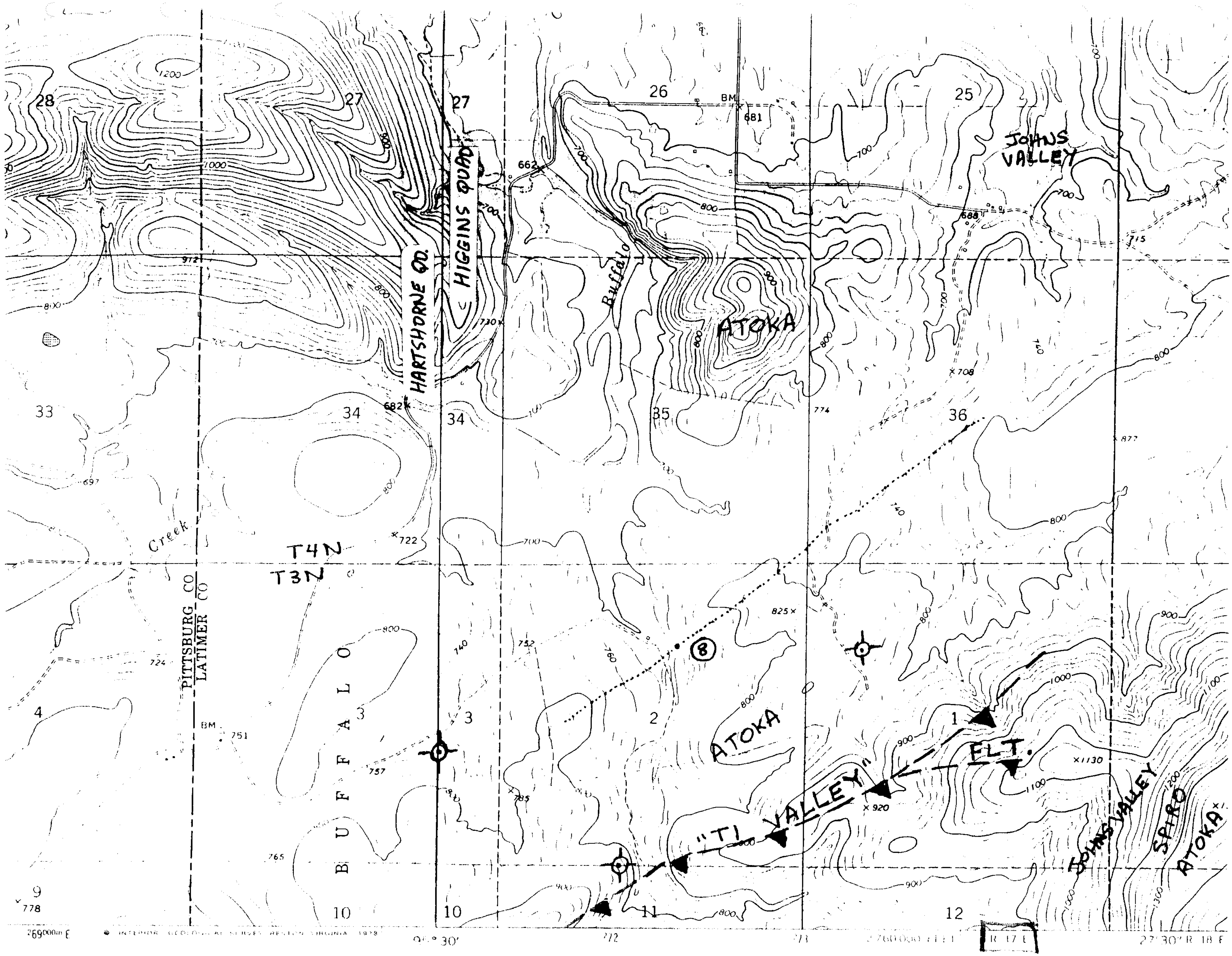
Adamson area, Pittsburg County, Oklahoma (Adamson 7.5′ Quadrangle map). Measured in eroded spillway of unnamed, small lake.

	Thickness (ft)
PENNSYLVANIAN	
KREBS GROUP	
Savanna Formation	
8. Sandstone to coarse siltstone, grayish orange (10YR7/4), very fine grained, massive to cross-stratified in lower part, wavy bedded in upper part, contains some soft-sediment deformation features, interbedded with shale, thickness laterally variable	4.5
7. Shale, grayish orange (10YR7/4) to pale yellowish brown (10YR6/2), soft, clayey, weathered	4.0
6. Siltstone, yellowish gray (10YR7/4), coarse-grained, poddy; contains cross-laminations and soft-sediment deformation features; laterally discontinuous	1.0
5. Shale, medium dark gray (N4), to medium bluish gray (5B5/1), slightly silty, soft; contains moderate yellowish brown (10YR5/4) limonitic, shaly, concretionary lenses	11.0
4. Shale, grayish black (N2) with moderate yellowish brown (10YR5/4) streaks, very silty and sandy, soft, highly carbonaceous; interlayered with upper part of underlying unit	0.05
3. Limestone, light gray (N7), weathers to dark yellowish orange (10YR6/6) and moderate red (5R4/6), iron-rich; occurs as stromatolitic beds with hemispherical growth forms; individual growth forms coalesce to produce both small and large domal mounds; base highly undulatory; thickness varies from 10 to 14 in.	1.0
2. Shale, grayish black (N2) with moderate yellowish brown (10YR5/4) streaks, very silty and sandy, soft, highly carbonaceous, thickness variable from 1 to 3 in.	0.2
1. Sandstone and silty shale, sandstone is medium light gray (N6), to light olive gray (5Y6/1), very fine grained, thin- to-medium-bedded, parallel-bedded, very strongly ripple-marked, numerous ripple bed forms exposed on bed surfaces, bioturbated, trace fossils on crests and in troughs of ripples, contains macerated plant fragments, beds up to 1 ft thick, includes several rooted Stigmarian systems ~18 in. below stromatolites; 4- to-10-in.-thick interbedded shale units are medium gray (N5) with pale reddish brown (10R5/4) staining, silty, sandy, micaceous, contains macerated plant material and millimeter-thick sandstone stringers; a 1.5-ft thick, sandy, silty shale bed is in contact with the overlying carbonaceous shale unit; base of lowermost sandstone bed is covered by spillway concrete	11.5
Total thickness of section	33.25

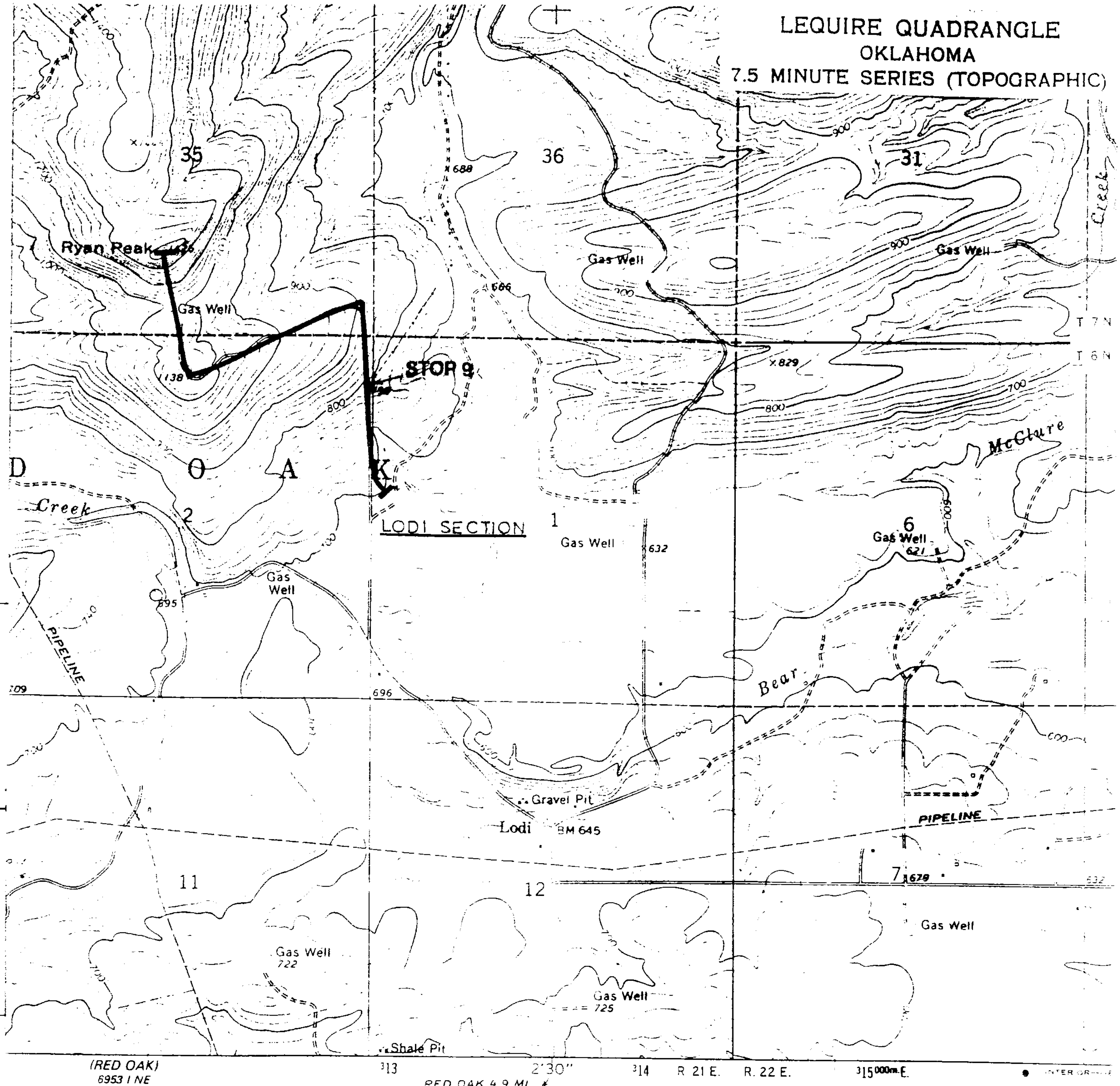
STOP 8 (OPTIONAL). CALCAREOUS TURBIDITE SANDSTONE IN ATOKA FORMATION SOUTH OF CHOCTAW FAULT

Location: On east side of tributary to Buffalo Creek, near center W/2 W/2 NE/4 sec. 2, T3N R17E, Higgins 7.5' quadrangle, Latimer County, Oklahoma.

Stratigraphic position: In upper(?) part of Atoka Formation. Queried because overlying formation (Hartshorne equivalent?) has never been recognized in the Ouachita Mountains. At least 3500' of Atoka Formation overlies this sandstone, before being cutoff by the "Ti Valley" fault. Bob Grayson (Baylor) reported upper Atokan conodonts from this unit, but left open the possibility that this or immediately overlying part of the Atoka Formation may actually be Desmoinesian.



JOHNS VALLEY
ATOKA
HIGGINS QUAD
HARTSHORNE QD.
Buffalo
Creek
T4N
T3N
PITTSBURG CO
LATIMER CO
B U F F A L O
ATOKA
"T1 VALLEY" FLT.
JOHNS VALLEY
SPIRO
ATOKA



SCALE 1:24000

1 MILE

1000 0 1000 2000 3000 4000 5000 6000 7000 FEET

1 KILOMETER

CONTOUR INTERVAL 20 FEET
NATIONAL GEODETIC VERTICAL DATUM OF 1929

ROA

Secondary highway, all weather, hard surface

Unimproved road, fair or dry weather

OKLAHOMA

QUADRANGLE LOCATION

...ES WITH NATIONAL MAP ACCURACY STANDARDS
...URVEY, DENVER, COLORADO 80225, OR RESTON, VIRGINIA 22092
...A GEOLOGICAL SURVEY, NORMAN, OKLAHOMA 73069
...OGRAPHIC MAPS AND SYMBOLS IS AVAILABLE ON REQUEST

STOP 9

APPENDIX

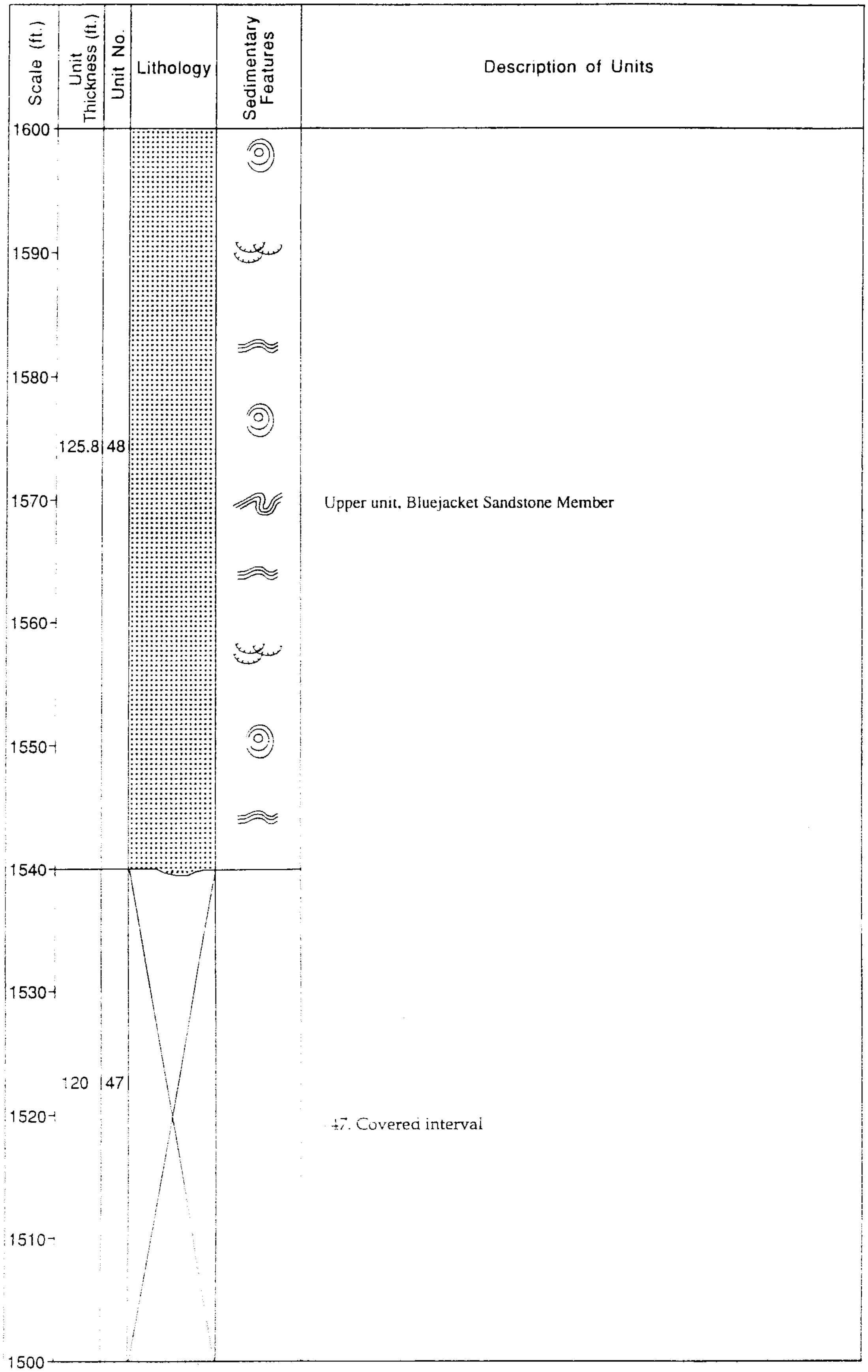
EXPLANATION

- Sandstone
- Sandstone, shaly
- Sandstone, silty
- Siltstone
- Shale
- Shale, sandy
- Black shale
- Shale, silty
- Covered interval

Sedimentary Features

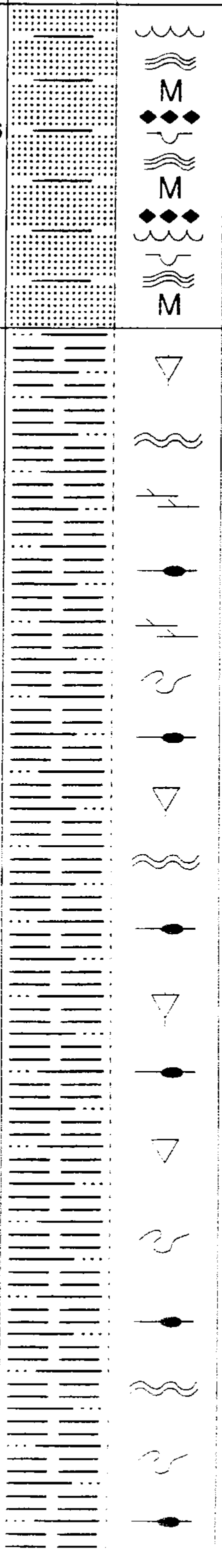
- Trough cross-stratification
- Low-angle cross-stratification
- Wavy bedding
- Nodular bedding
- Lenticular bedding
- Swaly bedding
- Pinch and swell
- Convolute bedding
- Slumped or contorted bedding
- Ripple marks
- Flow rolls
- Scour-and-fill
- Dewatering feature
- Groove cast
- Micaceous
- Calcareous
- Boxwork
- Ironstone band
- Ironstone concretion
- Fissile
- Stromatolites
- Plant stem
- Comminuted plant material
- Bioturbated
- Vertical burrow
- Horizontal burrow
- Coarsening-upward sequence

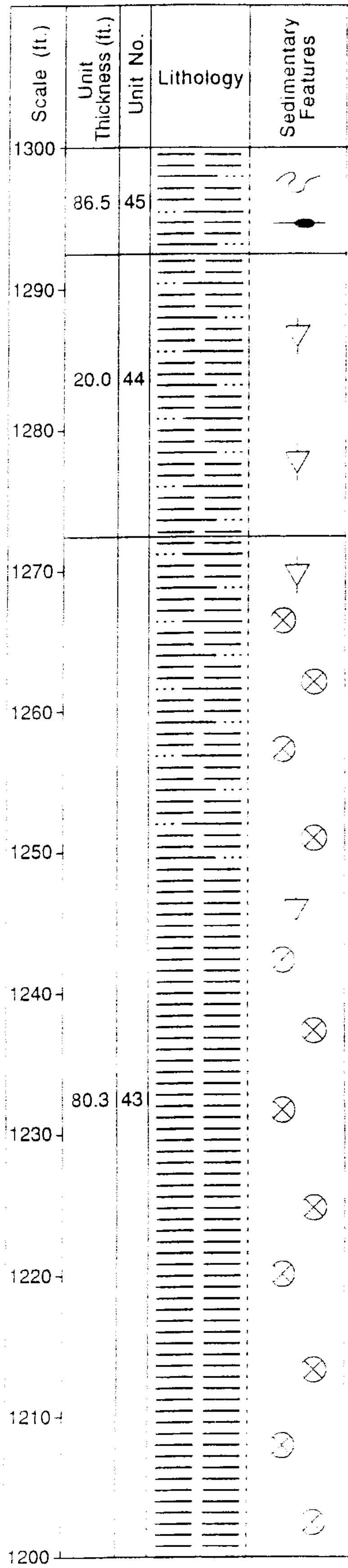
Scale (ft.)	Unit Thickness (ft.)	Unit No.	Lithology	Sedimentary Features	Description of Units
1700					
1690					
1680					
1670					
1660					
1650	125.8	48			
1640					KREBS GROUP Boggy Formation Bluejacket Sandstone Member: 48. Sandstone, dark yellowish orange (10YR6/6), weathers moderate yellowish 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)
1630					
1620					
1610					
1600					


Scale (ft.)
Unit Thickness (ft.)
Unit No.
Lithology
Sedimentary Features
Description of Units
1600
1590
1580
1570
1560
1550
1540
1530
1520
1510
1500
125.8
48
Upper unit, Bluejacket Sandstone Member
120
47
47. Covered interval

Scale (ft.)	Unit Thickness (ft.)	Unit No.	Lithology	Sedimentary Features	Description of Units
1500					
1490					
1480					
1470					
1460	120	47			47. Covered interval
1450					
1440					
1430					
1420					
1410	41.2	46			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)
1400					

Scale (ft.)	Unit Thickness (ft.)	Unit No.	Lithology	Sedimentary Features	Description of Units
1400–1380	41.2	46			Lower unit, Bluejacket Sandstone Member
					Boggy Formation
					Savanna Formation
1380–1300	86.5	45			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





Description of Units

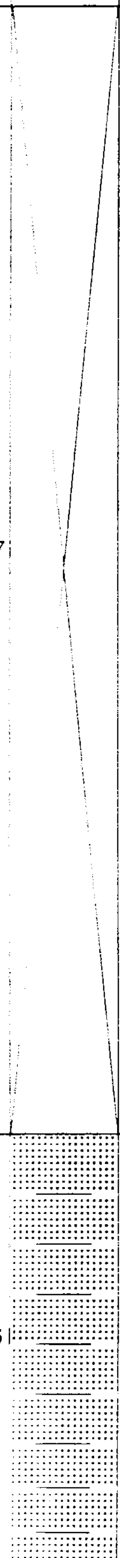
44. Shale, dark yellowish brown (10YR4/2), silty; contains well-indurated, light brown (5YR5/6) to moderate brown (5YR4/4) siltstone stringers that occur rhythmically about 1-2 ft apart and give the outcrop a ribbed appearance; base gradational

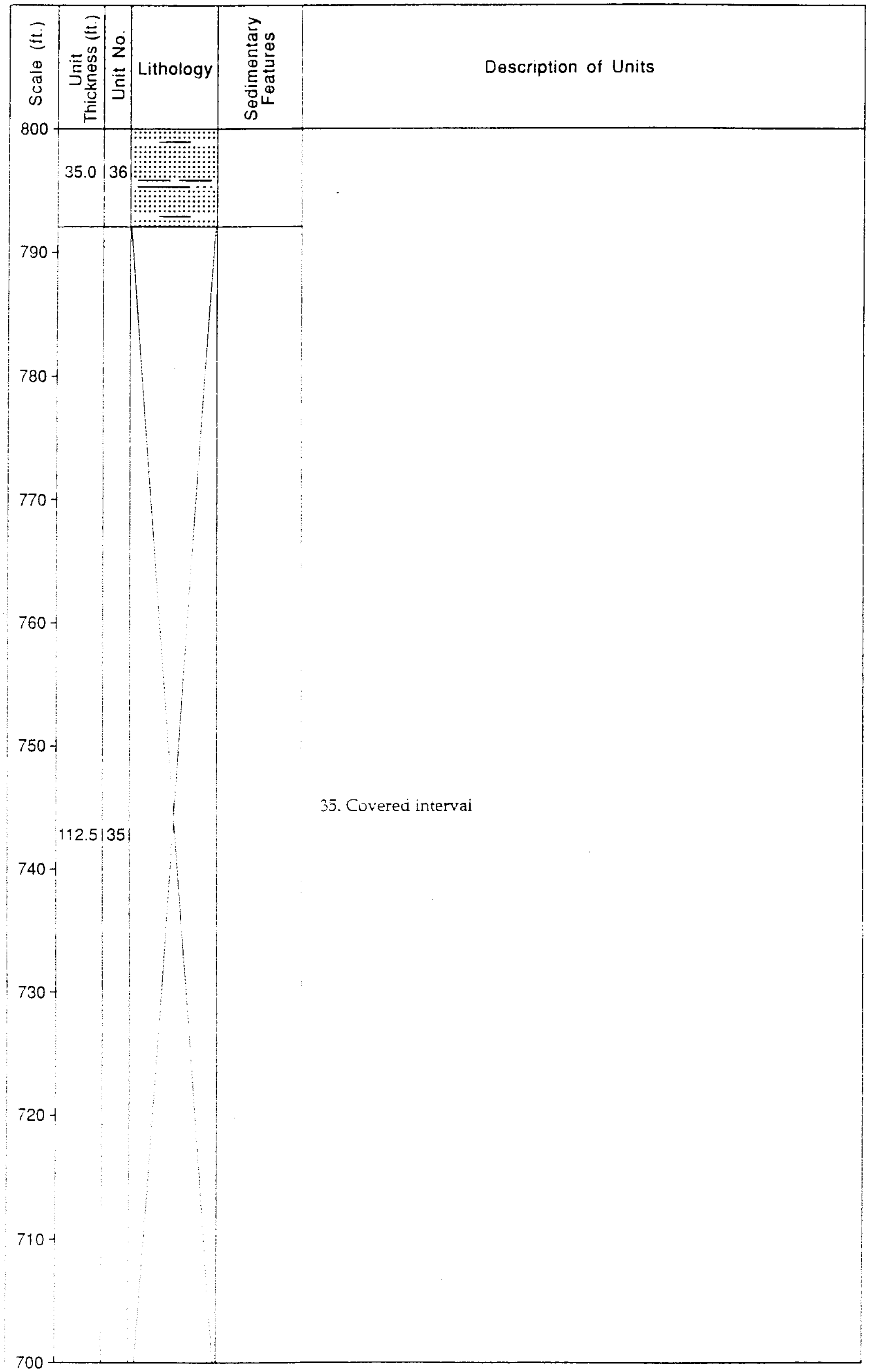
43. Shale, olive gray (5Y4/1), weathers moderate yellowish brown (10YR5/4); contains moderate reddish brown (10R4/6) iron-oxide crusts on some bedding surfaces as well as scattered ironstone concretions of the same color; becomes silty in upper 25 ft of unit

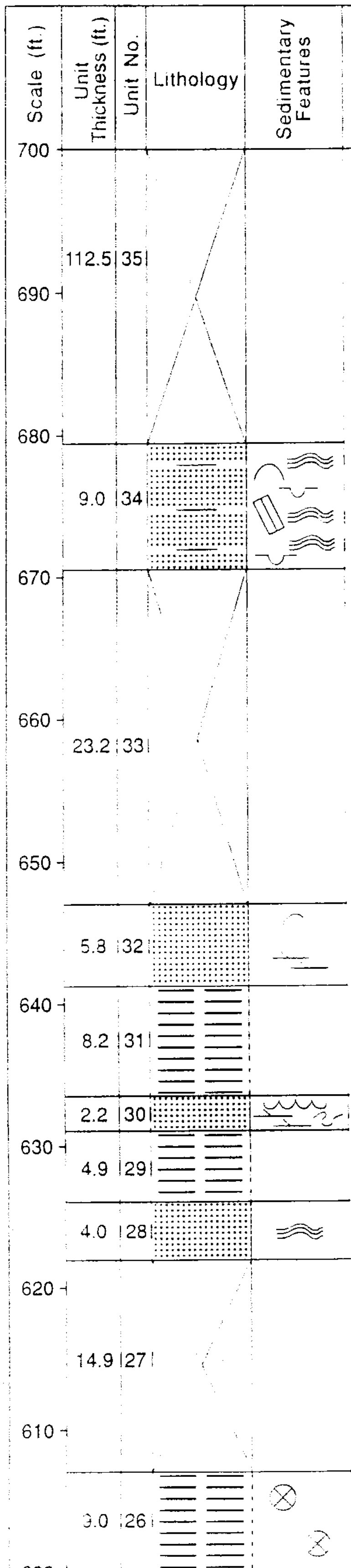
Scale (ft.)	Unit Thickness (ft.)	Unit No.	Lithology	Sedimentary Features	Description of Units
1200	80.3	43			
1190	8.0	42			42. Shale, black (N1), fissile; exposed at base of gully at northwest side of abandoned gas well pad
1180–1110	75.2	41			41. Covered interval
1110–1100	61.7	40			40. Sandstone, 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; reentrent erosion of dip-slope exposures in road bed indicate interbedded shales (covered) are present in this interval (Psv 7 ss)

Scale (ft.)	Unit Thickness (ft.)	Unit No.	Lithology	Sedimentary Features	Description of Units
1100–1047	67.1	40			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; reentrent erosion of dip-slope exposures in road bed indicate interbedded shales (covered) are present in this interval (Psv 7 ss)
1047–1000	122.1	39			39. Covered interval

Unit Thickness (ft.)	Unit No.	Description of Units
122.1	39	39. Covered interval
20.7	38	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 (Psv 6 ss)
77.8	37	37. Covered interval

Scale (ft.)	Unit Thickness (ft.)	Unit No.	Lithology	Sedimentary Features	Description of Units
900					
890					
880					
870					
	77.8	37			37. Covered interval
860					
850					
840					
830					
820					
	35.0	36			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; overlain by ~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 to the northeast along gas well road) (Psv 5 ss)
810					
800					


Scale (ft.)
Unit Thickness (ft.)
Unit No.
Lithology
Sedimentary Features
Description of Units
800
35.0
36
790
780
770
760
750
35. Covered interval
112.5
35
740
730
720
710
700



Description of Units

35. Covered interval

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 (Psv 4f ss)

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 (Psv 4e ss)

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

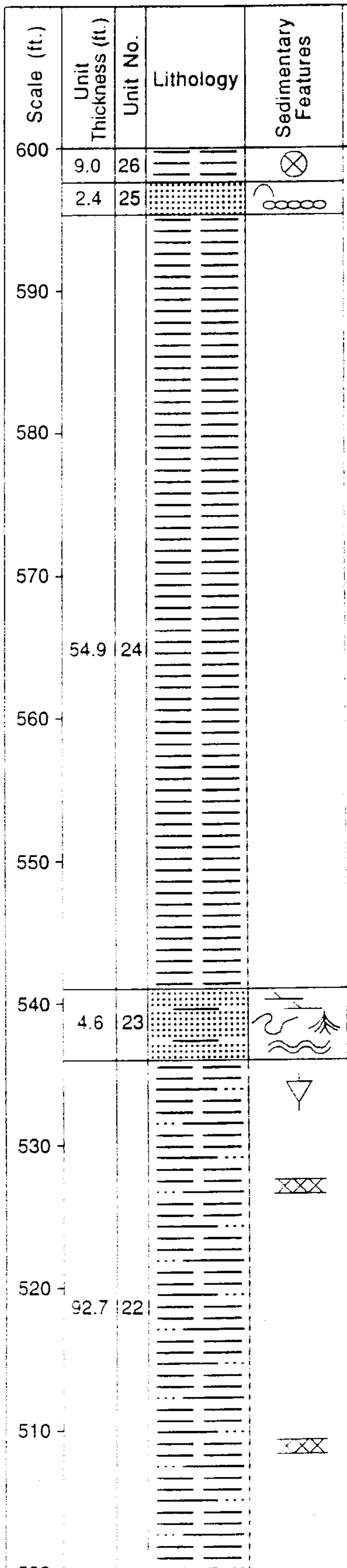
30. Sandstone, dark yellowish brown (10YR4/2), weathers grayish red (10R4/2) medium-bedded, contains low-angle cross-stratification, wavy-laminated to flat, parallel-bedded in part; minor bioturbation features on some surfaces; base sharp (Psv 4d ss)

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 (Psv 4c ss)

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



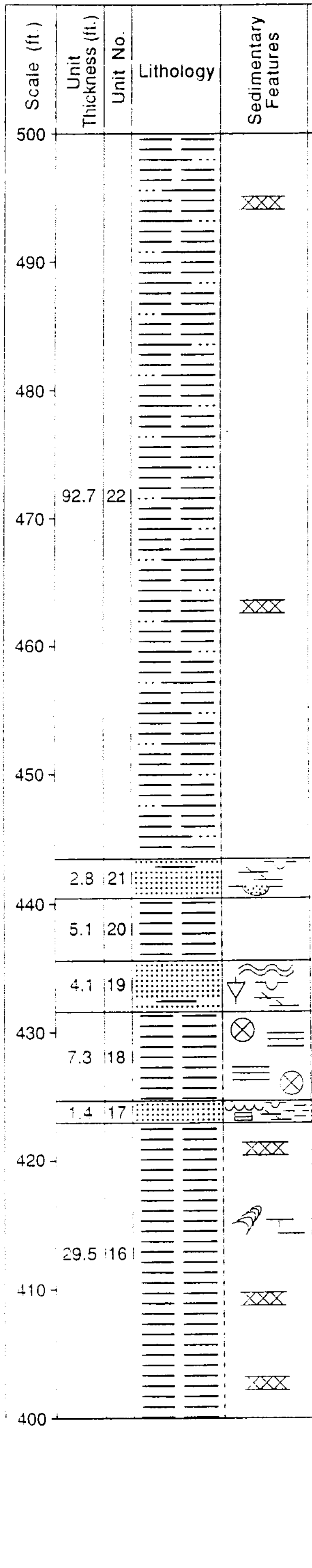
Description of Units

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 (Psv 4b ss)

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 (Psv 4a ss)

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



Description of Units

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

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 (Psv 3d ss)

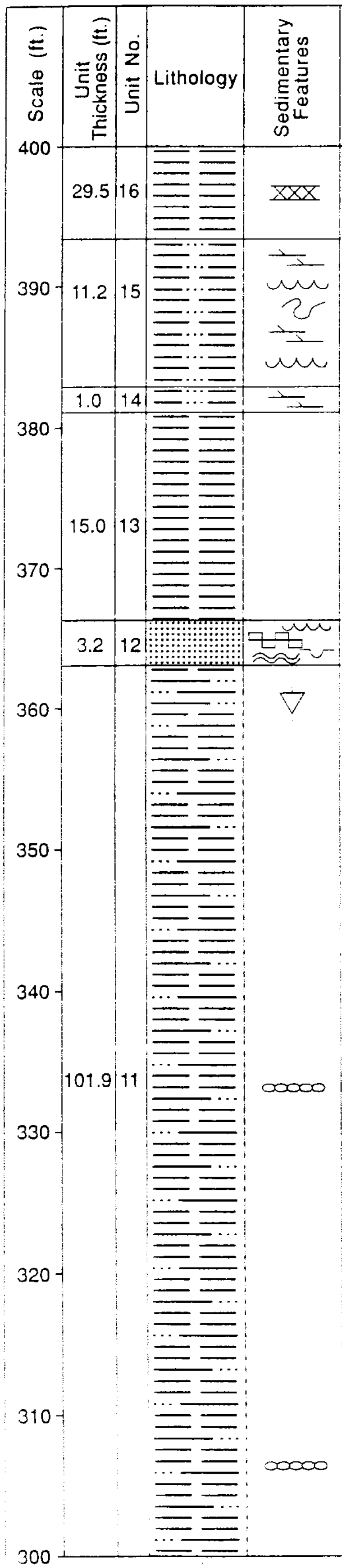
20. Shale, very light gray (N8) with dark yellowish orange (10YR6/6) and dusky brown (5YR2/2) staining; poorly exposed

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 (Psv 3c ss)

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 (Psv 3b ss)

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



Description of Units

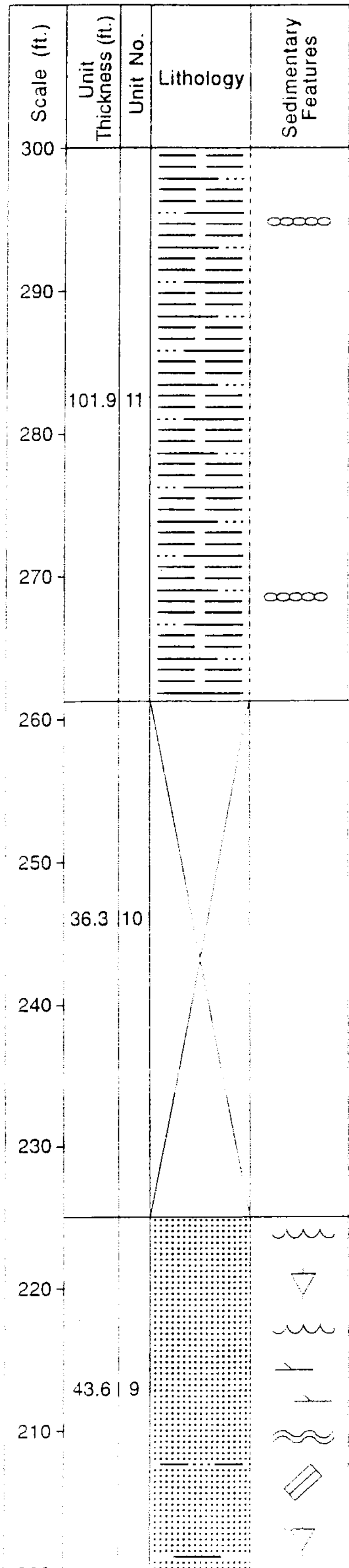
15. Siltstone and shale, interbedded, dusky yellow (5Y6/4), dark reddish brown (10R3/4) and blackish red (5R2/2) staining on bedding planes, very thin bedded, low-angle cross-laminations, indistinctly ripple marked, rare bioturbation features, base gradational

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 (Psv 3a ss)

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 in some intervals that form resistant ledges in gully; nodular bedded in places; some 0.5-in.-thick siltstone stringers in upper 3 ft

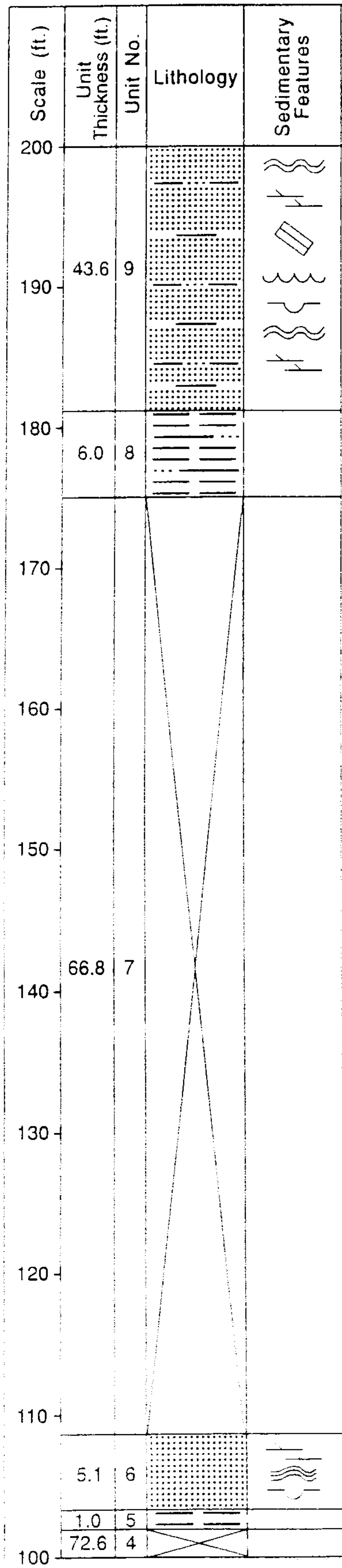


Description of Units

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 in some intervals that form resistant ledges in gully; nodular bedded in places; some 0.5-in.-thick siltstone stringers in upper 3 ft

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 (Psv 2 ss)



Description of Units

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

7. Covered interval

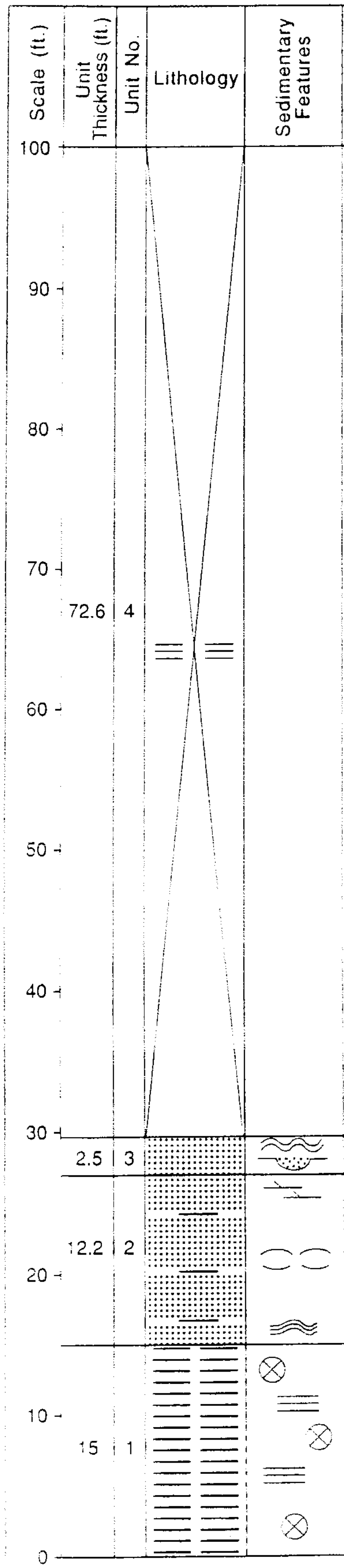
6. Sandstone, grayish orange (10YR7/4) to light brown (5YR6/4), weathers grayish red (5R4/2), very fine grained, mostly irregularly medium-bedded; massive in part, but has abundant internal low-angle cross-laminations in cross-section; trace fossils on some top and bottom surfaces; contains some lenses with soft-sediment deformation features; base sharp and irregular (Psv 1 ss) (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.)

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

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

Savanna Formation

McAlester Formation



Description of Units

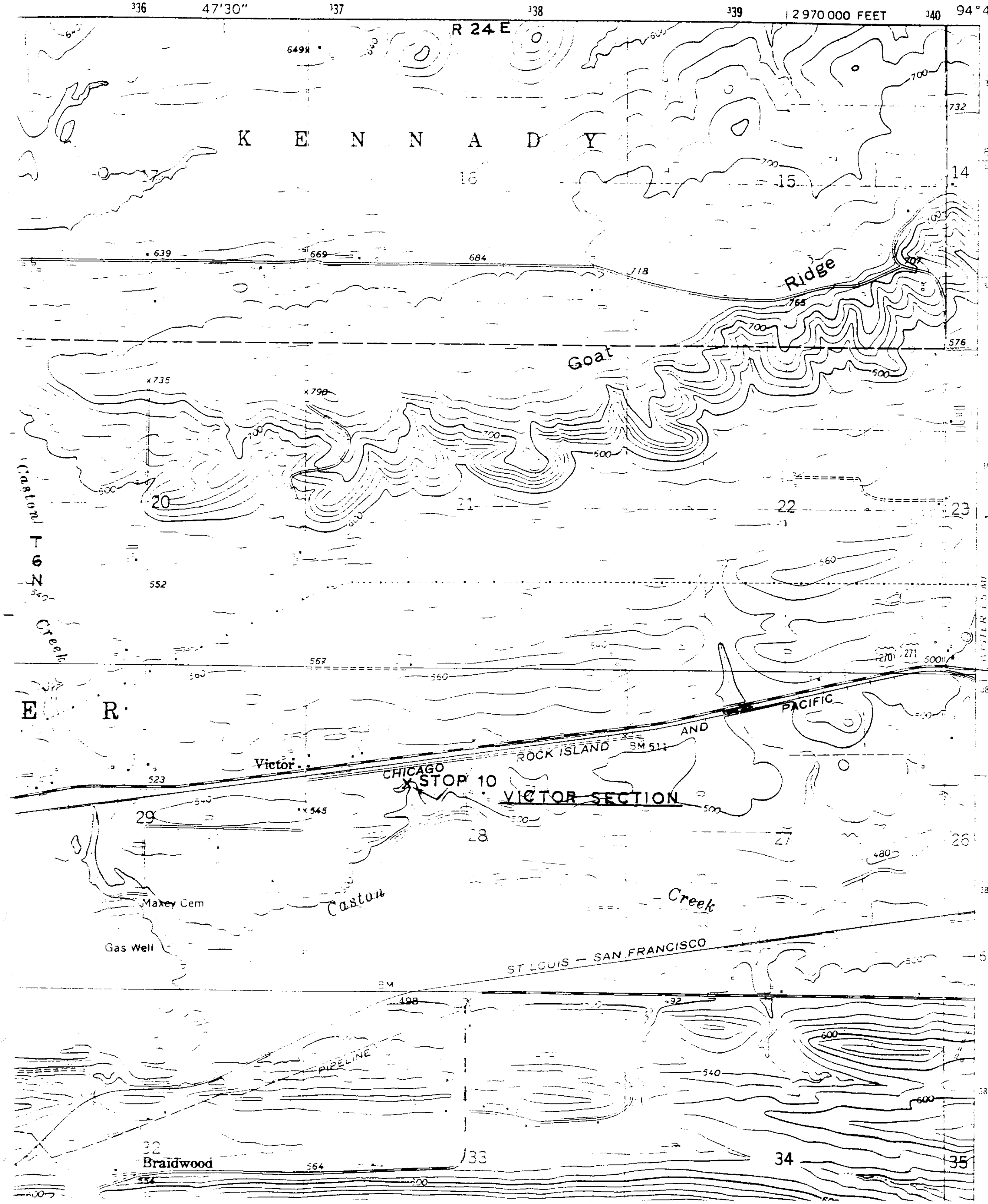
4. Covered interval with some poorly exposed shale; highly weathered, very pale orange (10YR8/2) shale with moderate reddish orange (10R6/6) mottling is exposed in road ditch east side of creek on north side of E-W road

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, top of unit covered

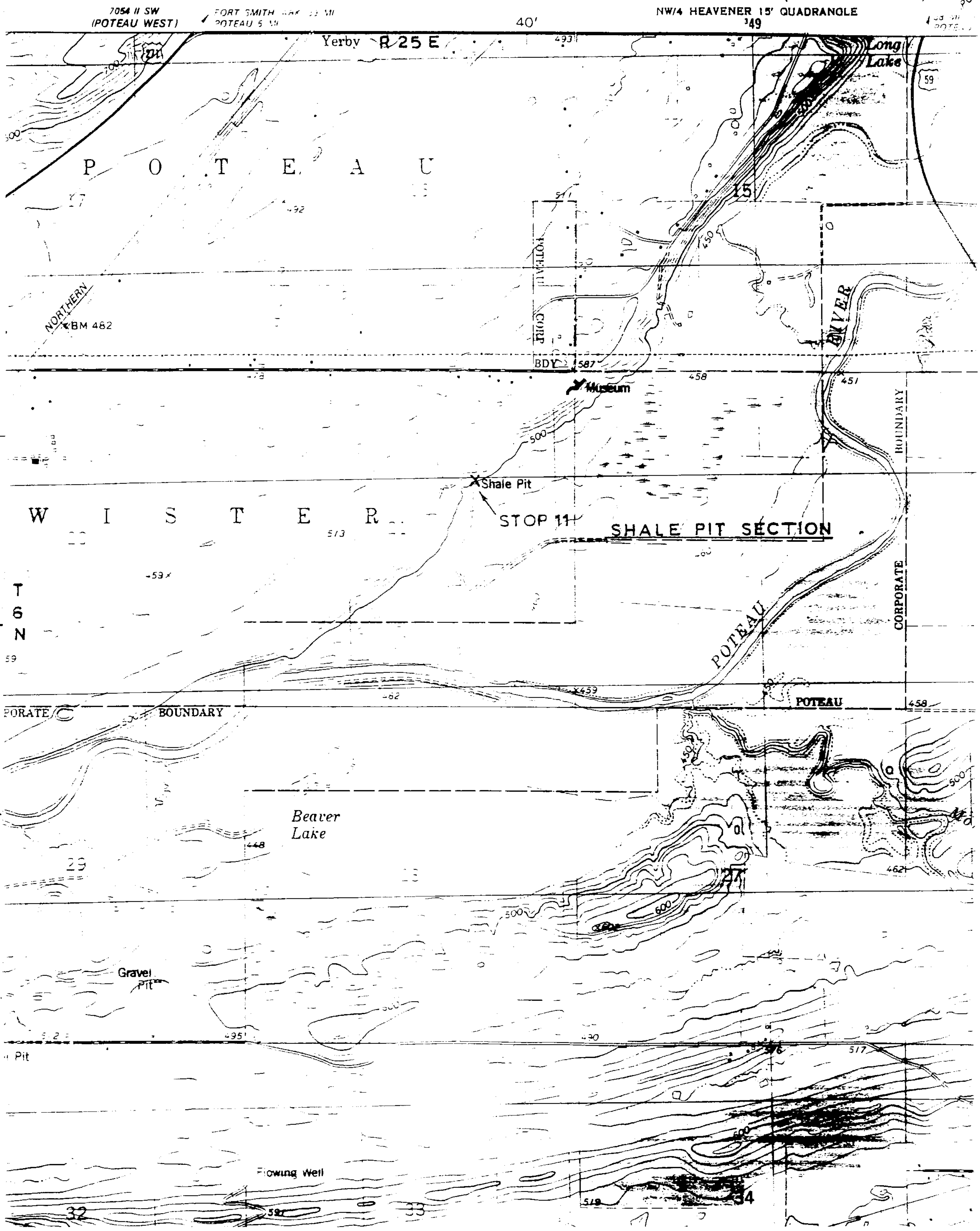
1. Shale, olive gray (5Y3/2) to light olive gray (5Y5/2); contains dark reddish brown (10R3/4) ironstone concretions about 3-4 in. in diameter and 0.5-1.0 in. thick; weathers to small flakes

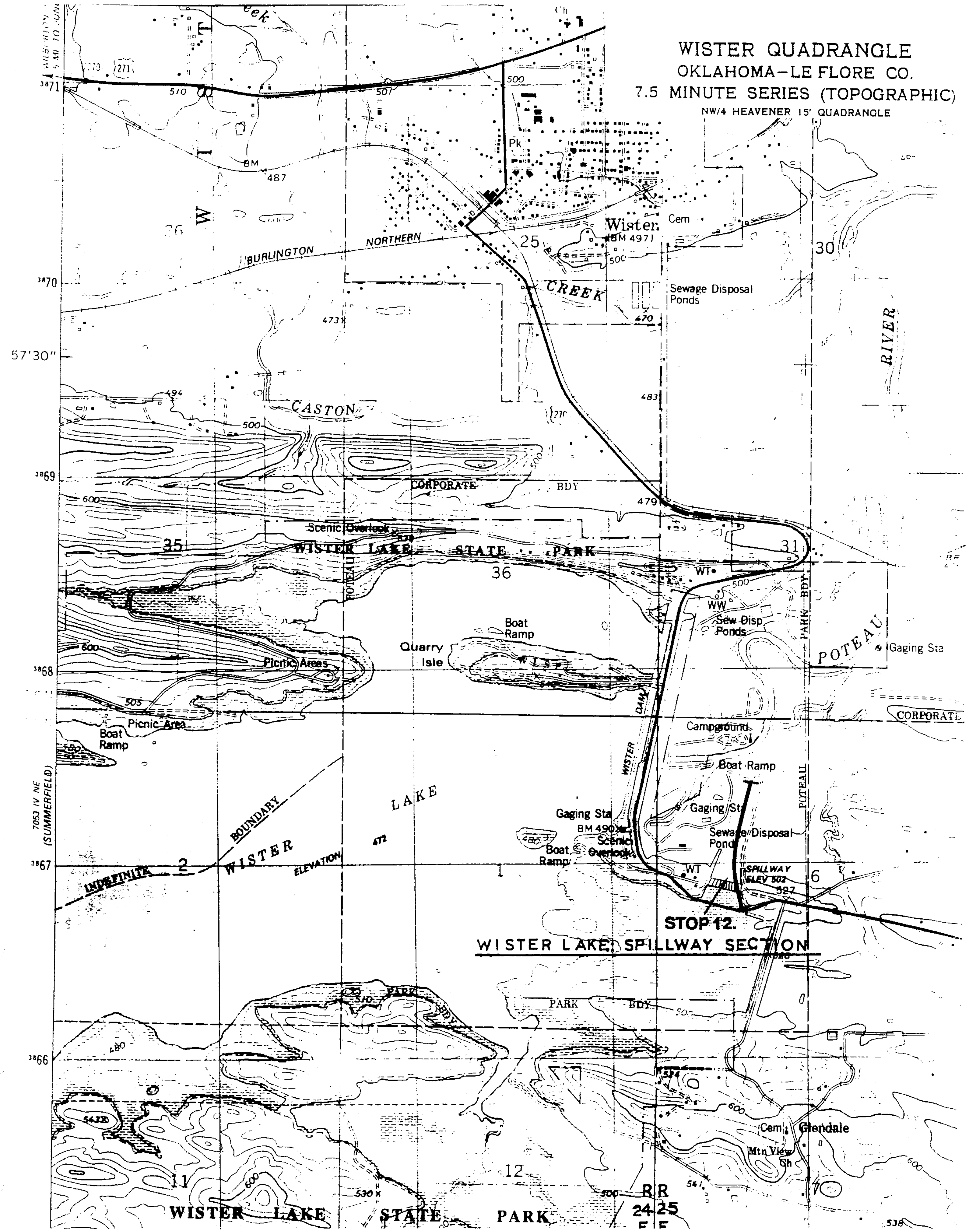
SUMMERFIELD QUADRANGLE
OKLAHOMA—LE FLORE CO.
7.5 MINUTE SERIES (TOPOGRAPHIC)



STATE OF OKLAHOMA

WISTER QUADRANGLE
OKLAHOMA-LE FLORE CO.
7.5 MINUTE SERIES (TOPOGRAPHIC)

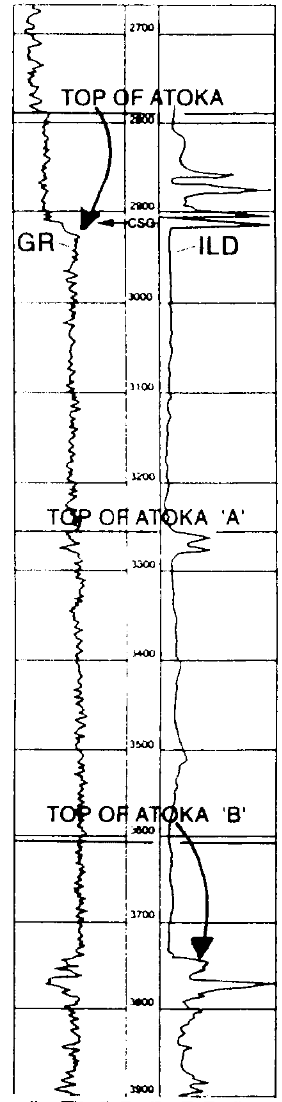




WISTER QUADRANGLE
OKLAHOMA–LE FLORE CO.
7.5 MINUTE SERIES (TOPOGRAPHIC)
NW/4 HEAVENER 15' QUADRANGLE
STOP 12.
WISTER LAKE SPILLWAY SECTION
Wister
BM 4971
Cem
BURLINGTON NORTHERN
CREEK
Sewage Disposal Ponds
CASTON
CORPORATE BDY
Scenic Overlook
WISTER LAKE STATE PARK
WT
WW
Sew Disp Ponds
POTEAU
RIVER
Gaging Sta
Boat Ramp
Quarry Isle
Picnic Areas
Picnic Area
Campground
WISTER DAM
Gaging Sta
BM 490
Scenic Overlook
Sewage Disposal Pond
SPILLWAY ELEV 502
INDEFINITE BOUNDARY
WISTER LAKE
ELEVATION 472
PARK BDY
Cem
Glendale
Mtn View Ch
WISTER LAKE STATE PARK
R 24 E
R 25 E
57'30"
7053 IV NE (SUMMERFIELD)

SYSTEM	SERIES	FORMATION	Stone, 1966	Hemish & Suneson 1993	Arco No. 1 Runestone 9 - 6N - 25E 1988
PENNSYLVANIAN	DESMOINESIAN	Upper Coal / HARTSHORNE / Lower Coal	HARTSHORNE	HARTSHORNE	HARTSHORNE
	ATOKAN	ATOKA	UPPER MEMBER	UNNAMED COALS	
				Ss. OF HORSESHOE RIDGE	* ATOKA "A" Ss.
				Ss. OF POTTS MTN.	* ATOKA "B" Ss.
				Ss. OF GLENDALE	ATOKA "C", "E", & "F" Ss.
			MIDDLE MEMBER		
			LOWER MEMBER		

* ATOKA "A"~ 400 ft. below base of Hartshorne Fm.
* ATOKA "B"~ 1000 ft. below base of Hartshorne Fm.



Major Gas Producing Sands
HARTSHORNE
"GILCREASE Ss."
"FANSHAWE Ss."
"RED OAK Ss"
"PANOLA Ss."
"DIAMOND Ss."
"BRAZIL Ss."
"BULLARD Ss."
"CECIL Ss."
"SHAY Ss."
"SPIRO Ss."
"FOSTER Ss."

STRATIGRAPHIC FRAMEWORK - ARKOMA BASIN

Stop 12

Sedimentology of the Upper Part of the Atoka Formation (Pennsylvanian), Wister Lake Spillway, Le Flore County, Oklahoma

James R. Chaplin
Oklahoma Geological Survey

Location: SW¼NW¼NE¼SW¼ sec. 6, T. 5 N., R. 25 E., Le Flore County

Permission to enter the spillway must be obtained at the U.S. Army Corps of Engineers' office located in Wister State Park.

SIGNIFICANCE

- spectacular exposures of the Atoka Formation (upper part), a stratigraphic interval rarely exposed
- superb sedimentary structures, particularly ripple bed forms that represent a range of flow velocities and directions
- overall thick, fining-upward transgressive shale sequence containing thin, coarsening-upward regressive sandstone sequences
- well-exposed tear fault on northern flank of the Heavener anticline that can be examined directly
- storm-influenced, mud-dominated shelf depositional setting
- first published petrographic or lithofacies study, of either a local or regional nature, on the upper part of the Atoka Formation in Oklahoma.

GEOLOGIC SETTING

Wister State Park is located in the southern part of the Arkoma Basin. The most prominent structural feature within the park is the Heavener anticline, which trends westerly across the area and extends well beyond the park boundaries. Wister Dam is located on the northern flank of the Heavener anticline where beds have a northward dip averaging ~26° and an average strike of N. 68° W. The Heavener anticline is broken on both flanks by numerous tear faults. One of these faults can be observed at this stop along the west side of the spillway where surface rocks (Unit 13) are offset ~10 ft (Fig. 7).

Figure 7. West side of Wister Dam spillway where a 3.3-ft.-thick sandstone bed (Unit 13, 199–202.3 ft interval) is offset ~10 ft by a fault. The Heavener anticline is broken on both flanks by numerous faults, but these faults rarely have surface expressions.

GENERAL STRATIGRAPHY

The rocks that crop out in Wister State Park are assigned to, in ascending order, the Atoka Formation (Atokan Series?) (~11,000 ft exposed in the vicinity of the park) and the Hartshorne (250–300 ft) and McAlester (900–950 ft) Formations (Desmoinesian Stage). Lithologically, the succession is composed dominantly of dark gray (N3) to medium dark gray (N4), noncalcareous, silty shale and subordinate amounts of ripple-marked, locally cross-bedded, very fine grained sandstones, some very discontinuous (Fig. 8). A detailed lithologic description of the upper part of the Atoka Formation is given in Measured Section, Stop 3. Figure 8 shows unit thicknesses, thin-section and shale-sampling intervals, lithologic succession, depositional textures, level of bioturbation, sedimentary features, and thin-section photomicrographs from certain intervals.

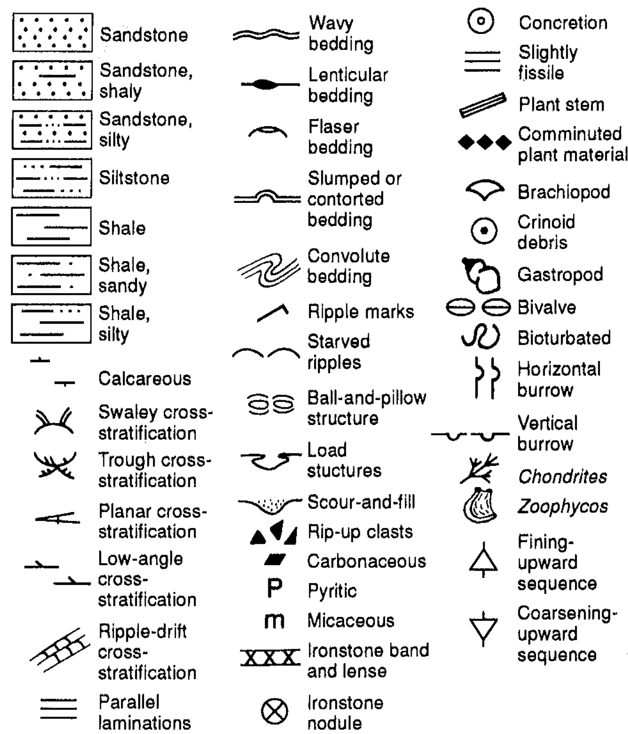


Figure 8 *(p. 15–22).* Diagram of measured stratigraphic section of the Atoka Formation (upper part) at Wister Dam spillway. Unit number and thickness, lithology, depositional texture, level of bioturbation, and sedimentary features are shown. Explanation of symbols is shown above.

The approximate stratigraphic positions from which shale samples (*) and thin sections (e.g., 26-1) were taken are marked. Thin sections have two numbers: the first number identifies the unit from which the sample was collected, and the second number designates the stratigraphic position of the sample within that particular unit (e.g., of the three thin sections collected from Unit 26, 26-1 was collected from the lowest stratigraphic position within that unit). Not all thin sections are represented by photomicrographs.

The level of bioturbation may vary slightly throughout any unit; therefore, the assigned ichnofabric index only represents the general overall intensity of bioturbation throughout that particular unit.

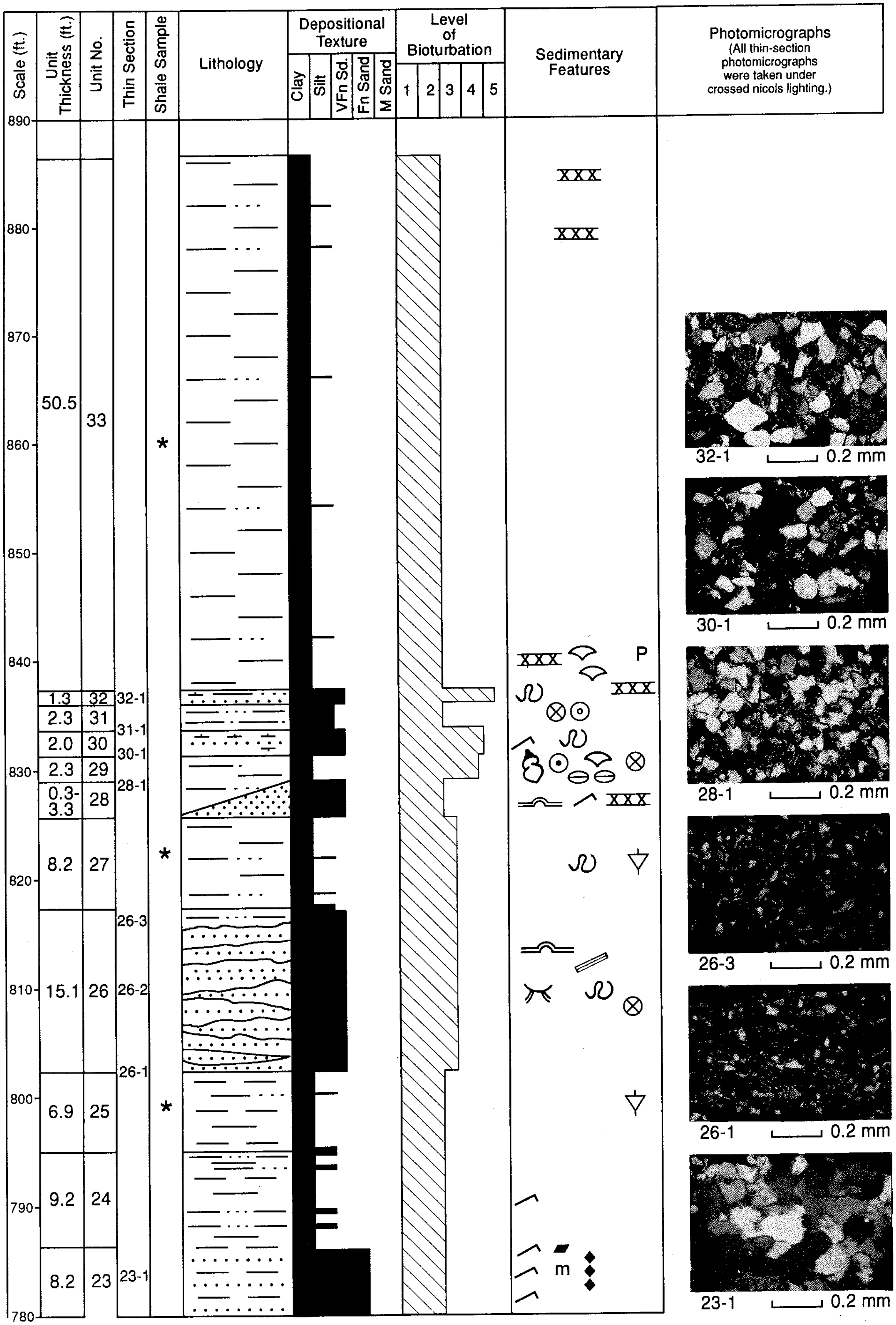


Figure 8 *(continued)*.

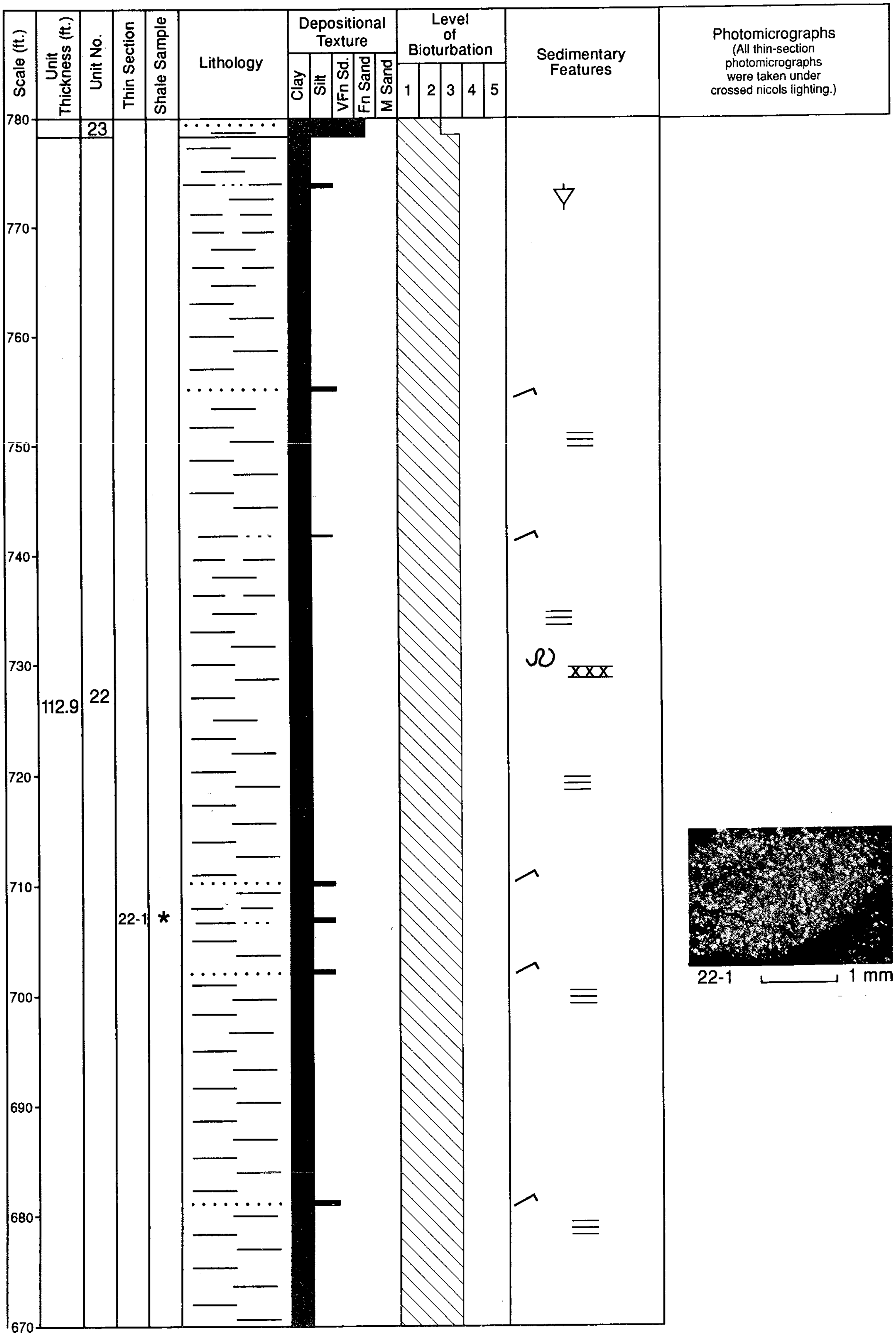


Figure 8 *(continued)*.

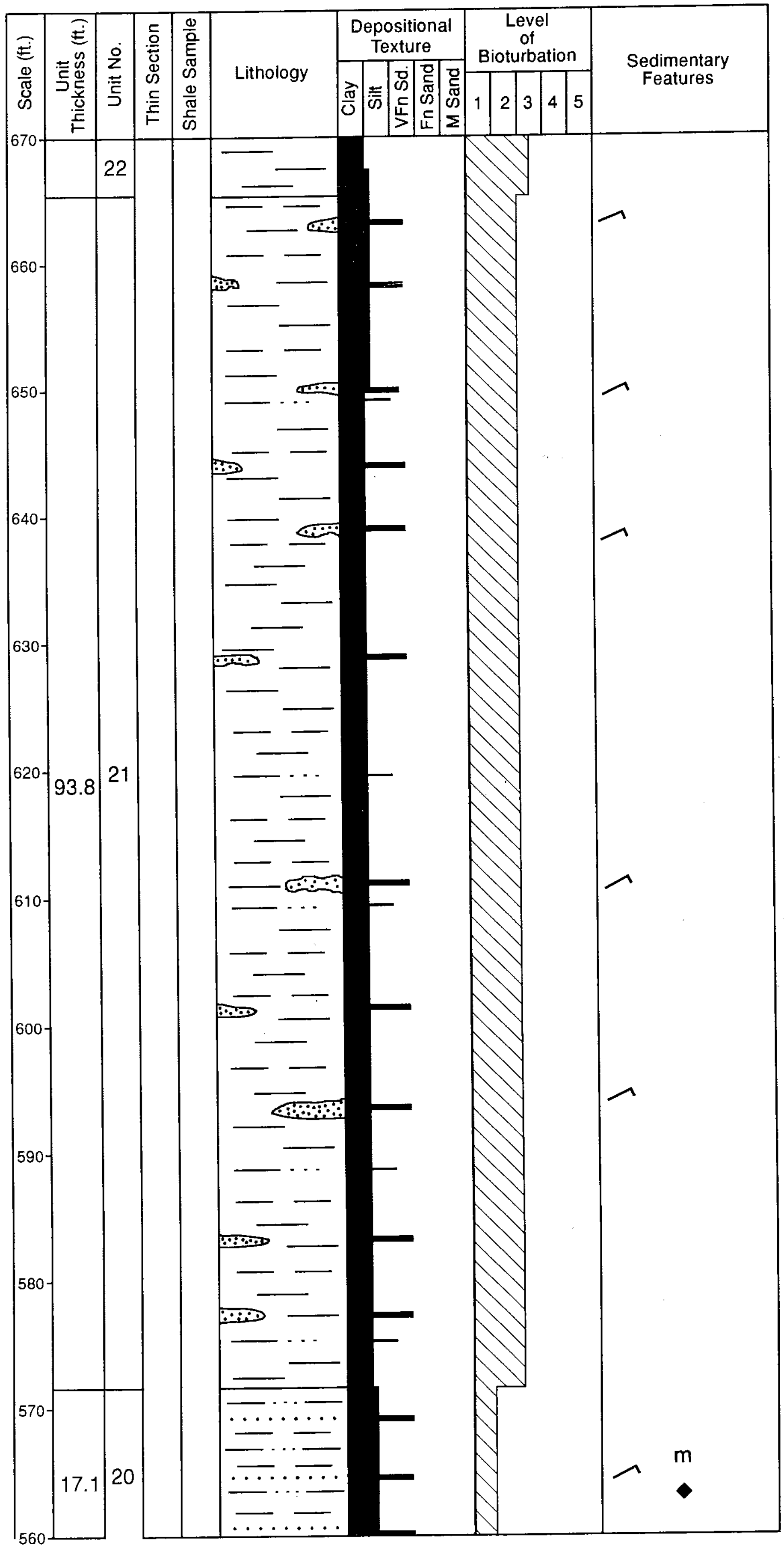


Figure 8 *(continued)*.

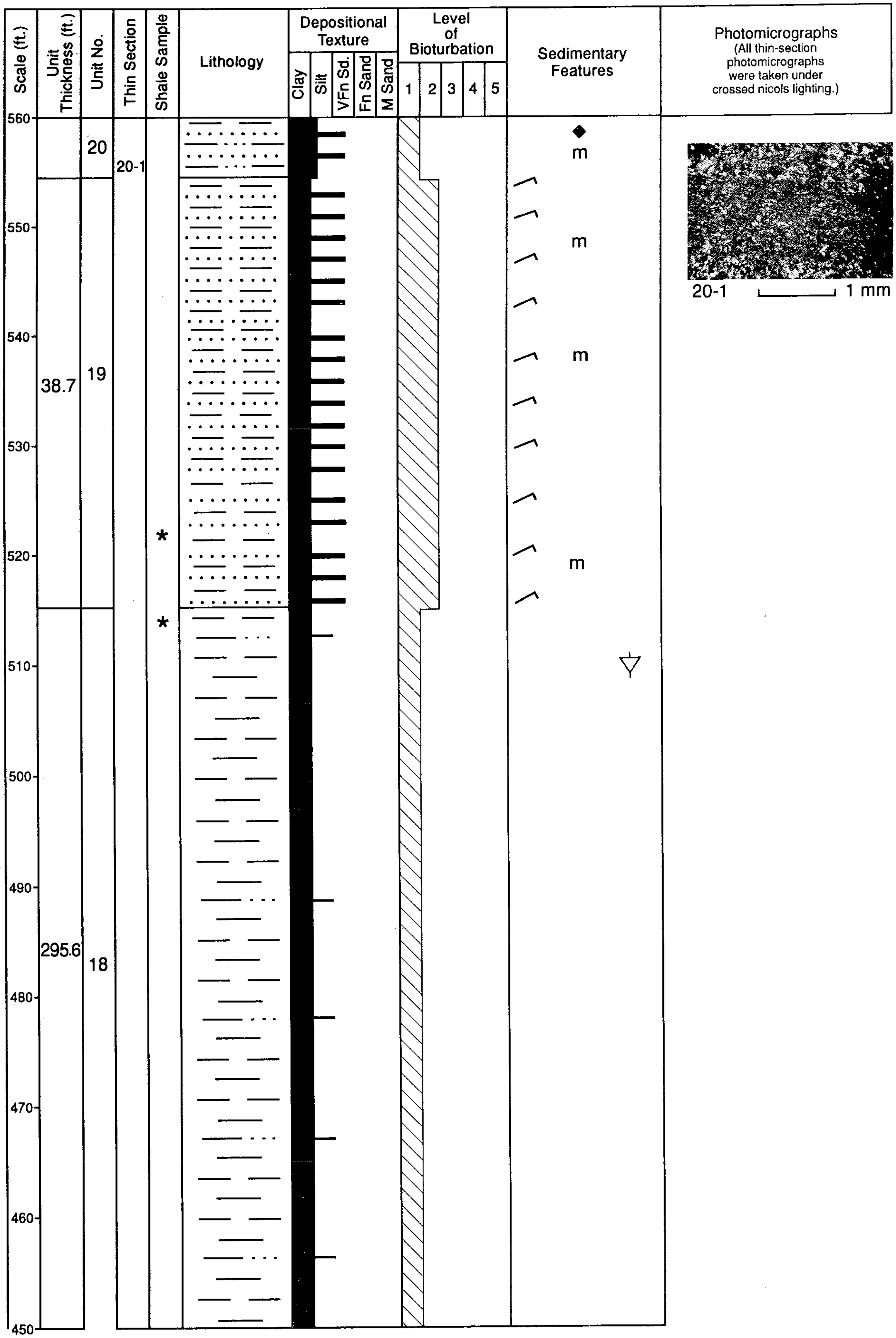


Figure 8 *(continued)*.

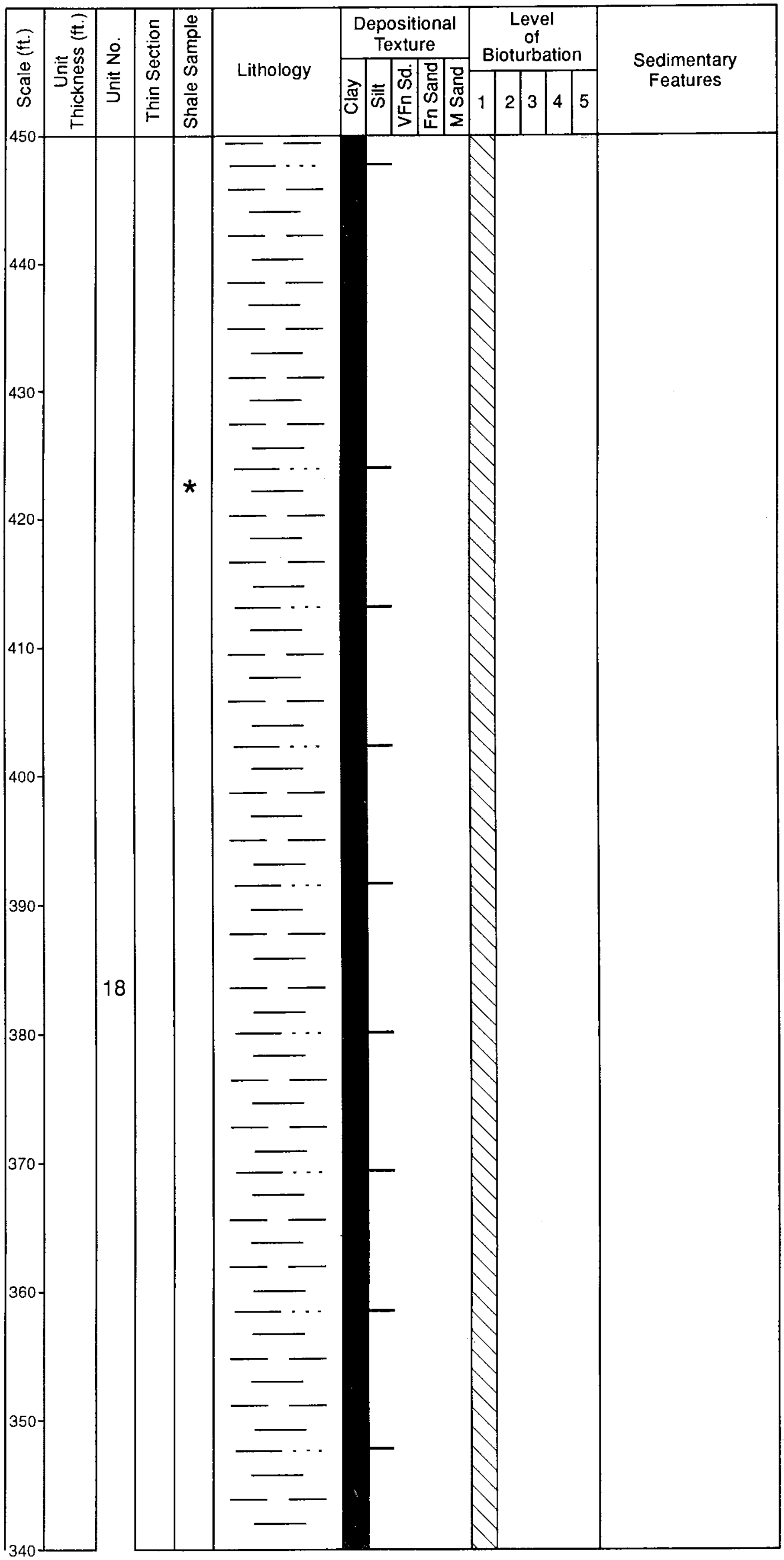


Figure 8 *(continued)*.

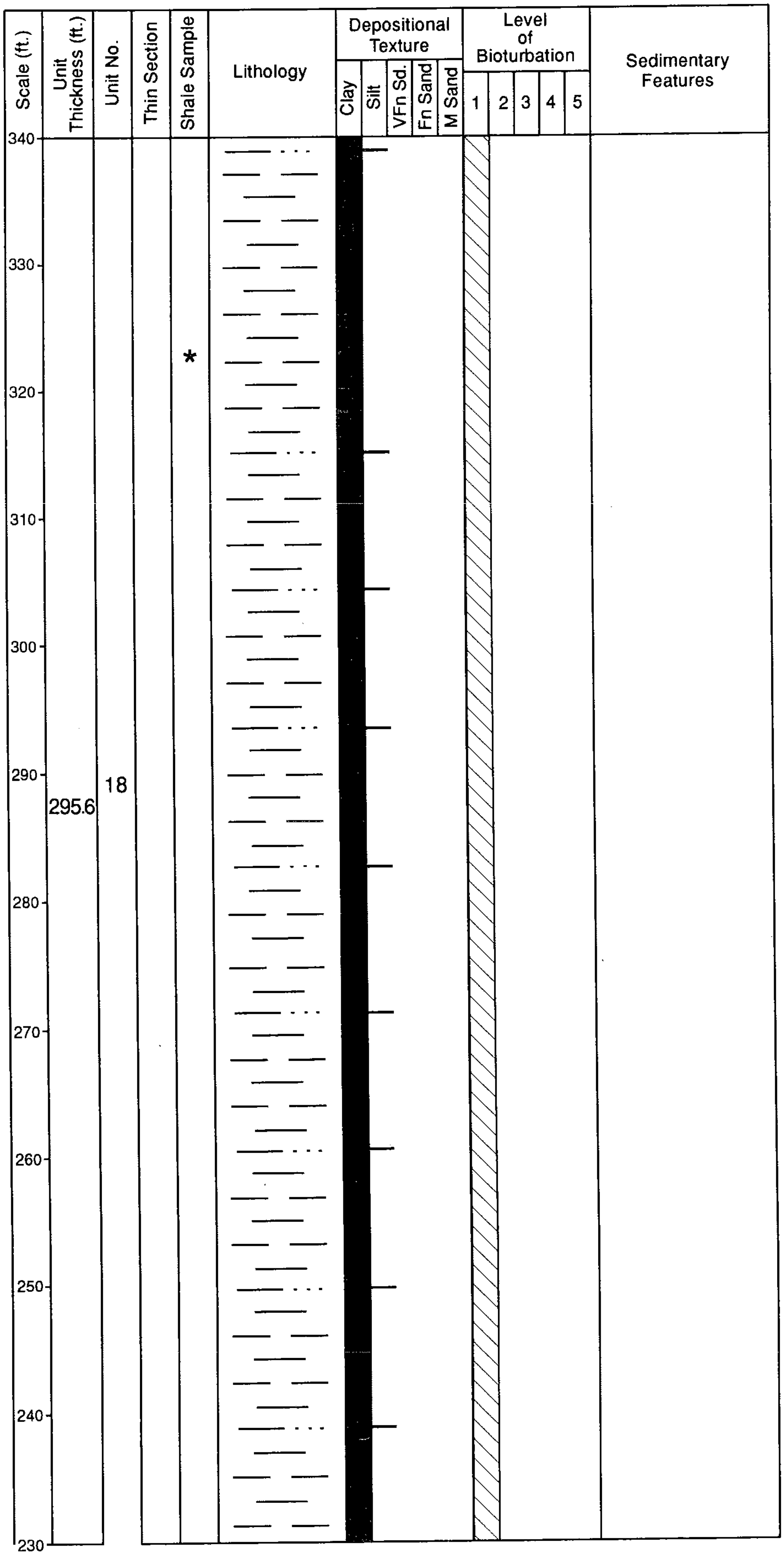


Figure 8 *(continued)*.

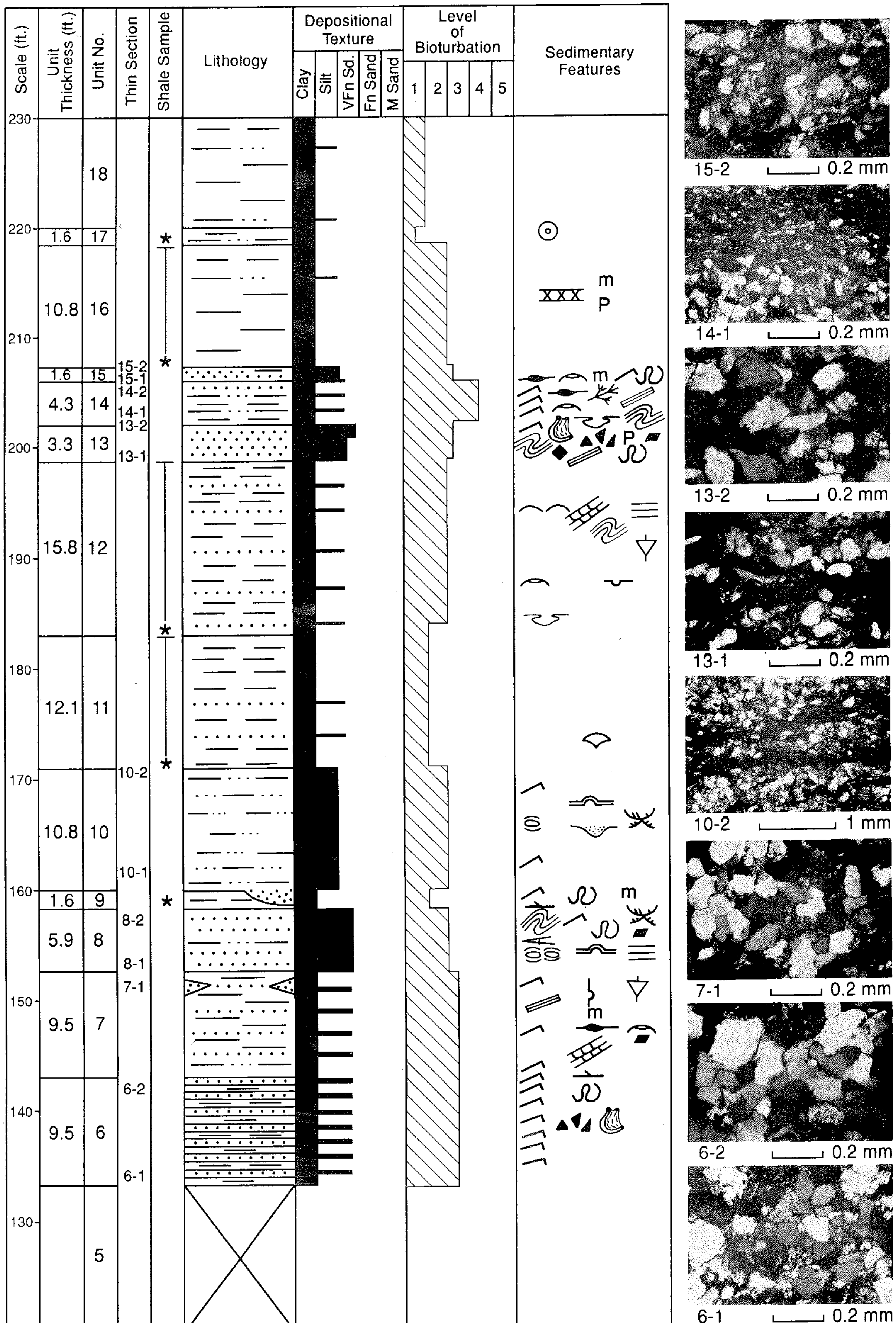


Figure 8 *(continued)*.

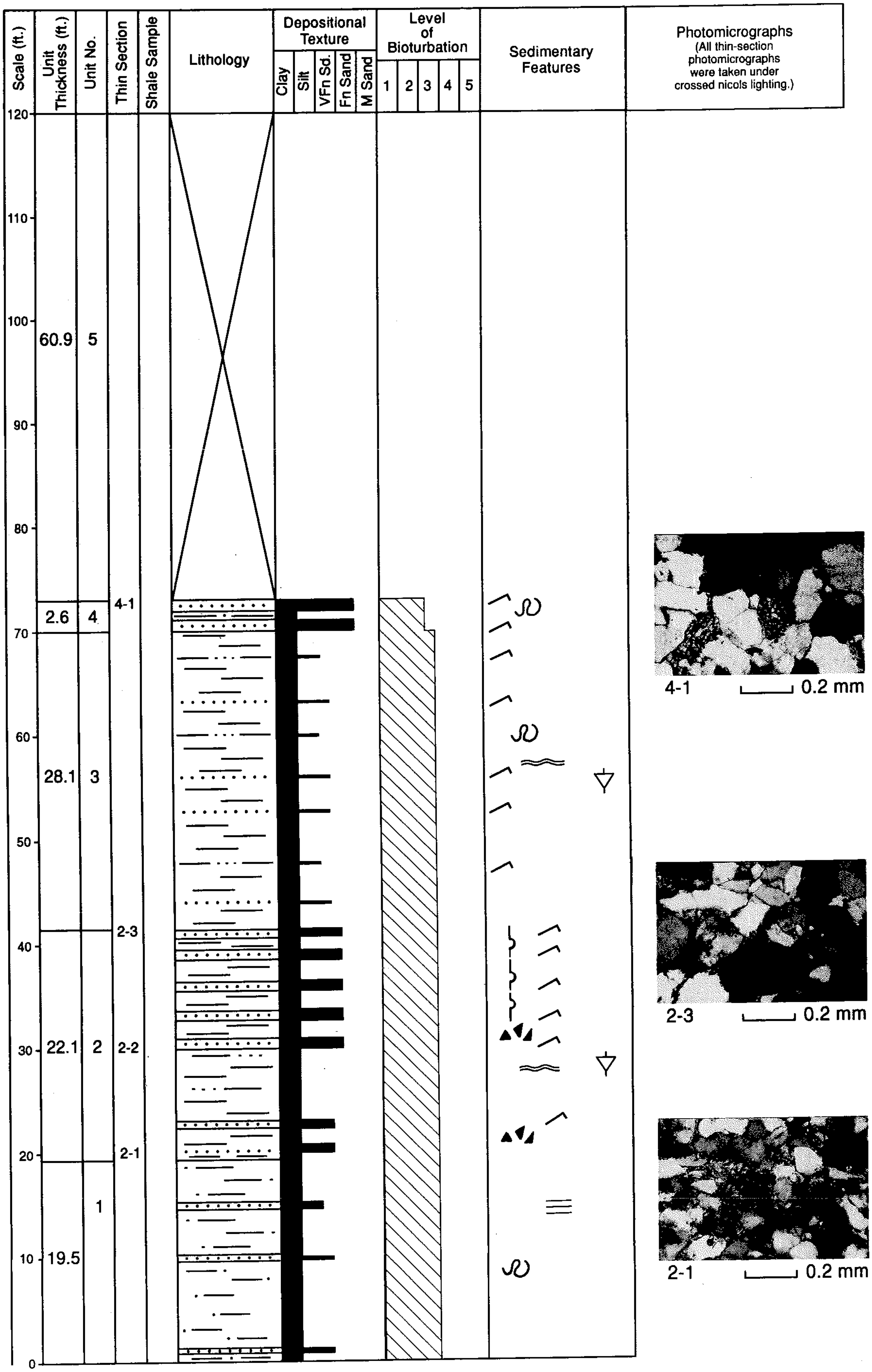


Figure 8 *(continued)*.

Measured Section, Stop 3

Atoka Formation (upper part)

SW¼NW¼NE¼SW¼ sec. 6, T. 5 N., R. 25 E., Wister quadrangle, Le Flore County. Measured from base of exposure just south of spillway overlook northward below spillway to gate at lower end of cut. Section measured perpendicular to east-west strike. Average strike N. 68° W., average dip 26° north-northeast. (Measured by James Chaplin, LeRoy Hemish, and Mark Keys.)

	Thickness (feet)
33. Shale, dark gray (N3) to very dusky red purple (5RP 2/2), silty, noncalcareous; contains some dark reddish brown (10R3/4) ironstone layers at top of unit; includes a 2–4 in. thick ironstone layer ~1 ft above the base containing abundant chonetid- and spiriferid-type brachiopods; some brachiopods are pyritized, others are calcareous; weakly (2) bioturbated; gradational base; nonresistant unit; top not exposed (shale sample A 33-1, middle of unit)	50.5
32. Interstratified medium gray (N5), very fine grained sandstone and siltstone, very shaly; calcareous in certain intervals; contains very abundant trace fossils; strongly (4) bioturbated to churned (5), top weathers to shaly siltstone with abundant brachiopods; gradational base; (thin section sample A 32-1)	1.3
31. Shale, dark gray (N3), sandy to silty, noncalcareous; includes some 1–2-in.-thick siltstone/sandstone layers and dark reddish brown (10R3/4) and dark yellowish orange (10YR6/6) ironstone lenses/nodules/concretions; weakly (2) bioturbated; gradational base (thin section sample A 31-1, very fine grained sandstone/siltstone stringer ~1 ft above base)	2.3
30. Interstratified medium light gray (N6) and medium dark gray (N4) siltstone/sandstone and grayish purple (5P4/2), silty shale, calcareous; highly ripple bedded; sandstone, very fine grained, noncalcareous; moderately (3) to strongly (4) bioturbated; gradational base; resistant unit; (thin section sample A 30-1, at base of unit)	2.0
29. Shale, medium dark gray (N4), sandy to silty, soft, noncalcareous; very fossiliferous, particularly at top with brachiopods, crinoidal debris, bivalves (some encrusting), and gastropods; includes some dark reddish brown (10R3/4), ironstone nodules; moderately bioturbated (3); base sharp; nonresistant unit; (shale sample A 29-1, continuous)	2.3
28. Sandstone, light bluish gray (5B7/1), medium light gray (N6), noncalcareous, very fine grained, thin- to medium-bedded, rippled; includes rare soft-sediment deformation feature (contorted bedding); contains some dark reddish brown (10R3/4) ironstone bands/lenses; weakly (2) bioturbated; irregular base; lenticular sandstone body ~26.3 ft wide; resistant unit; (thin section sample A 28-1, rippled sandstone lens near top)	0.3–3.3
27. Shale, medium bluish gray (5B5/1) and medium dark gray (N4), silty, noncalcareous; includes minor siltstone stringers; weakly (2) to moderately (3) bioturbated; weathers to flakes/chips; nonresistant unit; sharp base; (shale sample A 27-1, middle of unit)	8.2
26. Sandstone/siltstone, medium light gray (N6), light bluish gray (5B7/1), noncalcareous, very fine grained; grades into siltstone at top; irregular bedded; some small-scale soft-sediment deformation features; shaly near top; rare swaley cross-stratification; contains trace fossils, plant fossils, and ironstone nodules; fractured; dark yellowish orange (10YR6/6) staining on outcrop surface; weakly (2) to moderately (3) bioturbated in certain intervals; sharp base; very resistant unit; (thin section sample A 26-1, base of unit; A 26-2, middle of unit; A 26-3, just below top of unit)	15.1
25. Shale, medium bluish gray (5B5/1) and medium dark gray (N4), noncalcareous, silty, soft, weathers smoothly; includes some siltstone stringers/lenses; weakly (2) bioturbated; gradational base; (shale sample A 25-1, middle of unit, continuous)	6.9
24. Interstratified dark gray (N3) to grayish purple (5P 4/2), noncalcareous, micaceous, silty shale (60%) and shaly siltstone/sandstone (40%); 1–2-in.-thick, rippled, shaly siltstone/very fine grained sandstone beds throughout; weakly (2) bioturbated; gradational base	9.2
23. Interstratified silty shale (50%) and shaly siltstone/sandstone (50%); shale, dark gray (N3), silty, noncalcareous; sandstone, medium gray (N5) and grayish red purple (5RP4/2), noncalcareous, fine- to very fine grained, dominantly fine grained, rippled, highly micaceous and rippled unit; contains very abundant comminuted plant material; top of unit contains wavy, discontinuous, dark gray (N3) carbonaceous laminations; weakly (2) bioturbated; gradational base; (thin section sample A 23-1, rippled sandstone 4.9 ft above base)	8.2
22. Shale (80%), dark gray (N3), noncalcareous, silty, slightly fissile; includes rippled shaly siltstone (20%) laminations/stringers; contains more silty shale than Unit 21; includes rare ironstone stringers; weakly (2) to moderately (3) bioturbated; gradational base; base of unit approximately at end of concrete spillway apron; (shale sample A 22-1, 41.6 ft above base; thin section sample A 22-1, siltstone stringer 41.6 ft above base)	112.9
21. Shale (70%), dark gray (N3) and brownish gray (5YR 4/1) and shaly siltstone/sandstone (30%) stringers; shale, noncalcareous, micaceous, sandy; sandstone, noncalcareous, very fine grained, rippled, occurs mainly as lenses; white (N9) oxidized staining on outcrop surface; weakly (2) bioturbated; gradational base	93.8
20. Siltstone/silty shale (60%) and very fine grained sandstone (40%); shale, medium dark gray (N4) and grayish red (10R4/2), micaceous, noncalcareous except in certain intervals; includes some rippled, light gray (N7) sandstone streaks; contains some comminuted plant material; weakly (2) bioturbated to nonbioturbated; gradational base; (thin section sample A 20-1, 1.4 ft above base)	17.1
19. Alternating beds of grayish black (N2), micaceous, noncalcareous, silty shale (50%) and grayish red purple (5RP4/2) and brownish gray (5YR4/1), very fine grained sandstone/siltstone (50%); rippled sandstone/siltstone beds occur in 1–2-in.-thick layers/lenses; weakly (2) bioturbated; noncalcareous except where micro-size calcite crystals coat shale surfaces; gradational base; (shale sample A 19-1, 6.2 ft above base)	38.7
18. Shale, dark gray (N3), and brownish gray (5YR4/1), silty, noncalcareous, monotonous shale sequence; poor to moderate exposure due to slump blocks;	

weakly (2) bioturbated to nonbioturbated; nonresistant unit; gradational base; offset to the east of spillway floor to continue measurements; (shale sample A 18-1, just below contact with Unit 17; A18-2, ~102.7 ft above base; A18-3, ~202.4 ft above base; A 18-4 top of unit). 295.6

17. Shale, brownish gray (5YR4/1), silty, noncalcareous; deeply weathered limonitic concretionary horizon; contains abundant dark yellowish orange (10YR6/6) and dark reddish brown (10R3/4) ironstone concretions; spheroidal-like weathering; nonbioturbated; nonresistant; gradational base .. 1.6
16. Shale, grayish black (N3), brownish black (5YR2/1), and grayish red purple (5RP4/2), silty, micaceous, noncalcareous; includes some grayish red (10R 4/2) ironstone stringers/bands/ lenses, some with pyrite; weakly (2) bioturbated; nonresistant unit; sharp base; (shale sample A 16-1, continuous) 10.8
15. Sandstone/siltstone, medium light gray (N6), noncalcareous, micaceous, very fine grained, slabby, rippled, parallel-bedded; weathers dark yellowish orange (10YR6/6); interbedded with pale red (10R 6/2) rippled sandy shale/shaly sandstone showing small-scale ripple, lenticular and flaser bedding; ripple types include a mixture of current and interference ripples but current ripples are more common; unit becomes more shaly at the top; weakly bioturbated (2) to moderately (3) bioturbated in certain intervals; gradational to sharp base; (thin section A 15-1, just above base of unit; A 15-2, top of unit) 1.6
14. Interstratified shaly sandstone/sandy shale grading into very fine grained sandstone at top; small-scale heterolithic bedding; similar in lithology to Unit 12; shaly sandstone/sandy shale alternating with siltstone in 1–4-in.-thick beds; siltstone, light gray (N7), noncalcareous, occurs as streaks and rippled lenses; sandy shale, medium light gray (N6) and medium gray (N5); wavy and lenticular bedded; includes dark reddish brown (10R3/4) ironstone beds/lenses; highly rippled unit; certain intervals contain small-scale flaser/lenticular bedding and soft-sediment deformation features (convolute bedding, load casts); contains well-preserved, slightly coalified *Calamites* stems, some 30 in. in length; moderately (3) to strongly (4) bioturbated, contain some *Chondrites*; gradational to erosional base; (thin section sample A 14-1, ~1 ft above base of unit; A 14-2, top of unit) 4.3
13. Sandstone, yellowish gray (5Y7/2) weathers dark yellowish orange (10YR6/6), noncalcareous, micaceous, very fine grained; highly rippled unit, interference ripples dominant; convolute bedding at base; includes dark reddish brown (10R3/4) shale rip-up clasts, particularly near the top; some pyrite nodules with white (N9) halos; contains dark gray (N3) comminuted plant material and rare scoured *Calamites*; top highly rippled, contains indistinct scoured *Zoophycos*; weakly (2) to moderately (3) bioturbated, contains horizontal grazing/feeding trails; single very resistant bed; unit offset ~10 ft by faulting along west side of spillway; erosional base; (thin section sample A 13-1, base of unit; A 13-2, top of unit). 3.3
12. Shale, medium gray (N5), brownish gray (5YR4/1) and medium bluish gray (5B5/1), noncalcareous, very sandy, slightly fissile; small-scale heterolithic bedding; includes some 1–4-in.-thick, dark reddish brown (10R3/4), very fine grained, noncalcareous sandstone/siltstone stringers/lenses; starved ripples, flaser bedding, and truncated sets of small-scale ripple-drift laminations in certain intervals; some pin-stripe millimeter-thick laminations; certain intervals of very fine grained sandstone show small-scale soft-sediment deformation features including flame structure, convolute bedding and load casts; outcrop surface has white (N9) oxidized blotches; nonresistant unit; weakly (2) bioturbated; gradational base; (shale sample A 12-1, continuous) 15.8
11. Shale, dark gray (N3), brownish black (5YR2/1) and dark reddish brown (10R3/4), noncalcareous; includes light gray (N7) and grayish red purple (5RP 4/2) millimeter-thick very fine grained sandstone/ siltstone laminations/streaks; vertical plug; sandstone includes delicate, finely ribbed, thin-shelled brachiopods; weakly (2) bioturbated to nonbioturbated; nonresistant unit; gradational base; (shale sample, A 11-1, continuous) 12.1
10. Interstratified siltstone/sandstone and sandy shale; heterolithic bedded unit; highly contorted unit; siltstone, light gray (N7) and pale red (10R6/2) weathering dark yellowish orange (10YR6/6); flat bedded, thin-bedded; dominantly siltstone unit contains some rippled sandy shale/shaly sandstone; small- and large-scale soft-sediment deformation features include slumped sandstone bodies, contorted bedding, and ball-and-pillow structures; some scour channels filled with high-angle trough cross-stratified sandstone; rapid lateral changes in facies/thickness; weakly (2) bioturbated; gradational to erosional base; (thin section sample A 10-1, ~1.4 ft above base; A 10-2, top of unit) 10.8
9. Shale, medium dark gray (N4), brownish gray (5YR 4/1), and medium bluish gray (5B5/1), sandy, noncalcareous; includes light gray (N7), very fine grained, rippled sandstone lenses/streaks; slightly micaceous; shale unit pinches out laterally due to scouring by Unit 10; weakly (2) bioturbated to nonbioturbated; nonresistant unit; gradational base; (shale sample, A 9-1, continuous) 1.6
8. Sandstone, light gray (N7), very fine grained, micaceous, noncalcareous; weathers dark yellowish orange (10YR6/6); some siltstone in certain intervals; highly deformed unit; soft-sediment deformation features include pinch-and-swell bedding, ball-and-pillow structures, and convolute bedding; highly rippled unit, current and interference ripples most common; small-scale truncated sets of low-angle trough cross-stratification, particularly at the top; interlaminated, rippled sandy shale in certain intervals; rare low-angle planar cross-stratification; faint horizontal, even parallel, laminations in certain intervals where flat-bedded; some carbonaceous streaks/laminae; weakly (2) bioturbated; unit highly variable in facies/ thickness laterally; base sharp, planar to highly contorted; (thin section sample A 8-1, base of unit; A 8-2, top of unit) 5.9
7. Interstratified sandstone/siltstone and sandy shale, grayish red (10R4/2) and medium light gray (N6), noncalcareous; highly rippled unit; includes 1–2-in.-thick, very fine grained sandstone beds interlaminated with sandy shale; lenticular sandstone beds more common in upper 2.0 ft; micaceous, very carbonaceous, contain some comminuted plant material (*Calamites*); certain intervals con-

tain flaser/lenticular bedding and small-scale ripple-drift cross-stratification; weakly (2) to moderately (3) bioturbated, contains dominantly horizontal grazing trails; base gradational; (thin section sample A 7-1, ~1.4 ft below top of unit) 9.5

6. Sandstone, medium light gray (N6), fine- to very fine grained, noncalcareous; weathers to dark yellowish orange (10YR6/6); contains sandy shale partings/streaks; dominantly a highly rippled unit in which stacked bedding plane surfaces show a diversity of ripple types; includes certain horizons of shale rip-up clasts and low-angle cross-stratification; individual sandstone beds 2–6-in.-thick; certain intervals contain very abundant, scoured *Zoophycos* on top bedding-plane surfaces; irregular- to ripple-bedded; rippled surfaces stained dark reddish brown (10R3/4); weakly (2) bioturbated, certain intervals moderately (3) bioturbated; very resistant unit, exposed at edge of concrete apron; base not exposed; (thin section sample A 6-1, basal sandstone bed exposed; A 6-2, top of wavy-bedded sandstone) 9.5
5. Covered interval (concrete apron of spillway) 60.9
4. Sandstone, light brown (5YR5/6) to moderate brown (5YR4/4), dominantly fine grained but contains certain intervals of very fine grained sandstone, noncalcareous, porous; interval consists of two ~1-ft-thick sandstone beds separated by 0.8-ft-thick light brown (5YR5/6), noncalcareous, sandy shale; impure, contains abundant clay-alteration products; thin-bedded; low-angle cross-stratification; surfaces ripple-marked; weakly (2) bioturbated; (thin section sample A 4-1, uppermost rippled sandstone bed) 2.6
3. Shale, light brown (5YR5/6) interbedded with light gray (N7), grayish orange (10YR7/4), and light brown (5YR5/6), very fine grained sandstone and siltstone; noncalcareous; thin- to very thin bedded; wavy, parallel-bedded; surfaces ripple-marked; weathers to small, broken fragments on the outcrop; weakly (2) to moderately (3) bioturbated; gradational base 28.1
2. Sandstone, light brown (5YR5/6), moderate brown (5YR4/4), and very pale orange (10YR8/2), rhythmically alternating with dusky yellowish brown (10YR2/2) sandy shale that weathers light brown (5YR6/4, 5YR5/6); sandstone, fine- to very fine grained, noncalcareous, thin- to medium-bedded; wavy, parallel-bedded; sandstone beds are generally about 8–15 in. thick, particularly in upper part; sandstone beds are more common and thicker in upper part; certain intervals contain shale rip-up clasts; surfaces marked with interference ripples; top bedding plane surfaces covered with trace fossils (horizontal locomotion/feeding trails); weakly (2) to moderately (3) bioturbated; gradational base; (thin section sample A 2-1, base; A 2-2, top of 5.2-ft-thick rippled sandstone bed; A 2-3 top of unit) 22.1
1. Shale, very pale orange (10YR8/2) to light brown (5YR5/6) to brownish gray (5YR4/1), slightly fissile, sandy, noncalcareous; includes some moderate brown (5YR4/4), very fine grained, bioturbated sandstone beds; base covered 19.5

Total thickness, including covered interval ~886.0

STRATIGRAPHIC POSITION/THICKNESS

The thickness of the upper part of the Atoka Formation exposed at this stop is ~886 ft. The Hartshorne/Atoka contact is exposed ~1.3 mi northwest of this stop on the east point of Wister Ridge, just east of the picnic area at Area 2 campground (Fig. 9). On Wister Ridge, the uppermost erosion-resistant sandstone in the Atoka Formation is ~475 ft below the Atoka/Hartshorne contact. The same resistant sandstone (Unit 26, Fig. 8) is exposed in the lower part of the spillway section below ~69 ft of silty, sandy shale. Therefore, ~406 ft of the uppermost part of the Atoka Formation is not exposed in the spillway section. However, Hemish (1993a, p. 19) described 113.5 ft of this 406-ft interval on Wister Ridge. Lithologically, the interval is composed predominantly of olive gray (5Y4/1) to medium gray (N5) silty shales that are interstratified with light olive gray (5Y5/2) siltstones in the upper 25 ft.

GENERAL DESCRIPTION OF SUCCESSION

The succession can be divided informally into the following general lithologic subdivisions (Fig. 8).

Lower 207 ft (Units 1–15)—Composed of four coarsening-upward lithofacies. The lowermost (finest grained) part of each coarsening-upward sequence begins with an approximately 10–20-ft-thick shale or (less frequently) siltstone/sandstone interval. The uppermost (coarsest grained) part of each lithofacies usually is dominated by 5–20-ft-thick, very fine grained sandstone/siltstone beds or, less commonly, by fine-grained sandstone (Fig. 10). This part of the overall succession has the greatest contrast in lithologies and contains the most abundant and diverse sedimentary features, including ripple marks, scour-and-fill marks, low-angle cross-stratification, trough cross-beds, planar cross-beds, parallel laminations, lenticular and flaser bedding, contorted bedding, convoluted bedding, load structures, ball-and pillow structures, rip-up clasts, comminuted plant material, plant stems, carbonaceous matter, pyrite, mica, trace fossils, and brachiopods (Fig. 8).

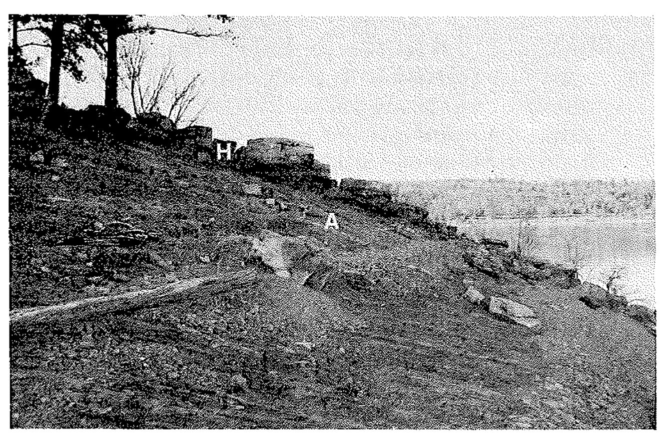


Figure 9. Contact of Atoka Formation (A) and Hartshorne Sandstone (H). Located at Area 2 campground in Wister State Park ~1.3 mi from spillway section (Fig. 8).

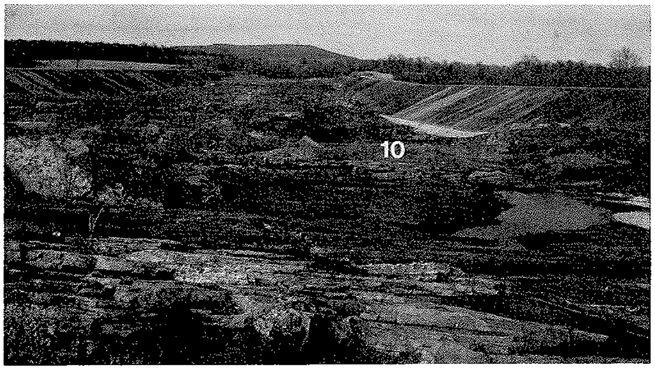


Figure 10. Northward dipping (26°) beds of the upper part of the Atoka Formation (133- to ~886-ft interval) exposed in Wister Dam spillway. Note the overall mud-dominated succession. Two small-scale coarsening-upward sequences can be seen, one in the immediate foreground and the other at about the middle of the photograph (Unit 10).

Figure 11. Lower part of mud-dominated part of succession. Contact of shale Unit 19 with shale Unit 20 (516–572-ft interval). Hoe pick head marks contact. Unit 20 is composed of medium dark gray (N4) and grayish red (10R4/2) siltstone and silty shale (60%) and 1–2-in.-thick, rippled, very fine grained sandstone streaks/lenses (40%). Hoe pick is 2.2 ft long.

Middle 207–516 ft (Units 16–18)—Consists mostly of a very thick, dark gray (N3), silty, noncalcareous, monotonous shale succession with streaks of siltstone and ironstone stringers locally. Sedimentary features are rare to absent in this interval. Ironstone bands, concretions, mica, and pyrite occur in the lower 10 ft.

Upper 516–886 ft (Units 19–33)—Composed of four coarsening-upward lithofacies.

516–572 ft (Units 19 and 20)—Represents the upper (coarsest grained) part of the lowest coarsening-upward lithofacies in this interval. Interval is composed of alternating beds of medium dark gray (N4) silty, micaceous, noncalcareous (except in a few intervals) shale and 1–2-in.-thick laminations/streaks/lenses of rippled, noncalcareous, very fine grained, light gray (N7) sandstone and siltstone (Fig. 11). Sedimentary features include ripple marks, mica, and comminuted plant material (Fig. 8). The lowermost part of this coarsening-upward succession is represented by Unit 18, a monotonous, 295.6-ft-thick shale sequence (Fig. 8).

572–787 ft (Units 21–23)—The lowermost (finest grained) part of this second coarsening-upward sequence is composed of 206.7 ft of dark gray (N3), silty, micaceous, slightly fissile, noncalcareous shale (65%) containing 1–2-in.-thick, light gray (N7), noncalcareous, rippled, very fine grained sandstone (35%) lenses and streaks. Sedimentary features include isolated ripple marks, bioturbation, and ironstone bands (Fig. 8).

The uppermost (coarsest grained) part of this coarsening-upward sequence is composed of 8.2 ft of interstratified dark gray (N3), noncalcareous, silty shale (50%) and medium gray (N5) and grayish red purple (5RP4/2), noncalcareous, micaceous, fine- to very fine grained (mostly fine grained) sandstone (50%) (Fig. 12). Sedimentary features include very abundant comminuted plant material, ripple marks, and wavy, discontinuous, carbonaceous laminations.

787–818 ft (Units 24–26)—The lowermost (finest grained) part of this third coarsening-upward lithofacies consists of 16.1 ft of interstratified dark gray (N3), noncalcareous, micaceous, silty shale (dominant) and 1–2-in.-thick beds of shaly siltstone and very fine grained sandstone. Sedimentary features consist mostly of ripple marks in the lower 9.2 ft.

The uppermost (coarsest grained) part of the lithofacies is composed of 15.1 ft of medium light gray (N6), noncalcareous, very fine grained sandstone. Sedimentary features, confined to the more sandy part of the interval, include small-scale, soft-sediment deformation features, rare swaley cross-stratification, ironstone nodules, trace fossils, and plant fossils.

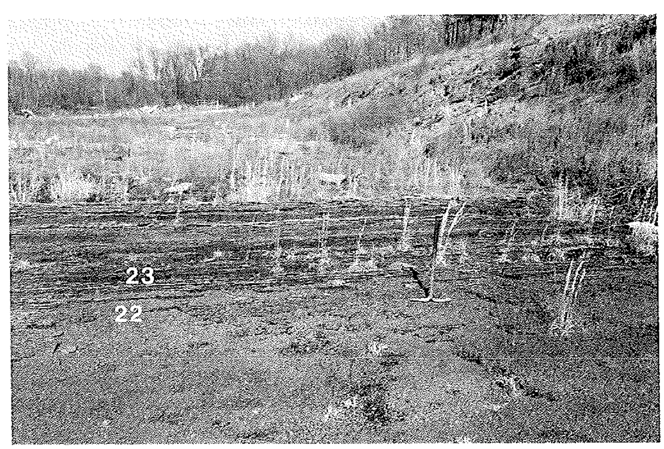


Figure 12. Upper part of mud-dominated part of succession. Contact of shale Unit 22 with shale Unit 23 (770–787-ft interval). Note the increase in rippled shaly siltstone streaks/lenses in Unit 23. Unit 23 contains abundant comminuted plant material. Hoe pick is 2.2 ft long.

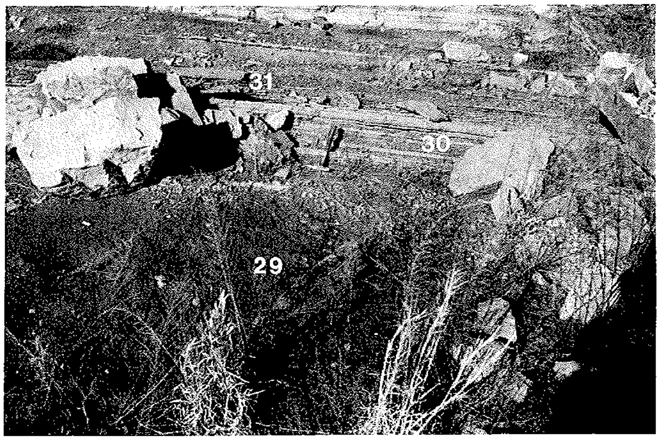


Figure 13. Contact of marine shale Unit 29 with interstratified siltstone/shale Unit 30 (830–834-ft interval). Unit 29 contains a good marine fauna of brachiopods, crinoid ossicles/stems, bivalves, and gastropods. Geologic pick is 1.1 ft long.

818–836 ft (Units 27–32)—The lowermost part of the fourth coarsening-upward sequence is composed of 12.4 ft of medium dark gray (N4), silty, noncalcareous shale (Fig. 8). A lenticular (0.3–3.3-ft-thick), very fine grained sandstone bed with contorted bedding, ironstone bands, and ripple marks occurs in this interval.

The uppermost (coarsest) part of this lithofacies is composed of 5.6 ft of mostly interstratified medium gray (N5), calcareous to noncalcareous, very fine grained sandstone and dark gray (N3), silty, noncalcareous, shale (Fig. 13). Sedimentary features include ripple marks, ironstone lenses/nodules/concretions, pyrite, contorted bedding, strong bioturbation, and marine fossils (e.g., brachiopods, crinoid ossicles, gastropods, and bivalves) (Fig. 8).

836–886 ft (Unit 33)—This 50-ft-thick interval represents only the lowermost (finest grained) portion of another, overlying coarsening-upward sequence. The interval is composed of dark gray (N3), silty, noncalcareous shale. Sedimentary features consist mostly of ironstone layers. One ironstone layer, near the base, contains an abundant brachiopod fauna (Fig. 8).

SEDIMENTOLOGY

Petrography

Twenty-seven thin sections from outcrop samples were prepared and studied to determine textural and mineralogical characteristics (Fig. 8). Sandstones are represented by 19 of the 27 thin sections; siltstones, by seven; shales by one. The coarsest sediment fraction observed in the thin sections was fine sand (0.12–0.16 mm).

Primary sedimentary structures are well developed in outcrop, but some also are discernible at thin-section scale. Some thin sections show stratification or grain fabric (Fig. 8, thin sections 14-1 and 20-1). Laminations, wispy clay layers, and bioturbation are visible in a few (Fig. 8, thin section 10-2). In one shale sample, centimeter-scale convolute bedding was noted (Fig. 8, thin section 22-1). Heterogeneities in grain size and color are present on a centimeter scale. One sample shows graded bedding on a millimeter scale (Fig. 8, thin section 14-1).

Sandstones

Sandstones are represented by 19 of the 27 thin sections. Most of the sandstones are classified as quartz arenites. Sandstones are mostly very fine grained (0.12–0.16 mm); some contain as much as 20% silt-size grains, whereas others may contain as much as 10% fine-sand-size grains. Some of the fine-grained sandstones may contain as much as 25% very fine sand-size grains. Grains are poorly to moderately well sorted in most samples.

Monocrystalline quartz is the dominant framework grain in all sandstone samples. A few of the monocrystalline quartz grains are brown and slightly turbid. Some grains appear welded together by quartz overgrowths (Fig. 8, thin section 2-3). Apparent suturing of grains is the result of quartz overgrowth cementation (Fig. 8, thin section 2-3). Iron oxides form pin-point rims around many of the quartz grains. Feldspar is present in small amounts (<8%) in most samples. Both K-feldspar (orthoclase, microcline) and plagioclase are present; plagioclase is more common. Some feldspar is twinned. Rock fragments, predominantly metamorphic(?), are scarce or absent in the samples.

Accessory minerals are present in trace amounts (<1%) in most samples. Mica, especially muscovite, is present in most samples and is a significant component, as much as 2–3%, in a few samples. Mica content increases with decreasing grain size. Organic matter and pyrite are the most abundant opaque grains.

Quartz is the most common and significant cement in many samples. Quartz cement occurs as well-developed crystal overgrowths on detrital quartz grains.

Clay generally is not abundant but is visible in most thin sections as delicate, brownish grain-coatings and pore-linings. Clay also is visible as a pseudomatrix, produced by compactional deformation of clay- or mica-rich rock fragments between less-ductile grains. In the very fine grained sandstones and in siltstones, detrital clay is present as continuous and discontinuous laminae. Opaque clay-sized particles, including organic matter, could not always be distinguished.

Siltstones

Siltstones are represented by seven of the 27 thin sections. The silt grains range in size from 0.02 to 0.06 mm. Grains are poorly to moderately well sorted in most samples. Grain shapes are generally subangular to angular (Fig. 8, thin section 10-2). The siltstone samples contain 5–30% very fine sand-size quartz grains. Detrital silt-size quartz grains and feldspar are mixed with larger, platy grains of muscovite and organic matter. Organic matter and pyrite constitute opaque grains. Laminations, consisting of millimeter-thick, closely packed silt and very fine sand grains of quartz, occur in some samples. Detrital clay is visible as diffuse brown patches and dark laminae.

Shale

Shale is represented in only one of the 27 thin sections. (Fig. 8, thin section 22-1). Principal constituents of the shale are terrigenous silt and clay. The terrigenous silt fraction is composed of subangular to angular grains of monocrystalline quartz and lesser amounts of mica, feldspar, and accessory minerals similar to those in the sandstones. Convolute bedding on a centimeter scale was noted in the sample. Part of that micro-scale soft-sediment deformation feature is shown in Figure 8, thin section 22-1. Carbonaceous organic matter is present, and pyrite occurs in trace amounts.

Sedimentary Features

Ripple Marks

The Atoka succession contains a variety of current and wave ripples representing a range of flow velocities and directions (Fig. 14). Some ripple patterns (interference) suggest the combined influence of waves and currents. In some cases, thin mud drapes occur on ripple foresets, or ripples have a more symmetrical form, which suggests wave and, possibly, tidal influence. Paleocurrents measured from current ripples on bedding-plane surfaces and from a limited number of cross-laminations tend to be highly variable and are of limited value in interpreting prevailing current directions. Superimposed ripple-bed forms show rapid lateral changes in size and orientation over short distances (Fig. 15). Ripple-bed forms typically are <2 in. high. In this study, small ripples are not regarded as distinct from the larger megaripples, as I believe that the two classes show considerable overlap. However, the bed-form scale of some of the ripple trains in the upper part of the Atoka Formation may well warrant their classification as megaripples. This possibility will be considered in ongoing studies.

Both symmetrical and asymmetrical wave ripples are present. Symmetrical wave ripples are essentially straight-crested and show, in part, a tuning-fork-like bifurcation. This type of ripple typically is produced by slow-moving waves on the margins of a water body in water a few inches deep and does not need a fetch (Reineck and Singh, 1980) (Fig. 16A,B).

Asymmetrical wave ripples are similar to straight-crested current ripples in possessing a steep lee side and a gentle stoss side (Reineck and Singh, 1980). These wave ripples may develop as climbing ripples or ripple laminae in-phase if sufficient sediment is available in suspension. Crests of both asymmetrical and symmetrical wave ripples show repeated bifurcation in the shape of a tuning fork, and the profile of crests is rather regular (Fig. 16C).

Climbing ripples and ripple-drift cross-laminations occur in the coarsening-upward sequences, particularly at, or near, the tops of sandstone beds. They represent current deposition in an environment where intermittent interaction with, or reworking by, waves produced the ripple laminae (Fig. 16D–F). Evidence for wave-influenced ripple laminations in the succession includes opposite ripple-foreset directions within single ripple horizons and laminations out-of-phase with ripple forms. Climbing-wave ripple laminations are highlighted by the presence of quartz-rich laminae distributed among clay-rich laminae. The climbing- ripple laminae are produced by low flow-velocity currents saturated with sediments (probable flood event). The high sedimentation rate from suspension produces local hydrodynamic conditions similar to those of waning turbidity currents. Some unusually thick ripple-drift cross-laminations observed suggest low-flow regime, but excessive bed-load sediment supply.

Figure 14. View (taken looking southward) of the lower part of the section, Units 6–8 (133–158-ft interval). Note the diversity and abundance of ripple-bed forms on the 26° northward-dipping bedding-plane surfaces.

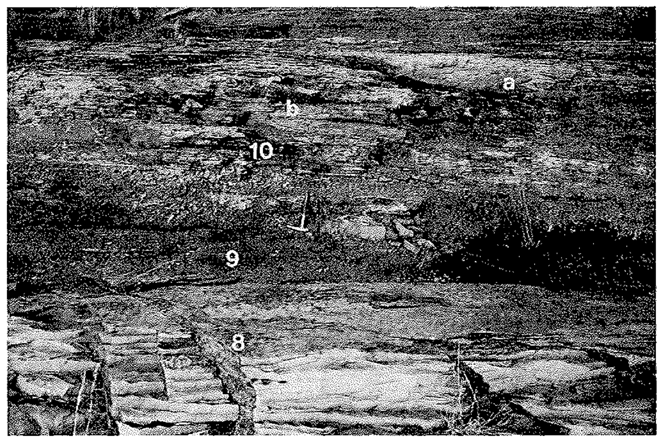


Figure 15. Top of highly deformed Unit 8, shale Unit 9, and lower part of heterolithic-bedded Unit 10 (156–165-ft interval). Note the stacked ripple-bed forms in Unit 8 and the cross-sectional view of planar cross-beds produced by migration of straight-crested current ripples into relatively deeper water during storm-events. In Unit 10, note the concave-upward erosional scour (a) and contorted bedding (b). Geologic pick is 1.1 ft long.

Current ripples are most common and are represented by both unidirectional and multidirectional bed forms. *Straight-crested current ripples*, with almost straight and parallel crests, are the most common form of current ripple (Fig. 17A). These ripples may show small, tongue-like projections in the down-current direction. Straight-crested current ripples form at relatively low velocities and, upon migration, may produce small-scale units of planar cross-bedding (Reineck and Singh,

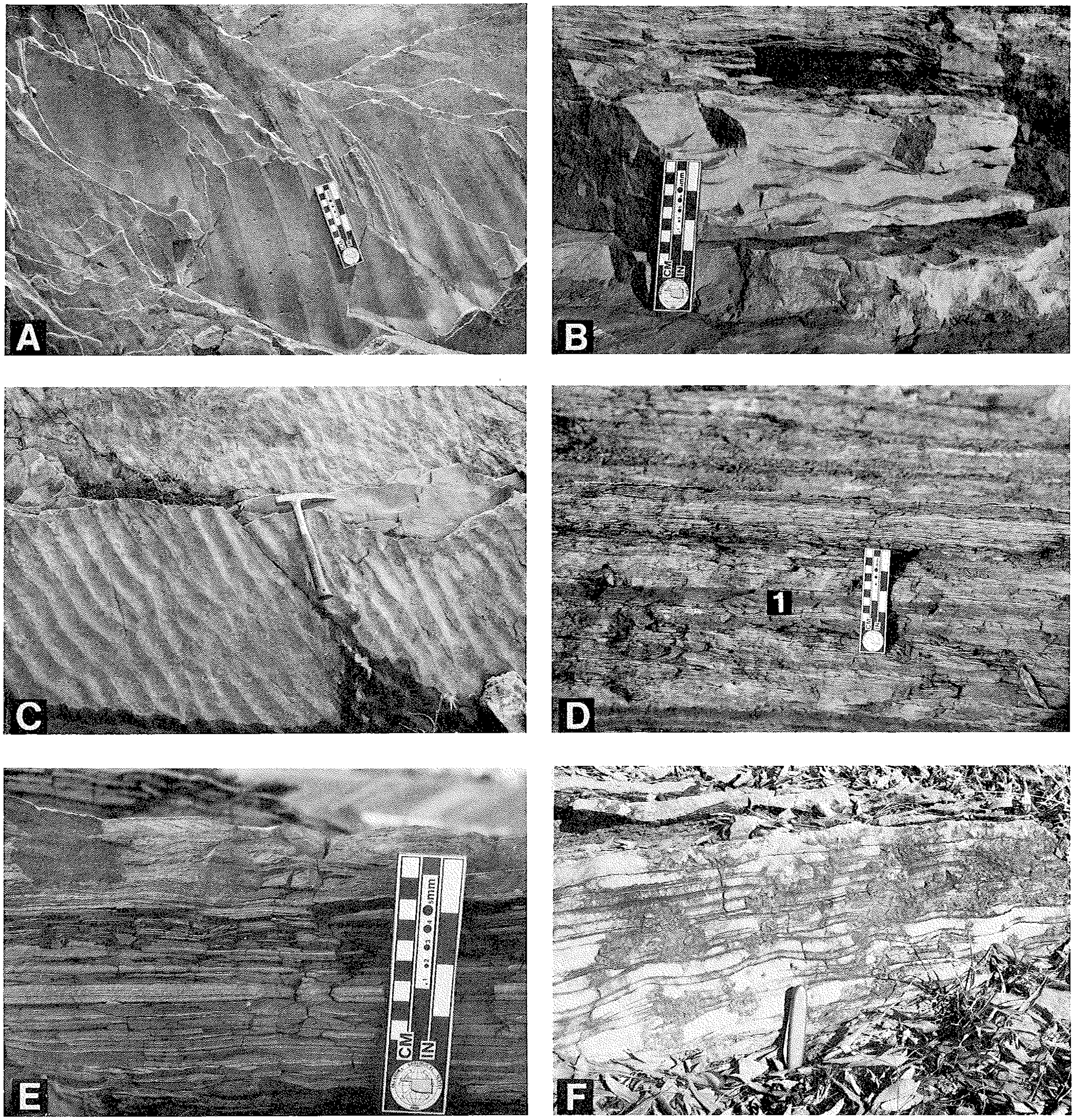


Figure 16

A. Unit 8, top. Straight-crested symmetrical wave ripples showing rounded troughs and parallel crests. Note bioturbation in troughs. Scale is 5 in. long.

B. Unit 13, upper part. Flaser bedding in wave-rippled (small-scale, symmetrical) sandstone suggests alternating deposition of sand (in turbulent water) and mud (in slack water). Note compressed (elongated), shale rip-up clasts at top. Scale is 5 in. long.

C. Unit 8, top. Asymmetrical wave ripples showing bifurcation of crests in the shape of a tuning fork. Note the rather regular profile of the crests. Geologic pick is 1.1 ft long.

D. Unit 14, lower part. Small-scale heterolithic bedding (i.e., centimeter-thick alternating couplets of siltstone and shale). Note starved ripples (flaser bedding) at top of scale and isolated, truncated sets of ripple-drift cross-laminations (1). Scale is 5 in. long.

E. Unit 7. Vertical sequence of small-scale sedimentary features: starved ripples (lenticular bedding) at the base; laminated small-scale planar bedding in the middle; and small-scale trough cross-beds at the top produced by small-scale climbing ripples. Scale is 5 in. long.

F. Unit 2. Climbing-ripple lamination with laminae in-phase. Ripples are asymmetrical and were produced under current action. Rippled-bed forms are preserved as wavy bedding. Knife is 3 in. long.

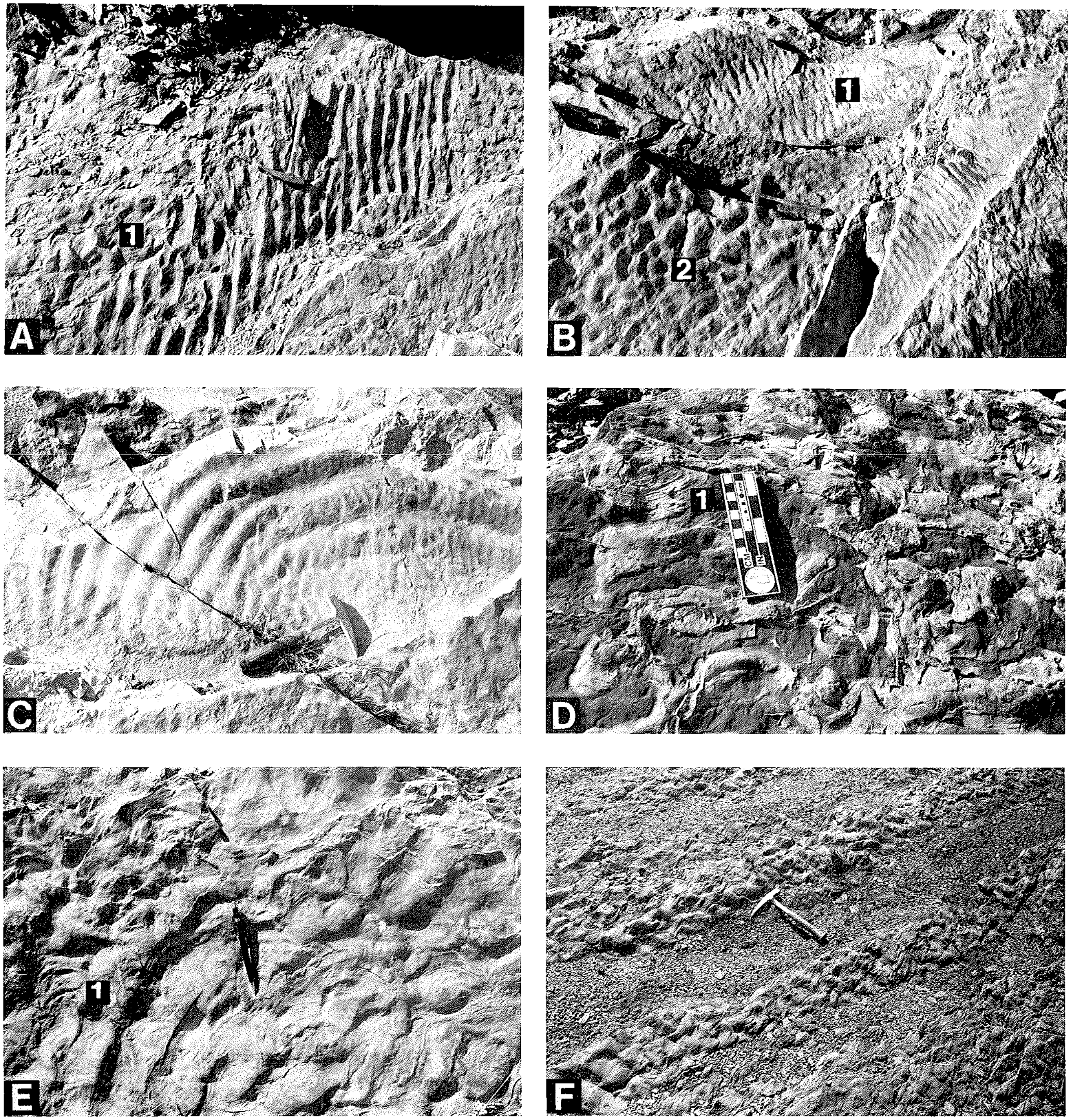


Figure 17

A. Unit 7, near top. Straight-crested current ripples with almost straight and parallel crests. Note superimposed ripple-bed forms and change in ripple pattern to strongly undulatory, almost linguoid-like, small-current ripples on left side of photo (1). Geologic pick is 1.1 ft long.

B. Unit 6. Bedding-plane surfaces showing weakly undulatory small-current ripples (1) and strongly undulatory, almost linguoid-like, small-current ripples (2). Geologic pick is 1.1 ft long.

C. Unit 6. Undulatory current-ripple train. Ripples have long, continuous, wavy or undulatory crests that project forward into tongue-like extensions. Geologic pick is 1.1 ft long.

D. Unit 13. Top bedding plane surface showing strongly undulatory, almost linguoid-like, current ripples with out-of-phase crests. Note the horizontal grazing (feeding) pattern of *Zoophycos* (1). Scale is 5 in. long.

E. Unit 6. Grazing (feeding) pattern of *Zoophycos* (1) on a strongly undulatory current-rippled bedding-plane surface. Probable trace maker of the spreiten was a surface deposit-feeding annelid. Pencil is 6 in. long.

F. Unit 23. Interstratified silty shale (50%) and shaly siltstone (50%). Siltstone beds show strongly undulatory, almost linguoid-like, current ripples. Geologic pick is 1.1 ft long.

1980) (Figs. 15,16E). *Undulatory small-current ripples* possess long, continuous, wavy or undulatory crests. The undulations may be arranged in-phase or out-of-phase, but usually they are out-of-phase. The crests are continuous but project forward into tongue-like extensions. These common ripple-bed forms represent a transition form between low-energy straight-crested, small-current ripples and higher-energy, linguoid, small-current ripples (Fig. 17B–F) (Reineck and Singh, 1980). The migration of undulatory current ripples may produce weakly festoon-shaped cross-bedding in side view and strongly trough-shaped cross-bedding in front view. *Linguoid current ripples* consist of small curved crests that extend forward in a tongue-like or lobe-like forms (Fig. 17C). The tongues are out-of-phase. The crests of the ripples are discontinuous and broken and have forward closures; thus, they cannot be traced over long distances. Migrating linguoid current ripples may produce strongly festoon-shaped cross-bedded units. In the coarsening-upward sequences within the upper part of the Atoka Formation, there is a gradual transition from straight-crested to undulatory, and undulatory to linguoid-like ripples, and all transition forms are found (Fig. 17A,B, D,F).

Some ripple patterns suggest the combined influence of waves, currents, and, possibly, tides. These longitudinal ripples (interference) are relatively straight-crested, and usually show no bifurcation of crests (Figs. 18,19A). The ripple crests ran parallel to the current and wave propagation was at right angles to the current. These ripple-bed forms may have originated in cohesive, muddy sediments with very low sand content. The sharp interbedding of wave-rippled siltstone/sandstone and shale suggests that deposition took place in conditions alternating between wave-influenced and quiet water (Fig. 16B). Discontinuous siltstone/sandstone lenses reflect the development of small-scale ripple bed forms (starved ripples) produced by stronger flows associated with storm waves (Fig. 16D,E). The starvation of the ripples suggests that sediment supply was limited, at least temporarily, and probably was episodic.

Stratification

Planar cross-bedding is not common. In some places, scour channels are filled with high-angle planar cross-stratified sandstone (Fig. 19B). The presence of planar cross-beds in solitary sets suggests deposition from straight-crested current ripples that migrated into deeper water during storm events (Figs. 15;16D,E).

Trough cross-stratification, present in some intervals, is usually small-scale and commonly truncated (Figs. 16E,19C). Trough cross-beds record the migration of sinuous-crested ripples from relatively low-flow velocity currents.

Thinner couplets of sandstone/siltstone and shale, without cross-laminations, suggest deposition below storm-wave base. These couplets are particularly characteristic of the heterolithic-bedded facies (i.e., Units 7, 10, 12, and 14) (Figs. 15,16D,19D).

Flaser/lenticular bedding is most common in the heterolithic-bedded units (Figs. 16D,E;19E). All variants of flaser bedding are present: simple flaser-bedding, bifurcated flaser-bedding, wavy flaser-bedding, and bifurcated, wavy flaser-bedding. Flaser bedding is associated with straight-crested current ripples, small current ripples with curved crests, and wave ripples. Lenticular bedding is associated both with sand lenses of current origin and with sand lenses produced by both symmetrical and asymmetrical wave ripples (Figs. 16E,19E). It results when incomplete ripples form on a muddy substrate that is covered later by another mud layer and then sand in the form of ripples. Thin sandstone beds contain wavy, discontinuous, clayey laminae, which developed as clay drapes that filled ripple troughs and outlined ripple lenses (Figs. 16B,D,E;19E). Flaser/lenticular bedding provides evidence for: (1) availability of both sand and mud, (2) alternating turbulent-water and slack-water intervals for deposition of sand and mud, respectively, and (3) high loads of suspended clay/silt/sand. The occurrence of streaks and lenticular siltstone/sandstone laminations in a shale-dominated interval, observed in certain intervals as load-casted ripples, suggests a depositional environment where the hydraulic regime is fluctuating constantly between periods of increased and decreased fluid motion and/or where sediment supply is episodic (Figs. 11,12).

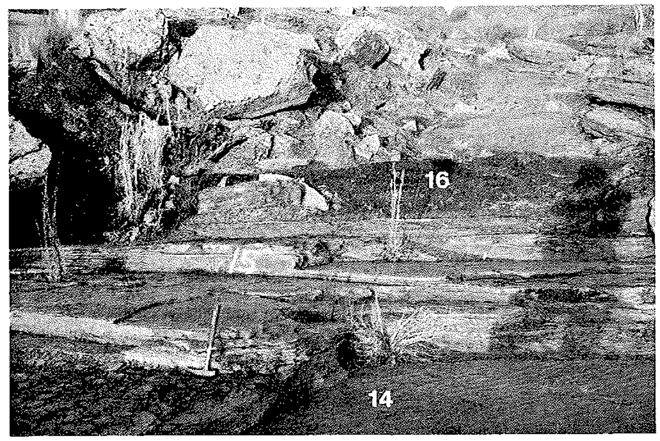


Figure 18. Tops of highly rippled (interference ripples) Unit 14, Unit 15, and lower part of grayish black (N3) shale Unit 16 (207–210-ft interval). Note sharp contacts. Geologic pick is 1.1 ft long.

Horizontal, parallel, continuous laminations are rare, but when present they are preserved as small-scale planar-bedding (Figs. 15,16E). The dominantly horizontal laminations are formed by grain-size and sorting variations, silt or mud laminations, or carbonaceous material. Such laminations are upper flow-regime sedimentary features probably formed by deposition of sediment from suspension in response to wave action, which suggests aggradation of the facies into a more energetic zone.

Rare intervals of intersecting, low-angle to slightly undulatory, subparallel laminations with a slight upward convexity suggest swaley cross-stratification as described by Leckie and Walker (1982) (Fig. 19F). The difference between swaley and hummocky cross-stratification, in my opinion, has not been resolved fully. Swaley cross-stratification is produced by large, storm-generated waves that scour and then deposit very fine to fine sand below the fair-weather breaker zone in broad, shal-

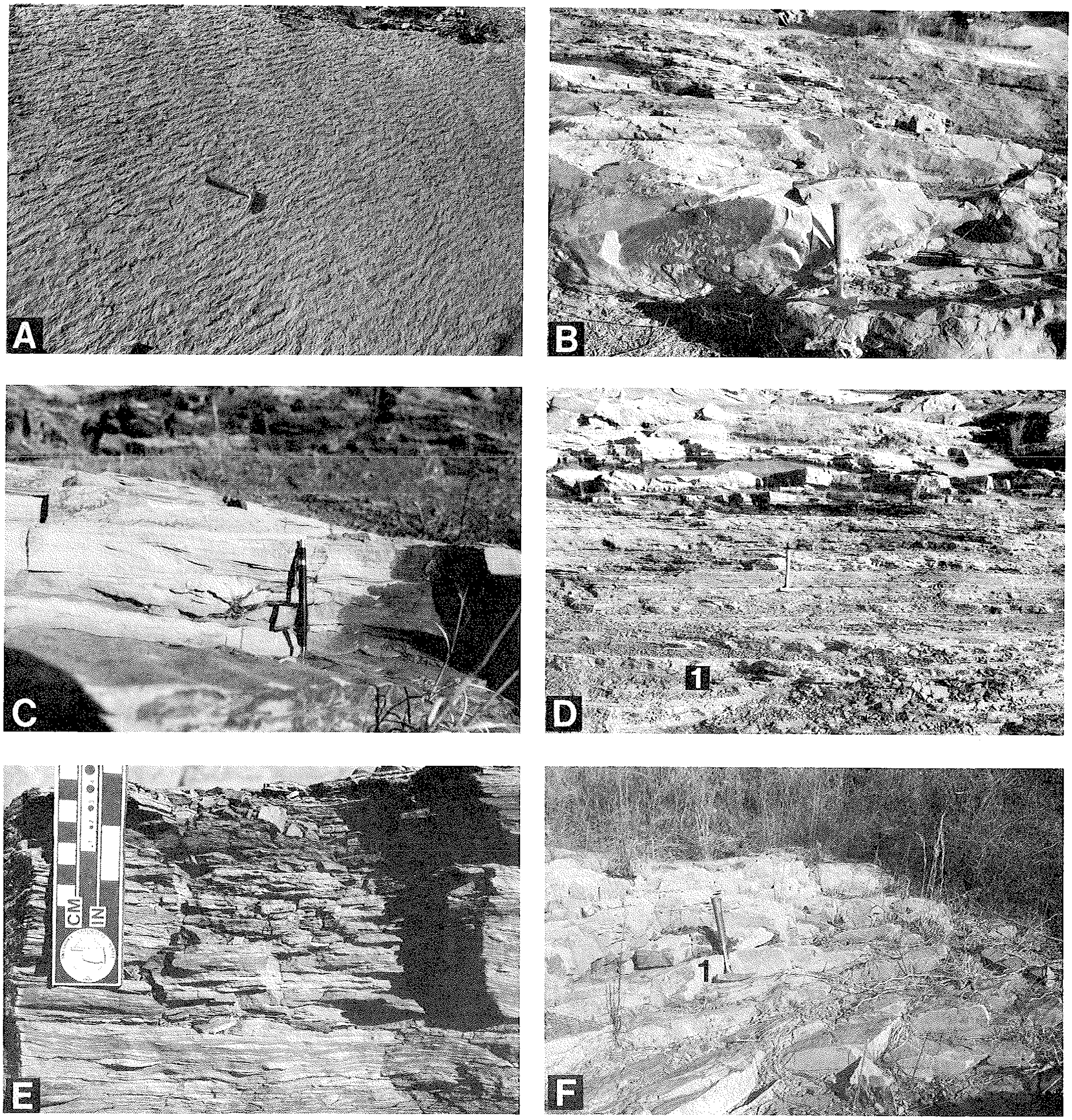


Figure 19

A. Unit 12, near top. Interference ripple pattern suggestive of both current and wave influence. Geologic pick is 1.1 ft long.

B. Unit 10. High-angle planar cross-stratified sandstone body filling in scour channel. Cross-bedding probably was produced by the migration of straight-crested current ripples into deeper water during storm-events. Geologic pick is 1.1 ft long.

C. Unit 8, top. Truncated set of low-angle, trough cross-stratified, very fine grained sandstone produced by the migration of sinuous-crested ripples from low-flow velocity currents. Pencil is 6 in. long.

D. Unit 7. Small-scale, coarsening-upward cycle with heterolithic bedding (alternating couplets of sandstone and shale) in lower part. Note concave-upward erosional scour (1). Geologic pick is 1.1 ft long.

E. Unit 12, upper 1 ft. Flaser/lenticular bedding in starved-ripple marked siltstone/sandstone. Clayey laminae developed as clay drapes that filled ripple troughs and outlined ripple lenses. Scale is 5 in. long.

F. Unit 26. Rare swaley cross-stratification (1) in very fine grained sandstone succession. Cross-stratification is produced by deposition in shallow swales related to increased wave energy. Geologic pick is 1.1 ft long.

low swales. This sedimentary structure is preserved best between fair-weather base and storm-wave base where low-energy conditions dominate (e.g., outer shelf, lower delta front).

Soft-Sediment Deformation Features

Penecontemporaneous, soft-sediment deformation structures include contorted/slumped beds, convolute bedding, ball-and-pillow structures, load-casted ripples, pinch-and-swell bedding, and small-scale recumbent folds. The abundance of the features suggests rapid sedimentation (such as that caused by storm waves or by gravity-induced slumping or sliding on oversteepened depositional slopes), which produced unstable substrates. Soft-sediment deformation also may occur where there is abundant disseminated organic material: trapped methane formed during organic decay may trigger sediment failure by helping to raise the pore-fluid pressure.

Contorted bedding (noted in Units 8, 10, 12, and 14 [Fig. 8]) is a product of syndepositional slumping of sandstone bodies due to loading and oversteepening of the depositional surface during periods of peak water discharge (Fig. 15). Contorted bedding indicates sufficient sand to induce load deformation and sufficient mud to initiate sediment failure. Contorted bedding results in considerable disruption of the original bedding (Fig. 20A,B).

Load casts and ball-and pillow structures (noted in Units 8, 10, 14, 26, and 28 [Fig. 8]) indicate rapid deposition of sand onto a water-rich "soupy" substrate. Discontinuous ball-and-pillow structures (pinch-and-swell bedding) are produced when a sand layer is broken up into several isolated ellipsoidal (pillows) masses (Fig. 20C,D). Sandstones soled by ball-and-pillow structures and/or other soft-sediment deformation features indicate in-place sediment failure after deposition (Fig. 20E). These soft-sediment features are evidence for intermittent storm cycles or shoaling events. In addition, these features are indicative of slope instability due to: (1) angle of slope, (2) sediment/water pore-pressure differences, and (3) sudden sediment influx.

Some beds pass laterally into a slumped horizon (contorted massive sandstone) that has been fluidized (Fig. 20D). The lateral variability in bed thickness produces a pinch-and-swell type bedding (ball-and-pillow structures) (Fig. 20D) similar to that in Units 8 and 10 (Fig. 8). Others beds have been deformed syndepositionally, which suggests that episodic depositional events (e.g., storms) caused rapid influx of sediments and subsequent dewatering and/or slumping of water-saturated sands/silts.

Another type of small-scale slump structure, a recumbent fold, was formed in a very fine grained sandstone in Unit 26 (Fig. 20F). The recumbent fold formed in place from original bedding failure. The single occurrence in Unit 11 of a sandstone plug suggests sand mobilization following burial.

Scours

Locally, isolated broad erosional scours, some as much as 8 ft wide and 2 ft deep, contain either low-angle trough cross-beds or high-angle planar cross-beds of very fine grained sandstone (scour-and-fill) (Figs. 19B, 21A). The scours and cross-bedded sandstones usually are encased within planar-bedded siltstone/sandstone. The erosional scours are concave-upward and sandstone beds commonly pinch out laterally above the erosional surfaces (Figs. 15;20A,C). Because of erosional scours and soft-sediment deformation, sandstone/siltstone beds generally are discontinuous laterally at outcrop scale. The sharp basal contacts of several sandstone bodies suggest that some erosion of the underlying strata may have occurred prior to deposition of the basal sand.

Shale/Mud Clasts

Shale/mud rip-up clasts are not common and are present only in Units 2, 6, and 13. Most of the clasts are deformed or "squeezed" and are oblong in shape, which suggests that the clasts were semi-consolidated during deposition and suffered plastic flow after burial (Fig. 16B). Some rounded clay/shale clasts occur at the tops of rippled sandstone beds and indicate reworking and redeposition of partially consolidated mud during a period of relatively higher flow-velocity. The occurrence of mud/shale clasts suggests that the sediment was broken up periodically by wave/current action in water probably shallower than the depth of the effective wave base.

Pyrite/Siderite

Pyrite occurs in both disseminated and nodular form and also as a replacement mineral for brachiopod shells. The presence of pyrite indicates deposition under reducing conditions, probably produced by organic decay.

Ironstone, commonly in the form of siderite, occurs as nodules, lenses, and bands. Its presence suggests anoxic reducing conditions due to organic decay. The presence of siderite also suggests that pore fluids lacked sulphate which, if present, would have produced pyrite.

Plant Material

Carbonaceous material is common at several stratigraphic levels and in several different forms. Comminuted plant material is common throughout the succession. Laminations highlighted by comminuted plant material are common. Partially coalified *Calamites* stems are present in Units 7, 13, and 14 (Fig. 21B). Some of the *Calamites* stems show evidence of scouring. The presence of comminuted plant material coincides with an increase in micaceous-rich sandstones/siltstones/shales.

Coalified plant stems, common comminuted plant material, and the dark gray (N3) color of the shales suggest a heavily vegetated and poorly drained, low-energy, marginal-marine source area as well as transportation by storm-influenced currents/waves over a mud-dominated shelf into a relatively low-energy, dysaerobic to anaerobic, relatively deeper-water setting.

Body Fossils

Body fossils are extremely rare in the succession. A dark gray (N3) noncalcareous shale (Unit 11) contains delicate, finely ribbed, thin-shelled, pyritized chonetid-type brachiopod shells. Brachiopods, crinoidal hash, bivalves, and gastropods were recovered from a medium

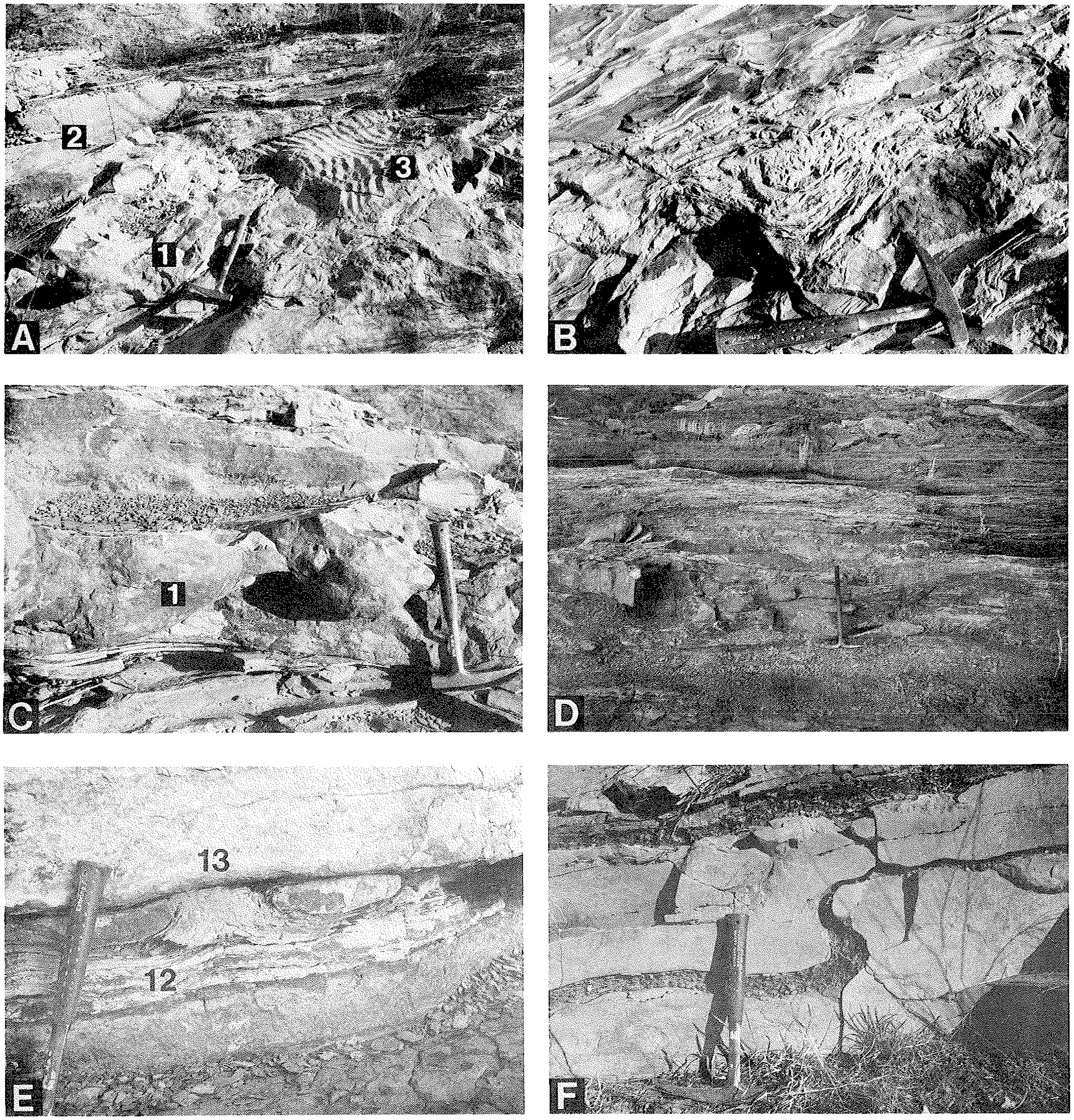


Figure 20

A. Unit 10. Highly contorted unit. Note contorted bedding (1), concave-upward erosional cut-and-fill scour (2), and weakly undulatory small-current ripple trains (3). Geologic pick is 1.1 ft long.

B. Unit 8. Penecontemporaneous soft-sediment deformation structure showing slumped or contorted bedding. Note strongly rippled bedding-plane surface at the top. Geologic pick is 1.1 ft long.

C. Unit 10. Ball-and-pillow structure (1), a product of soft-sediment deformation that indicates rapid deposition of sand onto an unstable water-rich "soupy" substrate. Note concave-upward erosional scour at the top of the photo. Geologic pick is 1.1 ft long.

D. Unit 10. Foundered sandstone body resulting from in-place sediment failure after deposition on a water-rich "soupy" substrate. Note the lateral variability in bed thickness. Hoe pick is 2.2 ft long.

E. Contact between Unit 12 and Unit 13. Note soft-sediment deformation feature (truncated flame structure) at contact. In-place sediment failure after deposition is suggested by soft-sediment deformation features on the sole of Unit 13. Geologic pick is 1.1 ft long.

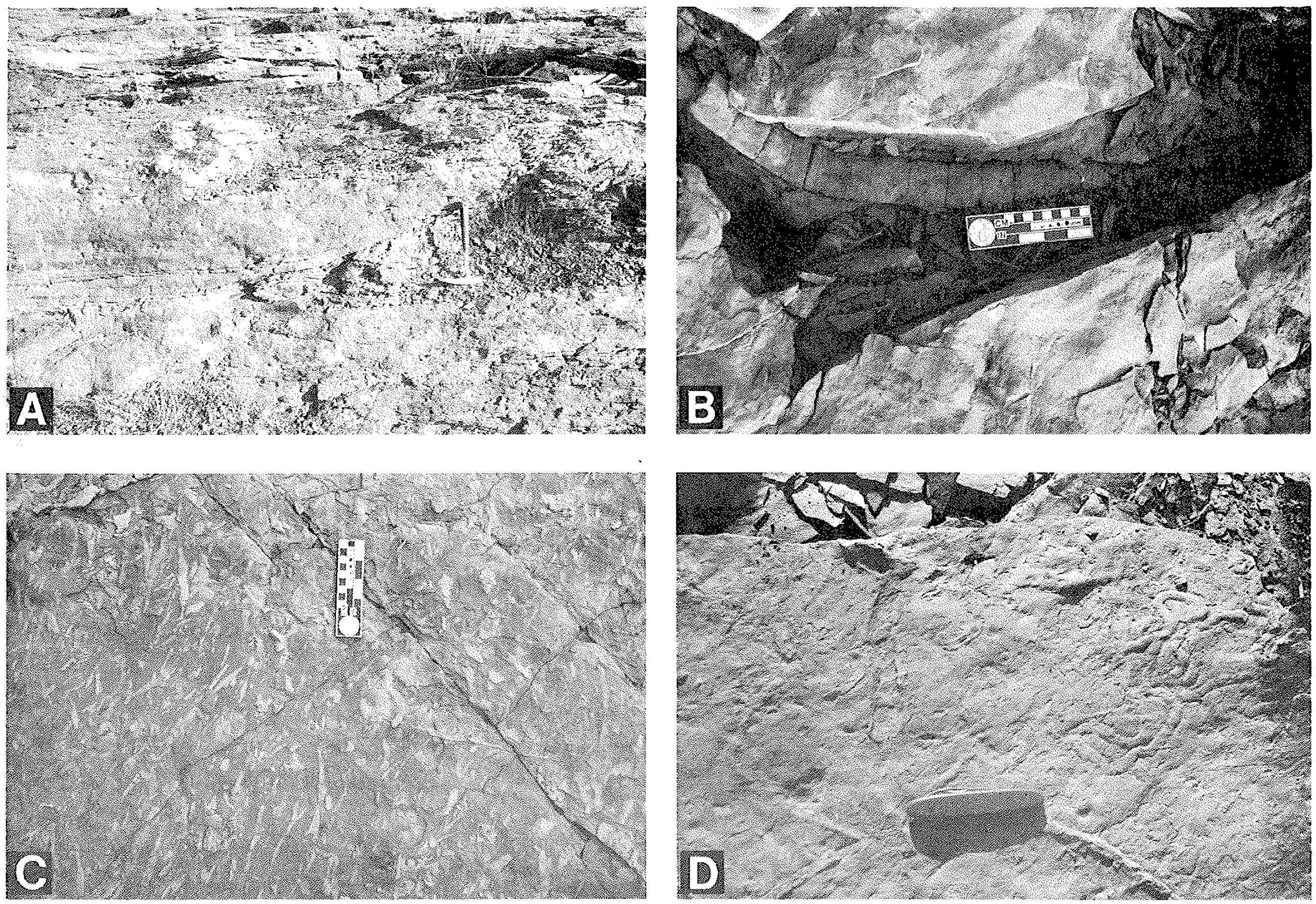
F. Unit 26. Recumbent fold, a type of slump structure, in a very fine grained sandstone, formed in place from original bedding failure. Geologic pick is 1.1 ft long.

dark gray (N4) sandy to silty, noncalcareous shale in the upper part of the mud-dominated succession (Unit 29, Fig. 13). In addition, a 2–4-in.-thick ironstone layer in shale Unit 33 contains chonetid- and spiriferid-type brachiopods in which some of the shells are pyritized. The representative fossils collected are from organisms adapted, for the most part, to soft substrate and relatively turbid water.

The overall paucity of body fossils in the upper part of the Atoka Formation suggests that sedimentation rates were very high and/or that the environment was hostile (e.g., oxygen-deficient) to benthic organisms. Thirteen shale samples are currently being processed for microfossil data (Fig. 8).

Biogenic Structures

The overall intensity or level of bioturbation is assigned an ichnofabric index of 1 to 5. These indices indicate the degree of bioturbation according to the visual scale of Droser and Bottjer (1986,1989): 1 = nonbioturbated (1–10%); 2 = weakly bioturbated (10–30%); 3 = moderately bioturbated (30–60%); 4 = strongly bioturbated (60–95%); 5 = churned (95–100%). The percentages arbitrarily assigned to each ichnofabric index above are the



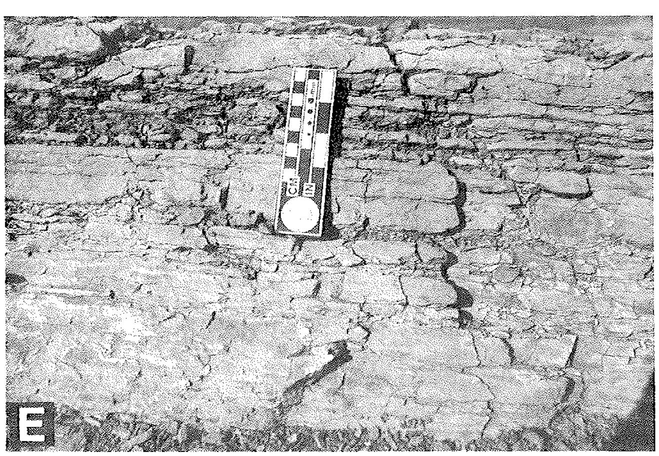


Figure 21

A. Unit 10. Isolated broad, concave-upward erosional scour containing trough cross-beds of very fine grained sandstone. Note that the scour is entirely encased within planar-bedded siltstone/sandstone that pinches out laterally above the scour. Geologic pick is 1.1 ft long.
B. Unit 14, top. Cast of partially coalified *Calamites* stem. Scale is 5 in. long.
C. Unit 12, top. Reddish brown oxidized bedding-plane surface showing sand-filled horizontal burrows. Note difference between burrow-fill color and color of surrounding matrix. Scale is 5 in. long.
D. Unit 30. Meandering, horizontal, back-filled grazing trail of surface deposit-feeder. Probable trace maker was an annelid. Similar traces occur in Unit 28. Knife is 3 in. long.
E. Unit 32. Highly bioturbated (churned) shaly sandstone lithofacies with an ichnofabric index of 5. Scale is 5 in. long.

author's (JRC). Some caution should be used when noting the indices assigned in Figure 8. The intensity of bioturbation may vary slightly throughout any unit; therefore, the assigned index only represents the general overall intensity of bioturbation throughout that particular unit.

Bioturbation structures are preserved best in the heterolithic-bedded units, that is, units with contrasting rock types (e.g., interstratified sandstone and shale). The most common bioturbation pattern is the alternation of weakly bioturbated (sparse, restricted fauna) intervals with nonbioturbated intervals (Fig. 8). This pattern suggests that, in general, deposition probably took place near the dysaerobic/anaerobic boundary and that there was periodic alternation between dysaerobic (low oxygen: dissolved oxygen between 1.0 and 0.1 mL/L) and anaerobic (dissolved oxygen <0.1 mL/L) conditions. Overall, biogenic structures are rare, and identifiable ichnogenera are rare to absent. This overall paucity of biogenic sedimentary structures probably indicates that there was an unusually rapid rate of fair-weather suspension sedimentation and/or that the environment was hostile (e.g., oxygen-deficient) to benthic organisms. The relatively high abundance of relatively few ichnogenera (e.g., *Zoophycos* and *Chondrites*) in certain intervals also suggests stressful environmental conditions (Fig. 8). These conditions may have been due to variable rates of sedimentation, fluctuating salinity, unstable substrate, or other associated environmental parameters.

The relative abundance of horizontal feeding-burrows of deposit feeders (e.g., *Zoophycos*) in some intervals of the succession indicates an intermittent low wave-energy environment and a relatively slow rate of deposition that permitted benthic organisms to colonize the substrate (Fig. 21C–E).

The occurrence of burrows throughout the coarsening-upward sandstone sequences suggests a marine setting that must have been relatively shallow in order to have had steady-to-episodic strong currents. The *Zoophycos* feeding traces, most common in sandstone beds at the top of the coarsening-upward sequences, are related to deposit-feeding organisms that lived in the overlying mud and burrowed down into the buried sand (Fig. 17D,E). Increased biogenic activity from the base to the top of the sandstone sequence is in response to the aggradation of the seafloor (i.e., moderately slow sedimentation), the development of more oxygenated marine conditions, and the relative absence of direct fluvial influence or marine reworking. The tracemaker of *Zoophycos* was most likely a deposit-feeding vermiform organism (e.g., annelid, sipunculid) that developed a complex feeding strategy. Some workers suggest that the occurrence of *Zoophycos* indicates middle- to outer-shelf conditions (Bottjer and others, 1984). More recently, other workers have shown that *Zoophycos* is a facies-crossing ichnogenus that may be found in many different depositional settings at all water depths, although it is associated generally with relatively quiet water conditions (Marintsch and Finks, 1978).

Chondrites was identified in Unit 14 (Fig. 8). *Chondrites* consists of dense, branching feeding probes probably of a worm-like animal. *Chondrites* may be a response to local anoxic conditions caused by the decay of storm-buried organic material (Vossler and Pemberton, 1988). The presence of pyrite, siderite, and the trace fossil *Chondrites* suggests that low oxygen levels existed locally in the interstitial waters within the sediment (Bromley and Ekdale, 1984).

DISCUSSION

This exposure of the upper part of the Atoka Formation contains a diverse suite of sedimentary features associated with current and/or wave processes. These include (1) small-scale cross-laminations, (2) current ripples, (3) wave ripples, (4) scour-and-fill features, (5) erosional truncations, (6) climbing wave-ripple laminations, and (7) swaley bedding. Lulls or pauses in current activity preceding deposition of rippled sandstone are shown by shaly partings lining basal scour surfaces. Periods of lower flow-velocities and/or shallowing of water, probably associated with fair-weather conditions, are indicated by the presence of ripple-bed forms on top of trough cross-bedded sets.

Evidence of deposition by infrequent (episodic) high-energy events of short duration (storms) characterizes the coarsening-upward sandstone lithofacies found throughout the overall mud-dominated lithofacies (Fig. 22). Some evidence for storm-influenced, episodic sedimentation includes: (1) laminated siltstone/sandstone lenses in silty shale intervals; (2) alternating flow-velocity characteristics of vertical-bedding sequences (e.g., basal rippled sandstone units [low-flow regime] overlain by sandstone cross-beds [higher flow regime] overlain by rippled sandstone units at the top [low-flow regime]); (3) asymmetric ripple laminations with flaser and thin, wavy shale beds; (4) symmetrical and climbing ripples; (5) rip-up clasts in cross-bedded sandstone facies; (6) sharp-based sandstone beds separated by shale interbeds; (7) rapid lateral variation in stratification; (8) horizontal trace fossils common, but restricted to rippled surfaces in upper part of sandstone facies; and (9) alternating variations in grain size vertically. Some units have been syndepositionally deformed, which suggests that epi-

Figure 22. Basal part of section, south of spillway overlook, showing Units 1, 2, and 3 (0–70-ft interval). Note the coarsening-upward, small-scale depositional packages within Unit 2. Note the increase in frequency and thickness of sandstone beds upward in Unit 2. Hoe pick is 2.2 ft long.

sodic depositional events (e.g., storms) caused rapid sediment influx and subsequent dewatering or slumping of water-saturated sands and silts.

Periods of moderate to intense sediment reworking are recorded by (1) abundance of storm deposits, (2) swaley cross-stratification, and (3) contorted/slumped beds.

High rates of sedimentation are suggested by (1) a truncated flame structure, (2) high-angle ripple-drift cross-laminations, (3) abundant comminuted plant material, (4) abundant soft-sediment deformation features, (5) relatively poor sorting of sandstones, and (6) paucity of body fossils and biogenic structures.

Dysaerobic to anaerobic environments during shale deposition are indicated by (1) weak bioturbation, (2) paucity of body fossils, (3) organic-rich shales, and (4) abundant pyrite and ironstone (siderite).

INTERPRETATION

Environmental interpretations regarding the probable depositional setting of this exposure of the upper part of the Atoka Formation are constrained by a limited data base. However, the overall succession of sediments are related genetically and are part of a single depositional system.

The textures, vertical succession of facies, and sedimentary features suggest conditions ranging from suspension fallout and, possibly, weak density flows below storm wave base (e.g., slightly fissile shale, graded sandstone/shale couplets, etc.) through the progressively higher energy and greater sediment supply of storm-wave influence (e.g., wave-rippled siltstone, swaley cross-stratification, etc.). All of the vertical stratigraphic trends of the succession, considered together, suggest deposition on a storm-influenced, mud-dominated shelf.

The lower part (Units 1–15) of the succession (less distal shelf) is mud-dominated, but it is more sand-rich and has higher sand/shale ratios than the upper part (Units 16–33) (Figs. 10,11,14,22). The lower part also shows more frequent indications of oscillatory flow and of sedimentary features recording deposition by less distal processes.

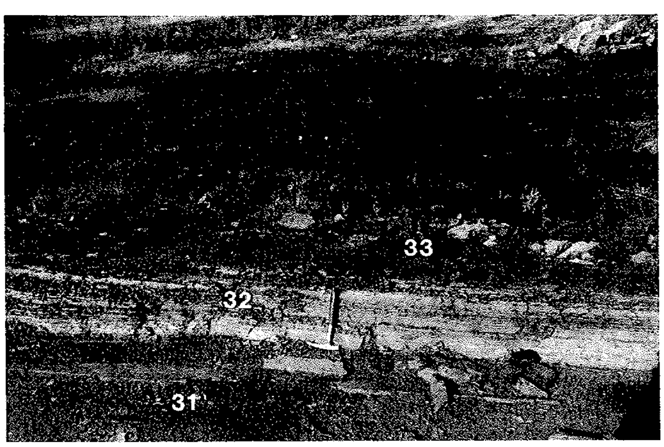


Figure 23. Upper part of Unit 31, Unit 32, and lower part of Unit 33 (836–860-ft interval). A 1.3-ft-thick sandstone lithofacies (Unit 32) is encased by two shale lithofacies, Units 31 and 33. Unit 32 contains abundant trace fossils and brachiopods. Geologic pick is 1.1 ft long.

The upper part (Units 16–33) of the succession (more distal shelf) is mud-dominated and has lower sand/shale ratios (Figs. 12,13,23). In addition, the upper part shows less frequent evidence of oscillatory flow and records deposition by more distal processes as evidenced by the dominance of finer grained sediments and paucity of shallow-water features. The upper part contains rare isolated sand lithofacies, which suggests only localized transport of sand (Fig. 23).

The gradational facies transition from lower, relatively shallow-water, more sand-rich, storm-dominated shelf deposits to an upper, relatively deeper-water, below-wave-base, mud-rich succession, is supported by: (1) the up-section increase in shale; (2) a progression up section to less frequent, thinner sandstone beds; and (3) the rare occurrence of swaley cross-stratification in the upper part of the section.

Transgressive Facies

On the whole, it is thought that the succession was deposited as part of a transgressive system. The vertical facies succession implies upwards deepening. The thick, mud-dominated (i.e., dark-gray, noncalcareous, slightly fissile shales) part of the succession records deposition from suspension in a relatively low-energy, moderate- to deep-marine setting. A subsiding basin during this relative sea-level rise provided accommodation space for accumulation and preservation of thick shale lithofacies within the upper part of the Atoka Formation. Continued subsidence and/or transgression resulted in a repetition of the infilling cycle. Storm-activity periodically interrupted the background shale sedimentation in the basin. The transgressive event was probably relatively slow overall as indicated by the preservation of sandstone beds encased in marine-shale lithofacies (Figs. 23,24).

As transgression continued, thick, dark gray, organic-rich, essentially nonbioturbated shales were deposited. The overall increase in organic-carbon content and the absence of burrowing organisms suggest that the bottom of the water column may have been oxygen-deficient. However, these conditions may have been present only at the sediment-water interface. Sparse horizontal burrowing within thin siltstone/sandstone interbeds is interpreted to represent brief oxygenated events resulting from storm-influenced currents. The oxygenated waters allowed a short-lived benthic community to colonize the substrate.

Regressive Facies

During a relative sea-level fall, base level is lowered and shelf sequences may record a shallowing-upward (coarsening-upward) sequence. At maximum sea-level fall, storms may effectively transport sediment far offshore. Sandstone lithofacies within the upper part of the Atoka Formation, at least at this stratigraphic level and geographic setting, are interpreted to record regressive intervals deposited during sea-level fall within an overall deepening-upward transgressive (flooding) event. Sandstones were deposited during sea-level lowstands when sand prograded across a mud-dominated shelf.

Figure 24. Unit 28. Lenticular, very fine grained sandstone body encased by bounding shale packages (i.e., Units 27 and 29). Hoe pick is 2.2 ft long.

Storm activity influenced transportation and deposition of sediment on the shelf within the basin. One possible mechanism of sand transportation, storm-induced geostrophic flows, would be consistent with the evidence for oscillatory currents. These currents were probably too weak to transport much sand except when enhanced by storm currents. Periodic flooding (storm events) during which sediments were transported seaward out of brackish, marginal-marine bays and marshes is indicated by: (1) the presence of crinoid stems and disarticulated brachiopod and bivalve shells, (2) wood fragments, and (3) organic fossil hash in sandstones.

The increasing frequency and upward thickening of sandstone beds, the diversity of ripple-bed forms, and the presence of small-scale cross-stratification suggest deposition in a relatively shallow marine-shelf setting in a zone seaward of fair-weather wave base, but within storm-wave base. Relatively deeper water, more distal shelf shales abruptly overlie each of these shallow-water, more proximal shelf sandstone lithofacies.

An inferred chronological development of the succession can be proposed and might include: (1) an initial transgressive event with a relative sea-level rise and concomitant, moderate reworking of sand in a shallow-marine setting; (2) a major transgression with subsequent flooding of the mud-dominated shelf and deposition of thick, open-marine shales; and (3) periodic interruption of background shale deposition by regressive events with relative sea-level falls and deposition in certain intervals of coarsening-upward sandstone lithofacies by storm-influenced transportation of sand across a mud-dominated shelf.

EXPLORATION SIGNIFICANCE

The key to effective exploration and to production and ultimate recovery of hydrocarbons from these sandstone reservoirs is the recognition of depositional controls and facies. Deep-sea fan deposits, deltaic sequences, and shelf deposits result from very different processes; they also have vastly different paleogeographic significance. But, because the three share a wide variety of common sedimentary features, distinguishing among these depositional controls and facies may be difficult. Therefore, the ability to identify the differences among turbidite-sandstone facies, deltaic-sandstone facies, and storm-influenced shelf sandstones will be a significant aid in successfully predicting the occurrence and trend in the Arkoma Basin/Ouachita Mountains frontal belt of sandstones that have hydrocarbon-production potential.

Return to vehicles and retrace route back through Wister on U.S. 270 to the intersection with U.S. 271.

12.3 4.1 Turn left (west) and proceed along U.S. 270/271.

12.9 0.6 Cross Mountain Creek and continue due west on U.S. 270/271. Low ridges on both sides of the road are formed by unnamed sandstone units in the Savanna Formation. (The Savanna Sandstone is described at Stop 17A.)

13.7 0.8 Leave Wister 7.5′ quadrangle, enter Summerfield 7.5′ quadrangle.

16.4 2.7 Turn right (north) at community of Victor.

16.5 0.1 Spoils from abandoned strip pits in the Cavanal coal are visible to the right (east) of the vehicle. Coal was mined from these pits at some unknown time prior to 1931. Hendricks (1939) did the field work for his publication on the geology and fuel resources of this area during the summer of 1931. His map shows the mine as abandoned at that time. However, he did measure sections of the Cavanal coal in mines that were active in 1931 (Hendricks, 1939, pl. 35). The coal varies in thickness from 1 ft 8 in. to 3 ft 2 in. in the area. Named mines in the vicinity mapped (and 1931 status noted) by Hendricks (1939, pl. 35) include: the Lewis Slope (SW¼ sec. 28, T. 6 N., R. 23 E., abandoned); Wister Coal

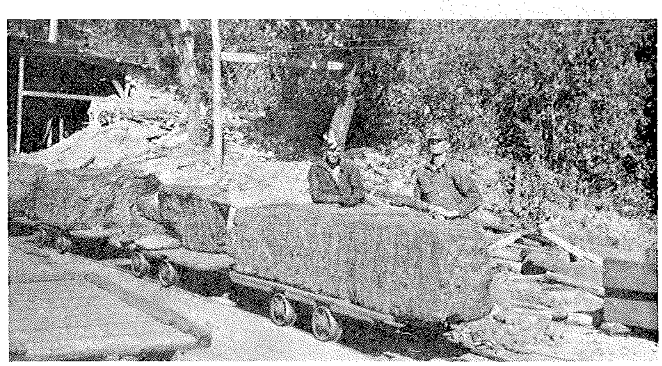


Figure 25. Blocks of Cavanal coal on mine flat cars (circa 1931). Oakland Coal Co.'s mine, sec. 4, T. 6 N., R. 25 E. (from Hendricks, 1939, pl. 32B).