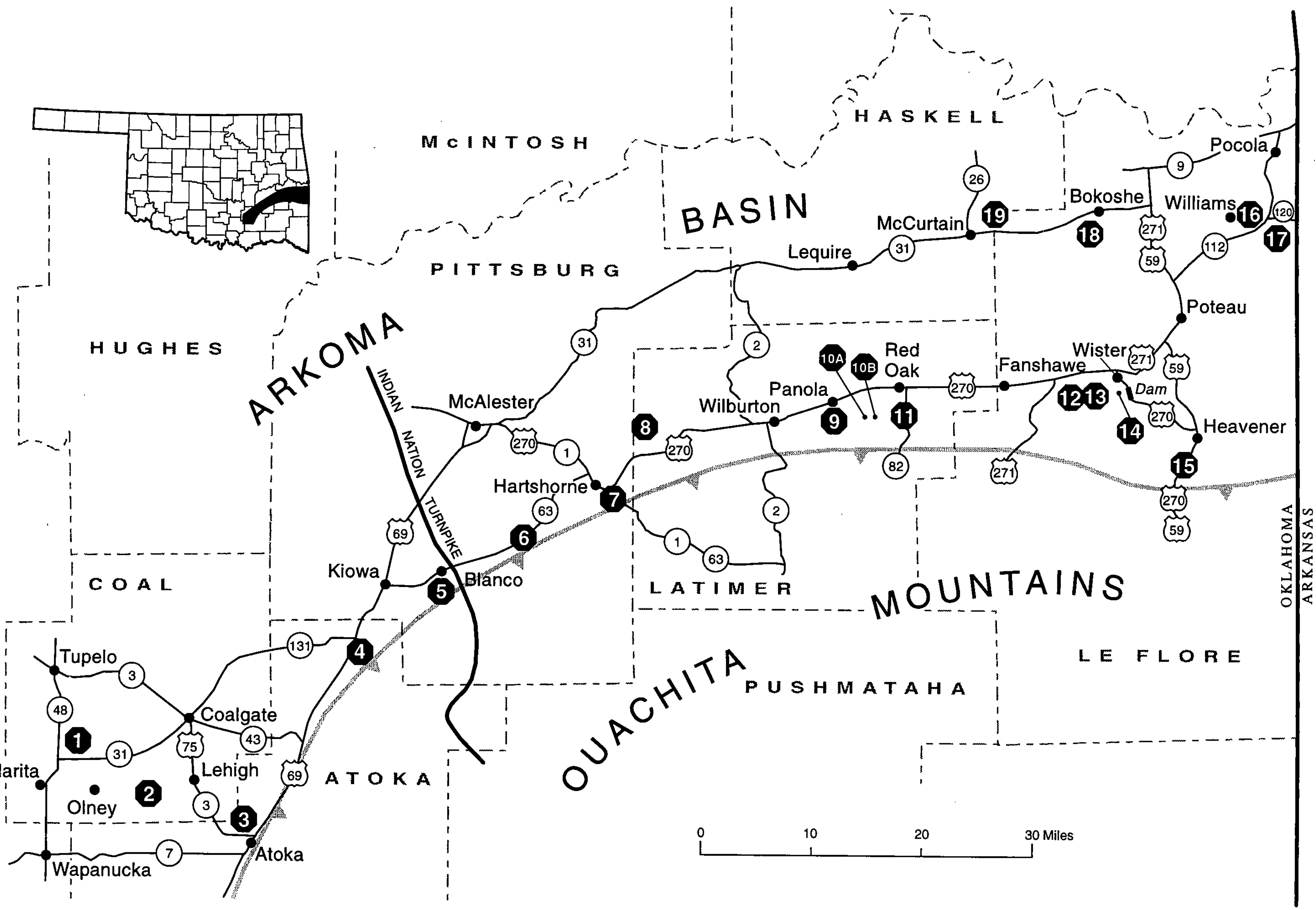
Geology of the Hartshorne Formation, Arkoma Basin, Oklahoma

Oklahoma Geological Survey

Guidebook 31

Map of Field-Trip Stops



Oklahoma Geological Survey
Charles J. Mankin, *Director*

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Geology of the Hartshorne Formation, Arkoma Basin, Oklahoma

Neil H. Suneson

Prepared for a two-day field trip, this volume is one in a continuing series that provides information and technical assistance to Oklahoma's oil and gas operators.

The Hartshorne field trip has been offered in conjunction with a one-day workshop on the Hartshorne play. The workshop information is covered in a companion publication, **The Hartshorne Play in Southeastern Oklahoma: Regional and Detailed Sandstone Reservoir Analysis and Coalbed-Methane Resources,** *by Richard D. Andrews, Brian J. Cardott, and Taylor Storm (OGS Special Publication 98-7).*

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1998

Front Cover

A distributary channel in the Hartshorne Formation cuts into the underlying distributary-mouth bar (delta front). The horizontal and uniformly bedded marine sandstone beds are being quarried for building stone, whereas the massive-bedded sandstone in the channel is of little commercial value.

The photograph was taken at the Green Country Stone Quarry near Rock Island in far eastern Oklahoma, on the south side of State Highway 120. This location is Stop 17 of the field trip.

Photograph by Neil H. Suneson

This publication, printed by the Oklahoma Geological Survey, is issued by the Oklahoma Geological Survey as authorized by Title 70, Oklahoma Statutes, 1981, Section 3310, and Title 74, Oklahoma Statutes, 1981, Sections 231–238. 2,000 copies have been prepared at a cost of $8,765 to the taxpayers of the State of Oklahoma. Copies have been deposited with the Publications Clearinghouse of the Oklahoma Department of Libraries.

PREFACE

This guidebook is a companion to Oklahoma Geological Survey (OGS) Special Publication 98-7, *The Hartshorne Play in Southeastern Oklahoma: Regional and Detailed Sandstone Reservoir Analysis and Coalbed-Methane Resources*, by Richard D. Andrews and Brian J. Cardott of the OGS, and Taylor Storm of West Virginia University. The guidebook and special publication are outgrowths of two well-received OGS programs: detailed geologic mapping in the Arkoma basin and Ouachita Mountains (STATEMAP), and the fluvial-dominated deltaic (FDD) oil reservoir project. The STATEMAP program in southeastern Oklahoma consisted of new geologic mapping at a scale of 1:24,000 with an emphasis on resource (gas, coal, limestone, sand and gravel) and environmental (waste-disposal siting, abandoned coal mines) issues. Twenty-two new maps have been produced under STATEMAP and its precursor, COGEOMAP, both of which were funded by the OGS and the U.S. Geological Survey. The FDD project was designed to identify and analyze all FDD light-oil reservoirs in Oklahoma and "to implement an information- and technology-transfer program to help the operators of FDD reservoirs learn how to increase oil recovery and sustain the life expectancy of existing wells." Funding from the U.S. Department of Energy's Bartlesville Project Office enabled eight plays to be studied and the results reported.

This guidebook is also a companion volume to two recently published OGS guidebooks. *Stratigraphy and Resources of the Krebs Group (Desmoinesian), South-Central Arkoma Basin, Oklahoma* (Guidebook 30) was prepared for a field trip held in conjunction with the Mid-Continent Section meeting of the American Association of Petroleum Geologists on September 13–14, 1997. *Geology and Resources of the Eastern Ouachita Mountains Frontal Belt and Southeastern Arkoma Basin, Oklahoma* (Guidebook 29) was prepared for a one-day workshop and two-day field trip organized by the OGS and held November 15–17, 1994.

I would like to especially thank two individuals without whose help this guidebook would not have been possible. LeRoy A. Hemish, coauthor or sole author of most of the geologic maps on which this guidebook is based, is largely responsible for the success of the COGEOMAP and STATEMAP projects. In addition, he coauthored several papers and guidebooks with me and taught me most of what I know about Arkoma basin stratigraphy. LeRoy recently retired from the OGS. Equally important to the success of this guidebook is Richard D. Andrews, petroleum geologist with the OGS. His knowledge of facies relations and log interpretations was invaluable to me, and he proved to be a patient teacher with a slow learner (me). Much of what is written in this guidebook about the depositional environment of the Hartshorne Formation reflects Rick's thinking. I would also like to thank Rick for reviewing an early draft of this guidebook.

Several other individuals deserve credit for producing this guidebook and coordinating the field trip. I thank Christie Cooper, OGS editor, and her staff (particularly Bill Rose, technical editor, and Tracy Peeters, associate editor) and T. Wayne Furr, manager, OGS Cartographic Section, and his staff (Jim Anderson, Charlotte Lloyd) for their efforts. I also thank the landowners who gave us permission to examine the rocks on their property. Their names are given in the descriptions of the stops. I appreciate Michelle Summers' efforts in planning and coordinating the field trip.

NEIL H. SUNESON
Field-Trip Leader

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PART I

Hartshorne Formation (Desmoinesian) in the Arkoma Basin of Oklahoma: A Review

The following review of the Hartshorne Formation is modified from a recently published description of the Krebs Group by Hemish and Suneson (1997).

GENERAL

The Hartshorne (pronounced HARTS-horne) Formation is the basal Desmoinesian (Middle Pennsylvanian) unit in the Arkoma basin of Oklahoma and Arkansas (Figs. 1,2). It is the oldest formation in the Krebs Group, which includes (from oldest to youngest) the Hartshorne, McAlester, Savanna, and Boggy Formations (Fig. 3). The Hartshorne conformably to disconformably overlies the Atoka Formation and generally conformably underlies the McAlester Formation. The Atoka Formation is generally considered to be Atokan, but the lack of diagnostic fossils makes the exact position of the Atokan-Desmoinesian contact difficult to locate.

The Hartshorne Formation consists of sandstone, siltstone, shale, coal, and rare conglomerate. In general, the formation forms a ridge bordered on both sides by valleys underlain by the shale-dominated Atoka and McAlester Formations. In outcrop, the base of the Hartshorne Formation is typically chosen as the first prominent, mappable, laterally continuous sandstone above the Atoka Formation; in places, this sandstone forms cliffs, is many tens of feet thick, and fills channels eroded into the Atoka Formation. In other places, the sandstone is thin, silty, poorly exposed, and appears to be gradational and conformable with the underlying Atoka Formation. The basal sandstone is typically overlain by a unit composed of interbedded shale, siltstone, and sandstone; this, in turn, is overlain by a widespread coal. The coal is overlain by interbedded shales, siltstones, and thin sandstones of variable thicknesses; locally, the sandstones thicken to form a mappable unit. This sequence is overlain by an upper coal, also of variable thickness, the top of which is the top of the Hartshorne Formation.

It should be noted that, in contrast to geologists mapping surface exposures, where the contact between the Atoka and Hartshorne Formations is gradational, the contact is typically picked by electric-log analysts where there is a relatively sharp inflection resulting from a (downward) reduction in resistivity. This is usually at the top of the highest thick sequence of

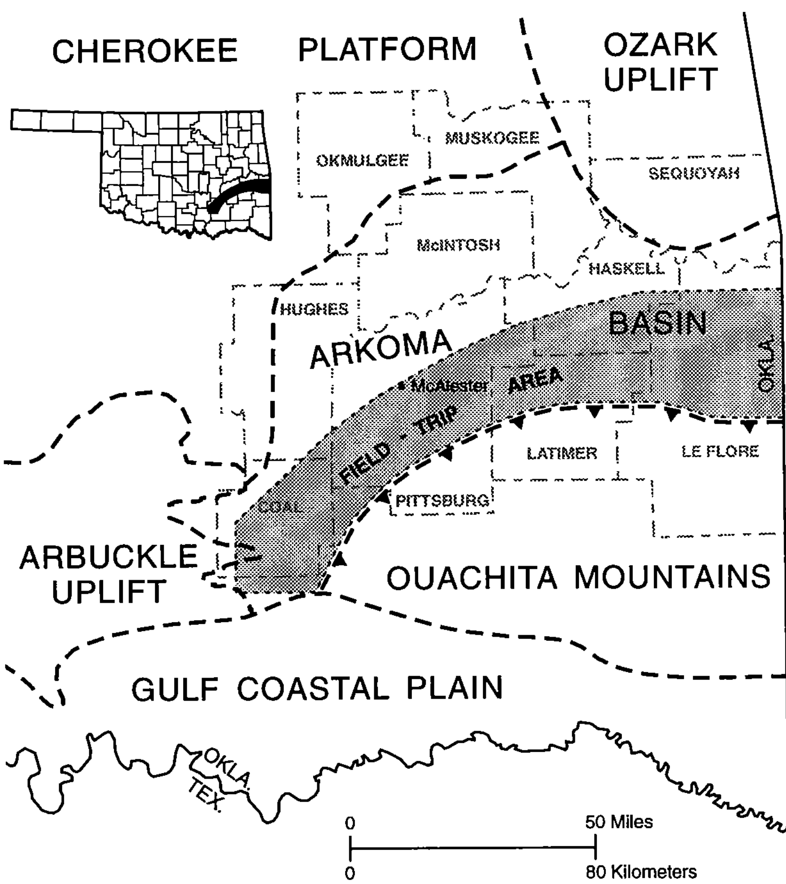


Figure 1. Map of eastern Oklahoma, showing geologic provinces (modified from Northcutt and Campbell, 1996). Choctaw fault shown with sawtooth pattern; other province boundaries shown as dashed lines. (From Hemish and Suneson, 1997, fig. 1.)

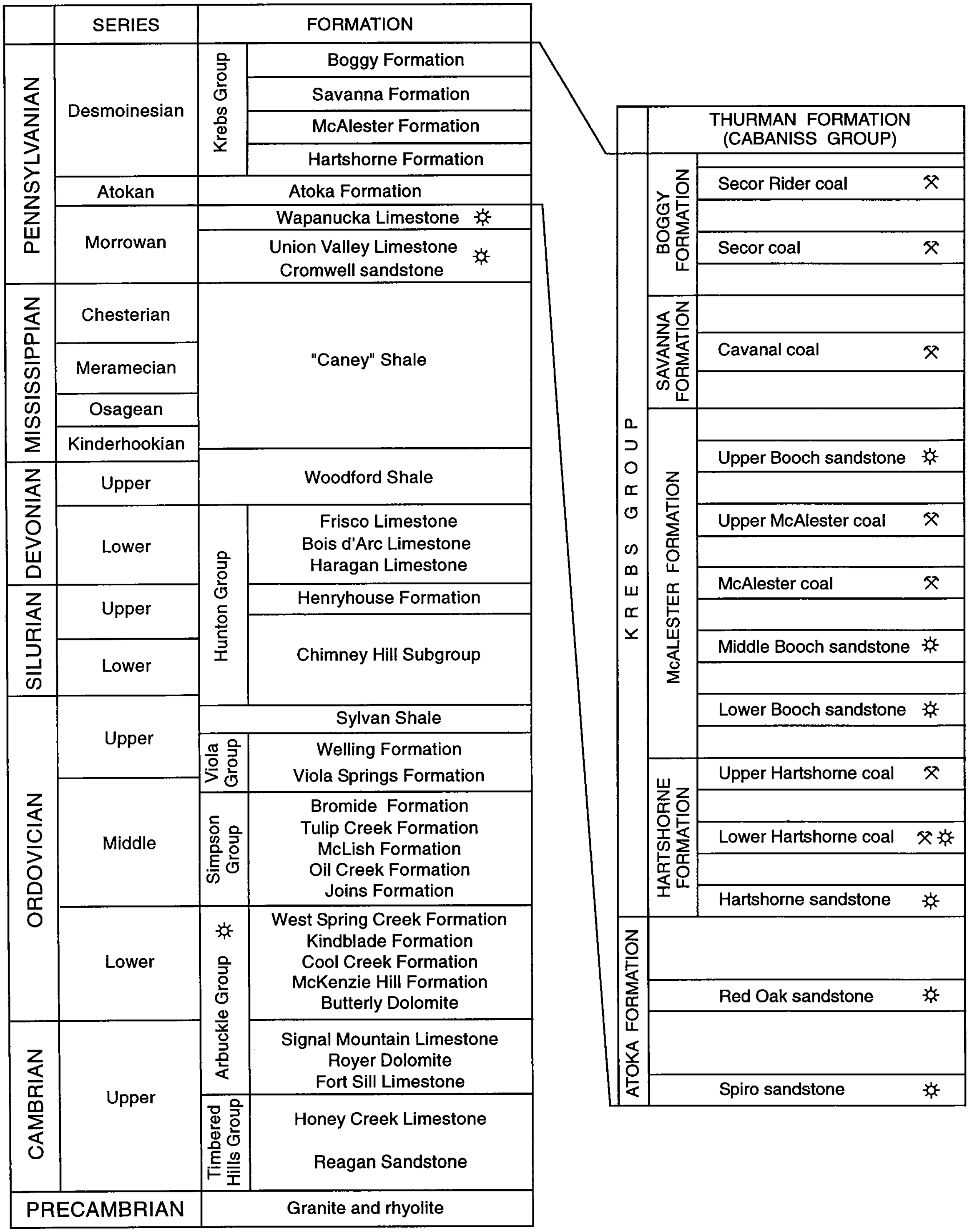


Figure 2. Stratigraphic chart for the Arkoma basin in the field-trip area, showing principal coal beds and petroleum-producing units. Left column (from Johnson, 1988) shows detailed stratigraphy of lower and middle Paleozoic units present only in the subsurface. Right column shows relative positions of principal gas reservoirs (☼) and coal beds (⚒). (From Hemish and Suneson, 1997, fig. 2.)

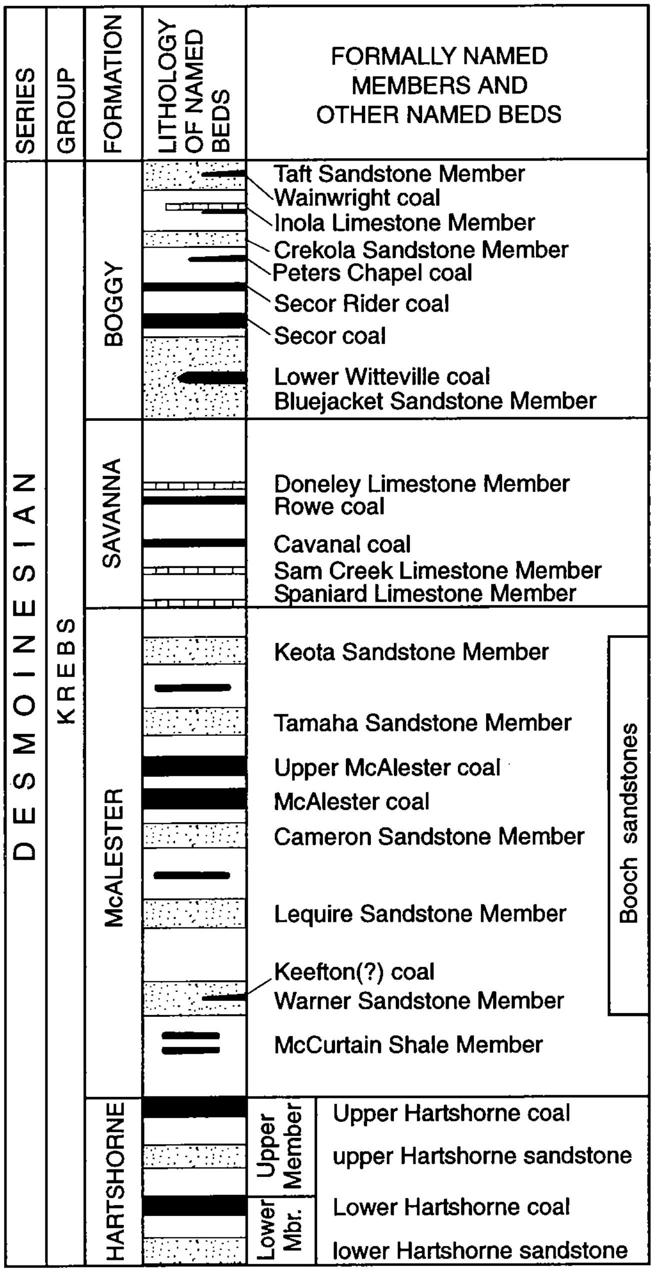


Figure 3. Generalized stratigraphic column of the Krebs Group, showing the relative positions of formally named members, names of coal beds, and other informally named beds. (From Hemish and Suneson, 1997, fig. 3.)

marine shale, as determined from resistivity logs (R. Andrews, personal communication, 1998). Basal shales in the Hartshorne typically have a slightly higher resistivity than those in the upper Atoka. In addition, the upper part of the Atoka generally contains more shale than the Hartshorne, and sandstone sequences in the Atoka are relatively thin and appear as widely separated individual "spikes" on well logs. This paper follows descriptions of the Hartshorne Formation as used by surface mappers.

In the northwestern part of the Arkoma basin, the upper shale/siltstone/sandstone sequence in the Hartshorne Formation pinches out, and the upper and lower coals merge to form a single coal bed (Fig. 4). In this area, the Hartshorne consists of a single sandstone, shale/siltstone, coal sequence.

In the southern part of the Arkoma basin, which is the focus of this guidebook, the Hartshorne Formation is divided into two members (Fig. 4). The Lower Member extends from the base of the lower Hartshorne sandstone to the top of the Lower Hartshorne coal. The Upper Member extends from the top of the Lower Hartshorne coal to the top of the Upper Hartshorne coal and includes the upper Hartshorne sandstone. Where only one coal bed is present, the Hartshorne Formation consists of the Hartshorne sandstone through the Hartshorne coal. It is important to emphasize, however, that the lowest mappable sandstone in the Hartshorne Formation varies greatly in character and that in many places it is similar to sandstones higher in the Lower Member directly below the Lower Hartshorne coal.

The different rock types in the Hartshorne Formation vary considerably in thickness. The lower Hartshorne sandstone in the marine and fluvial facies (discussed below) is relatively continuous, but it varies from about 150 ft thick to barely identifiable. The Lower Hartshorne coal is also relatively continuous, but it thins or is absent in those areas where the lower sandstone is thickest or where channels in the Upper Hartshorne Member have eroded it (Houseknecht and Iannacchione, 1982). Sandstone in the Upper Hartshorne Member is generally discontinuous and varies from zero to a few tens of feet thick, although an exception is incised channel deposits 50–100 ft thick that continue for many miles (Andrews, 1998, pl. 2). The Upper Hartshorne coal is less continuous than the lower coal and is locally absent where the upper sandstone is thickest. A third coal, informally named the middle Hartshorne coal by Donica (1978), is locally present in the central part of Le Flore County. Craney (1978) noted a thin coal between the Upper Hartshorne coal and the upper Hartshorne sandstone in northern Le Flore County, and Rieke and Kirr (1984) reported that the Hartshorne coal locally consists of three separate beds in the McAlester district. Yeakel (undated) noted that the Lower Hartshorne coal consists of as many as three beds.

HISTORY OF NOMENCLATURE

The Hartshorne Formation was originally named by Taff (1899) for exposures in the McAlester and Lehigh coal fields. He referred to the unit as the *Hartshorne sandstone* (Fig. 5), noted that it was overlain by what he termed the *Hartshorne coal,* and stated that the most suitable area for mining the coal was in the Hartshorne basin. (Taff [1899] located the Hartshorne basin at what he considered to be the eastern end of the Kiowa syncline. Later mapping suggests that the basin is probably the low, relatively flat area underlain by the McAlester Formation in the middle of the Hartshorne syncline just east of the town of Hartshorne, where it is surrounded on three sides by ridges underlain by the Hartshorne Formation.) Taff (1899) did not state why he named the unit *Hartshorne,* nor did he designate a type section. Taff (1899, p. 437) mentions that Chance (1890) called the Hartshorne coal the *Grady coal* and referred to the Hartshorne basin as the *Grady basin,* but Taff (1899) does not say why he changed the names. Chance (1890) had also named the sandstone beneath the coal the *Tobucksy sandstone.* Branson (1956, p. 96) offers the following information:

> The name Tobucksy appears to come from the Choctaw word tobaksi, meaning coal pit. The geographic unit for which the sandstone was named is Tobucksy County, Mosholatubbee District . . . Choctaw Indian Nation. The county seat of Tobucksy County was the town of McAlester, and the sandstone crops out in the county.

As with the coal and basin, Taff (1899) appears to have changed the name of the sandstone from *Tobucksy* to *Hartshorne* somewhat arbitrarily.

A year later, Taff and Adams (1900, p. 287) recognized that the Hartshorne coal consists of two coal beds ("upper" and "lower") and stated that the "coals are so named because of their early and most successful mining at the town of Hartshorne, . . . and because of their association with the Hartshorne sandstone." This statement strengthens the assumption made by later workers that the sandstone was named for the town.

The definition of the Hartshorne sandstone was changed by Taff and Adams (1900) to include the "lower" coal. The "upper" coal was above the Hartshorne sandstone and separated from it by a shale interval of variable thickness. Taff and Adams (1900) maintained that the "upper" coal was the basal unit of the McAlester shale, but chose to retain the name *Hartshorne coal.*

The southern part of the Arkoma basin was mapped by Hendricks (1937a), Knechtel (1937), and Hendricks and others (1936). These authors accepted the established definition and considered the Hartshorne sandstone to consist of (from bottom to top) sandstone, a shale interval containing the Lower Hartshorne coal, and an upper locally shaly sandstone. The Upper Hartshorne coal was included at the base of the McAlester shale. A key observation made by Hendricks and his coworkers is that the character and thickness of the Hartshorne sandstone vary greatly, in some cases over relatively short distances.

The geology of the northern part of the Arkoma basin in Oklahoma was mapped by Oakes and Knechtel (1948) and Knechtel (1949). These workers recognized that the Upper and Lower Hartshorne coals merge, and they suggested that the definition of the Hartshorne sandstone be extended to include both coals (where present) (Fig. 5). This eliminated the necessity of including the Upper Hartshorne coal in the McAlester shale. Branson (1956), however, doubted that the Upper and Lower Hartshorne coals merged and suggested that the upper coal divided locally. Branson (1956) appears to suggest that Oakes and Knechtel (1948) incorrectly identified a lower split of the Upper Hartshorne coal for the Lower Hartshorne coal.

Branson (1956) reviewed the history of Hartshorne nomenclature and stated that *Tobucksy sandstone* had priority over *Hartshorne sandstone* and that Tobucksy be restored as the name of the lower member of the unit that extended to the top of the upper Hartshorne

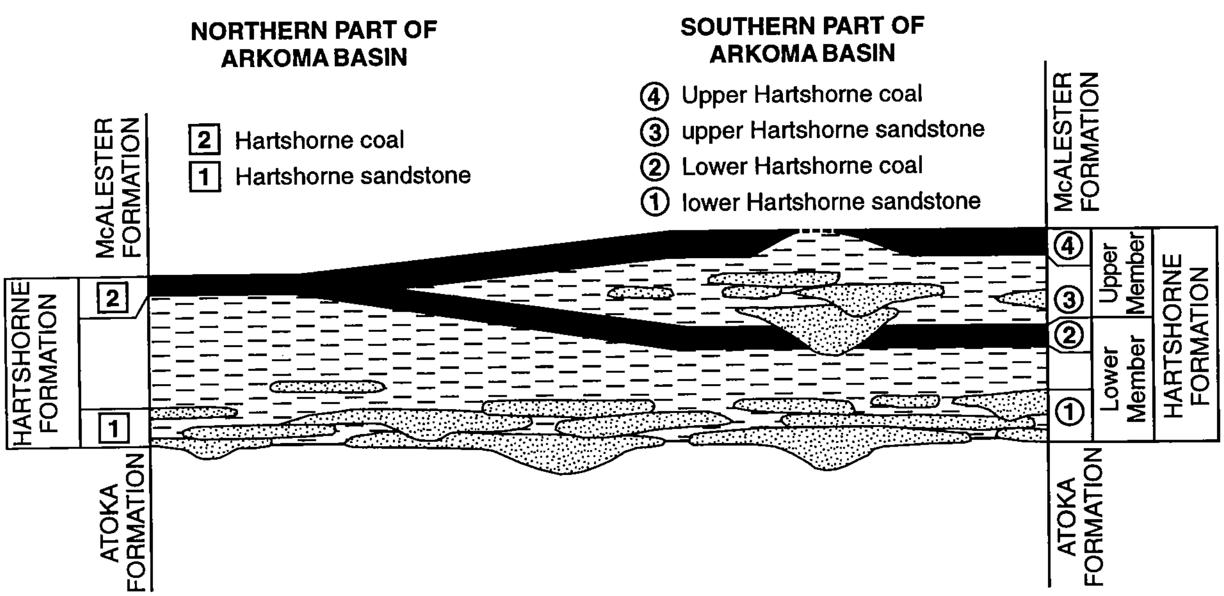


Figure 4. General relationship of different stratigraphic units (formal and informal) that constitute the Hartshorne Formation in the northern and southern parts of the Arkoma basin in Oklahoma. Note: Locally (including areas within the field-trip area) the Upper Hartshorne coal merges with the Lower Hartshorne coal, or the Upper Member of the Hartshorne Formation appears to pinch out. (From Hemish and Suneson, 1997, fig. 4.)

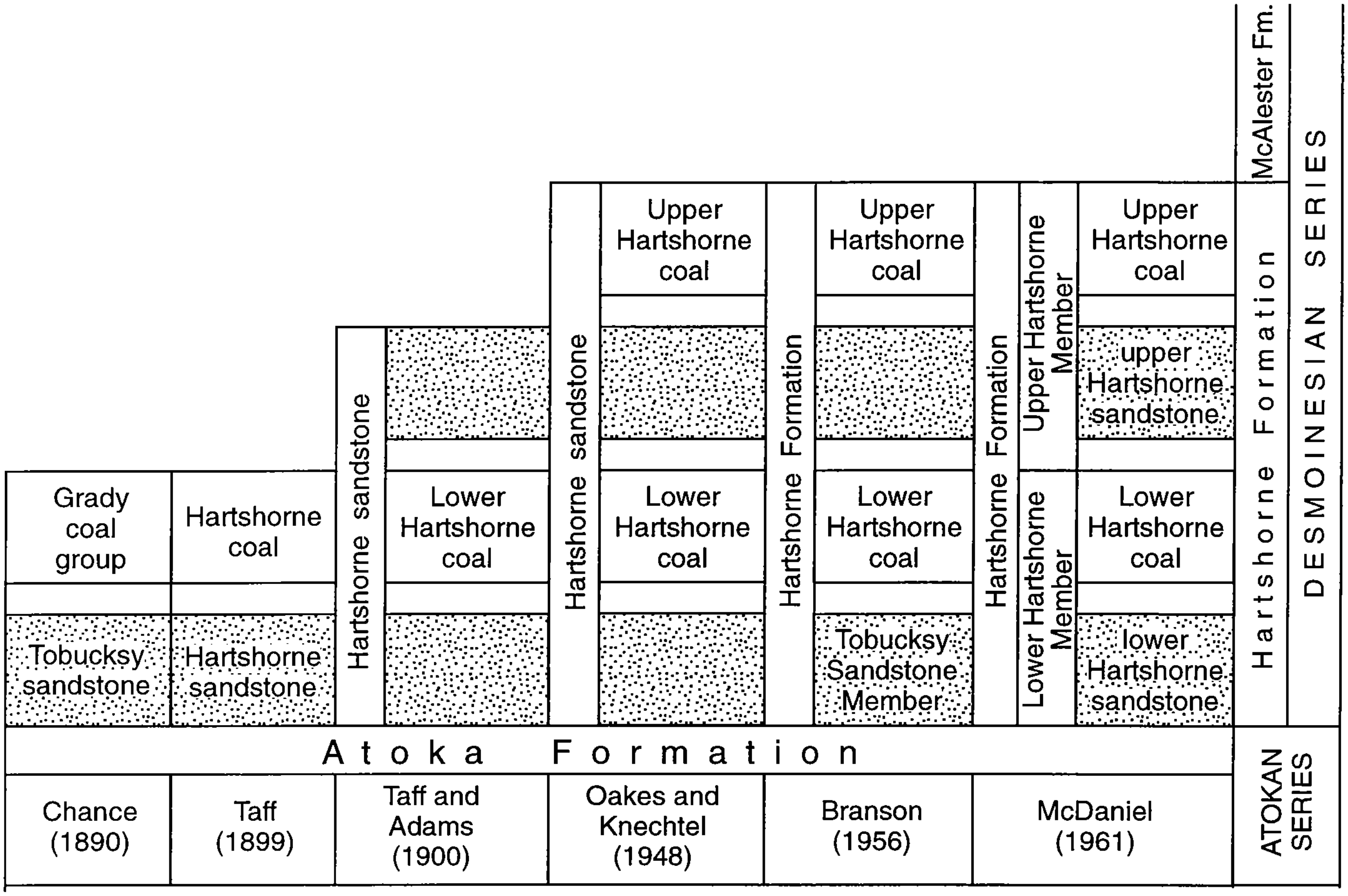


Figure 5. History of nomenclature and definitions of the Hartshorne Formation, 1890–1961. (Modified from Suneson and Hemish, 1994, p. 58.) This report follows the terminology proposed by McDaniel (1961). (From Hemish and Suneson, 1997, fig. 5.)

coal (Fig. 5). Branson (1956, p. 96) also recommended that the term *Hartshorne sandstone* be abandoned in favor of *Hartshorne formation:*

> It is here proposed that the beds from the base of the Des Moines series (top of Atoka formation where present) to the top of the Upper Hartshorne coal be referred to as the Hartshorne formation. The Tobucksy sandstone member is its lowermost member throughout the basin. Above the Tobucksy in Pittsburg and Latimer Counties and in Arkansas is the Lower Hartshorne coal, a sandstone tongue or tongues, and the upper [sic] Hartshorne coal. In Haskell and Northern LeFlore [sic] Counties only the Hartshorne coal and associated underclay are above the Tobucksy in the Hartshorne formation.

The most recent definition of the Hartshorne Formation is that proposed by McDaniel (1961) based on surface exposures in the central and eastern parts of the Arkoma basin in Oklahoma. McDaniel (1961) refined the definition of the Hartshorne Formation as proposed by Oakes and Knechtel (1948) and Knechtel (1949) by suggesting that it be divided into two members. The Lower Hartshorne Member consists of (from bottom to top) sandstone (Tobucksy sandstone of Chance [1890]), shale, and the Lower Hartshorne coal. The Upper Hartshorne Member consists of sandstone, siltstone, and/or shale in highly variable proportions overlain by the Upper Hartshorne coal. Where sandstones are well developed, they are referred to as the lower or upper Hartshorne sandstones. Houseknecht and others (1983, p. 57) and Houseknecht and others (1984, p. 28) noted that McDaniel's (1961) redefinition of the Hartshorne Formation into two members "accurately combines genetically-related facies."

Recent 1:24,000-scale OGS geologic maps of the southern part of the Arkoma basin (Appendix 1) do not divide the Hartshorne Formation into members, because the Lower Hartshorne coal (top of the Lower Hartshorne Member) is rarely exposed. However, the OGS accepts the division of the Hartshorne Formation into two members as proposed by McDaniel (1961).

DISTRIBUTION

Surface exposures of the Hartshorne Formation extend from near Morrilton, Arkansas (on the east), to Harden City, Oklahoma (on the southwest), to Muskogee, Oklahoma (on the northwest) (Fig. 6). To a large degree, the northern and southern exposures in Oklahoma reflect the margins of the Arkoma basin as mapped by Northcutt and Campbell (1996); exposures in the central part of the basin occur on the flanks or

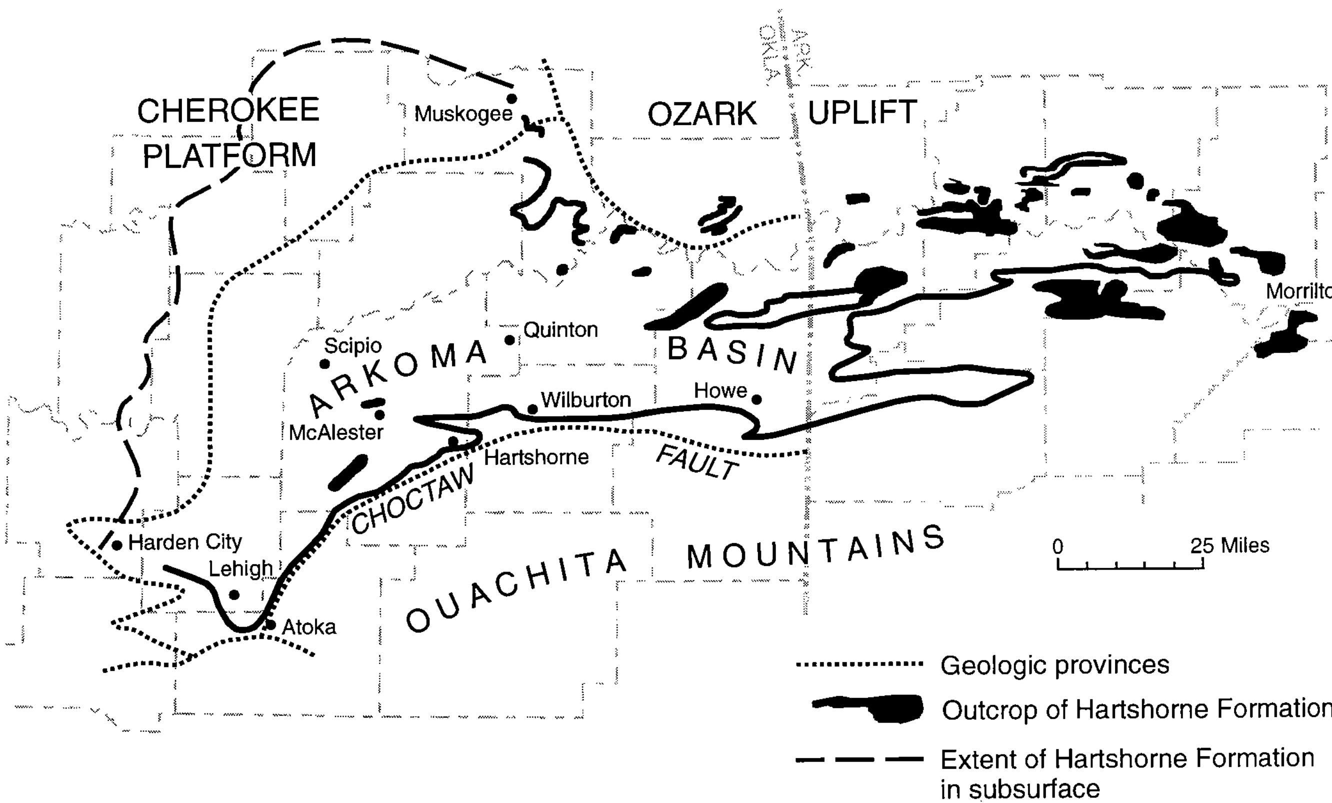


Figure 6. Map showing generalized outcrop pattern of the Hartshorne Formation in Arkansas and Oklahoma. Dashed line is western extent of Hartshorne, based on well penetrations reported on Oklahoma Corporation Commission form 1002-A. Dotted lines are margins of geologic provinces in Oklahoma, based on Northcutt and Campbell (1996). (From Hemish and Suneson, 1997, fig. 6.)

crests of anticlines. Strata older than the Hartshorne crop out north and northeast (Ozark uplift) and south and southwest (Ouachita Mountains, Arbuckle uplift) of the surface exposures in Oklahoma; it is possible that the Hartshorne has been eroded from at least parts of these areas. Therefore, the original extent of the Hartshorne Formation cannot be determined.

In much of the western part of the Arkoma basin, the Hartshorne Formation is buried by younger strata. Well-log data indicate that the Hartshorne extends as far west as eastern Pontotoc, Seminole, and Okfuskee Counties. Therefore, the minimum original areal extent of the Hartshorne Formation is ~8,470 mi^2.

The following descriptions of the Hartshorne Formation as exposed on the surface are based on previous studies (Figs. 7,8; Table 1). The descriptions are broken down on a county-by-county basis for ease of regional comparisons.

Pontotoc County

The western limit of the surface expression of the Hartshorne Formation extends into southeastern Pontotoc County (Morgan, 1924; Hart, 1974). However, there is disagreement on exactly how far west the Hartshorne crops out. Hart (1974) extends the Hartshorne Formation into sec. 8, T. 1 N., R. 7 E., whereas Morgan (1924) ends Hartshorne outcrops a mile to the east in the south part of sec. 9. The surface extent of the Hartshorne Formation in Pontotoc County may only be known through new detailed surface mapping, and such mapping would have to extend sufficiently far to the east to include strata that are undeniably Hartshorne as well as the underlying Atoka Formation and the overlying McAlester Formation.

The only description of the Hartshorne Formation in Pontotoc County is from Morgan (1924), who admits that it "is with difficulty distinguished from the overlying McAlester and the underlying Atoka formations [and that therefore] the limits are indefinite and preclude the possibility of accurate mapping" (p. 65). The Hartshorne Formation in the area mapped by Morgan (1924) is about 100 ft thick and consists of "brown or yellowish-brown sandstones with interbedded shales" (p. 66). In contrast, the McAlester and Atoka Formations are mostly shale. Morgan (1924) noted that the Hartshorne is unfossiliferous and that no coal was observed in the area.

Morgan (1924) suggested that the Hartshorne was unconformably deposited across the "uplifted, folded, and peneplaned" (p. 64) Atoka Formation. He further suggested that the Hartshorne was "overlapped by the upper part of the McAlester formation" (p. 66) at its farthest western extent. My interpretation of Morgan's (1924) statement is that the McAlester onlaps the Atoka.

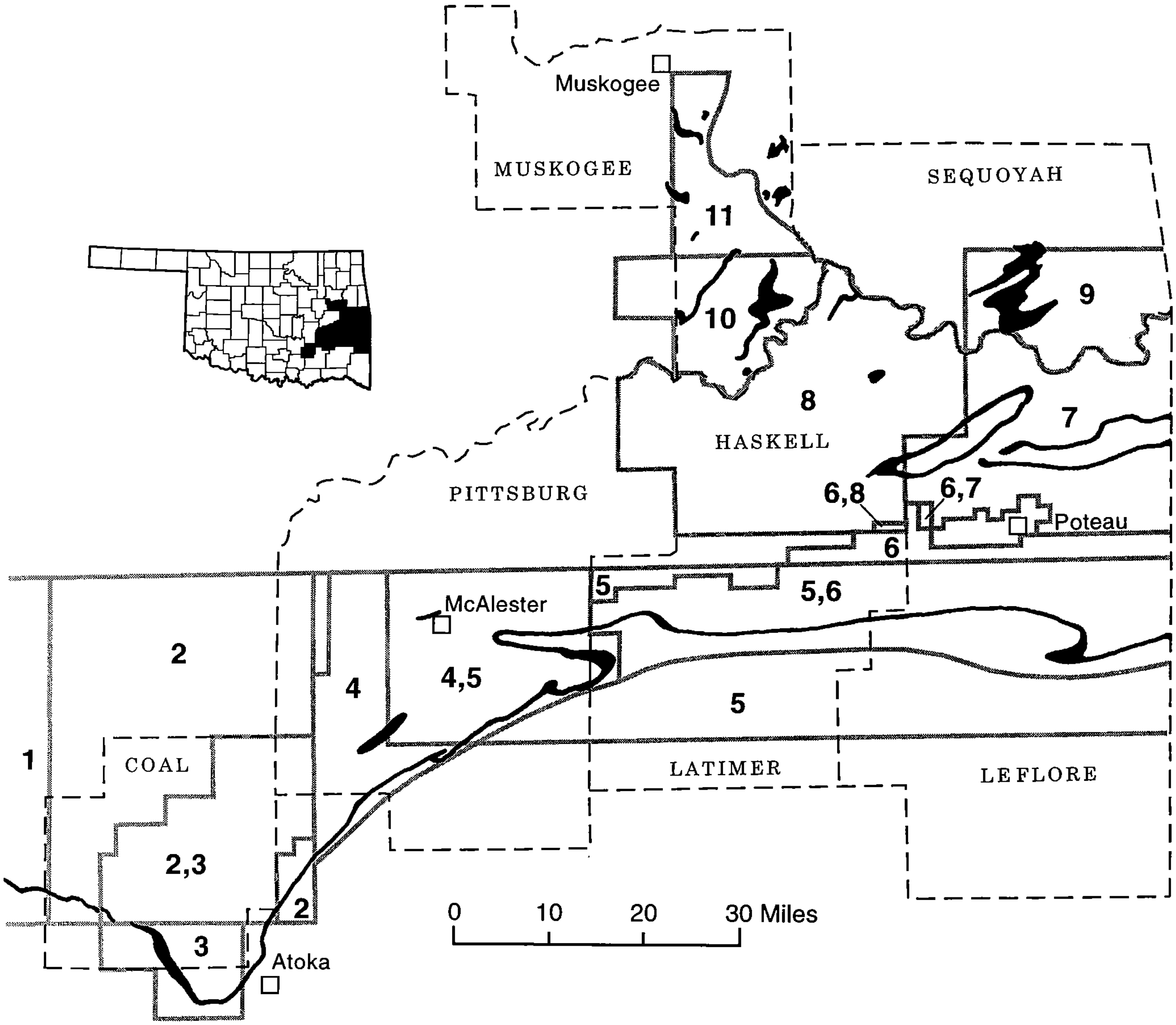


Figure 7. Map showing significant previous map studies that include the Hartshorne Formation. 1, Morgan (1924); 2, Taff (1901); 3, Knechtel (1937); 4, Hendricks (1937a); 5, Oklahoma Geological Survey (Appendix 1); 6, Hendricks (1939); 7, Knechtel (1949); 8, Oakes and Knechtel (1948); 9, Crumpley (1949); 10, Stine (1958); 11, Gregware (1958).

Coal County

The Hartshorne Formation is present in the southwestern and south-central parts of Coal County (Taff, 1901; Knechtel, 1937; Hart, 1974). Although there are disagreements about the detailed outcrop pattern of the Hartshorne, the general geology of the area is well known.

Taff (1901) described the Hartshorne Formation in Coal County as consisting of thin- to thick-bedded (as thick as 3 ft) fine-grained sandstones interbedded with rarely exposed shale. He believed that the formation is about 200 ft thick, though he admitted that it graded into the adjacent shale-dominated Atoka and McAlester Formations, making its lower and upper contacts arbitrary.

Knechtel (1937) noted that the Hartshorne varies widely in thickness (from 80 to 500 ft and, in some cases, over short distances) and that the thickness variations "are accompanied by variations in lithology, especially in the lower part of the formation. Where the formation is thin it is made up largely of thin-bedded bluish-gray shale and fine-grained light-gray to yellow sandstone; the thickest sections are composed mainly of massive hard white to gray, somewhat coarse-grained sandstone" (p. 102–103). Of particular importance is Knechtel's (1937) observation that the Hartshorne locally contains pebble-sized chert fragments, and that sandstones in the Atoka and McAlester Formations contain similar chert fragments generally in the same areas.

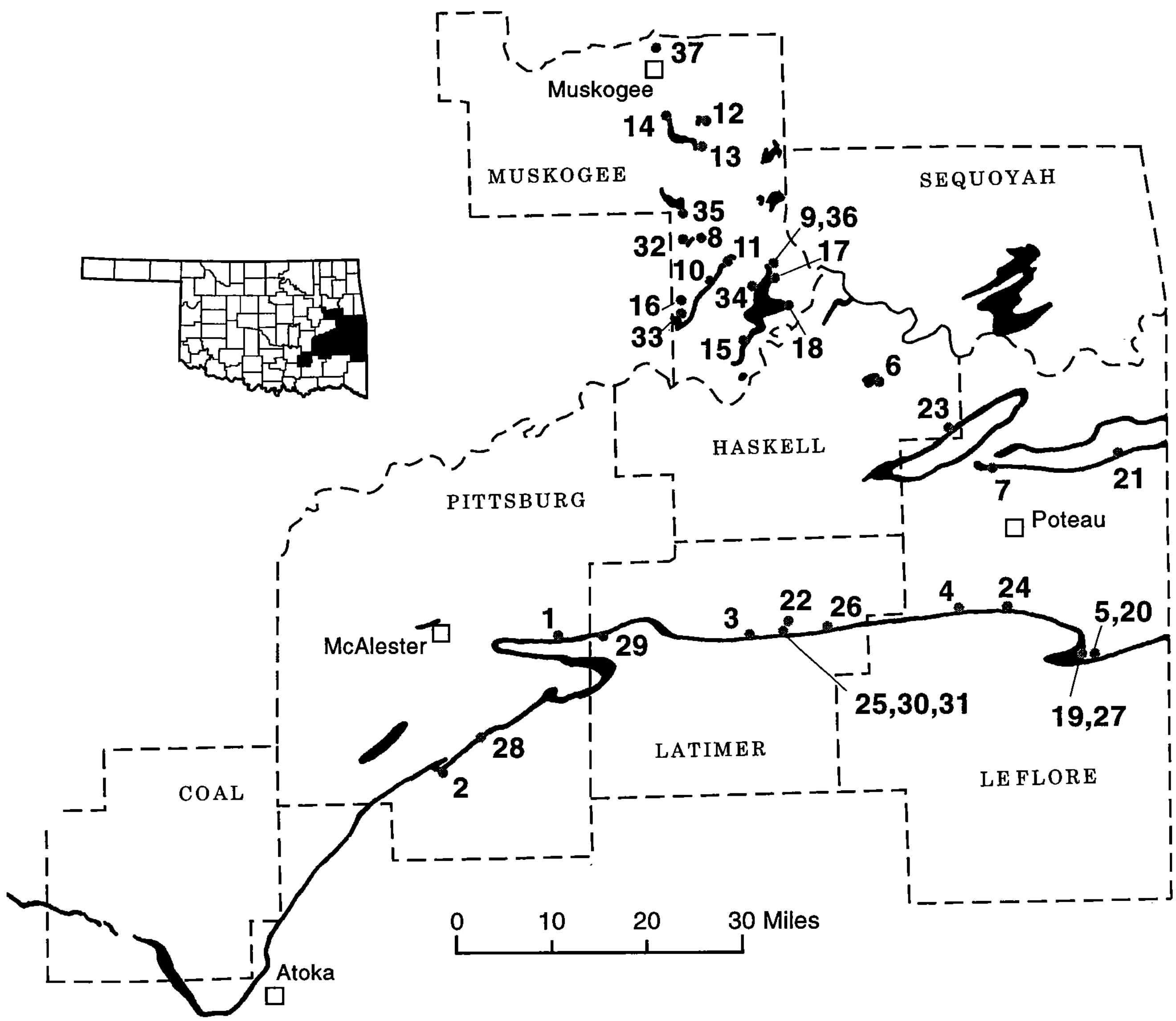


Figure 8. Map showing locations of previously described measured sections and cores of the Hartshorne Formation. Numbers refer to locations given in Table 1.

Knechtel (1937) identified two coal beds associated with the Hartshorne Formation in Coal County. The Lower Hartshorne coal is as thick as 4 ft and crops out above the sandstone throughout the southern part of the county. Knechtel (1937, pl. 11) did not map any coal beds in the extreme western part of the county. Although he mentioned that "a thin bed of coal of little or no value, known as the Upper Hartshorne coal, occurs at the base of the McAlester shale" (p. 134), he did not say where he saw it, nor did he map it on his geologic map (pl. 11).

In Coal County, Knechtel (1937) mapped the contact between the Hartshorne and the underlying Atoka Formation as a minor disconformity, and that between the Hartshorne and the overlying McAlester Formation as a conformity. Recent field work and subsurface interpretations indicate that these contacts are typically gradational.

Atoka County

The Hartshorne Formation in Atoka County has been mapped by Hendricks (1937a), Hendricks and others (1947), Hart (1974), and Marcher and Bergman (1983), although the last two maps are compilations of the first two. There is very little disagreement among these workers about the outcrop distribution of the Hartshorne.

The Hartshorne Formation in the western part of Atoka County (at the south end of the Lehigh syncline) is similar to that described by Knechtel (1937) for Coal

TABLE 1. – Measured Sections and Core Descriptions of Hartshorne Formation in Oklahoma

Map no.[a]	Location	Total measured thickness (feet)	Top observed ?	Base observed ?	Reference	Notes
1	East Line 7/5N/17E	237	Y	Y	Hendricks (1937a, p. 12)	
2	East Line 13/3N/14E	128	N	N	Hendricks (1937a, p. 13)	
3	Center 8/5N/20E	211	Y	Y	Hendricks (1939, p. 266)	
4	SE¼ 35/6N/23E	243	Y	Y	Hendricks (1939, p. 266–267)	
5	NW¼ 31/5N/26E	330	N	Y	Hendricks (1939, p. 267)	Petry's Cut
6	SE Cor. 33/10N/22E	2	Y	N	Oakes and Knechtel (1948, p. 133–134)	
7	SE Cor. 16/8N/24E	53	N	N	Knechtel (1949, p. 66)	
8	S Sec. Line 16/12N/19E	1.5	Y	Y	Gregware (1958, p. 85–86)	Oakes (1977) #18
9	Strip Pits 35/12N/20E	5.3	Y	Y	Gregware (1958, p. 87)	Oakes (1977) #22; same as 36
10	NW¼ 31/12N/20E	3.0	Y	Y	Gregware (1958, p. 87–88)	Oakes (1977) #21
11	NE¼ 30/12N/20E	15.5	Y	N	Gregware (1958, p. 88)	Oakes (1977) #20
12	14/14N/20E	21.1	N	Y	Gregware (1958, p. 98–99)	Oakes (1977) #72
13	27/14N/19E	10	Y	Y	Gregware (1958, p. 100)	
14	NE¼ 18/14N/19E	1.5	N	Y	Gregware (1958, p. 100–101)	Oakes (1977) #74
15	4/10N/20E	38.1	Y	N	Stine (1958, p. 81)	Oakes (1977) #6
16	29/11N/19E	4.0	Y	Y	Stine (1958, p. 85)	Oakes (1977) #12
17	NE¼ 2/11N/20E	13.1	N	Y	Stine (1958, p. 88–89)	Oakes (1977) #13
18	19/11N/21E	58.5	N	Y	Stine (1958, p. 89)	Oakes (1977) #16
19	NW¼ 36/5N/20E	101	N	Y	Donica (1978, p. 125–126)	Heavener Road Cut; same as 27
20	NW¼ 31/5N/26E	286.7	N	Y	Donica (1978, p. 127)	Petry's Cut
21	SW¼ 12/8N/26E	98	N	N	Houseknecht (1983, p. 97)	
22	NE¼ 12/5N/20E	124.6	Y	N	Hemish (1988, p. 16–17)	
23	NW Cor. 36/9N/23E	4.8	Y	N	Hemish (1988, p. 22)	
24	SW¼ 36/6N/24E	152.6	N	Y	Hemish (1993, p. 19)	
25	NW¼ 12/5N/20E	18.0	N	Y	Suneson and Hemish (1994, p. 56)	Craven Road Section; same as 30
26	NW¼ 10/5N/21E	72.7	N	Y	Suneson and Hemish (1994, p. 59)	
27	NW¼ 36/5N/20E	101	N	Y	Suneson and Hemish (1994, p. 100)	Heavener Road Cut; same as 19
28	25,26/4N/15E	86.0	N	Y	Hemish and Suneson (1997, p. 53–56)	Gardner Creek Section
29	10,11/5N/17E	376.0	N	Y	Hemish and Suneson (1997, p. 61–62)	Clonsilla Hill Road Section
30	NW¼ 12/5N/20E	18	N	Y	Hemish and Suneson (1997, p. 63)	Craven Road Section; same as 25
31	NE¼ 12/5N/20E	80.5	N	Y	Hemish and Suneson (1997, p. 63–65)	Red Oak Ridge Section
32	SW Cor. 16/12N/19E	17.9	Y	Y	Hemish (1998, p. 81)	
33	NW Cor. 33/11N/19E	11.8	Y	N	Hemish (1998, p. 41)	
34	NE¼ 10/11N/20E	6.0	Y	N	Hemish (1998, p. 42)	
35	NE Cor. 5/12N/19E	4.2	Y	N	Hemish (1998, p. 43)	
36	NE¼ 35/12N/20E	5.4	Y	N	Hemish (1998, p. 44–45)	Same as 9
37	Center 11/15N/18E	20.3	Y	Y	Hemish (1998, p. 100)	

[a]Numbers correspond to those in Figure 8.

County. To the east and northeast, in the central and northern parts of Atoka County on the southeast flank of the Lehigh syncline and just northwest of the trace of the Choctaw fault, the Hartshorne forms a well-defined to subtle ridge underlain by mostly steeply northwest-dipping strata. Hendricks (1937a) described the northern segment of this part of the Hartshorne outcrop belt in detail, but because most of his report pertains to the McAlester coal district in Pittsburg County, that description is given below. He does note, however, that a relatively widespread upper sandstone in the Hartshorne "grades laterally into sandy shale" (p. 11) in the southwestern part of the district (Atoka County). The description of the Hartshorne Formation by Hendricks and others (1947) is generalized for a large area; they did not focus on Atoka County except to report that the Hartshorne near the town of Atoka is a pebble conglomerate, similar to some of the beds in the underlying Atoka Formation. (The pebble conglomerate in the Hartshorne Formation is described more fully at Stop 3, Part II, this guidebook.)

Hendricks (1937a, pl. 7) mapped the Lower and Upper Hartshorne coals in T. 2 N., R. 13 E., in the northern part of Atoka County, although he shows both as a long-dashed line (defined as "approximate outcrop of minable coal bed"). He identified both coals in outcrop near the center of the W½ sec. 10; the lower coal there is 1 ft 3 in. thick, and the upper coal, 2 ft 1 in. thick.

Hendricks and others (1947) reported that the Hartshorne conformably overlies the Atoka in the Arkoma basin. According to Hendricks (1937a), the Hartshorne-Atoka contact is gradational, and that of the Hartshorne-McAlester, "gradational and conformable" (p. 13).

Pittsburg County

The Hartshorne Formation crops out extensively in Pittsburg County, where it has been mapped by Hendricks (1937a), Marcher and Bergman (1983), and more recently by the Oklahoma Geological Survey (Hemish, 1995, 1996, 1997a; Suneson, 1996, 1997; and Suneson and Hemish, 1996). The map by Marcher and Bergman (1983) is a compilation and provides little original material or description. In general, the outcrop pattern of the Hartshorne as mapped by these authors is the same; however, Hendricks (1937a) places the Upper Hartshorne coal and subjacent shale in the McAlester Formation, whereas the OGS places the Hartshorne-McAlester contact at the top of the Upper Hartshorne coal.

The Hartshorne Formation in Pittsburg County crops out in three principal areas: in the footwall of the Choctaw fault just northwest of the trace of the fault on the south flanks of the Kiowa and Hartshorne synclines, on the flanks of the doubly plunging Savanna anticline, and on the flanks of the west-plunging Adamson anticline. In addition, a small outlier of Hartshorne is near the core of the McAlester anticline just south of the Penitentiary fault. In these areas, it typically forms conspicuous topographic ridges that vary from high and with relatively steep sides to low and subdued to barely perceptible. Dips range from approximately vertical and locally overturned to gentle.

Most of Pittsburg County lies within the McAlester coal district of Hendricks (1937a, p. 11), who described the Hartshorne Formation in some detail:

> The character of the Hartshorne varies greatly in different parts of the district.... The lower sandstone of the formation ranges from massive, medium-grained, and pure in some parts of the area to thin-bedded, shaly, ripple-marked, and fine-grained at other places.... The middle shale interval is present throughout the district but varies somewhat in thickness. The upper sandstone is the most variable part of the formation.... [In places] it is a massive coarse-grained pure-white, poorly cemented sandstone that... ranges from 50 to 100 feet in thickness. In other parts of the district this sandstone ranges from 10 to 50 feet in thickness and has much the same character as the lower sandstone.

Based on recent mapping by the OGS, the Hartshorne Formation in Pittsburg County varies from 0 to 1,000 ft thick and is dominantly fine- to very fine grained sandstone interbedded with silty shale, and it contains two coal beds. The unusually thick section of the Hartshorne Formation is described for Stop 7, Part II, this guidebook. The sandstone beds range from thin bedded to massive and unstratified to cross stratified and ripple bedded. Evidence for bioturbation is common in the thin-bedded strata. Ripple marks, cross-bedding, and wavy-bedding are common locally, and bedding planes typically contain abundant carbonized plant debris.

Hendricks (1937a, pl. 7) mapped both the Lower and Upper Hartshorne coal beds throughout Pittsburg County and provided detailed township-by-township descriptions based largely on observations in operating or abandoned mines or exploration pits. In this county, the Lower Hartshorne coal ranges from 2 ft 5 in. to 6 ft thick, and the Upper Hartshorne coal, from 1 ft 8 in. to 5 ft 7 in. thick (Hendricks, 1937a). Hendricks (1937a) states that "the Upper Hartshorne coal is present in the same parts of the area as the Lower Hartshorne coal" (p. 49); but his map (pl. 7) shows one coal bed as a solid line ("outcrop of minable coal"), and the other as a dashed line ("approximate outcrop of minable coal"). This may be due to the quality of outcrops examined, because Hendricks (1937a) observed both coals in adjacent outcrops or workings at several places along the outcrop belt in Pittsburg County. Exposures of both coals at many of these localities have been confirmed by recent OGS mapping.

Locally, the base of the Hartshorne Formation in Pittsburg County is a disconformity; relatively thick channel-form deposits of Hartshorne sandstone appear to have been deposited on truncated beds of shale and siltstone in the Atoka Formation. Elsewhere, the Atoka Formation appears to grade (coarsen) upward into the Hartshorne (e.g., Stop 6, Part II, this guidebook). The contact between the Hartshorne and the overlying McAlester Formation is conformable in Pittsburg County.

Latimer County

The Hartshorne Formation forms a moderately well defined east-west–trending ridge through the center of Latimer County (Hendricks, 1939; Marcher and Bergman, 1983; Hemish, 1992; Hemish and others, 1990a,b,c). Along this ridge, the Hartshorne generally dips moderately to the north on the south flank of the San Bois and Cavanal synclines. The Hartshorne also crops out in west-central Latimer County on the east end of the Hartshorne syncline, where it plunges west and forms a low, curved ridge (Hendricks, 1937a). The outcrop pattern of the Hartshorne as mapped by OGS and previous workers is generally the same, the only difference being that Hendricks (1939) included the Upper Hartshorne coal and directly underlying shale in the McAlester Formation, whereas OGS workers map the top of the Hartshorne Formation at the top of the Upper Hartshorne coal. These differences are the same as in Pittsburg County to the west.

Hendricks (1939, p. 264–266) included the Howe-Wilburton coal district in Latimer and Le Flore Counties; and his description of the Hartshorne applies to both:

> The Hartshorne sandstone is highly variable in thickness and character throughout the district. At many places it consists of thin-bedded, fine-grained sandstone [interbedded] with much sandy shale and is about 50 feet thick. At other places it is made up of two beds of massive, coarse-grained, pure sandstone separated by about 30 feet of sandy shale and reaching a total thickness of as much as 350 feet. Even in the places where it consists mostly of sandy shale with some interbedded sandstone the sandstone beds fall into two groups situated near the top and base of the formation and separated by a sandy shale unit in which lies the Lower Hartshorne coal. . . . Where the formation is thick and made up mostly of sandstone, it forms the crests of high ridges. . . . Locally the sandstone appears to have been deposited in a series of stream channels, and at some places the streams that deposited the sand in the upper part of the formation swept across forests growing in what is now the shale roof of the Lower Hartshorne coal, and buried hundreds of calamites and cordaites trunks, which now stand upright in the shale and overlying sandstone and even cross the contact between the two.

In 7.5′ quadrangles recently mapped by the OGS, the Hartshorne consists of very fine grained, thin-bedded to massive sandstone interbedded with silty shale. The sandstones are typically ripple marked and bioturbated. In Latimer County, the formation contains two coal beds and ranges from 250 to 400 ft thick.

The Lower and Upper Hartshorne coals crop out in Latimer County. Hendricks (1939) noted several adjacent localities along the outcrop belt where both were mined, but he mapped much of the Upper Hartshorne coal bed in the eastern part of the county as a "horizon of coal bed, thickness unknown," suggesting that it was more discontinuous in the east than in the west. In contrast, the Lower Hartshorne coal bed is mapped as a solid line ("outcrop of coal bed") throughout the county. Recent maps by the OGS show only one locality where both coals occur in nearby outcrops. This locality is described in Part II of this guidebook as the Panola Section (Stop 9). In Latimer County, the Lower Hartshorne coal ranges from 3 ft 10 in. to 6 ft 7 in. thick, and the Upper Hartshorne coal, from 2 ft 8 in. to 4 ft 8 in. thick (Hendricks, 1939).

Hendricks (1939) noted that the Atoka-Hartshorne contact is gradational in places but that it is sharp and appears to be a local unconformity in other places. Suneson and Hemish (1994, p. 56–57) noted that the change in character of the contact from gradational and "arbitrary" to abrupt and unquestionably erosional can occur over very short distances. An example of the abrupt change in character of the Hartshorne Formation occurs at the top of Red Oak Ridge southwest of the town of Red Oak (Stops 10A and 10B, Part II, this guidebook). Throughout Latimer County, the McAlester Formation conformably overlies the Hartshorne.

Le Flore County

Geologic maps of the Hartshorne Formation in Le Flore County include those of Hendricks (1939), Knechtel (1949), Marcher and Bergman (1983), Hemish (1991), Hemish and Mazengarb (1992), Hemish and Suneson (1993, 1994), Suneson and Hemish (1993), and Mazengarb and Hemish (1993). Marcher (1969) published a compilation geologic map at a scale of 1:250,000 but did not divide the Hartshorne and McAlester Formations.

The Hartshorne Formation in Le Flore County crops out in two principal areas. The first is a generally east-west–trending belt through the middle of the county, where it forms the south flank of the Cavanal and Poteau synclines. The only deviation from the east-west trend is near the town of Heavener, where the outcrop belt crosses the east-plunging Heavener anticline and the Pine Mountain syncline. The second area of widespread exposure of the Hartshorne is in the northern part of Le Flore County, where it crops out on the flanks of the Backbone (Brazil) and Milton anticlines.

In general, the Hartshorne forms relatively high to moderate ridges, although locally the ridges are low to barely distinguishable from the surrounding land. In places, isolated, elongate hills underlain by the Hartshorne mark what would otherwise be a virtually unrecognizable outcrop trace (e.g., Stop 16, Part II, this guidebook).

Hendricks (1939) described in some detail the Hartshorne as it occurs in the Howe-Wilburton coal district; this description is included in the subsection on Latimer County. Knechtel (1949) added little: "The formation consists mostly of sandstone and hard siltstone, with a smaller amount of shale. It ranges in thickness from about 100 feet to about 400 feet and in general thins in a northwestly direction across northern Le Flore County" (p. 16). Knechtel (1949) did follow currently accepted usage in defining the Hartshorne Formation, however, by extending the definition upward to include the Upper Hartshorne coal. He also noted that the Lower and Upper Hartshorne coals are so close together on the Milton anticline that they could only be mapped as a single bed.

Recent work by the OGS provides detailed descriptions of the Hartshorne Formation along its southern outcrop belt in Le Flore County. Here, the Hartshorne ranges from 250 to 400 ft thick and consists of very fine grained, thin-bedded to massive sandstone interbedded with silty shale, and containing two coal beds. Ripple marks and trace fossils are common in the thin-bedded strata. In the eastern part of the southern outcrop belt, the Hartshorne consists mostly of silty shale interbedded with siltstone, many minor sandstone beds, and two major sandstone beds. The sandstones typically are cross-bedded and locally contain upright *Calamites*. Plants in growth position in many beds at Stop 15, Part II, this guidebook, are evidence for a nonmarine origin for parts of the Hartshorne Formation (discussed below). Sideritic nodules are common in the shales.

The Upper and Lower Hartshorne coals are present, though generally poorly exposed, along the southern outcrop belt of the formation. Hendricks (1939, pl. 27) did not map the upper coal east of sec. 23, T. 6 N., R. 24 E., but did measure it in sec. 31, T. 6 N., R. 25 E. (pl. 34); Donica (1978) mapped it in the subsurface to the west edge of T. 5 N., R. 27 E. Along the southern outcrop belt, the Lower Hartshorne coal ranges from almost 7 ft thick to about 3 ft thick (Hendricks, 1939, pl. 34). Donica (1978, pl. 4) showed that the Upper Hartshorne coal ranges from about 1 to 2.5 ft thick in the subsurface.

In the northern part of Le Flore County, the Upper and Lower Hartshorne coals merge north of the Backbone anticline and south of the Milton anticline (see discussion, Stop 18, Part II, this guidebook). Based on drill holes and outcrops in mines and prospects, Knechtel (1949, table 3) showed that the Lower Hartshorne coal ranges from about 1 to 8.5 ft thick, the Upper Hartshorne coal from about 1 to 9 ft thick, and the Hartshorne coal (undivided) from 1 to 7 ft thick.

Contact relations with the underlying Atoka and overlying McAlester Formations are the same as in Latimer County: The Hartshorne gradationally to disconformably overlies the Atoka and conformably underlies the McAlester.

Haskell County

The Hartshorne Formation in Haskell County crops out in three widely separated areas. The northernmost of these is in the north-central part of Haskell County just south of the Arkansas River on the northwest flank of the Stigler syncline. The Hartshorne also crops out on the crest of the Round Prairie dome in northeastern Haskell County and on the southwestern nose and northwest flank of the Milton anticline on the eastern side of the county. The Hartshorne in these areas was mapped by Oakes and Knechtel (1948) and shown on the regional compilation by Marcher (1969), who combined it with the McAlester Formation. No more-recent geologic maps of the Hartshorne Formation have been published since Oakes and Knechtel's (1948) excellent work.

Oakes and Knechtel (1948, p. 25) provide little in the way of a detailed description of the Hartshorne Formation:

> The Hartshorne sandstone in Haskell County consists of a lower sandstone zone which is generally less than 50 feet thick, but is locally thicker, and an upper zone 50 feet thick, maximum, which is composed mostly of shale and contains the Hartshorne coal at the top.

They did, however, recognize the convergence of the Lower and Upper Hartshorne coals in the southern part of the county and were the first to recommend that the Hartshorne Formation be redefined to include both Hartshorne coals.

The Hartshorne coal is mapped as a single bed in Haskell County, although "at many places [it] consists of two benches of coal separated by a shale parting a few inches thick. These benches represent the Upper and Lower Hartshorne coal beds" (Oakes and Knechtel, 1948, p. 79). The coal thins northwestward from about 3 to 5 ft on the west crest of the Milton anticline to about 1 ft in the northern part of the county.

Throughout Haskell County, the Hartshorne is conformably underlain by the Atoka Formation and conformably overlain by the McAlester Formation (Oakes and Knechtel, 1948).

Northern Part of Arkoma Basin

Although Sequoyah and Muskogee Counties are north of the field-trip area, the Hartshorne Formation in these areas is described below because some workers (e.g., Scruton, 1950) believe that some parts of the formation may have been derived from the adjacent Ozark uplift in northeastern Oklahoma. In addition, future work (beyond the scope of this paper) on the Hartshorne should include these areas.

Sequoyah County

The Hartshorne Formation may crop out extensively in the southern part of Sequoyah County, but its exact extent is unknown. The most recent geologic map of Sequoyah County is by Marcher (1969); unfortunately, it is at a scale of 1:250,000 and does not differentiate the Hartshorne and McAlester Formations.

Miser (1954) shows several outcrop belts of the Hartshorne Formation but bases his map of the area on Crumpley (1949), who mapped only one of the five belts shown by Miser (1954). At present, more detailed mapping east and southeast of Sallisaw is necessary to define the outcrop pattern of the Hartshorne Formation.

Crumpley (1949) mapped a single ridge underlain by the Hartshorne Formation north of the Mulberry fault. He described the Hartshorne as a "thin-bedded, fine-grained, buff sandstone which grades into shaley zones locally along the outcrop. There are coal beds both above and below it which may correlate with the upper and lower Hartshorne coals . . . ." (p. 19). The outcrop distribution and thickness of the coals are unknown. Miser (1954) mapped the Hartshorne Formation south of the Mulberry fault in areas that were mapped by Crumpley (1949) as the McAlester Formation.

Muskogee County

The Hartshorne Formation in Muskogee County was mapped by Oakes (1977), whose work is based largely on several University of Oklahoma master's theses—in particular, those of Stine (1958), Gregware (1958), and Bell (1959). From south to north, the Hartshorne crops out on the flanks of the Porum syncline, the Warner uplift, and the Rattlesnake Mountain anticline. In the northern part of the county, the outcrop belt trends generally north-south but is offset by several east-west–striking faults such as the Keefton fault (Oakes, 1977).

Oakes (1977) noted the extreme variability in thickness and distribution of the Hartshorne Formation in Muskogee County. The thickest and most continuous outcrops are in the southern part of the county, where the Hartshorne is a "fine- to medium-grained sandstone, with small-scale cross-bedding" (p. 15) and forms a prominent topographic scarp. To the north, the Hartshorne is a "fine- to very fine grained, (finely cross-bedded,) thin-bedded to massive sandstone, which commonly forms a low bench wherever it crops out" (p. 15). In general, the lithologic character of the Hartshorne throughout Muskogee County doesn't change, but it is thinner and more discontinuous to the north than to the south. For example, Stine (1958) mapped 50–60 ft of Hartshorne Formation on the east flank of the Porum syncline but less than 5 ft in the Warner uplift about 10 mi to the west. Similarly, Gregware (1958) was able to identify only a single 1.5-ft-thick sandstone bed as the Hartshorne in the thick shale interval between unnamed sandstones in the Atoka Formation and the Warner Sandstone Member of the McAlester Formation on the southeast flank of the Rattlesnake Mountain syncline. However, the Hartshorne is present on the north flank of the syncline.

In the northeastern part of Muskogee County, Bell (1959) mapped two small outcrops of Hartshorne along the banks of the Arkansas River in sec. 21, T. 15 N., R. 19 E. This outcrop was reinterpreted as the Savanna Formation by Oakes (1977) and is not shown in Figure 7 as the Hartshorne Formation.

The Hartshorne coal is also present only locally in Muskogee County. It has been mined on the northeast end of the Porum syncline (Gregware, 1958; Hemish, 1998), where it is about 1 ft thick, but it appears to be absent about 4 mi to the south-southeast (Stine, 1958, measured section 28). Elsewhere in the county, the Hartshorne coal ranges from about 0.5 ft thick to absent. Hemish (1998, core hole 30) identified 0.6 ft of Hartshorne coal in the extreme northern part of the county.

The Hartshorne Formation in Muskogee County conformably overlies the Atoka Formation and conformably underlies the McAlester Formation (Oakes, 1977).

Wagoner, Mayes, and Craig Counties

The existence of the Hartshorne Formation north of Muskogee County is controversial. Govett (1959) mapped the Hartshorne Formation in a generally north-south–trending outcrop belt across the eastern part of Wagoner County and to the southern edge of Mayes County. He noted that the Hartshorne averaged about 20 ft thick and consisted mostly of "black fissile shale with clay ironstone zones" (p. 47). However, his description of the Hartshorne is nearly identical to his descriptions of the Atoka and McAlester Formations. In addition, Govett (1959) mapped the base of the McAlester as the base of the Warner Sandstone Member, which indicates that his Hartshorne might be, in fact, the McCurtain Shale Member of the McAlester Formation.

Branson and Huffman (1965) mapped the Hartshorne throughout the southeastern part of Craig County and described it as containing shale, siltstone, coaly clay, coal, underclay, fissile shale, a clay-ironstone bed, silty shale, and sandstone. Like Govett (1959), Branson and Huffman (1965) mapped the base of the McAlester as the base of the Warner Sandstone Member and appear to discount the presence of the McCurtain Shale Member.

Three cross sections by Hemish (1990) illustrate different interpretations of Atokan and early Desmoinesian stratigraphic relations in northern Muskogee, Wagoner, Mayes, and Craig Counties. Hemish (1990) identified the Hartshorne Formation in core holes in northern Muskogee County in all three of his cross sections. On sections A–A′ and B–B′, he queried the existence of the Hartshorne Formation north of Muskogee County and the correlation of the Riverton coal with the Hartshorne coal. On section C–C′, his preferred interpretation (Hemish, personal communication, 1998), he shows the Hartshorne Formation pinching out in the subsurface north of Muskogee County and somewhere south of west-central Mayes County.

Until more detailed surface mapping is completed, it is premature to extend the Hartshorne Formation north of Muskogee County. The presumed absence of the McCurtain Shale Member of the McAlester Formation in Wagoner County (Govett, 1959) and Craig County (Branson and Huffman, 1965), and the similarity of descriptions of presumed Hartshorne Formation to overlying and underlying formations, suggest that the Hartshorne is unmappable and therefore may not exist north of Muskogee County.

THICKNESS

The thickness of the Hartshorne Formation (as defined in Oklahoma) varies greatly and is difficult to determine from the literature because of the different definitions of the unit. For example, in Arkansas, the Hartshorne Formation is equivalent to the lower Hartshorne sandstone of Oklahoma terminology (McDaniel, 1961), and the Hartshorne coal is included in the McAlester Formation. The Hartshorne Formation (Arkansas terminology) is ~350 ft thick (Haley, 1961). The top of the Hartshorne coal, where present, is no more than 80 ft above the top of the sandstone (C. G. Stone, personal communication, 1997). Therefore, the maximum thickness of the Hartshorne Formation (Oklahoma terminology) in Arkansas is ~430 ft.

In Oklahoma, the thickness of the Hartshorne Formation varies widely. Along its northern outcrop belt, the following thicknesses have been reported: northern Le Flore County, 100–400 ft, thins to northwest (Knechtel, 1949, p. 16); Haskell County, maximum 100 ft (Oakes and Knechtel, 1948, p. 25); Muskogee County, 50 to ~5 ft (Oakes, 1977, p. 15). Along its southern outcrop belt, the following thicknesses have been reported for the Hartshorne Formation: southern Le Flore County, 250–400 ft (OGS mapping, Appendix 1); Latimer County, 250–400 ft (OGS mapping, Appendix 1); Pittsburg County, 0–1,000 ft (OGS mapping, Appendix 1); Coal County, <80 to 500 ft (Knechtel, 1937, p. 102). The Hartshorne Formation pinches out westward onto the Arbuckle uplift in southern Pontotoc County (Hart, 1974), where it appears to be unconformably overlain by the McAlester Formation.

In Oklahoma, the contact between the Hartshorne Formation and the underlying Atoka Formation is conformable to disconformable. The overlying McAlester Formation mostly overlies the Hartshorne conformably (Fig. 4). Where the Hartshorne was not deposited in the shelf area of the Cherokee platform of Northcutt and Campbell (1996) north of the Arkoma basin, the McAlester appears to overlie the Atoka paraconformably. In one area in Sebastian County, Arkansas, the Hartshorne-Atoka contact is reported to be an angular unconformity (Frezon, 1962, p. 22, based on personal communication from B. R. Haley).

SANDSTONE PETROLOGY AND COAL CHEMISTRY

The Hartshorne Formation consists of interbedded sandstone, siltstone, shale, and coal. No petrographic studies have been published on the siltstones and shales of the Hartshorne. Most descriptions of the Hartshorne Formation focus on the sandstones and coals, which are better exposed and/or have economic value. No studies have differentiated the upper and lower Hartshorne sandstones petrographically, nor have any studies of the petrography of subsurface cores or cuttings been published.

Sandstones

Most sandstones in the Hartshorne Formation that are exposed at the surface are fine grained, although medium-grained and, rarely, coarse-grained sandstones have been reported. In the southern part of the Arkoma basin near Atoka (Fig. 6), the Hartshorne contains conglomerate beds with chert pebbles as large as 1 in. in diameter (Hendricks and others, 1936, p. 1347; Knechtel, 1937, p. 103; Stop 3, Part II, this guidebook). Scruton (1950, p. 417), in his study of the Hartshorne along its northern outcrop belt in Oklahoma, identified a "Hartshorne facies" and noted that it "is characterized by poor sorting, fine grain size, poor to fine lamination, and large quantities of silt, clay, and limonite." This description applies equally well to most of the Hartshorne Formation along its southern outcrop belt.

Given the potential for the Hartshorne Formation as a significant natural-gas reservoir, it is surprising how few studies have addressed regional or temporal variations in petrography. Dyman (1989) combined the Hartshorne and the Warner Sandstone Member of the McAlester Formation and, based on five widely scattered samples in eastern Oklahoma, divided them into two petrofacies. Petrofacies I contains an average of 84% monocrystalline quartz, 5% polycrystalline quartz, 0–14% lithic grains, and no, or only a trace of, feldspar. Petrofacies II contains less monocrystalline quartz (average 75%) and more chert (average 8%), polycrystalline quartz (average 10%), lithic grains (average 12%), and feldspar (2%). Dyman (1989) suggested that post-Hartshorne/Warner Desmoinesian sandstones (Cabaniss and Marmaton Groups) contain more lithic grains and are compositionally more heterogeneous than the Hartshorne and Warner sandstones.

Yeakel (undated) identified two petrofacies in the lower Hartshorne sandstone, which he suggested reflected eastern and southern source terranes. Eastern-source sandstones vary from sublithic to quartz sandstones. Southern-source sandstones are sublithic to rarely arkosic sandstones and contain more abundant twinned albitic plagioclase and untwinned sodic plagioclase than eastern-source sandstones. Untwinned and twinned potash feldspar and cryptocrystalline chert are present only in southern-source sandstones. Both petrofacies contain a heavy-mineral suite dominated by tourmaline, zircon, and rutile, but garnet and staurolite occur only in southern-source sandstones. (Scruton [1950] identified muscovite, leucoxene, and minor zircon, rutile, and [interestingly] staurolite in the Hartshorne sandstones along the northern outcrop belt.) Yeakel (undated, p. 18) suggests that eastern-source sandstones are dominant and extend as far west as McAlester at the surface. Southern-source sandstones occur southwest of McAlester and underlie the eastern-source sandstones.

Coals

The Upper and Lower Hartshorne coals in Oklahoma have been studied extensively, because they are thick enough over widespread areas to be mined economically. In fact, it was coal, and the railroads built to transport the coal to existing markets, that were largely responsible for much of the late 19th-century settlement and development of the Arkoma basin area. The Lower and Upper Hartshorne coals are as thick as 6 and 5.6 ft, respectively, in the McAlester district and ~7 and 4.7 ft thick, respectively, in the Howe-Wilburton district (Hendricks, 1937a; Hendricks, 1939). In the same areas, both coals locally thin to ~2 ft, and both coals thin to the southwest (Lehigh district) and to the north (Haskell County, Quinton-Scipio district).

Trumbull (1957) and Cardott (1990) showed that the rank of the Hartshorne coals ranged from high-volatile A bituminous to low-volatile bituminous, based on proximate analyses and vitrinite reflectance; the rank generally increases from west to east. In the extreme southwestern part of the Arkoma basin, the rank ranges as low as high-volatile C bituminous (Iannacchione and others, 1983). Iannacchione and Puglio (1979) reported that the rank ranged as high as semianthracite, and Friedman (1991) reported that the rank approaches semianthracite at depths >1,500 ft in northern Le Flore County. Coal analyses are reported by Hendricks (1937a, 1939) and summarized by Trumbull (1957, p. 344): in general, the Hartshorne coals (Upper and Lower) are low to high sulfur (0.5–4.2%) and low to medium ash (3–15%) with calorific values of 13,000–15,000 Btu; fixed carbon ranges from 49% to 79%, increasing to the east. Friedman (1974, p. 19) reported the following ranges of average analytical values for the Upper Hartshorne coal in Coal, Haskell, Pittsburg, Latimer, and Le Flore Counties: sulfur, 1.0–4.1%; ash, 5.5–10.1%; Btu, 13,230–13,969; fixed carbon, 53.7–71.9%. The ranges of average analytical values for the Lower Hartshorne coal are as follows: sulfur, 0.8–1.5%; ash, 5.6–9.1%; Btu, 12,782–14,233; fixed carbon, 50.5–73.5% (Friedman, 1974, p. 19).

ENVIRONMENT OF DEPOSITION AND PROVENANCE

Previous Work

Hendricks and others (1936) were the first to describe the depositional environment of the Hartshorne Formation. Their interpretation was based on their studies of the coal districts of the Arkoma basin (Hendricks, 1937a; Knechtel, 1937; Dane and others, 1938; Hendricks, 1939). Hendricks and others (1936, p. 1348) suggested that the lower Hartshorne sandstone "was deposited beneath an extensive body of water. Such parts of it as are thick and coarse-grained probably represent deposition in submarine channels cut in the front of the mouths of streams flowing into the basin of deposition from the south. The thin, fine-grained and shaly parts of the formation probably were formed by littoral currents distributing and depositing the finer sediments in less agitated waters away from the stream mouths." This description of the depositional environment of the lower Hartshorne sandstone in Oklahoma is essentially identical to that suggested for the same unit in Arkansas by Hendricks and Parks (1937).

The overlying Lower Hartshorne coal represents a period of stability in the Arkoma basin and was deposited across a "comparatively level, poorly drained lowland that received little clastic sediment" (Hendricks, 1937b, p. 1413). Agbe-Davies (1978, p. 35) suggested that deposition of the peat that formed the Lower Hartshorne coal occurred during a "period of regression or still stand." He also showed that both the Lower and Upper Hartshorne coals in Le Flore County are autochthonous and formed from forest peat in a dominantly freshwater environment. Williams (1978) identified the primary coal-forming plants in the Lower Hartshorne coal as *Calamites*, lycopods (e.g., *Lepidodendron* and *Sigillaria*), and ferns (e.g., *Neuropteris*).

Hendricks and others (1936, p. 1348) noted that, in the eastern part of the basin, the Lower Hartshorne coal is directly overlain by shale containing plant fossils and brackish-water or freshwater invertebrate fossils, which suggests a "continental or lacustrine" environment. In contrast, the coal in the western part of the basin is overlain by shale containing marine fossils. Hendricks and others (1936, p. 1348) also noted that the presence of marine beds in the west at the same stratigraphic level as continental beds to the east was evidence for the existence of a "Pennsylvanian sea [that] extended roughly north and south along the western part of the basin in post–lower Hartshorne time." Hendricks and others (1936) observed that the upper Hartshorne sandstone is coarse grained and irregularly bedded in places, which they interpreted as probable stream-channel deposits.

Scruton (1950) also noted the mixed continental and marine character of the Hartshorne Formation and was the first to use the term *deltaic:*

> The Little Cabin [now Warner Sandstone Member of the McAlester Formation], with its subparallel ridges of coarse-grained, cross-laminated, cut-and-fill, fossiliferous . . . sandstone is the product of the river channel and the submarine channel with their near channel associates. . . . The Hartshorne . . . is undoubtedly of similar origin [p. 420].
>
> The site of deposition was a region where a river, or group [of] rivers, flowing generally southwest off of the positive Ozark Dome entered the sea. At some place within the area every characteristic feature of the deltaic environment can be found [p. 424].

McDaniel (1961, p. 68) vaguely furthered the concept that the Hartshorne Formation is deltaic by referring to "sand deposits in stream or distributary channels."

Most recent studies of the Hartshorne Formation have focused on its depositional environment within a delta system. Houseknecht and others (1983), Houseknecht and others (1984), and Yeakel (undated) recognized the many abrupt lateral facies changes within the Hartshorne Formation and related the different lithofacies to sedimentation on different parts of a delta. The following list is a summary of the interpretations (in bold type) of the different lithofacies associated with the Hartshorne Formation by Houseknecht and coworkers.

1. The **prodelta** facies consists of dark gray to black laminated shales and silty shales; it is represented by that part of the Atoka Formation directly below the Hartshorne.

2a. The **distal-bar** subfacies of the **delta-front** facies consists of laminated siltstones and shaly siltstones that grade upward into lenticular-, flaser-, and ripple-cross-bedded siltstones and fine-grained sandstones, interbedded with thin, tabular sandstones.

2b. The **distributary-mouth-bar** subfacies of the **delta-front** facies consists of ripple-bedded and ripple-cross-bedded sandstone with clay drapes, and thicker trough-cross-bedded sandstone.

2c. The **frontal-splay** subfacies of the **delta-front** facies consists of trough-cross-bedded channelform sandstone lenses, with intraformational shale rip-up clasts locally.

3. The **distributary-channel** facies consists of fining-upward, locally massive or contorted, trough- and festoon-cross-bedded sandstones that are channelform and have erosional basal contacts.

4. The **interdistributary-bay/tidal-flat** facies consists of dark gray to black highly burrowed shale and silty shale that contain abundant macerated plant debris; lenticular-, wavy-, flaser-, and ripple-bedded siltstone and fine-grained sandstone; and tabular sandstones locally.

5. The **crevasse-splay** facies consists of coarsening-upward sequences of (from bottom to top) shale with lenticular siltstones, lenticular- to flaser-bedded sandstone and siltstone, and ripple- and trough-cross-bedded sandstone.

6. The **marsh-swamp** facies consists of coal and rooted mudstone (underclay).

7. The **fluvial** facies consists of fining-upward sequences of sandstone characterized by large-scale festoon cross-bedding.

A different interpretation of the upper part of the Atoka Formation was proposed by Donica (1978), who noted two thin coal beds in the upper part of the formation in Le Flore County and suggested that the Atoka represents interdistributary-bay deposits. He also suggested that the Hartshorne represents prograding delta-plain deposits, including crevasse splay, overbank, distributary channel, and interdistributary marshes. Donica (1978) did not recognize delta-front facies in the Hartshorne. Williams (1978, p. 20) suggested that the upper part of the Atoka Formation consists of "delta-front or delta-fringe clastics" grading upward to delta-plain marsh and swamp deposits.

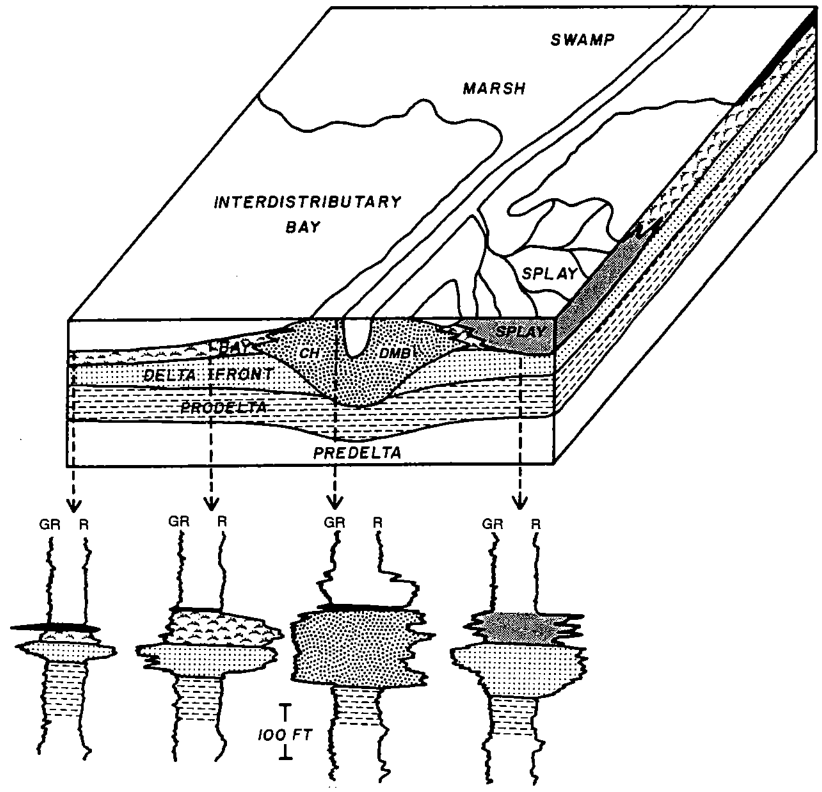


Figure 9. Idealized block diagram of Hartshorne deltaic environments and facies showing typical gamma-ray (*GR*) and resistivity (*R*) log responses. (From Houseknecht and others, 1983, p. 59; reproduced courtesy of Society of Economic Paleontologists and Mineralogists, Mid-Continent Section.) *CH*, channel; *DMB*, distributary-mouth bar. (From Hemish and Suneson, 1997, fig. 7.)

McQueen (1982), Houseknecht and others (1983), and Houseknecht and others (1984) recognized that the different lithofacies of the Hartshorne have characteristic electric-log signatures (Fig. 9), and Houseknecht and others (1983) and Houseknecht and others (1984) mapped the subsurface distribution of the different Hartshorne lithofacies throughout the Arkoma basin. These authors suggested that in eastern Oklahoma, the Lower Hartshorne Member consists of a delta-front facies overlain by two west- to southwest-trending, relatively narrow distributary channels, separated by widespread interdistributary-bay deposits. In the western part of the basin, strata of the distributary-channel facies are relatively thin, more narrow than to the east, and show repeated bifurcations. The interdistributary facies is widespread, and the delta-front facies is absent. The Upper Hartshorne Member is generally similar to the Lower Member, except that a delta-front facies has not been recognized. In Oklahoma, the prodelta(?) shales of the Atoka Formation are widespread, as is the marsh-swamp facies (Hartshorne coals).

The provenance of the sediments that constitute the Hartshorne Formation is controversial. Based on cross-bedding orientation and the trends of major sandstone bodies, Houseknecht and others (1983) and Houseknecht and others (1984) suggested east-to-west axial transport across the Arkoma basin, from source terranes to the northeast, southeast, and possibly east of the eastern part of the basin. Haley (1961) suggested an additional source to the north of the eastern part of the basin but did not present any supporting data. McDaniel (1961) supported an east-northeast to west-southwest transport direction for Hartshorne sediments along the southern outcrop belt but did not present supporting data.

Based on petrography and sand:shale ratios, Scruton (1950) suggested that the Ozark uplift was the source area for the Hartshorne Formation. Based on ripple-mark and cross-bedding orientations, Agterberg and Briggs (1963) and Briggs and Cline (1967) also thought that a significant sediment source for much of the Krebs Group was the Ozark uplift, but it does not appear that their data included measurements from the Hartshorne Formation. Briggs and Cline (1967, p. 997) suggested an additional sediment source for the Krebs Group to the east, based on an increasing amount of sand, coal, and plant fragments in that direction.

Several authors suggested a southern source area for parts of the Hartshorne Formation in the southwestern part of the Arkoma basin. Based on the presence of conglomerate beds in the Hartshorne in the Lehigh coal district, Knechtel (1937) suggested that "Llanoria," the uplifted Ouachita Mountains, or "rocks of the Arbuckle and adjoining areas" (p. 125) supplied most, if not all, of the sediments to the Hartshorne and other Krebs Group formations. Dyman (1989) suggested that the Hartshorne (his petrofacies I) was derived from the south (orogenic terrane, including foreland thrust belts) and the north (cratonic shield and platforms). Yeakel (undated) also identified a southern source for some of the sandstones in the Hartshorne Formation.

Current Work

Atoka and McAlester Formations

(Stop numbers refer to those in Part II of this guidebook.)

The depositonal environment of the Hartshorne Formation must be considered in the context of the origin of the directly underlying Atoka Formation, particularly the upper part north of the Choctaw fault, and the McAlester Formation, especially the McCurtain Shale Member. As discussed above, the contact between the Atoka and Hartshorne Formations is conformable in most places in the Arkoma basin; in places, the contact is gradational (Stops 6, 9, 10A, 15). In Pontotoc County, however, the contact may be an angular unconformity (Morgan, 1924). Elsewhere, the contact locally is a disconformity (Stop 10B). The contact between the Hartshorne and McAlester Formations is also generally conformable in the Arkoma basin (Stop 9), except in Pontotoc County, where the McAlester and/or the Hartshorne may onlap the Atoka. Therefore, the upper part of the Atoka Formation and the lower part of the McAlester Formation are probably depositionally related to the Hartshorne Formation (Stops 6, 9, 10A, 11, 15, 16, 19).

Parts of the Atoka Formation in the southern part of the Arkoma basin contain marine invertebrates and/or marine limestones, and other parts contain evidence (e.g., coal beds) for a nonmarine origin. Diagnostic evidence for a marine origin for the Atoka Formation includes (1) impure limestone at the base (Pontotoc County; Morgan, 1924), (2) marine fossils (Coal County; Morgan, 1924), (3) "shells" noted on well logs about 1,600 ft below the top (Latimer County; Hendricks, 1939), (4) marine fossils near the top (Le Flore County; Knechtel, 1949; Chaplin, 1994), and (5) limestone and marine fossils (Muskogee County; Oakes, 1977). In contrast to a marine origin, the presence of coal beds (Stop 15) is evidence that at least some parts of the Atoka Formation formed in a nonmarine environment. For example, Donica (1978) mapped several thin coals in the upper part of the Atoka Formation in Le Flore County, and Oakes (1977) noted coal in the Atoka in Muskogee County. Based on the presence of diagnostic features, it appears that the Atoka Formation is marine in the western part of the Arkoma basin and marine and nonmarine in the eastern part, although no regional studies have focused only on the upper part of the formation subjacent to the Hartshorne.

No studies have been published on the provenance of the upper part of the Atoka Formation in the southern part of the Arkoma basin in Oklahoma. Some workers (e.g., Houseknecht and others, 1983; Houseknecht and others, 1984) suggest that the uppermost part of the Atoka Formation is the prodelta facies of the Hartshorne (e.g., Stop 16); this interpretation suggests that part of the Atoka was derived from the east. Where the Atoka Formation contains coal beds, it is probably closely related in origin to the Hartshorne (Donica, 1978) and may have had a similar provenance. In contrast, Chaplin (1994) showed that a significant part of the upper part of the Atoka Formation was deposited in a muddy-shelf environment; this would suggest that the source of the sand and mud is difficult, if not impossible, to determine.

Like the Atoka Formation, parts of the McAlester Formation contain diagnostic evidence for a marine origin (e.g., marine invertebrate fossils and limestone), and other parts, for a nonmarine origin (e.g., coal beds, including the McAlester/Stigler coal). Counties where a marine fauna and/or limestone has been identified in the McAlester Formation include Pontotoc (Morgan, 1924), Coal (Knechtel, 1937), Atoka (Knechtel, 1937), Pittsburg (Hendricks, 1937a; Hemish and others, 1995; Suneson and Hemish, 1996), Le Flore (Knechtel, 1949; Hemish and Suneson, 1994), Haskell (Oakes and Knechtel, 1948), and Muskogee (Oakes, 1977; Hemish, 1998). Coal beds have been recognized at many horizons throughout the McAlester Formation in the Arkoma basin by most mappers. Throughout the basin, the McAlester appears to consist of marine and nonmarine strata.

The marine and nonmarine origin for the McAlester Formation is consistent with modern interpretations that the sandstone members consist of deltaic deposits (summarized by Hemish and Suneson, 1997). However, no studies present surface evidence for the existence or the extent of specific delta facies in any of the members of the McAlester. It is also likely that parts of the sandstone members of the McAlester Formation are fluvial and fill falling-stage incised channels (R. Andrews, personal communication, 1998).

Few workers have documented evidence for a marine versus a nonmarine origin for the McCurtain Shale Member of the McAlester Formation. Hendricks (1937a) noted that the "lower part" (probably McCurtain Shale) of the McAlester Formation locally contains coal beds. Hemish and others (1995) identified marine invertebrate fossils in the McCurtain in Pittsburg County. Knechtel (1949) and Oakes and Knechtel (1948) identified marine fossils and coal beds in the McCurtain Shale in Le Flore and Haskell Counties, respectively. Clearly, the McCurtain Shale Member of the McAlester Formation, like the rest of the overlying McAlester Formation, contains evidence for a marine and nonmarine origin, but the specific depositional environments, with or without respect to deltas, are unknown.

The provenance of the sandstone members of the McAlester Formation is well known and is summarized by Hemish and Suneson (1997). In contrast, the provenance of the McCurtain Shale Member, which directly overlies the Hartshorne, is unknown and unstudied.

Hartshorne Formation

The Hartshorne Formation in the southern part of the Arkoma basin of Oklahoma is fluvial-deltaic in origin. (This guidebook follows the terminology described by Andrews [1995] for fluvial-dominated deltaic oil reservoirs in Oklahoma. Andrews' [1995] paper is based, in part, on Brown [1979], Coleman and Prior [1982], Galloway and Hobday [1983], and Swanson [1993].) In general, the Hartshorne consists of two progradational sequences, both of which consist of delta-front strata in the lower part, overlain by delta-plain strata. In places, the delta-plain strata may be overlain by flood-plain strata that correlate with thick sandstones that fill channels eroded into the underlying delta-plain and/or delta-front strata. Not all sequences are everywhere present, and the general "shallowing-upward" character of the sequences locally is reversed. To a large extent, the lower progradational sequence makes up the Lower Hartshorne Member of the Hartshorne Formation, and the upper sequence makes up the Upper Member.

Despite the near absence of marine fauna, most of the exposed part of the Hartshorne Formation is marine, and, in general, the Hartshorne overlies marine shale in the uppermost part of the Atoka Formation. This shale may be part of a prodelta or marine shelf. The only exceptions to this sequence are in the eastern part of the Arkoma basin of Oklahoma, where parts of the upper Atoka contain coal (Stop 15).

The base of the Hartshorne is marked by the lowest mappable sandstone, which typically is within a unit dominated by siltstone and shale. In general, these lower Hartshorne strata represent a bar-transition or a lower-distributary-mouth-bar facies (e.g., Stops 6, 9). Thick sandstone beds within these otherwise well-stratified, ripple-bedded, fine-grained deposits generally resulted from a deepened wave base caused by storms (e.g., Stops 6, 8, 14). The lower-distributary-mouth-bar deposits are typically overlain by sandstone-dominated upper-distributary-mouth-bar deposits (e.g., Stops 6, 9, 16). The principal difference between the upper- and lower-distributary-mouth-bar deposits is the higher amount of sandstone in the former. Thick sandstone beds in the upper deposits typically show large-scale, high-angle cross-stratification and are the result of shallow-marine processes (waves, strong currents) reworking the top of the bar (e.g., Stops 6, 14). Facies in the Hartshorne along the margin of the active delta front are also called delta fringe or delta margin in this volume (Stop 15).

It is possible that some of the Hartshorne in the southern part of the Arkoma basin is not associated with deltaic processes, in which case it would be preferable to use marine-coast terminology—e.g., marine transition, lower shoreface, upper shoreface. The sedimentary facies and associations deposited in these environments are similar to those deposited on a delta. The abundance of terrigenous debris (particularly macerated organic material) and mica, the association of major sandstone bodies with unequivocal fluvial channels in the Hartshorne Formation (Andrews, 1998), and their close association with delta-plain strata (see below) are evidence that most of the lower part of the Hartshorne Formation was deposited on a delta front.

Delta-plain sediments of varying thickness overlie the delta-front strata and constitute the upper part of the Lower Hartshorne Member (Stop 15). The most widely recognized part of this sequence is the Lower Hartshorne coal, which was deposited in a swamp and/or marsh environment. Other delta-plain facies associated with the coal are interdistributary bay-fill shales, crevasse-splay sandstones, and distributary-channel sandstones.

This progradational sequence of delta-front overlain by delta-plain strata is locally overlain and eroded into by deep, sandstone-filled fluvial channels (Stops 10A, 12). Andrews (1998) correctly interprets this facies as generally unrelated to the preceding deltaic facies and suggests that it formed as a result of relative-sea-level lowering. The disconformity at the base of the Hartshorne in places reflects this lowering and the resultant erosion of the Hartshorne delta-plain and/or delta-front sediments. Sediments deposited in a flood-plain environment and associated with the fluvial channels may, in places, overlie those of the delta plain; however, the flood- and delta-plain sequences are difficult to distinguish from each other.

The Upper Hartshorne Member of the Hartshorne Formation overlies the Lower Hartshorne coal and exhibits the same general progradational sequence as the Lower Member (Stop 4). Distal delta-front strata are progressively overlain by more proximal delta-front and delta-plain strata, and locally by incised channel-fill (Stop 7) and/or flood-plain sediments.

The provenance of most of the Hartshorne sediments is to the east (Andrews, 1998; summary in Hemish and Suneson, 1997). As described above, some workers have suggested a source in the Ozark uplift (Scruton, 1950). The presence of conglomeratic sandstone in the Hartshorne in the southern part of the Arkoma basin (Stops 2, 3) is clear evidence for a source terrane in the Ouachita Mountains or, possibly, a southern extension (now buried) of the Arbuckle Mountains. How far into the basin these southern-derived sediments extended is unknown, however.

RESOURCES

Coal

Although coal in Oklahoma was first reported by Nuttall in 1821 (*in* Lottinville, 1980), the first scientific investigations of coal in the Arkoma basin were not completed until nearly 70 years later (Chance, 1890). Since that time, no aspect of the Hartshorne Formation has been studied in greater detail than the coal. Comprehensive reports on Hartshorne coal distribution, thickness, chemistry, and production (through about 1930) along its southern outcrop belt were published by the U.S. Geological Survey (Hendricks, 1937a, 1939; Knechtel, 1937). Knechtel (1949) and Oakes and Knechtel (1948) discussed the geology and coal resources along the northern outcrop belt of the Hartshorne coal in Le Flore and Haskell Counties. The coal resources (including the Hartshorne coal) of Muskogee County were described by Hemish (1998). Trumbull (1957) and Friedman (1974) published estimates of Hartshorne coal production and reserves.

Extensive underground mining of the Hartshorne coals began in 1872 (Iannacchione and others, 1983; Friedman, 1995). Surface-mining methods were first used in about 1915, and the ratio of production from surface mines to that from underground mines gradually increased until about 1970. Since then, very little coal in Oklahoma has been mined underground. Currently, S. A. Friedman and B. J. Cardott of the OGS are compiling historical production data for the Hartshorne coal, county by county. Table 2 shows the total tonnage (short tons) of Hartshorne coals "mined and lost in mining" through 1973.

The most recent year for which statewide bed-by-bed production is available is 1995; in that year, 337,611 short tons of coal was produced from the Lower Hartshorne coal, and 43,804 short tons from the Hartshorne coal (S. A. Friedman, unpublished data, 1996). These figures represent ~20% of Oklahoma's total coal production for that year. The Hartshorne coal was mined only in Le Flore County in 1995.

TABLE 2. – Hartshorne Coal Mined and Lost in Mining[a]
(thousands of short tons)

County	Lower Hartshorne	Upper Hartshorne	Hartshorne[b]
Atoka	809	0	0
Haskell	1,260	0	11,683
Latimer	41,318	2,622	0
Le Flore	30,861	12,116	15,512
Pittsburg	54,385	2,940	0

[a]Modified from Friedman, 1974.
[b]Hartshorne coal north of where upper and lower Hartshorne coals merge (Fig. 4).

Friedman (1991, based on Friedman, 1974) estimates that the Hartshorne coal (undivided) contains 1,552 million short tons of remaining resources; the Lower Hartshorne coal bed, 1,541 million short tons; and the Upper Hartshorne coal bed, 663 million short tons. Murrie (1977) calculated ~2.0 billion tons of remaining Lower Hartshorne coal resources in Le Flore and Haskell Counties.

Coalbed Methane

Note: Cardott (1998) published an updated appraisal of coalbed-methane resources in the southern part of the Arkoma basin.

Geologists and miners have long recognized that the Hartshorne coal contains significant volumes of methane. Friedman (1982) reported that the Howe No. 1 mine in Le Flore County yielded an average of 1.6 million cubic feet (MMCF) of methane in 24 hours. Methane emission reached 400 thousand cubic feet per day (MCFPD) in the Choctaw mine, Haskell County. Forgotson and Friedman (1993) estimated that as the rank of the Hartshorne coals increases from high-volatile C bituminous in the western part of the Arkoma basin in Oklahoma to low-volatile bituminous in the eastern part, the gas content increases from 300 cubic ft/ton to 600 cubic ft/ton at depths of 800–2,000 ft.

Hartshorne coalbed methane was first produced in 1989 from a 4-ft-thick bed 800 ft deep in Haskell County (Friedman, 1995). Since that time, and as a result of tax incentives, about 170 coalbed-methane wells have been drilled into, and produce from, a Hartshorne coal bed (data current to June 1996, B. J. Cardott, personal communication). The major operators of coalbed-methane wells in the Arkoma basin, with the number of wells they have drilled, are Amoco (1), Aztec Energy (12, including one McAlester well), Bear Production (39), Continental Resources (11), CWF Energy (8), OGP Operating (18), ONEOK (3, all McAlester wells), and Redwine (43).

Figure 10 shows the areas where most of the Hartshorne coalbed methane has been produced in the Arkoma basin. Production rates vary from about 25

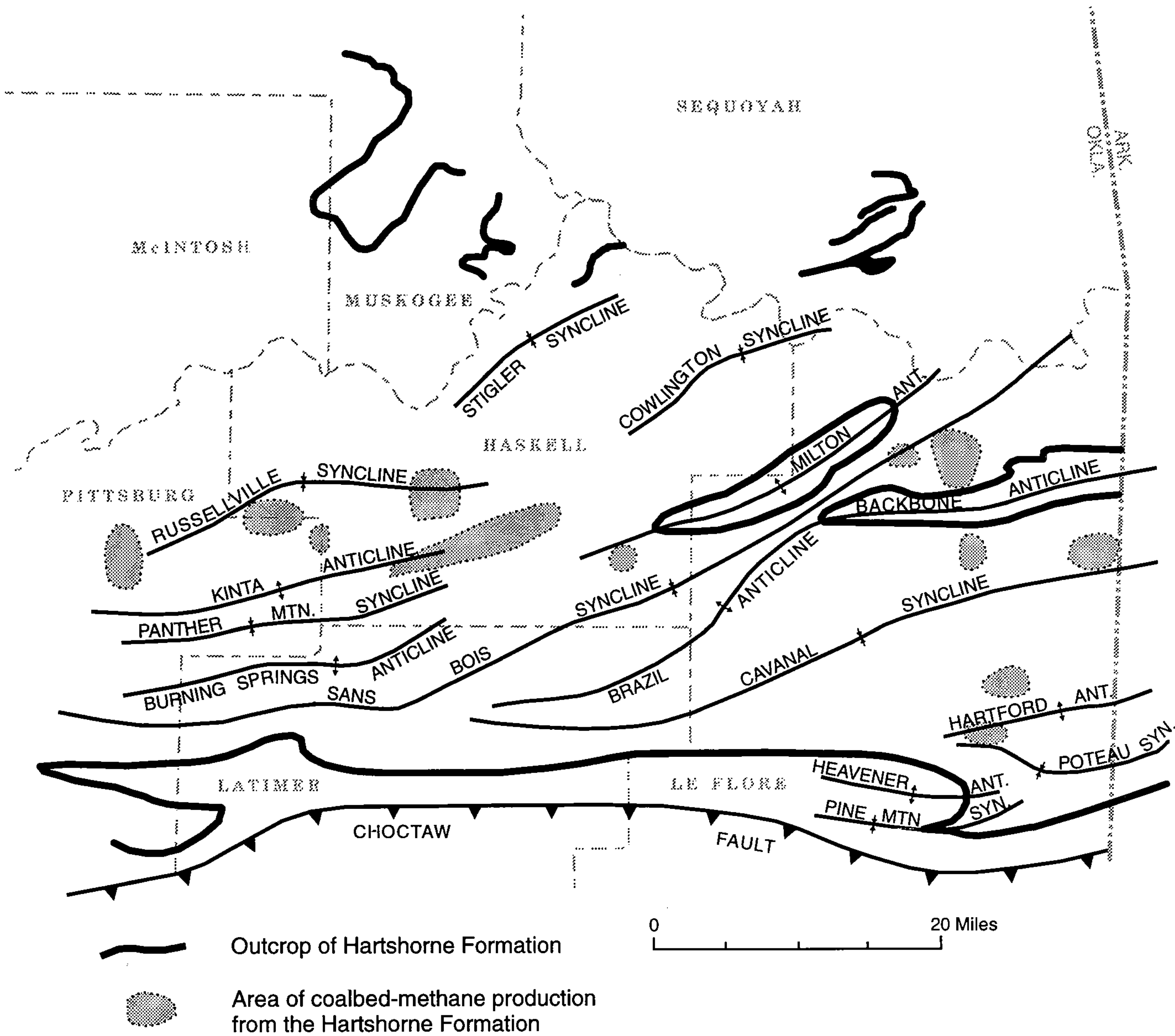


Figure 10. Map showing major surface folds and areas of coalbed-methane production from the Hartshorne Formation. Also shown are Hartshorne outcrops. (Modified from Hemish and Suneson, 1997, fig. 8.)

MCFPD to 250 MCFPD, with little or no water (Forgotson and Friedman, 1993). There is no apparent relation between coalbed-methane production and structural position relative to the major folds of the Arkoma basin. Kemp and others (1993) suggested that the major factors controlling the amount of methane in the Hartshorne coals are thickness, thermal maturity, ash content, and reservoir pressure. They also suggested that the primary controls on methane producibility include water content and permeability (including cleat intensity and tectonic fracturing). Locally, permeability is reduced by diagenetic cements.

Estimates of coalbed-methane resources for the Oklahoma part of the Arkoma basin and the Hartshorne coal vary slightly. Iannacchione and others (1983) estimated that the Hartshorne coal beds in Atoka, Coal, Hughes, and Pittsburg Counties contain 325 billion cubic feet (BCF) of methane. They considered this estimate to be conservative because it includes only coals >28 in. thick and <3,000 ft deep. Iannacchionne and Houseknecht (1981) suggested that the deeper parts of the basin in Pittsburg, Coal, and Hughes Counties contain about 1 trillion cubic feet (TCF) of methane. They also suggested that the coal beds in the western part of the Arkoma basin contain less methane than those in the eastern part because the thermal maturity at similar depths increases from west to east.

Iannacchione and Puglio (1979) estimated that the Hartshorne coal beds in Haskell and Le Flore Counties contain 1.1–1.5 TCF of methane at 0–3,000-ft depths. Friedman (1989) estimated that, in Haskell, Latimer, and Le Flore Counties, the Hartshorne and 11 other coal beds contain 1.8 TCF of methane at 500–3,000-ft depths, and an additional 1.2 TCF of methane at 3,000–7,000-ft depths. Based on a revised estimate of Hartshorne coal resources, Gossling (1994) identified 3.1–3.5 TCF of methane in the Hartshorne coals in the eastern and central parts of the Arkoma basin in Oklahoma.

Natural Gas

Note: Andrews (1998) published an updated appraisal of natural-gas resources in the southern part of the Arkoma basin.

Gas was discovered in sandstones of the Hartshorne Formation in 1910 in Le Flore County. The discovery well for Poteau-Gilmore field was the Poteau Light and Ice Co. No. 1 Poteau-Gilmore; the well was drilled in sec. 27, T. 7 N., R. 26 E., and was completed on July 19, 1910. In 1929, 59 wells were producing in Poteau-Gilmore field (Hendricks, 1939, p. 290). The total cumulative gas produced in the field through 1943 was 33 BCF, nearly all of which came from the Hartshorne at 1,300–1,800-ft depths (Knechtel, 1949, p. 57). Gas in the Hartshorne was discovered in nearby Gilmore field by the Le Flore County Gas and Electric Co. No. 9 Tucker, in sec. 3, T. 7 N., R. 26 E. The well was completed in 1911 at a depth of 1,526 ft in the Hartshorne (Knechtel, 1949, p. 58).

Since the discovery of gas in the Hartshorne in 1910, the Hartshorne has been developed in the following fields (Fig. 11): Poteau-Gilmore, Red Oak–Norris, Quinton, Southeast Reams, South Pine Hollow, Ashland, South Ashland, Centrahoma, Brooken, Kinta, Northwest Stuart, Cameron, Carney, Featherston-Blocker, Scipio, Northwest Scipio, West McAlester, Northeast Savanna, Ulan, Northwest Cabaniss (McDaniel, 1961; Iannacchione and others, 1983, fig. 21; Houseknecht and others, 1983; Fields, 1987; Brown and Parham, 1994). The first 11 fields are considered major gas fields, each having produced >10 BCF of natural gas through 1990. (However, not all of the gas produced in those fields is from the Hartshorne.) Through 1990, the Hartshorne Formation has produced >655 BCF of gas in the Arkoma basin (Brown and Parham, 1994).

The discovery of South Pine Hollow field by the Carter No. 1 Morris well (sec. 24, T. 5 N., R. 12 E.) in 1959 and the subsequent analysis by McDaniel (1968) showed that distributary-channel sandstones (incised channels of Andrews, 1998) in the Hartshorne are a prime exploration target. McDaniel (1968, p. 1697) also noted that the alignment of producing wells in the South Pine Hollow area (as of December 1967) was "not the result of structural entrapment, because it corresponds more closely to the axis of the Talawanda syncline than to the McAlester anticline." The concept of distributary channels as exploration targets was further developed by Houseknecht and others (1983) and Iannacchione and others (1983), who believed that the greatest amount of gas is produced from sandstones in the Hartshorne Formation where the relatively thick distributary-channel sandstones cross anticlines in the Arkoma basin. Fields (1987) noted that gas is produced in Southeast Reams field from an east-west–trending distributary channel where it crosses the crest of the Flowery Mound anticline. West McAlester field produces from an east-west–trending Hartshorne channel where it crosses the McAlester anticline, and Northeast Savanna field, from a northeast-southwest channel where it crosses the Savanna anticline. Faulting is probably an additional component in gas entrapment for many of the fields producing from elongate channel-sandstone deposits (R. Andrews, personal communication, 1998).

Fields (1987) also noted that the Hartshorne produces from crevasse-splay deposits. Fields that produce gas from these deposits are Northwest Scipio (updip pinch-out), Ulan (structural high), and Northwest Cabaniss (updip pinch-out). In contrast, Andrews (1998) suggested that the Northwest Cabannis field produces from fluvial-channel and distributary-mouth-bar sandstones.

Several possible sources for the natural gas in the Hartshorne sandstones are marine shales of the underlying Atoka Formation, Hartshorne coal beds, and carbonaceous shales of the overlying McAlester Formation (Iannacchione and Puglio, 1985). The gas in the Hartshorne Formation in Cameron and Poteau-Gilmore fields was derived from the coal; in contrast, the gas in Quinton field was derived from organic material in the adjacent shales, possibly with some gas coming from the coal (Iannacchione and Puglio, 1985).

SUMMARY

The Desmoinesian Hartshorne Formation has long been recognized as an important coal- and natural-gas-bearing formation in the Arkoma basin of southeastern Oklahoma. Early differences over the precise upper and lower contacts are now resolved; in Oklahoma, the Hartshorne extends from the first widespread, mappable sandstone overlying the shale-dominated Atoka Formation to the top of the Upper Hartshorne coal, or, where the Lower and Upper Hartshorne coals have merged, to the top of the Hartshorne coal. This apparently clear definition is based on surface exposures of the Hartshorne, however; and recent studies of the subsurface geology of the Arkoma basin show that in many places the contact between the Atoka and Hartshorne is gradational and that the contact may be placed at the top of the marine shale of the Atoka Formation. The basal contact of the Hartshorne generally is conformable but locally is disconformable; the upper contact with the McCurtain Shale Member of the McAlester Formation is almost everywhere conformable.

The Hartshorne Formation consists of sandstone, siltstone, shale, coal, and rare conglomerate in varying proportions. In most of the southern part of the Arkoma basin, the formation is made up of two members (Lower and Upper), each of which consists generally of a fining-upward sequence capped by coal. In many

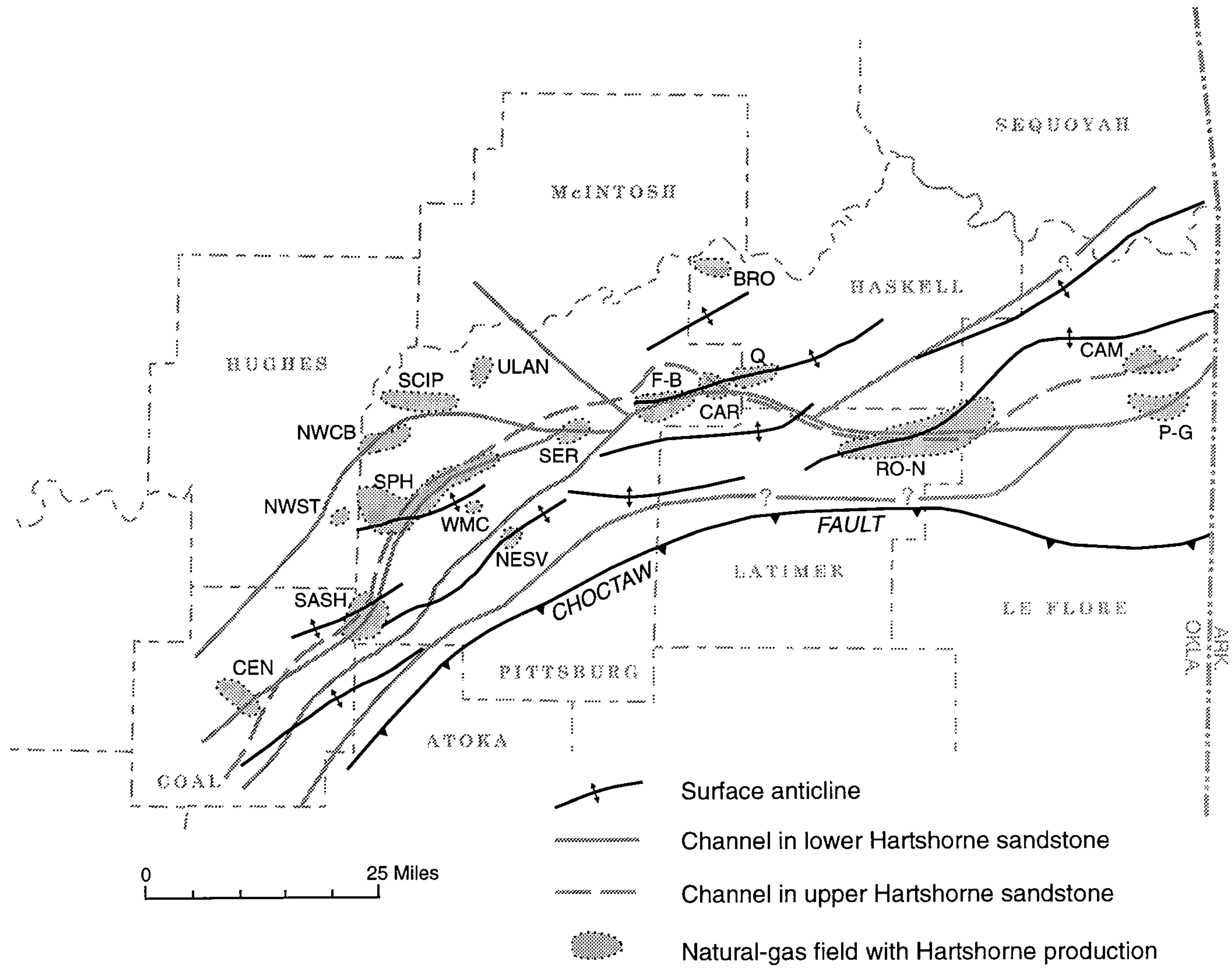


Figure 11. Map showing (1) major surface anticlines (from Arbenz, 1989, pl. 8), (2) major distributary channels in the Hartshorne Formation (from Houseknecht and others, 1983, fig. 12), and (3) gas fields with Hartshorne production (from Burchfield, 1985). The very large Kinta gas field (not shown on map) covers much of northwestern Latimer, southern Haskell, and northwestern Le Flore Counties. Abbreviations for names of gas fields (roughly west to east on map): *CEN,* Centrahoma; *SASH,* South Ashland and Ashland; *NWST,* Northwest Stuart; *SPH,* South Pine Hollow; *WMC,* West McAlester; *NESV,* Northeast Savanna; *NWCB,* Northwest Cabaniss; *SCIP,* Scipio and Northwest Scipio; *ULAN,* Ulan; *SER,* Southeast Reams; *F-B,* Featherston-Blocker; *BRO,* Brooken; *CAR,* Carney; *Q,* Quinton; *RO-N,* Red Oak–Norris; *CAM,* Cameron; *P-G,* Poteau-Gilmore. (From Hemish and Suneson, 1997, fig. 9.)

places, several smaller-scale coarsening-upward sequences characterize the section below the coals. The Hartshorne also varies from very thin to 1,000 ft thick, but generally it is 400–500 ft thick.

Evidence for marine (invertebrate fossils) and nonmarine (plant fossils, coals) origins for parts of the Atoka, Hartshorne, and McAlester Formations was noted in much of the early literature on the Arkoma basin in Oklahoma. This apparently conflicting evidence was reconciled by Scruton (1950), who first suggested that the Hartshorne Formation was deposited as a delta. Nearly all subsequent workers have accepted the delta model. Houseknecht and others (1983) attempted to relate gamma-ray and resistivity profiles on electric logs to different deltaic facies.

Most outcrops of the Hartshorne Formation in the southern part of the Arkoma basin in Oklahoma were deposited in a marine environment, probably within a bar-transition (distal-bar) or a lower- or upper-distributary-mouth-bar environment. Uncommonly thick sandstone beds represent reworking by storms. Sediments deposited in a delta-plain environment overlie those deposited in the delta front and generally are thin. Incised-channel-fill sandstones occur in places along the outcrop belt of the Hartshorne and were mapped throughout the Arkoma basin by Andrews (1998). These channels clearly represent east-to-west development of the Hartshorne delta.

Locally, the general sequence representing an east-to-west prograding delta complex is interrupted. Ma-

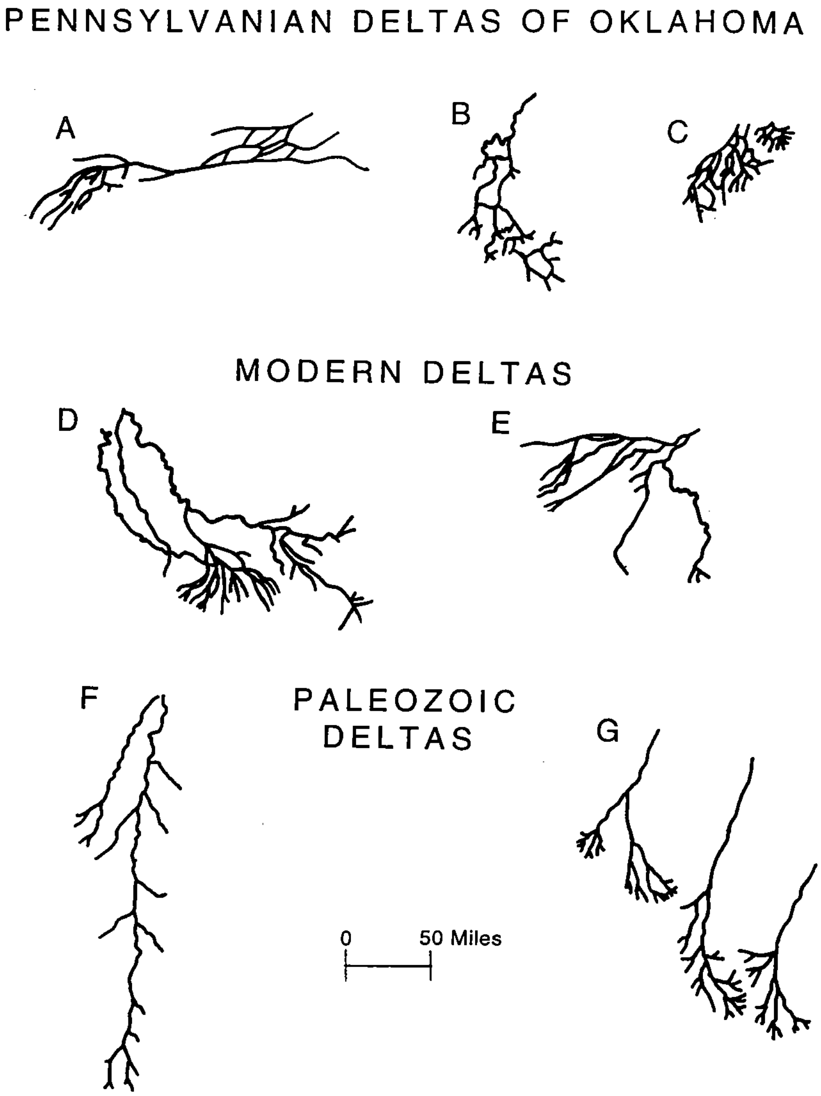


Figure 12. Diagrams of selected well-studied Phanerozoic deltas at same scale. (A) Hartshorne. (B) Bartlesville. (C) Booch. (D) Mississippi. (E) Orinoco. (F) Red Bedford. (G) Catskill. Hartshorne delta based on Andrews (1998) in Oklahoma and Houseknecht and others (1984) in Arkansas. Other deltas from various sources.

rine invertebrates in the Hartshorne in the southwestern part of the Arkoma basin are evidence for a reduced input of easterly-derived clastic material, which suggests that a marine environment was important. The presence of a source area in the Ouachita Mountains or the now-buried eastern Arbuckle Mountains is supported by conglomerate beds in the Hartshorne along the southwestern outcrop belt. In contrast, to the east the Hartshorne locally consists mostly of delta-plain strata derived from the east.

The Hartshorne delta in Oklahoma and Arkansas is comparable in extent to some well-studied Paleozoic deltas such as the Catskill (Devonian) in Pennsylvania and the Red Bedford (Mississippian) in Ohio (Fig. 12). The Hartshorne delta is also similar in size to some Holocene deltas—for example, the Mississippi and Orinoco (Fig. 12). It is larger, however, than some other well-mapped Desmoinesian deltas of Oklahoma such as the Bartlesville and Booch (Fig. 12). A critical difference between the Hartshorne and modern deltas, despite their similarity in extent, is that the strata that make up the Hartshorne delta are considerably thinner (hundreds of feet) than the modern deltas (thousands of feet). This is evidence that the Arkoma basin during Hartshorne time was relatively shallow and easily filled by the easterly-derived prograding deltaic sediments (Andrews, 1998). The long incised channels and widespread coals are additional evidence that the basin was shallow; both would form over extensive areas in response to a relatively moderate drop in sea level.

PART II

Stop Descriptions

STOP 1

Clarita Measured Section

Directions: From the intersection of State Highways 31 and 48 between Wapanucka and Tupelo, Oklahoma, drive north 1 mi on State Highway 48, then east 0.5 mi on county road. Hartshorne outcrop is on left (north) side of road.

Map reference[1]: Knechtel (1937).

This exposure of the Hartshorne(?) Formation (queried by Knechtel, 1937) is the westernmost of the field trip. The quality of exposures along roads to the west is generally poor; more importantly, however, is that poor exposure, complicated structure and stratigraphic relations, abrupt facies changes, and the absence of recent mapping make the exact location of the Hartshorne Formation uncertain. In fact, Knechtel (1937) queried whether this outcrop was the Hartshorne Formation, although he did map the Atoka Formation to the south and the McAlester Formation to the north. (Knechtel [1937] mapped the Hartshorne–McAlester contact as a fault at least partly because the topography and the outcrop pattern of the Lehigh [now McAlester] coal are highly oblique to the contact.) The reasons for his uncertainty are probably (1) the structural complexity noted above; (2) the presence of undoubted Hartshorne Formation on Flagpole Mountain to the east (Stop 2), offset by the east-west–striking Clarita (Phillips) fault; and (3) relations along the Clarita fault, which are covered by the nearly 1-mi-wide alluvium of Clear Boggy Creek. Knechtel (1937, p. 103) "tentatively assigned [these beds] to the Hartshorne because of their lithologic resemblance to the beds that crop out on the prominent ridge of Hartshorne sandstone about 3 mi to the southeast" [Flagpole Mountain].

The Hartshorne(?) Formation at Stop 1 lies along the south edge of the Arkoma basin, and the strata dip ~30° north into the basin. Based on the map by Knechtel (1937, pl. 11), the strata exposed in the outcrop are in the lower part of the formation; about 1 mi to the southeast, the Hartshorne(?) Formation contains two sandstone units. Neither the Upper nor Lower Hartshorne coal is present west of Clear Boggy Creek, adding validity to Knechtel's (1937) use of a question mark.

The exposure of the Hartshorne(?) Formation at Stop 1 (Fig. 13) is important for several reasons: (1) It is the westernmost relatively good exposure of the Hartshorne(?) Formation, albeit that detailed mapping might prove that the exposure is, in fact, a sandstone in the Atoka or McAlester Formation. (2) The Hartshorne(?) is definitely marine and was most likely deposited in a relatively nearshore environment. The absence of exposures of surrounding strata makes more detailed interpretation difficult. (3) The Hartshorne(?) contains small fragments of chert. (The Hartshorne near here may contain more chert fragments than are present in the measured section. Knechtel [1937, p. 103] noted that "a ridge supported by steeply inclined beds of sandstone containing angular fragments of chert lies . . . near the south line of sec. 30, T. 1 N., R. 30 E.") These observations suggest that much, if not all, of the Hartshorne Formation in the western part of the Arkoma basin is marine and was derived from a relatively nearby source terrane, probably to the south or east. It is important to note, however, that there does not appear to be any clear separation between Hartshorne sediments derived from nearby uplifts to the south or east and more widespread Hartshorne sandstones that fill channels that originated in Arkansas.

Measured Section, Stop 1

Hartshorne Formation(?)

Clarita Section

Location: C S½S½ sec. 30, T. 1 N., R. 9 E. (Tupelo 7.5′ quadrangle). About 3 mi north-northeast of Clarita. Coal County, Oklahoma.

	Thickness (feet)
KREBS GROUP:	
HARTSHORNE FORMATION(?):	
1. Sandstone, medium- to fine-grained, grayish orange (10YR7/4) to light gray (N7). Unstratified to large- and small-scale cross-stratified and/or wavy-bedded, locally showing cut-and-fill structure. Porous with minor silica cement to very well cemented and calcareous. Locally contains weathered chert fragments as large as 0.125 in., shale rip-up clasts, and small brachiopods and gastropods. Rare soft-sediment-deformation structures. Minor siltstone and shale partings	4.5
Total thickness of section	4.5

[1]Map reference is citation for most recent geologic map of area of field-trip stop.

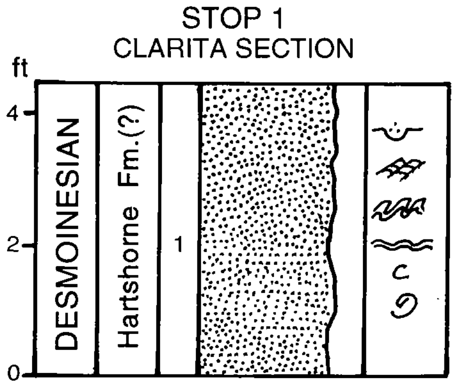


Figure 13. Graphic columnar section of exposed part of Hartshorne(?) Formation at Stop 1 (Clarita section). The presence of invertebrate fossils is unusual in the Hartshorne Formation. Explanation of symbols in Appendix 2.

STOP 2

Flagpole Mountain Measured Section

Directions: From school building in Olney, Oklahoma, drive due east past small cemetery. Road turns north, then northeast across Clear Boggy Creek, then east. About 0.5 mi after crossing creek, road forks; take right (southeast) fork. Drive mostly due east for about 2.5 mi from fork in road. Road turns south for 1 mi, then east. Measured section begins about 0.5 mi after road turns east and continues over Flagpole Mountain.

Alternate directions: From intersection of U.S. Highway 75–State Highway 3 and Main Street in Lehigh, Oklahoma, drive west 0.8 mi on Main Street. Turn right (north) on Pecan Street (follow sign to cemetery) and drive 0.3 mi. Turn left (west) on section-line road and drive 1.5 mi. Turn left (south), drive 0.5 mi, and turn right (west). Drive 1.5 mi to top of hill and park at intersection with section-line road to north. Intersection is in unit 6 of measured section.

Map reference: Knechtel (1937).

Flagpole Mountain rises nearly 200 ft, in places, above the surrounding countryside. The relatively steep west-facing scarp suggests that the Hartshorne Formation underlying Flagpole Mountain contains more sandstone than the Hartshorne to the northwest or southeast. Knechtel (1937, p. 102) noted that "from sec. 33 to sec. 29 [about 1 mi south of measured section], T. 1 S., R. 10 E., the thickness increases from about 80 ft to nearly 500 ft within a distance of 2 mi northwestward along the strike," and that "where the formation is thin it is made up largely of thin-bedded bluish-gray shale and fine-grained light-gray to yellow sandstone; the thickest sections are composed mainly of massive hard white to gray, somewhat coarse-grained sandstone" (p. 103).

This section of Hartshorne Formation on Flagpole Mountain is along the south edge of the Arkoma basin. The strata dip about 6° east. Based on Knechtel's (1937) map, the Hartshorne Formation on Flagpole Mountain consists of a single, thick sandstone unit. To the west, just east of Clear Boggy Creek, Knechtel (1937) mapped two sandstone units. The Lower Hartshorne coal is discontinuously exposed above the sandstone and was strip mined about 4 mi to the southeast, where it is about 4 ft thick. Several small mines and prospect pits mark the outcrop pattern of the coal on the east side of Flagpole Mountain. The coal bed(?) noted in unit 17 in the measured section is about 50 ft below the Lower Hartshorne coal as mapped by Knechtel (1937). The Upper Hartshorne coal is about 45 ft above the Lower Hartshorne coal but is thin and "is of little or no value" (Knechtel, 1937, p. 134).

Despite the extensive amount of cover, particularly in the upper part of the Flagpole Mountain section (Fig. 14), several inferences can be made about the depositional environment of the Hartshorne Formation in this area. The anomalously thick and coarse-grained nature of the Hartshorne Formation on Flagpole Mountain suggests that it was deposited as a channel in an incised valley or as a distributary channel. The Flagpole Mountain section is not through the thickest and presumably most sandstone-rich part of the formation (channel axis?); however, it probably was deposited near the axis(?). The lower part of the section (units 1, 3, and 5) may be a coarsening-upward lower- to upper-distributary-mouth-bar sequence, but the amount of cover (particularly unit 2) makes such an interpretation difficult. Unit 6 is clearly a channel-fill deposit and possibly a distributary channel. This thick sandstone probably is the surface expression of a thick channel and distributary-mouth-bar sandstone sequence that extends to the northeast into the subsurface (Andrews, 1998, pl. 1). The upper part of the section (units 7 and above) is too covered to interpret, but the abundance of ripple marks and organic debris suggests relatively shallow water.

Measured Section, Stop 2
Hartshorne Formation
Flagpole Mountain Section

Location: Near common corner of secs. 17, 18, 19, and 20, T. 1 S., R. 10 E. (Olney 7.5′ quadrangle). About 4 mi west of Lehigh. Coal County, Oklahoma.

Note: Composite measured section based on 8° dip for unit 1, 6° dip for units 3–18, and projected positions of units 3 and 5 onto east-west section-line road (Fig. 15). Thickness of covered intervals, especially thicker ones, are approximate.

Thickness (feet)

KREBS GROUP:
HARTSHORNE FORMATION:

18. Sandstone, very fine grained, dark yellowish orange (10YR6/6). Stratified. Poorly exposed. 1.0

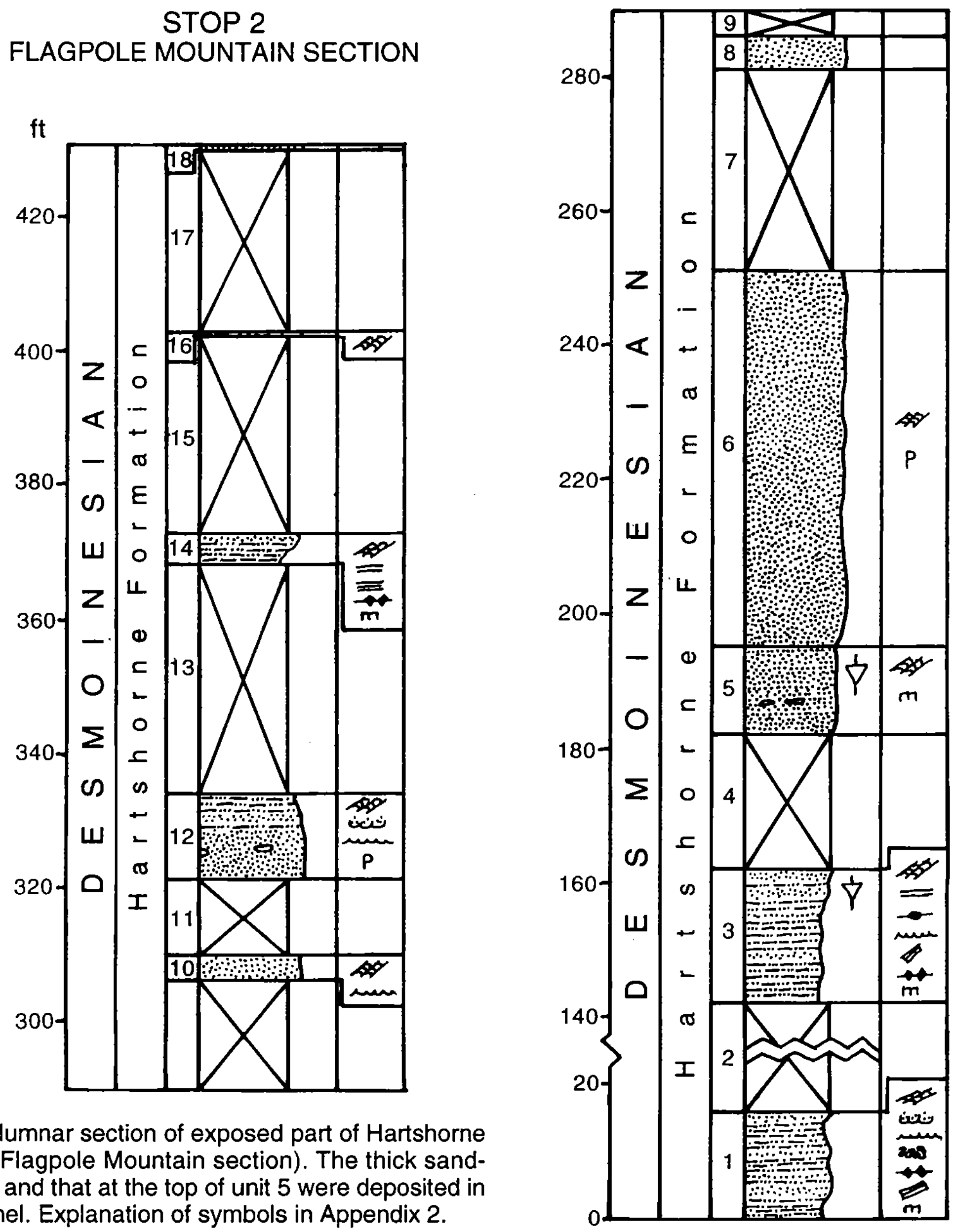


Figure 14. Graphic columnar section of exposed part of Hartshorne Formation at Stop 2 (Flagpole Mountain section). The thick sandstone shown as unit 6 and that at the top of unit 5 were deposited in a (distributary?) channel. Explanation of symbols in Appendix 2.

17. Covered. Highly iron oxide-stained sediments in small spring on east side of road in this interval may indicate presence of a coal bed. 27.0
16. Sandstone, very fine grained, moderate yellowish brown (10YR5/4). Flaggy, cross-stratified. Poorly exposed. 0.5
15. Covered. 29.0
14. Siltstone, pale yellowish brown (10YR6/2); minor shale; and sandstone, grayish orange pink (5YR 7/2). Siltstone fissile, parallel-stratified, contains trace amounts of macerated carbonized organic debris on laminations. Weathers to conspicuous yellowish gray (5Y8/1). Sandstone at top, highly cross-stratified, contains abundant mica. 5.0
13. Covered. 34.0
12. Sandstone, medium-grained, light brown (5YR5/6) to dark yellowish orange (10YR6/6); and minor siltstone. Sandstone, large-scale cross-stratified, locally with abundant ripple marks. One set of asymmetric ripple marks trends north-south with a paleocurrent direction to the west; another set of trough cross-beds indicates paleocurrent direction to N. 55° E. (Fig. 16). Locally contains vugs that probably are eroded rip-up clasts. Highly variable iron oxide stain. Includes thin covered intervals that probably are siltstone. 13.0
11. Covered. 11.0
10. Sandstone, fine- to medium-grained, dark yellowish orange (10YR6/6). Slabby to flaggy weathering. Interference and asymmetric ripple marks common. One set of asymmetric ripple marks trends N. 60° E., with a paleocurrent direction to the northwest. Locally contains large-scale cross-stratification. Dip-slope outcrop. 4.0
9. Covered. 20.0

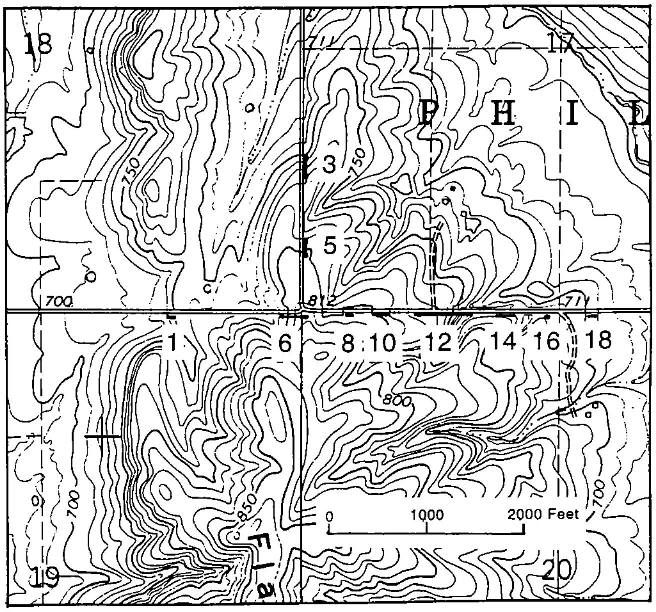


Figure 15. Part of Olney, Oklahoma, 7.5′ topographic quadrangle (1969 edition), showing common corners of secs. 17, 18, 19, and 20, T. 1 S., R. 10 E., and outcrops used in Flagpole Mountain measured section. Numbers refer to units in Figure 14. Units 3 and 5 projected onto east-west section-line road.

8. Sandstone. Poorly exposed, mostly rubble.	5.0
7. Covered.	30.0
6. Sandstone, medium-grained, light brown (5YR5/6) to very pale orange (10YR8/2) or pale yellowish orange (10YR8/6). Mostly massive and unstratified, locally large- and small-scale cross-stratified. Cavernous weathering, abundant iron oxide stain. Very porous. Probable channel deposit.	56.0
5. Sandstone, very fine grained to rarely medium-grained, dark yellowish orange (10YR6/6). Flaggy and cross-stratified at base to unstratified and porous near top. Abundant mica on bedding planes. Contains rare siltstone rip-up clasts.	13.0
4. Covered.	20.0
3. Sandstone, fine- to very fine grained, grayish orange (10YR7/4) to very pale orange (10YR8/2); and siltstone, dark yellowish orange (10YR6/6). Sandstone platy to flaggy, cross-stratified on small scale, locally with interference ripple marks. Mica, macerated plant debris on bedding planes. Siltstone platy, well-laminated, mostly parallel-bedded but locally wavy-bedded. Interbedded with thin, very fine grained sandstone lenses in places. Contains carbonized macerated plant debris and locally well-preserved plant compressions.	20.0
2. Covered.	126.0
1. Silty shale; siltstone; and sandstone, very fine grained to fine-medium–grained, grayish orange (10YR7/4). Sandstone platy to flaggy, cross-stratified and/or ripple-bedded and/or with rare large-scale trough cross-stratification. Trace fossils on base and ripple marks on top of some beds. One set of ripple marks trends N. 40° E. Locally contains well-preserved plant impressions as long as 1 in. Abundant mica and rare carbonized plant debris on bedding planes.	16.0
Total thickness of section	430.5

Figure 16. Trough current ripples in unit 12, Flagpole Mountain measured section. Direction of paleocurrent flow is from upper right to lower left (to N. 55° E.). Geologic hammer for scale.

STOP 3

Atoka Measured Section

Directions: From intersection of U.S. Highways 69 and 75 just north of Atoka, Oklahoma, drive north 1 mi on Highway 69. Turn west on county road and drive 0.75 mi. Turn north and drive about 1 mi to house at end of road. Ask at house for permission to visit outcrop and directions.

This outcrop is on private property, and permission for us to examine it has been generously given by Mr. Danny Gabbart, Route 3, Box 3750, Atoka, Oklahoma 74525; telephone (580) 889-6460.

Map reference: Hendricks and others (1947).

The Hartshorne Formation at Stop 3 (Fig. 17) forms a well-defined ridge that extends for many miles to the northeast. To the south, south of Muddy Boggy Creek, the Hartshorne forms a very poorly defined low ridge and is not exposed. This outcrop is the southernmost outcrop of Hartshorne Formation exposed in the footwall of and adjacent to the Choctaw fault, which defines the geologic boundary between the Ouachita fold-and-thrust belt and the Arkoma basin. Here, the strata dip steeply to the northwest toward the axis of the Lehigh syncline, one of several synclines that mark the triangle-zone structural transition from the fold-and-thrust belt to the basin.

This outcrop of the Hartshorne Formation is different from all the others described in this guidebook, because it consists of a significant proportion of chert-pebble conglomerate (Fig. 18). As such, it is one of the most enigmatic outcrops of the Hartshorne Formation in the Arkoma basin. The conglomeratic sandstone beds are convincing evidence that at least parts of the Hartshorne were derived from uplift of the Ouachita Mountains. Andrews (1998, pl. 1) shows the Hartshorne in this area as having an eastern (proximal) source area. Knechtel (1937), Hendricks (1937a), and recent OGS mapping have shown that conglomerate beds occur in the McAlester, Savanna, and Boggy Formations south of McAlester. It appears, however, that conglomerates are restricted to the lower stratigraphic units (Atoka, Hartshorne) to the south, and occur higher in the section to the north. This suggests that the Ouachita Mountains were progressively uplifted and exposed to erosion from south to north.

The lower part of the Hartshorne Formation at the Atoka section (units 1–5) was deposited in channels, possibly close to a marine environment. Unit 7 may be a subaerial channel or a shallow-marine channel that has been slightly reworked by upper-shoreface processes. Units 8–11 are a classic, upward-coarsening sequence representing progradation of a "more classic" Hartshorne delta complex, most likely a prodelta (unit 8), a distal-marine bar or a bar transition (unit 9), and lower- and upper-distributary-mouth bars (units 10 and 11). Based on the presence of conglomerates, units 1–7 were likely derived from a nearby source terrane to the east(?), whereas units 8–11 may represent more common, distantly derived sediments from the east.

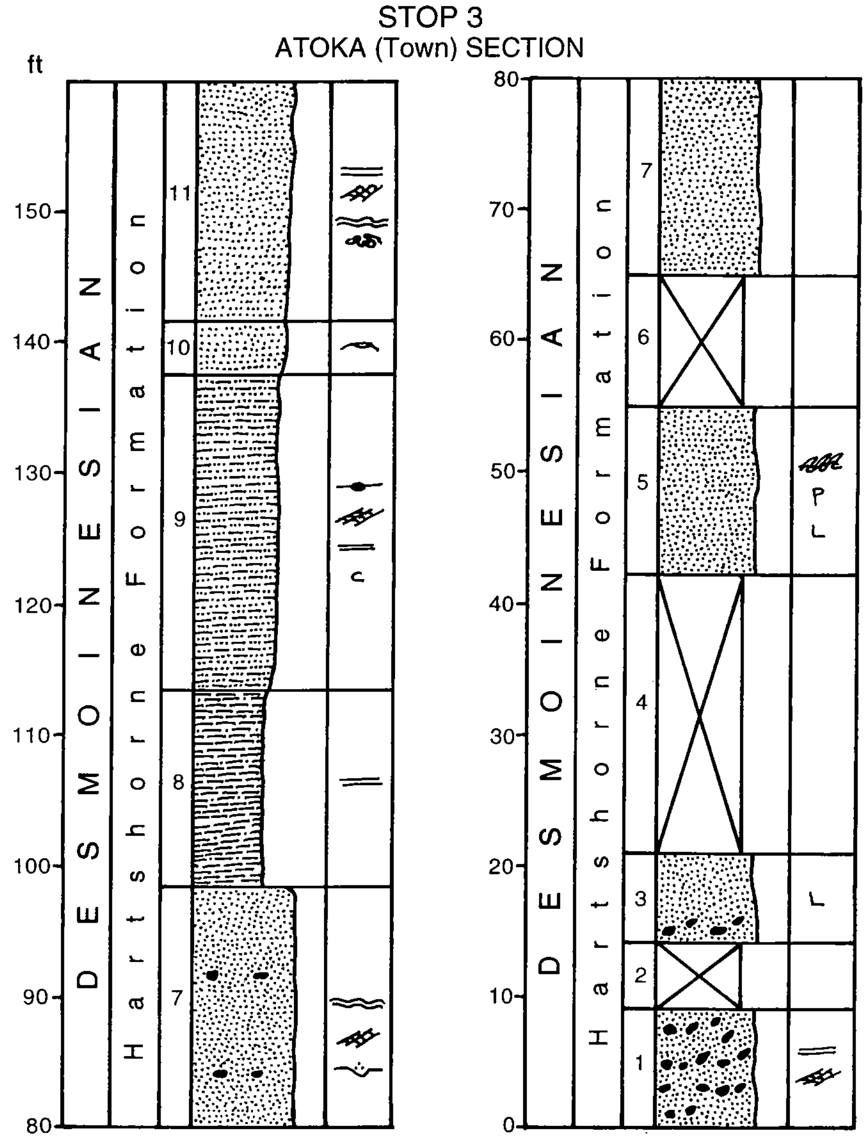


Figure 17. Graphic columnar section of exposed part of Hartshorne Formation at Stop 3 (Atoka section). Chert-pebble conglomerates, which are present in the Hartshorne Formation only in the southwestern part of the Arkoma basin, make up most of the lower part of the section. Explanation of symbols in Appendix 2.

Measured Section, Stop 3

Hartshorne Formation
Atoka Section

Location: C N½NE¼ sec. 3, T. 2 S., R. 11 E. (Lehigh 7.5′ quadrangle). At south end of narrow ridge about 1.5 mi north-northwest of intersection of U.S. Highways 69 and 75 just north of Atoka. Atoka County, Oklahoma.

Thickness (feet)

KREBS GROUP:
HARTSHORNE FORMATION:

11. Sandstone, very fine grained. Locally cross-, ripple-, plane-parallel-, and/or wavy-bedded. Platy weathering. Trace fossils on base of some beds at top of unit. Beds continuous. 18.0
10. Sandstone, very fine grained, light brownish gray (10YR6/1). Flaser-bedded. Beds tabular, continuous. Unit partly covered. 4.0
9. Siltstone; minor sandstone, very fine grained. Siltstone platy, very well stratified, locally contains thin sandstone lenses, lenticular-bedded. Near base, some continuous 1-in.-thick siltstone beds, partly calcareous. Sandstone cross-stratified. 24.0
8. Shale, slightly silty, light olive gray (5Y5/2). Laminated. Poorly exposed. 15.0
7. Sandstone, medium-fine–grained, pale orange (10YR 8/2). Flaggy, well-stratified, mostly gently wavy bedded; rarely cross-stratified and with cut-and-fill structures. Contains two thin chert-pebble-conglomerate layers. Pebbles as large as 0.25 in., matrix-supported. 33.5
6. Covered. 10.0
5. Sandstone, medium-fine–grained, pale yellowish orange (10YR8/6) to dark yellowish orange (10YR

6/6). Highly soft-sediment deformed. Massive to slabby to flaggy. Liesegang rings common. Locally with abundant vugs that appear to be eroded rip-up clasts. As viewed from above, unit appears to consist of a series of very large foreset beds dipping generally to south. Forms top of ridge.	13.0
4. Covered. Possibly some thin sandstone beds in this interval. Pinches out north of section.	21.0
3. Sandstone, medium-grained, pale yellowish orange (10YR8/6); and chert-pebble conglomerate. Irregularly bedded. Sandstone quartzose and unstratified but with common fractures, partings, and common Liesegang rings. Chert pebbles subangular, as large as 0.5 in., concentrated in basal 2 ft of unit.	7.0
2. Covered.	5.0
1. Chert-pebble conglomerate (Fig. 18). Cross- and plane-parallel-stratified. Weathered chert pebbles subrounded, concentrated along bedding planes, matrix supported in medium-grained sandstone.	9.0
Total thickness of section	159.5

Figure 18. Cross-stratified chert-pebble conglomerate (unit 1) in Hartshorne Formation at Stop 3. Geologic hammer for scale.

STOP 4

Reynolds Lake Measured Section

Directions: From the intersection of U.S. Highway 69 and State Highway 63 in Kiowa, Oklahoma, drive 4.5 mi south on U.S. 69. This is also about 1.1 mi south of the Pittsburg-Atoka county line and at the intersection of U.S. 69 and State Highway 131. Turn east on county road, drive 0.3 mi, and cross railroad tracks. Continue east 0.1 mi and turn south. Drive 0.4 mi to large bulldozed outcrop on east side of road.

This outcrop (Stop 4) is on private property. Permission to visit the exposures has been given to us by the owner, Mr. J. R. Duval. Individuals wishing to visit this outcrop should contact Mr. Duval at 1618 N.W. 7th, Grand Prairie, Texas 75050; telephone (972) 262-3546.

Map reference: Hendricks (1937a).

This excellent outcrop (Fig. 19) of the Hartshorne Formation may not be representative of the Hartshorne in this area. The outcrop is at the south end of a relatively well defined ridge about 1 mi long; northeast and southwest of the ridge, little or no topographic expression of the Hartshorne is apparent.

The Hartshorne in this area dips steeply to the west or northwest toward the axis of the Kiowa syncline. The trace of the Choctaw fault is about 0.2 mi east of this outcrop. These relations, and the observation that the dip of the strata overlying the Hartshorne decreases progressively westward away from the fault, are evidence that the structural transition from the Ouachita fold-and-thrust belt to the Arkoma basin is a triangle zone. Like the Lehigh syncline (see Stop 3 discussion), the Kiowa syncline, as well as the Hartshorne, San Bois, Cavanal, and Pine Mountain synclines, mark the triangle zone.

Hendricks (1937a) mapped the Upper and Lower Hartshorne coals in this area, although he noted that they are dipping too steeply to mine. He noted that in an exposure in the C W½ sec. 10, the Lower Hartshorne coal is 1 ft 3 in. thick and that about 200 ft above it stratigraphically, the Upper Hartshorne coal is 2 ft 1 in. thick. Based on logs of wells just west of this outcrop, R. Andrews (personal communication, 1998) noted that the Upper Hartshorne coal is 100 ft above the Lower Hartshorne coal.

Most of the Reynolds Lake section above the Lower Hartshorne coal consists of siltstone and very fine grained, thin sandstones (Fig. 20). The log character of these strata are well represented on the log of the Sunset International No. 1 Bennett (Fig. 21), particularly below and directly above the Lower Hartshorne coal. (The well is located ~2.5 mi northwest of the measured section.) The shale intervals (e.g., lower part of unit 11) may be prodelta deposits, and interbedded siltstone–sandstone units (units 12–14) may be bar-transition and/or lower-distributary-mouth-bar deposits. The sandstone in the upper part of unit 15 may be a thin upper-distributary-mouth-bar deposit. This coarsening-upward sequence (units 11–15) is similar to that directly above the Lower Hartshorne coal on the log.

Several differences between the measured section (Fig. 19) and the log (Fig. 21) are apparent, however. Based on mapping by Hendricks (1937a), the Upper Hartshorne coal is probably directly above the measured section. The delta-plain(?) sequence shown on the log is not present in the measured section, most likely because it is eroded or was not developed at the outcrop locality. The sandstones at the base of the measured section (units 1, 3, and 5) may be represented by a single sandstone on the log at about 4,556 ft; most of this lower part of the section that contains the sandstones is covered, but the log suggests that it is mostly shale and siltstone. The three sandstone units at the base of the section probably were deposited during storm events in an area that was otherwise characterized by the deposition of finer-grained sediments.

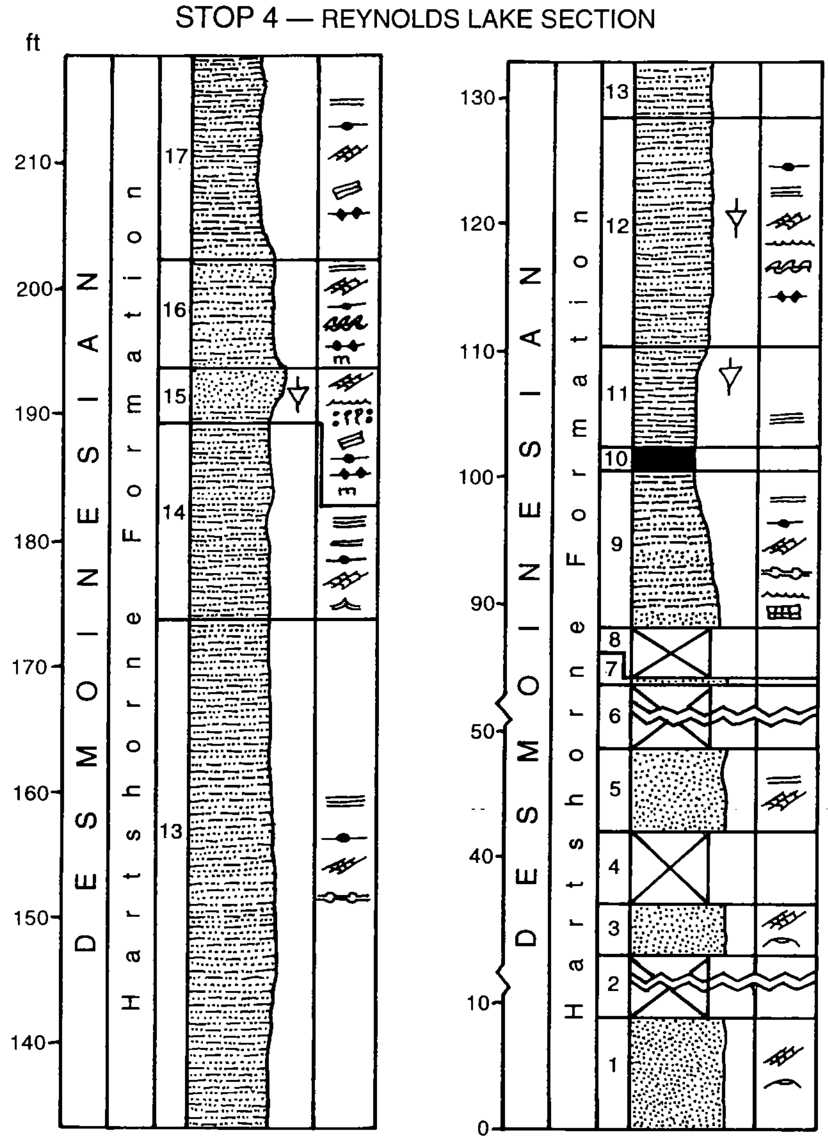


Figure 19 *(right)*. Graphic columnar section of exposed part of Hartshorne Formation at Stop 4 (Reynolds Lake section). The general fine-grained character of most of the section above the Lower Hartshorne coal (unit 10) is typical of bar-transition and lower (distal) distributary-mouth-bar deposits in the Hartshorne Formation. Explanation of symbols in Appendix 2.

Figure 20. Middle part of Reynolds Lake section, showing overall well-stratified character of beds. Stratigraphic top is to the left. Unit 13 is exposed in most of the photograph, and the base of unit 14 is on the far left side.

Measured Section, Stop 4

Hartshorne Formation
Reynolds Lake Section

Location: *N½S½NW¼ sec. 10, T. 2 N., R. 13 E. (Kiowa 7.5′ quadrangle). Directly east of Reynolds Lake about 4.5 mi south-southwest of Kiowa. Atoka County, Oklahoma.*

Thickness (feet)

KREBS GROUP:

HARTSHORNE FORMATION:

17. Silty shale, moderate yellowish brown (10YR5/4); siltstone; and minor sandstone, very fine grained. Shale and siltstone plane-parallel-laminated, locally with abundant organic debris as long as 1 in. on bedding planes. Sandstone lenticular- and cross-bedded. Poorly exposed. 16.0
16. Siltstone, dark yellowish orange (10YR6/6); and sandstone, very fine grained, yellowish gray (5YR8/1). Siltstone well-stratified, plane-parallel-laminated.

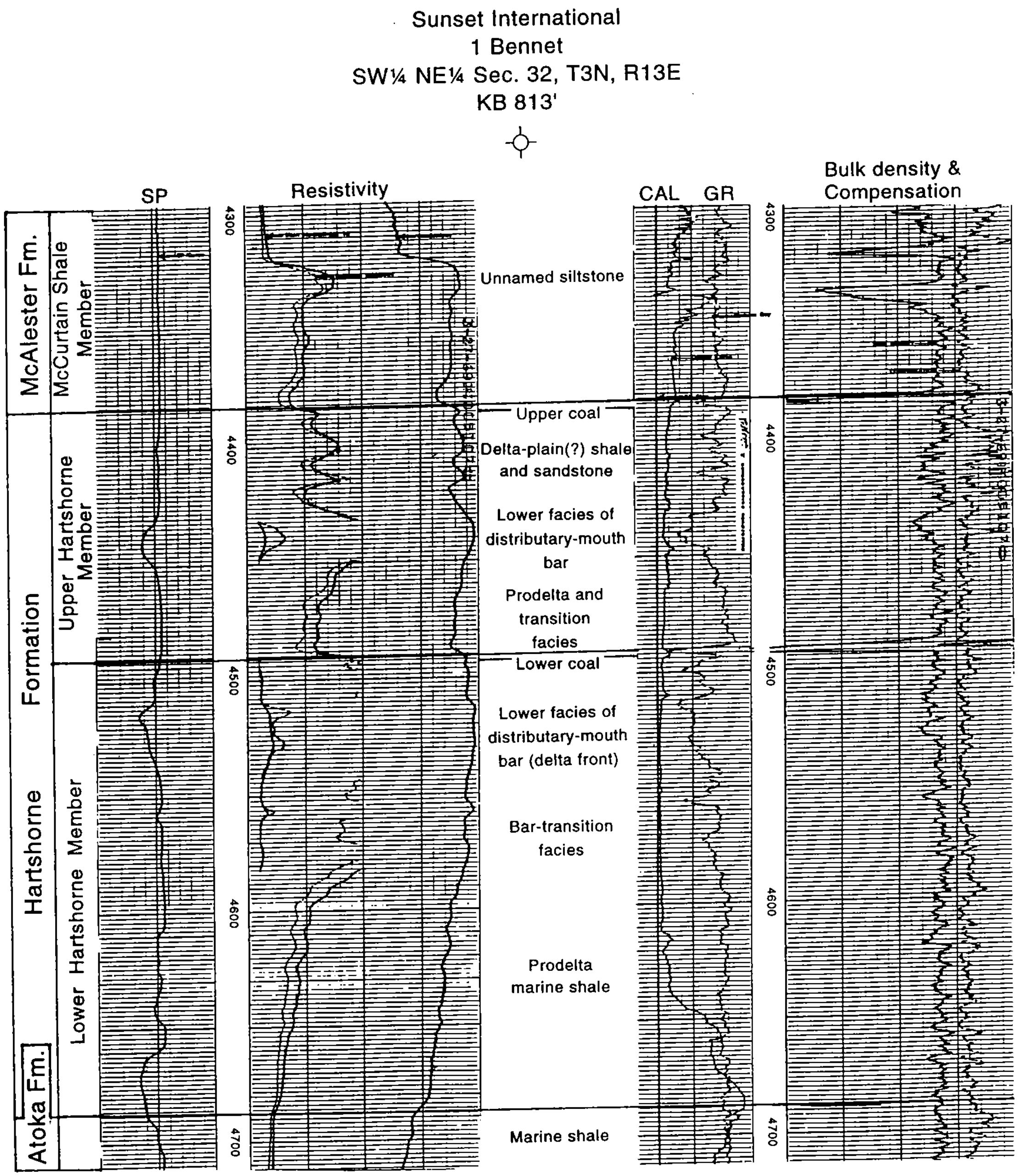


Figure 21. Part of log from the Sunset International No. 1 Bennett well, drilled about 2.5 mi northwest of the Reynolds Lake section. The log signature of most of the Hartshorne Formation is typical of bar-transition and lower-distributary-mouth-bar strata. The delta-plain(?) strata interpreted directly below the Upper Hartshorne coal are not present at the Reynolds Lake section. Interpretation of depositional environments from R. Andrews (personal communication, 1998). *SP* = spontaneous potential, *CAL* = caliper, *GR* = gamma ray.

Mica and macerated organic material common on bedding planes. Sandstone cross- and lenticular-bedded (Fig. 22), rarely with soft-sediment-deformation structures. Micaceous. Rare, completely iron oxidized sandy siltstone inclusions in one bed. 8.5

15. Sandstone, very fine grained, pinkish gray (5YR8/1; lower part) to bluish white (5B9/1; upper part); and minor siltstone, dark yellowish orange (10YR 6/6). Lower 2 ft flaggy, lenticular- and cross-bedded, with ripple marks on tops of sandstones, and siltstone draped over ripples. Mica and macerated carbonized plant debris on bedding planes. Upper part of unit consists of well-parted sandstone beds 1–6 in. thick (Fig. 23). Beds vary from flaggy and unstratified to ripple-bedded. Top of uppermost bed with rare vertical trace fossils and a large (1- by 4-in.) plant impression. Unit forms conspicuous ledge. 4.5

14. Siltstone, yellowish gray (5Y7/2) to moderate yellowish brown (10YR5/4); and minor sandstone, very fine grained, yellowish gray (5Y8/1) to dark yellowish orange (10YR6/6). Siltstone fissile, plane-parallel-laminated. Sandstone lenticular- and cross-bedded. Top locally with dish-and-pillar structures. 15.5

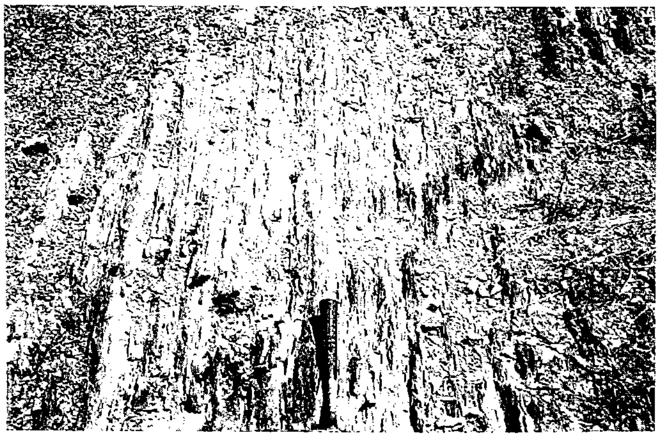


Figure 22. Unit 16, Reynolds Lake section, showing well-stratified siltstone and minor lenticular-bedded sandstone typical of lower-distributary-mouth-bar deposits. Stratigraphic top is to the left. Geologic hammer for scale.

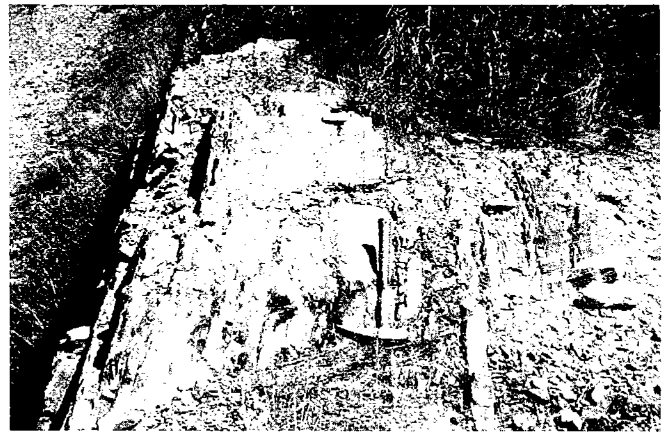


Figure 23. Unit 15 and top of unit 14, Reynolds Lake section. The coarsening-upward sequence (stratigraphic top is to the left) and sedimentary structures are typical of a progradational lower- to upper-distributary-mouth bar. Geologic hammer for scale.

13. Sandstone, very fine grained, very pale orange (10YR 8/2); and siltstone, dark yellowish orange (10YR 6/6). Sandstone fissile, lenticular-, cross-, and ripple-bedded (Fig. 24). Some sandstone beds are continuous but thicken and thin owing to ripples. Siltstone draped over ripples in sandstone. Base of unit draped over eroded top of unit 12.	45.5
12. Sandstone, very fine grained, yellowish gray (5Y8/1); and siltstone, grayish orange (10YR7/4). Sandstone platy, fissile, lenticular-, ripple-, and cross-bedded. Rare sandstone beds in upper part slightly soft-sediment deformed. Trace of carbonized organic debris on bedding planes in siltstone. Approximately 14 in. of top of unit 12 eroded.	18.0
11. Shale, dark gray (N3); and siltstone. Shale fissile, soft, laminated. Siltstone papery, occurs at top of unit.	8.0
10. Coal. Smutty, abundant iron oxide stain. Probably Lower Hartshorne coal. Poorly exposed.	2.0
9. Siltstone, light olive gray (5Y6/1); sandstone, very fine grained, dark yellowish gray (10YR6/6); and minor shale. Siltstone platy, laminated. Sandstone lenticular-bedded, ripple-bedded; thickens and thins owing to abundant ripples. Locally shows boxwork weathering. Unit poorly exposed.	12.5
8. Covered.	4.0
7. Sandstone, fine-grained, grayish orange (10YR7/4). Poorly exposed.	0.5
6. Covered.	35.0
5. Sandstone, fine-grained, pale orange (10YR8/2). Cross-stratified and plane-parallel-laminated. Consists of series of amalgamated beds about 1 ft thick, some with flat bases. Beds relatively continuous. Weathers slabby to flaggy. Lichen-covered.	6.5
4. Covered.	6.0
3. Sandstone, fine-grained, pinkish gray (5YR8/1). Cross-stratified, locally flaser-bedded. Weathers flaggy to slabby. Lichen-covered.	4.0
2. Covered.	~23.0
1. Sandstone, fine-grained, pale orange (10YR8/2). Weathers slabby to flaggy; cross-stratified and flaser-bedded, locally ripple-bedded.	9.0
Total thickness of section	218.5

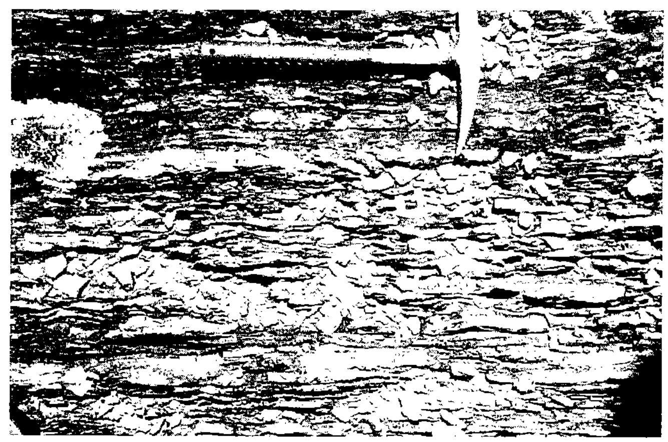


Figure 24. Unit 13, Reynolds Lake section, showing ripple-bedded sandstone and siltstone typical of a lower-distributary-mouth bar. Stratigraphic top is at the bottom. Geologic hammer for scale.

STOP 5

Blanco Measured Section

Directions: From the first sharp bend (coming from the west) in State Highway 63 in Blanco, Oklahoma, drive 1 mi south to the top of the second low ridge.

Map reference: Hendricks (1937a).

Geologic reference[1]: Hendricks (1937a, p. 13).

The first low ridge about 0.5 mi south of Blanco is underlain by the moderately northwest-dipping and northwest-facing Hartshorne Formation. The Hartshorne outcrop at Stop 5 (second low ridge) is vertical

[1]**Geologic reference** is citation for previously published outcrop description at stop.

and also faces north. Hendricks (1937a) mapped a small syncline (Brushy syncline) here in which the north limb is cut off by a small south-directed reverse fault (Blanco fault). Based on detailed mapping of similar small folds to the east, the Brushy syncline is probaby an out-of-the-syncline (Kiowa syncline) flexural-slip fold, and the Blanco fault probably dips steeply north. The trace of the Choctaw fault is a few tenths of a mile to the south; its exact location is difficult to determine because it juxtaposes poorly exposed Atoka Formation in the footwall against poorly exposed Atoka Formation in the hanging wall.

Hendricks (1937a, p. 13) measured this section (Table 3). He also noted that the only exposures of the Lower Hartshorne coal in the Blanco area are on the southwest nose of the Brushy syncline. Hendricks (1937a) makes no reference to specific outcrops of the Upper Hartshorne coal but does note that it was mined along the main ridge on the north side of the Blanco fault near the town of Blanco, where it is about 3.5 ft thick.

The strata at the Blanco section consist of two coarsening-upward sequences capped by the Lower Hartshorne coal (Fig. 25). The sequences either represent the progradation of two distributary-mouth-bar sequences or two shallowing-upward offshore-marine sequences. The second alternative suggests that units 1 and 2 represent a bar-transition facies overlain by lower- to upper-marine-bar sediments, respectively, and that units 3–5 represent a lower- to upper- marine-bar sequence overlain by a shallow-water, wave-reworked sandstone (unit 6). Interval 7 (covered) may be lagoonal shales, which are overlain by the Lower Hartshorne coal. The first alternative would indicate that the strata of unit 1 are prodelta shales, overlain by unit 2 distributary-mouth-bar sediments. Unit 3 would comprise slightly more distal distributary-mouth-bar sediments, overlain by progressively more proximal sediments. Unit 6 in this model may be a channel-margin facies, which is overlain by bay-fill shales and coal. The abundance of macerated plant debris in the section suggests that a delta depositional setting may be more likely than an offshore-marine setting.

TABLE 3. — Measured Section Through Part of the Hartshorne Sandstone on East Line of Sec. 13, T. 3 N., R. 14 E., 500 Feet South of Northeast Corner
(from Hendricks, 1937a, p. 13)

	Feet
Top covered.	
Dark-gray shale containing much fragmental plant material	5.0
Black carbonaceous shale, fissile; contains streaks of coal	1.0
Weathered coal (Lower Hartshorne)	3.5
Light-gray shale with underclay at top	0.9
Massive fine- to medium-grained sandstone that weathers light brown	6.0
Sandstone, shaly and thin-bedded	40.0
Sandy shale	24.0
Thin-bedded sandstone with some thicker massive beds; contains many worm tubes	48.0
Total	128.4
Base covered.	

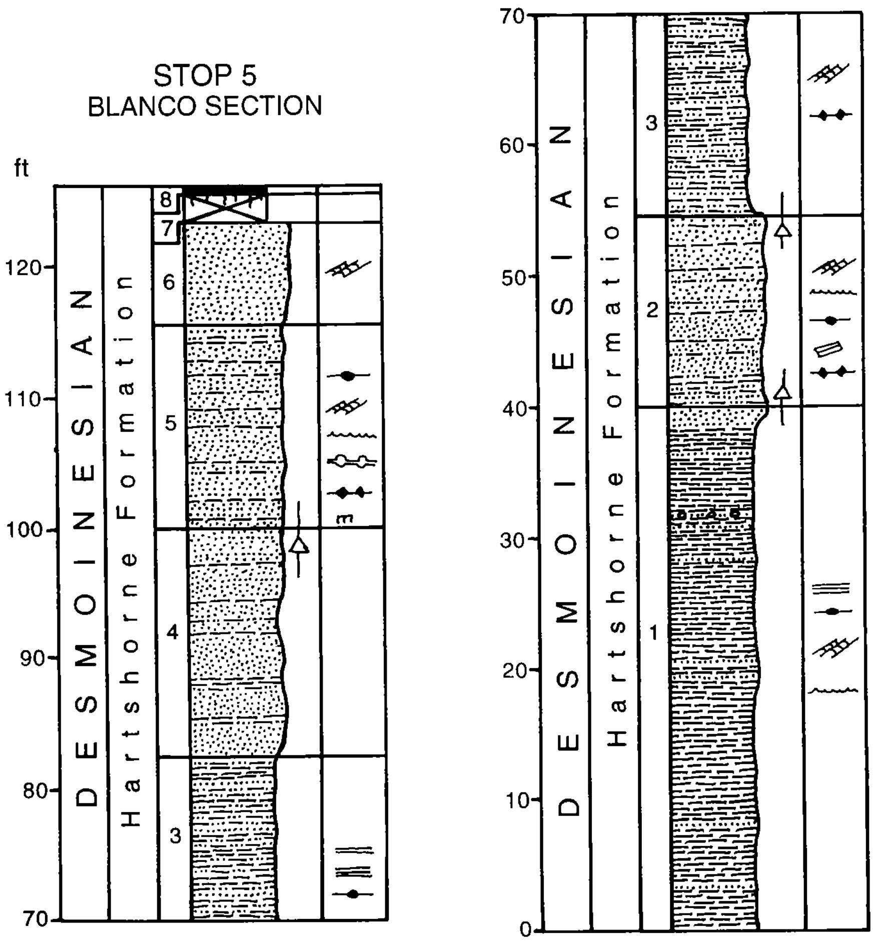


Figure 25. Graphic columnar section of exposed part of Hartshorne Formation on south flank of Brushy syncline at Stop 5 (Blanco section). Explanation of symbols in Appendix 2.

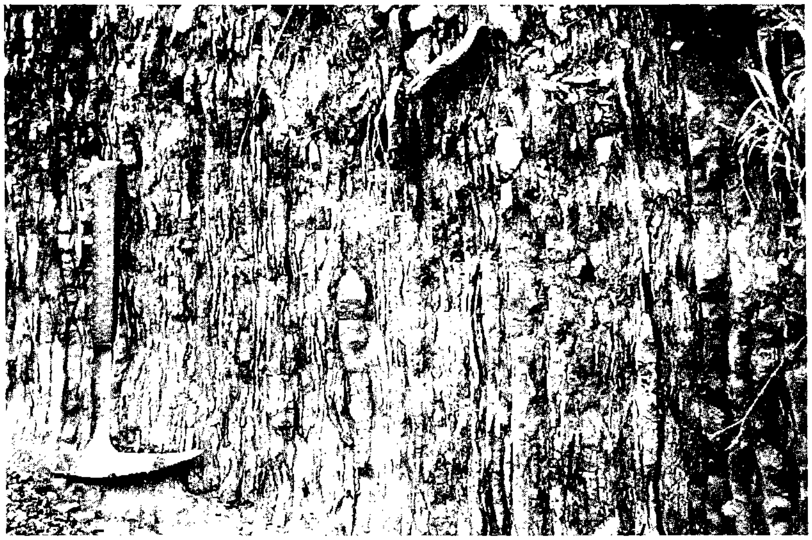


Figure 26. Unit 2, Blanco section. The well-stratified, ripple- and lenticular-bedded character of the sandstone, siltstone, and shale in this outcrop is characteristic of distributary-mouth bars. Stratigraphic top is to the right. Geologic hammer for scale.

Measured Section, Stop 5

Hartshorne Formation
Blanco Section

Location: SE¼NE¼NE¼ sec. 13, T. 3 N., R. 14 E. (Pittsburg 7.5′ quadrangle). Along section-line road about 1 mi south of Blanco. Pittsburg County, Oklahoma. Units 8–4 measured on east side of road; units 3–1 measured on west side.

	Thickness (feet)
KREBS GROUP:	
HARTSHORNE FORMATION:	
8. Coal. Weathered smut, fragments observed. Underclay present, weathered. Top covered.	1.0
7. Covered.	~2.0
6. Sandstone, fine-grained, dark yellowish orange (10YR 6/6). Poorly cross-stratified. Soft, poorly cemented.	8.0
5. Sandstone, very fine grained, dark yellowish orange (10YR6/6); shale, medium dark gray (N4); and minor siltstone. Sandstone cross- and ripple-bedded with much thickening and thinning. Paleocurrent direction based on cross-beds is generally east to west, rarely west to east. Shale and siltstone draped over small lenses of lenticular- and cross-bedded sandstone; plane-parallel-laminated siltstone rarely truncates lenticular-bedded sandstone. Abundant macerated carbonized organic debris and mica on bedding planes.	15.5
4. Sandstone, very fine grained, dark yellowish orange (10YR6/6); and minor shale. Sandstone ripple- and cross-bedded; paleocurrent direction based on cross-beds generally east to west. Sandstone also lenticular-bedded in shale. Similar to unit 5 but with more sandstone.	17.5
3. Siltstone, light olive gray (5Y5/2); shale, medium dark gray (N4); and sandstone, very fine grained. Siltstone fissile, papery, plane-parallel-stratified, interbedded with shale and very thin lenticular-bedded sandstone. Contains very finely macerated organic debris. Sandstones finely cross-stratified.	28.0
2. Sandstone, very fine grained, dark yellowish orange (10YR6/6); siltstone; and shale. Sandstone ripple- and lenticular-bedded in siltstone and shale (Fig. 26). Weathers platy to flaggy. Siltstone and shale draped over ripples in sandstone beds. Carbonized plant debris on bedding planes, some with fine detail well preserved.	14.5
1. Shale; and minor sandstone, mostly very fine grained to rarely fine-grained, dusky yellow (5Y6/4). Shale fissile, contains finely lenticular-bedded sandstone. Sandstone beds relatively continuous, have ripple-marked tops, and are ripple bedded throughout. Two sandstone beds with large-scale cross-beds, one with east-to-west paleocurrent based on cross-beds, and limonitized rip-up clasts.	40.0
Total thickness of section	126.5

STOP 6

Gardner Creek Measured Section

Directions: From Blanco, Oklahoma, drive 5.9 mi east on State Highway 63. Outcrop on both sides of bridge over Gardner Creek.

Map reference: Suneson and Hemish (1997).

Geologic reference: Hemish and Suneson (1997, p. 53–56).

Most of the Hartshorne Formation along the south side of the Arkoma basin between Blanco and Haileyville is probably similar to this well-exposed section (Fig. 27), except that outcrops generally are poor. The slabby to flaggy nature of the weathered sandstone on this ridge near Stop 6 is similar to that 5 mi to the southwest and 10 mi to the northeast. The generally shallow-marine (distributary-mouth-bar) character of the Hartshorne in this area was mapped by Andrews (1998, pl. 1) in the subsurface to the north, based on interpretations of well logs.

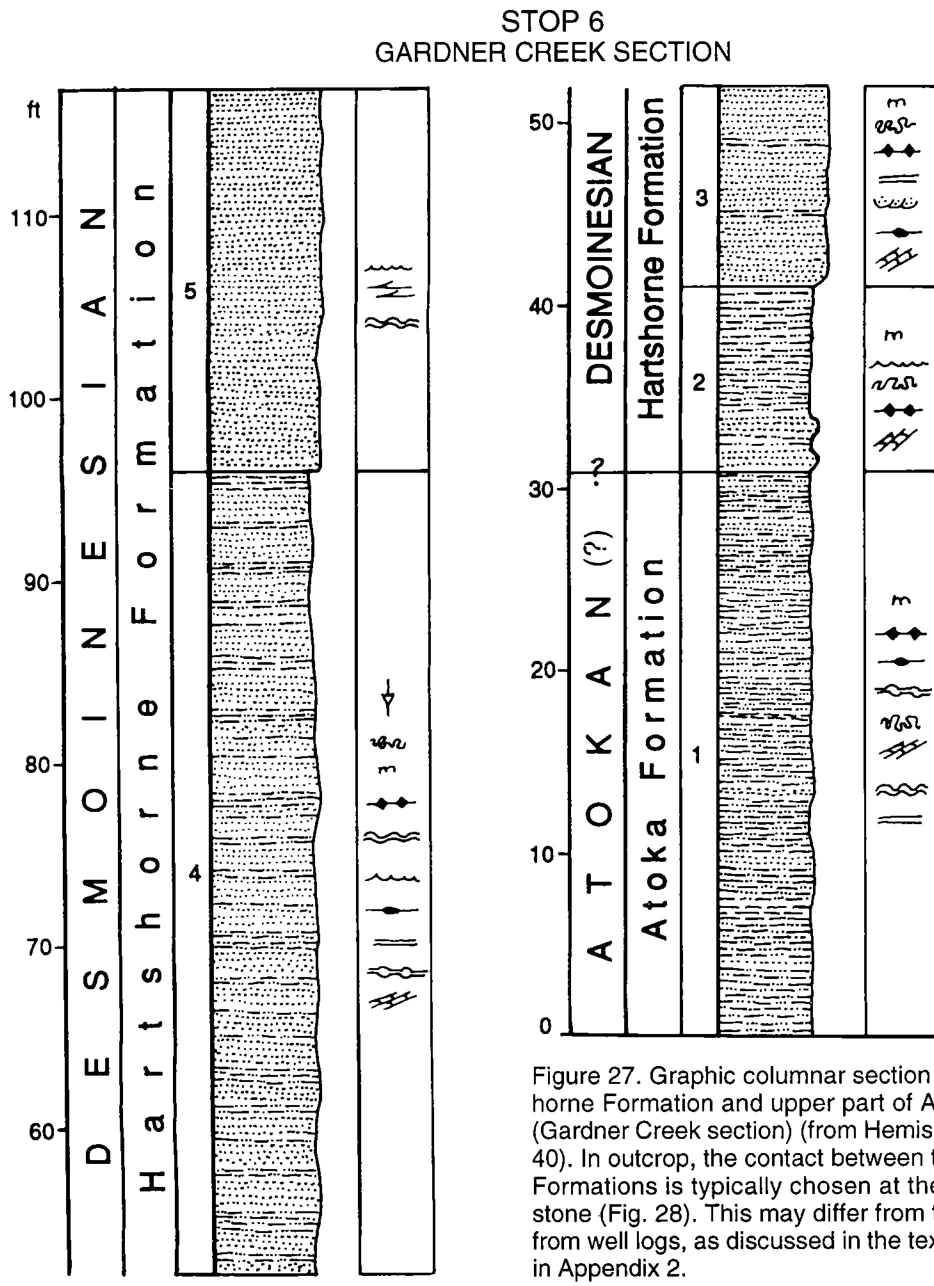


Figure 27. Graphic columnar section of exposed part of Hartshorne Formation and upper part of Atoka Formation at Stop 6 (Gardner Creek section) (from Hemish and Suneson, 1997, fig. 40). In outcrop, the contact between the Atoka and Hartshorne Formations is typically chosen at the lowest mappable sandstone (Fig. 28). This may differ from the contact as interpreted from well logs, as discussed in the text. Explanation of symbols in Appendix 2.

This stop was the westernmost outcrop of the Hartshorne Formation visited on a field trip held by the American Association of Petroleum Geologists, Mid-Continent Section, in 1997. The following description is modified from the guidebook for that trip (Hemish and Suneson, 1997, p. 53).

The contact between the Atoka and Hartshorne Formations at Stop 6 (Gardner Creek section) is gradational and/or arbitrary (Fig. 28). We have picked the contact at the first prominent sandstone, which is only slightly more than a foot thick. This sandstone is not exposed to the west or east along the ridge. Given the general poor quality of exposures away from streams or artificial cuts, a geologist mapping in this area would probably identify the base of the Hartshorne Formation at the base of what is identified here as unit 5. We have not identified any channels in Hartshorne Formation outcrops in this area; as a result, the nature of the contact is conformable to paraconformable. This contrasts with the same contact at Stop 10B, where the contact is clearly disconformable. Hemish and Suneson (1997) interpreted the Gardner Creek section to be a delta-front sequence (units 1 and 2) overlain by delta-plain sediments (units 3, 4, and 5).

An alternate interpretation of the strata at this outcrop is as follows:

Unit 1—Mostly bar transition to offshore shelf. The sandstone beds at the top of the unit may represent storm events or a transition to shallower water.

Unit 2—Mostly bar transition to lower-distributary-

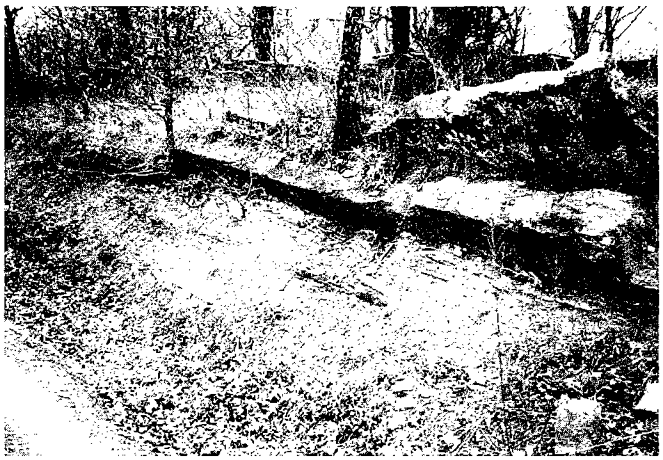


Figure 28. Contact between Atoka Formation (below prominent sandstone) and Hartshorne Formation (above base of sandstone). Geologic hammer for scale. (From Hemish and Suneson, 1997, fig. 44.)

mouth bar at top. The sandstone beds at the base of the unit (lower sandstone bed, mapped as the base of the Hartshorne Formation by Suneson and Hemish, 1997), may represent storm events.

Unit 3—Mostly lower-distributary-mouth bar.

Unit 4—Lower-distributary-mouth bar.

Unit 5—Upper shoreface or wave-reworked (storm?), shallow-water distributary-mouth bar.

Hendricks (1937a, p. 52) noted that the Lower and Upper Hartshorne coals were both exposed "along a freshly graded highway that crosses the two beds near the east side of sec. 26, [but that] outcrops were too deeply weathered for the thickness of the coal beds to be determined." Suneson and Hemish (1997) mapped an exposure of the Upper Hartshorne coal along State Highway 63 about 800 ft east of the bridge over Gardner Creek.

Figure 29 is part of the electric log from the Mustang Production No. 1 Browne well, which is located ~3 mi northwest of the Gardner Creek section. Several aspects of the interpreted log pattern closely resemble the outcrop strata (Fig. 27). The abrupt base, thickness, and relatively clean character of unit 5 are similar to the sandstone at 4,780–4,800 ft on the log. The interbedded sandstone and siltstone of units 2, 3, and 4 are about 65 ft thick and may correlate with the irregular gamma-ray profile labeled "lower-bar and transition facies" on the log. Also, based on recent mapping by Suneson and Hemish (1997), the top of the exposed section is about 145 ft below the Upper Hartshorne coal. The lack of outcrop between the Upper Hartshorne coal and unit 5 suggests that most of that interval is shale and siltstone (and includes the Lower Hartshorne coal). On the log, much of this interval is also shale.

Of greater importance is that the log-determined thickness of the Hartshorne Formation is about 450 ft, whereas the

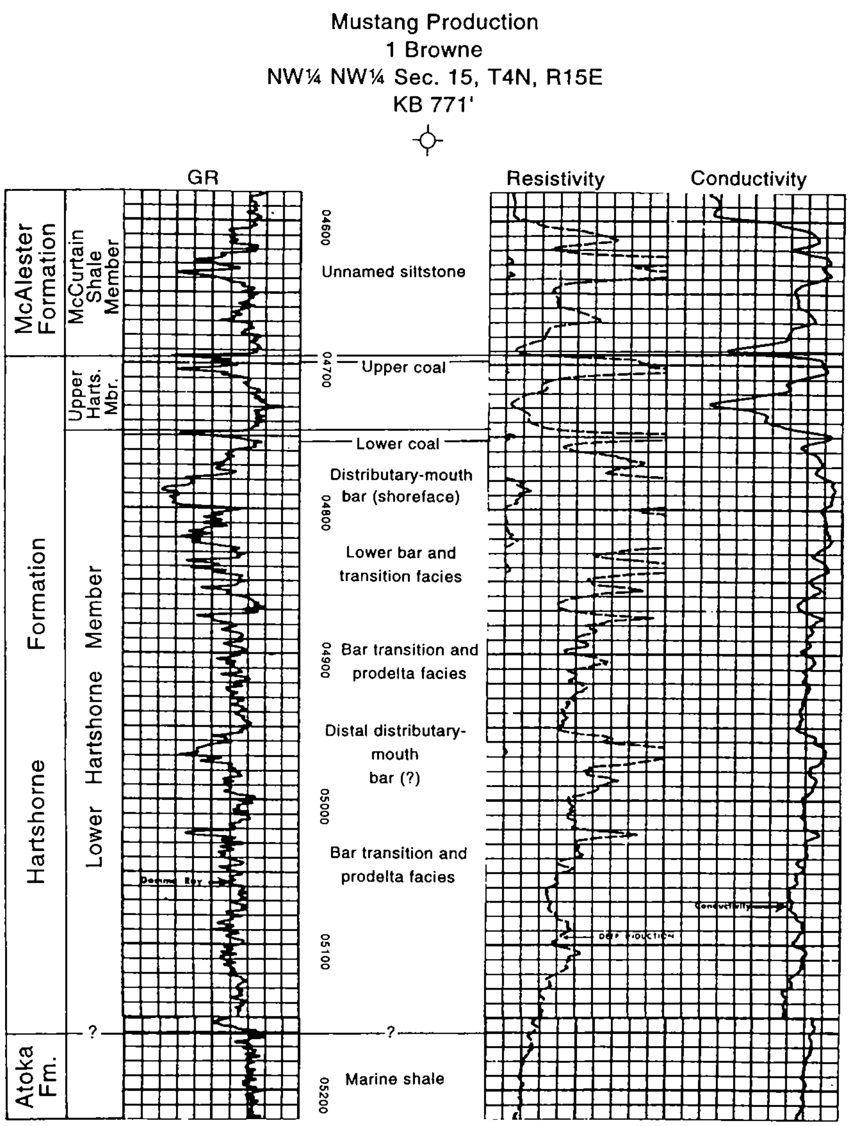


Figure 29 *(left)*. Part of log from the Mustang Production No. 1 Browne well, showing the Hartshorne Formation. The log exhibits a thick prodelta and bar-transition facies within the Hartshorne Formation (log interpretation by R. Andrews, personal communication, 1998). This sequence is probably included in the Atoka Formation as shown in Figure 27. An alternative choice for the Hartshorne-Atoka contact at 4,880 ft would more closely match that observed in outcrop. See text for discussion of identification of the Hartshorne-Atoka contact as recognized by surface mapping versus subsurface-log evaluation. *GR* = gamma ray.

outcrop-measured thickness is about 230 ft (assuming that the Upper Hartshorne coal is 145 ft above unit 5). The different thicknesses are due to differences in how the Atoka-Hartshorne contact is recognized. Most surface mappers place the base of the Hartshorne Formation at the stratigraphically lowest mappable sandstone exposed at the surface (e.g., Fig. 28). Geologists evaluating electric logs might place the contact at the top of the nearly featureless marine shale that shows a baseline gamma-ray and resistivity profile (5,160 ft, Fig. 29). In most cases, the contact between the Atoka and Hartshorne Formations is gradational. (See discussions for Stops 9 and 10A.) Marine shale, clearly part of the Atoka Formation, grades upward through an interval of variable thickness composed generally of unexposed interbedded shale, siltstone, and thin sandstone beds. This interval, in turn, is overlain by thick, commonly well-exposed sandstone beds that are clearly within the Hartshorne Formation. The surface mapper would include the unexposed shale, siltstone, and thin-sandstone interval within the Atoka Formation, whereas the log interpreter would include it within the Hartshorne Formation. An alternative basal Hartshorne contact at 4,980 ft on the well log (Fig. 29) would more closely match the measured surface interval.

Figure 30. Upper-shoreface or storm-reworked deposits (unit 5) in Hartshorne Formation at Stop 6. Note faint to well-developed plane-parallel partings and large-scale cross-stratification. Large-scale, high-angle cross-stratified beds commonly are associated with distributary-mouth-bar deposits in the Hartshorne Formation and indicate periods of high-energy deposition and, more rarely, erosion. Geologic hammer for scale. (From Hemish and Suneson, 1997, fig. 41.)

Figure 31. Lenticular-bedded, highly cross-stratified fine-grained sandstone and siltstone characteristic of lower-distributary-mouth-bar deposits in unit 4 at Stop 6. Geologic hammer for scale. (From Hemish and Suneson, 1997, fig. 42.)

Measured Section, Stop 6
Hartshorne and Atoka Formations
Gardner Creek Section

Location: *C E½E½ sec. 26, T. 4 N., R. 15 E., and SW¼SW¼NW¼ sec. 25, T. 4 N., R. 15 E. (Hartshorne SW 7.5′ quadrangle). Section measured near State Highway 63 bridge over Gardner Creek. Unit 1 measured in borrow pit ~250 ft southwest of bridge; unit 2 measured ~350 ft southwest of unit 1 up driveway; unit 3 measured ~200 ft southwest of unit 2 up driveway; unit 4 measured ~300 ft southwest of unit 3 up driveway for ~150 ft along ridge top and ~250 ft east of bridge on slope southeast of ridge top; unit 5 measured ~100 ft east of bridge on ridge top. Pittsburg County, Oklahoma.*

Thickness (feet)

KREBS GROUP:

HARTSHORNE FORMATION:

5. Sandstone. Fine-grained, grayish orange (10YR7/4). Cross-stratified, locally with wavy partings. Stacked beds, locally with large-scale cross-stratification as thick as 2 ft (Fig. 30). Paleocurrent direction, based on large-scale cross-beds, approximately southeast to northwest. Tops symmetrically rippled with approximate N. 40° E. orientation. Weathers to slabs. 21.0
4. Sandstone and siltstone. Sandstone mostly very fine grained, pale yellowish brown (10YR6/2), mica parallel to laminations. Well-stratified, mostly platy weathering. Cross-stratified, much pinch-and-swell structure, shale drapes on ripples (Fig. 31). Locally plane-parallel-stratified, lenticular-bedded, and/or wavy-bedded. Unit contains a 1-ft-thick sandstone that consists of four stacked beds that have interference ripple marks and show flaggy weathering. Sandstone is fine-grained, pinkish gray (5YR8/1), cross-stratified to locally flaser-bedded, and contains conspicuous organic material and mica on the cross-laminations. Very small trace fossils are uncommon on the tops of the beds. Unit appears to coarsen upward slightly. Contact with unit 3 gradational. 44.0

Figure 32. Flaggy-weathering unit 3 at Stop 6. The similarity of this unit to unit 4 (Fig. 31) suggests a similar depositional environment, but the higher percentage of sandstone (Fig. 27) in unit 3 suggests that it is higher on the distributary-mouth bar. Geologic hammer for scale. (From Hemish and Suneson, 1997, fig. 43.)

3. Sandstone and minor siltstone. Sandstone fine-grained, grayish orange pink (5YR7/2), with abundant mica and organic debris on laminations. Cross-stratified to lenticular-bedded and plane-parallel-stratified. Troughs of cross-beds locally with thin shale, organic debris, mica. Orientation of cross-stratification (unidirectional) indicates paleocurrent direction approximately northeast to southwest. Some small-scale scouring. Tops of beds ripple-marked. Locally, plane-parallel laminations appear to truncate tops of ripples. Trace fossils common on bottoms of beds. Flaggy and platy weathering (Fig. 32). Contact with unit 2 gradational. 11.0
2. Siltstone and sandstone. Siltstone poorly exposed and mostly covered. Two sandstone beds at base separated by covered interval ~13 in. thick. Lower sandstone, 13 in. thick, is base of Hartshorne Formation (Fig. 27). Fine-grained, well-sorted, grayish orange pink (5YR7/2). Cross-stratified, trace of shale and organic material on cross-laminations. Base planar, no evidence for erosion, locally contains trace fossils. Locally thickens to 16 in. Upper sandstone 8 in. thick, fine-grained, faintly flaser-bedded. Base planar, contains trace fossils. Top with interference ripple marks. Locally thins to 6 in. Upper part of unit sandy siltstone, minor sandstone, platy weathering, with conspicuous mica and organic material on laminations. 10.0

ATOKA FORMATION:

1. Siltstone, sandstone, minor shale. Sandstone very fine grained, pale yellowish brown (10YR6/2) to moderate yellowish brown (10YR5/4). Shale silty. Well-stratified; laminations defined by mica- and/or organic-rich layers. Locally lenticular-bedded. Sandstone beds show pinch-and-swell structure, contain trace fossils. About 6 ft below unit 2, 1-5-in.-thick sandstone beds that are fine-grained, silty, contain trace amount of organic debris, and are wavy-bedded to cross-stratified. Sandstones light gray (N7) to pale yellowish brown (10YR6/2), trace fossils on tops of beds. 31.0

Total thickness of section 117.0

STOP 7

Hartshorne (Town) Measured Section

Directions: From the intersection of U.S. Highway 270 and State Highway 1/63 just east of the town of Hartshorne, drive 0.5 mi east on State Highway 1/63 to the top of a low ridge. The Hartshorne Formation is exposed in low road cuts and in the bar ditch along the highway to the east and west.

Map reference: Suneson (1996).

The nomenclature of much of the Desmoinesian strata in this part of the Arkoma basin is shrouded in confusion, mostly because the geologists who originally named the formations did not designate type sections. In many cases, the formation in its presumed type area is poorly exposed, is not representative of the formation over most of the basin, and/or has not been studied in sufficient detail in its type area. For example, the McAlester Formation presumably was named for the town of McAlester, Pittsburg County, Oklahoma, by Taff (1899); but the currently accepted McAlester Formation includes several formally named members originally identified in Muskogee and Haskell Counties (Wilson, 1935; Oakes and Knechtel, 1948). Hemish (1997b, p. 200) recognized this problem for the McAlester Formation and designated a composite-stratotype near its presumed type locality.

A similar problem exists for the Hartshorne Formation. Although named by Taff (1899) presumably for the town of Hartshorne, no type section or locality exists for the formation. Based on recent geologic mapping by the OGS, this outcrop (Fig. 33) along State Highway 1/63 is the best exposed, most complete, and most representative of the Hartshorne Formation near the town of Hartshorne. Although much of the measured section is covered, the position of the Lower Hartshorne coal, which has been extensively mined in the area, can be approximated. A noteworthy aspect of this section is that it is unusually thick; the Hartshorne Formation throughout most of this part of the Arkoma basin is rarely over 500 ft thick.

Most of the lower part of the Hartshorne Formation at the Hartshorne (town) section is moderately well exposed (Fig. 33). The exposed strata in this part of the section are mostly well-stratified and fine-grained, and consist of siltstone and very fine grained sandstone. Most of these strata were probably deposited in a relatively distal delta-fringe environment, either as lower-distributary-mouth-bar or lower-shoreface sediments. Uncommon thicker sandstone beds may represent storm events or more proximal bar facies. Unexposed intervals are probably mostly shale and siltstone that were deposited in slightly deeper water. The upper part of the Hartshorne beneath the Lower Hartshorne coal is too poorly exposed to interpret a depositional environment.

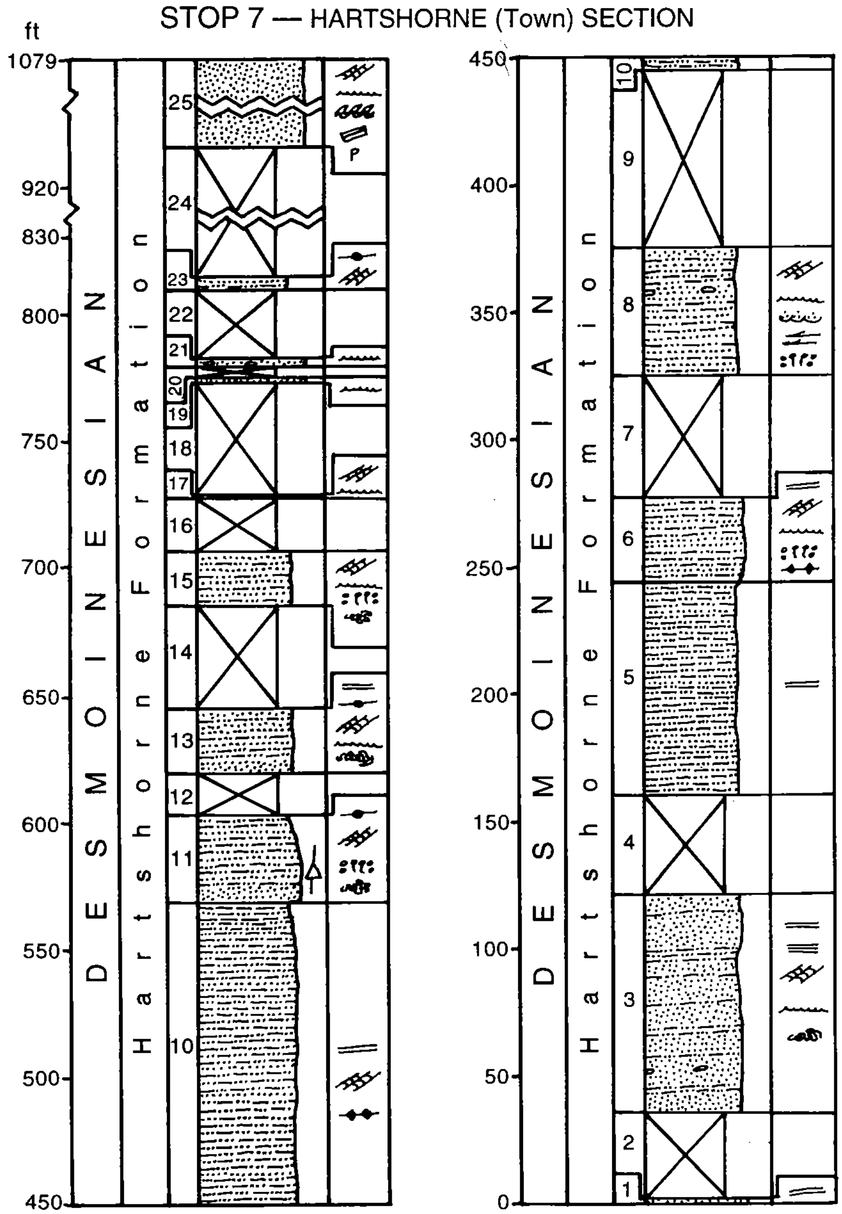


Figure 33. Graphic columnar section of exposed part of Hartshorne Formation at Stop 7, Hartshorne (town) section. The thick sandstone (unit 25) in the upper part of the formation was deposited in an incised valley. Explanation of symbols in Appendix 2.

Of particular interest in the Hartshorne (town) section is the thick (minimum 143 ft) channel sandstone in the upper part of the formation. Although the base is covered, the thickness and sedimentary structures associated with the sandstone suggest that it is an incised channel sandstone, possibly similar to that observed in the lower part of the formation at Stop 10B. This channel sandstone does not appear on logs of wells about 2 to 3 mi north of the measured section.

Figure 34 *(right)*. Base of unit 13 at Hartshorne (town) measured section. The flaggy, ripple-bedded character of this outcrop is typical of lower-distributary-mouth-bar strata. Geologic hammer for scale.

Measured Section, Stop 7

Hartshorne Formation

Hartshorne (Town) Section

Location: *N½NW¼ sec. 9, and N½N½NE¼NE¼ sec. 8, T. 4 N., R. 17 E. (Hartshorne 7.5′ quadrangle). Road cut along State Highway 1/63 about 0.5 mi east of intersection of U.S. Highway 270 and State Highway 1/63 east of Hartshorne. Pittsburg County, Oklahoma.*

Note: Thicknesses shown below (especially covered intervals) are approximate because of extensive cover and variable attitude of beds. Units 1–19 and 23 are exposed in road cut and bar ditch on north side of State Highway 1/63; units 21 and 25 are exposed on south side of State Highway 1/63.

	Thickness (feet)
KREBS GROUP:	
HARTSHORNE FORMATION:	
25. Sandstone, medium-grained, pinkish gray (5YR8/1). Weathered and poorly exposed. Porous. Bedding planes locally oblique to outcrop pattern, may represent large-scale cross-stratification. Locally soft-sediment-deformed. Contains interference ripple marks, small trace fossils, plant impressions, and vugs that probably represent weathered rip-up clasts. This sandstone is in the Upper Hartshorne Member.	143.0
24. Covered. Includes Lower Hartshorne coal, based on alignment of mine adits directly north of highway.	121.0
23. Siltstone, moderate yellowish brown (10YR5/4); and sandstone, very fine grained. Siltstone mostly platy, interbedded with thin, lenticular, very fine grained sandstone. Flaggy sandstone cross-stratified.	5.0
22. Covered. Occupied by State Highway 1/63.	27.0
21. Sandstone, very fine grained, very light gray (N8). Slabby, interference ripple marks on top of bed, small shale rip-up clasts parallel to bedding planes.	3.0
20. Covered.	4.0
19. Sandstone. Flaggy to unstratified, top with ripple marks.	2.0
18. Covered.	45.0
17. Sandstone, very fine grained, yellowish gray (5Y8/1); and siltstone, moderate yellowish brown (10YR5/4). Sandstone ripple-bedded, platy. Unit 17 may represent much of covered intervals 18 and 16.	1.0
16. Covered.	20.0
15. Sandstone, fine-grained, grayish orange (10YR7/4), and siltstone. Sandstone flaggy, cross-stratified, ripple-marked, locally burrowed. Much of unit is poorly exposed or covered and is probably siltstone.	22.0
14. Covered.	40.0
13. Sandstone, very fine grained, pinkish gray (5YR8/1); and siltstone. Sandstone flaggy, ripple-bedded, tops of some beds with ripple marks (Fig. 34). Uncommon sandstone beds plane-parallel-laminated or unstratified. Small trace fossils on bases of some beds. Siltstone plane-parallel-laminated, locally draped over ripple marks on tops of sandstone beds. Locally lenticular-bedded sandstone in siltstone. Thin covered intervals probably siltstone.	26.0
12. Covered.	16.0
11. Siltstone, moderate yellowish brown (10YR5/4); and sandstone, fine-grained, pinkish gray (5YR8/1). Sandstone beds flaggy, locally cross-stratified, rarely extensively horizontally and vertically burrowed. Also very fine grained lenticular-bedded sandstone in siltstone. Thin covered intervals, probably siltstone. Unit appears to thin upward—thick sandstone beds common at base of unit, thin sandstone beds present in middle, and siltstone common at top.	35.0
10. Siltstone, slightly sandy, platy, moderate yellowish brown (10YR5/4); minor sandstone, very fine grained, pinkish gray (5YR8/1); and minor shale at top. Siltstone noticeably plane-parallel-stratified with finely disseminated macerated plant material on bedding planes, some of which is large and preserves fine detail. Siltstone weathers papery. Sandstone cross-stratified on very small scale.	123.0
9. Covered.	70.0
8. Sandstone, very fine grained, pinkish gray (5YR8/1); and minor siltstone. Sandstone ripple-bedded, cross-bedded, flaggy, locally with large-scale trough cross-stratification. Rare shale rip-up clasts on cross-beds. Beds as thick as 3.5 ft. Some sandstone beds extensively burrowed. Some thin covered intervals, possibly siltstone.	50.0
7. Covered.	48.0
6. Siltstone, similar to unit 5; and minor sandstone, very fine grained, grayish orange (10YR7/4). Sandstone beds ripple-bedded and with ripple-marked tops, to plane-parallel-stratified. Sandstone probably about 10% of unit. Trace amounts of macerated plant material on sandstone bedding planes. One sandstone bed with abundant burrows in top 3–6 in. of bed.	34.0
5. Siltstone, moderate yellowish brown (10YR5/4), plane-parallel-stratified. Beds continuous.	83.0
4. Covered.	39.0
3. Sandstone, very fine grained, yellowish gray (5Y7/2); and siltstone. Plane-parallel-stratified and cross-stratified, micaceous, locally with shale rip-up clasts. Tops of beds ripple-marked; trace fossils on tops and bottoms of beds. Sandstone beds separated by platy to fissile, mostly plane-parallel-stratified, light olive gray (5Y5/2) to dark yellowish gray (10YR6/6) siltstone. Minor ripple-bedded sandstone, locally with small shale rip-up clasts on cross-laminations. Thicker sandstone beds with rare large-scale, high-angle cross-stratification.	85.0
2. Covered.	37.0
1. Sandstone, fine-grained, grayish orange (10YR7/4). Platy, parallel-stratified. Covered below.	0.2
Total thickness of section	1,079.2

STOP 8

Clonsilla Hill Road Measured Section

Directions: From the intersection of U.S. Highway 270 and State Highway 1/63 just east of the town of Hartshorne, Oklahoma, drive 3.5 mi east on Highway 270. Turn left (north) on county road and drive about 0.3 mi north and cross an east-west section-line road. Road bends to right (northeast). Drive 1.2 mi northeast, up and over ridge underlain by gently south-dipping

Hartshorne Formation on the north flank of the Hartshorne syncline. Road turns north. Drive north 2 mi. Road turns to right (east) and begins to ascend Hartshorne ridge, then switches back to left (west). Park at top of ridge.

Map reference: Hemish (1992).

Geologic reference: Hemish and Suneson (1997, p. 59–62).

This stop was described in a guidebook published for a field trip held in conjunction with the Mid-Continent Section meeting of the American Association of Petroleum Geologists in September 1997. The following description is modified slightly from that guidebook (Hemish and Suneson, 1997, p. 59–62). Significant additions are noted in brackets: [ ].

The Clonsilla Hill section at Stop 8 (Fig. 35) provides a look at various sandstone units in the part of the Hartshorne Formation stratigraphically below the Lower Hartshorne coal. The coal is not exposed, but its outcrop can be traced approximately by visually aligning the adits to abandoned underground mines on the north slope of Clonsilla Hill. [The Lower Hartshorne coal is approximately 55 ft above the top of unit 16.]

The lower part of the Hartshorne Formation at Stop 8 is a series of sandstone beds (generally <10 ft thick) separated by thick shales (generally 36–88 ft thick). The lower two sandstone units, units 4 and 2, are ~21 ft and ~41 ft thick, respectively. The trough cross-bedding, [shale rip-up] conglomerates, soft-sediment-deformation features, and channel-form configuration of some beds (Fig. 36) indicate deposition within a distributary channel. Figure 36 shows low-angle, trough cross-bedding at one side of a filled channel.

The series of thinner sandstone beds, separated by thick shales, in the interval below the coal generally are thin, wavy-, and parallel-bedded with abundant trace fossils and a variety of ripple marks. Such features suggest deposition in a shallow-marine environment [possibly as a distributary-mouth bar].

The shales and interbedded thin sandstones in the upper part of the Atoka Forma-

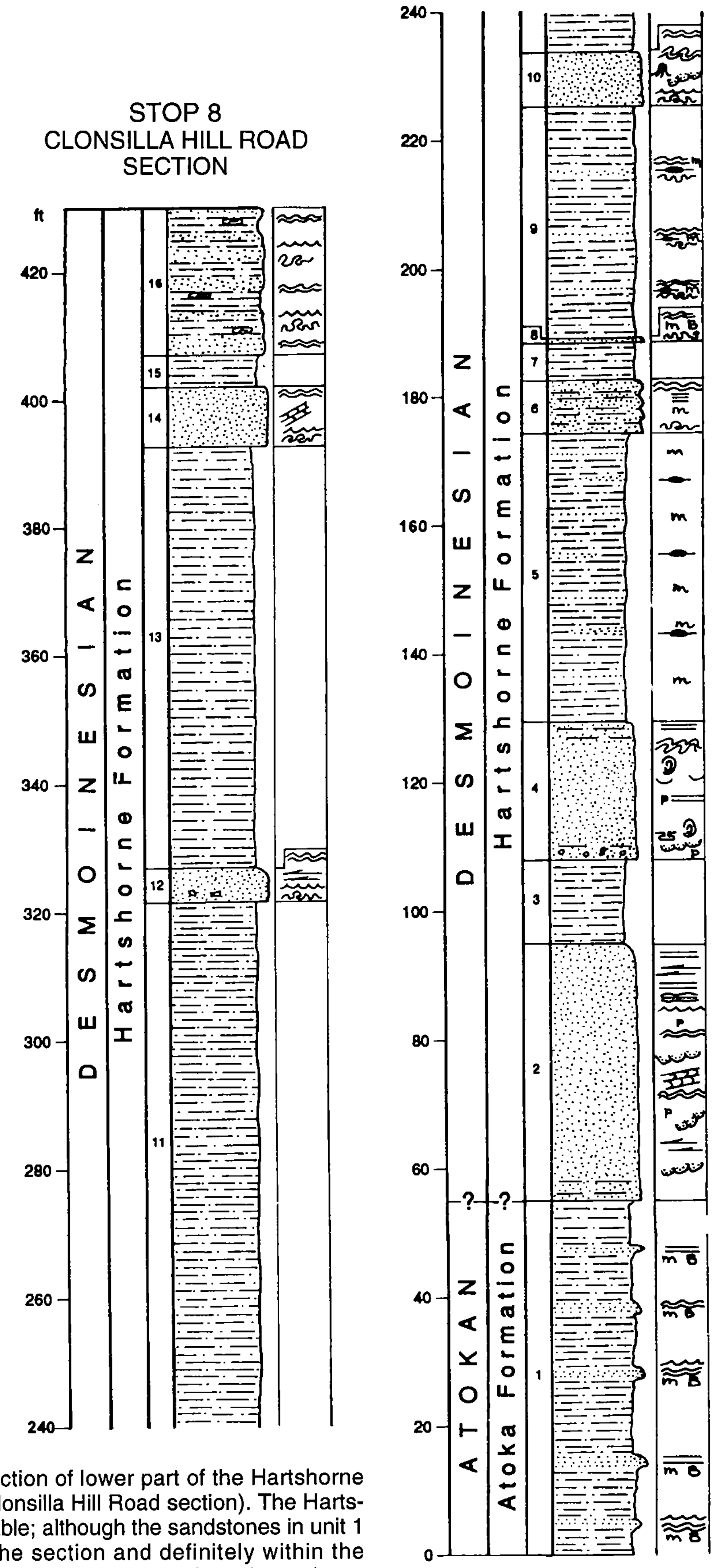


Figure 35. Graphic columnar section of lower part of the Hartshorne Formation exposed at Stop 8 (Clonsilla Hill Road section). The Hartshorne-Atoka contact is questionable; although the sandstones in unit 1 are similar to those higher in the section and definitely within the Hartshorne Formation, they are too thin to be mappable and may therefore be in the Atoka Formation. Explanation of symbols in Appendix 2. (From Hemish and Suneson, 1997, fig. 51.)

Figure 36. Trough-cross-bedded sandstone filling a channel eroded into underlying plane-bedded sandstone (unit 2, Stop 8) interpreted as storm-reworked sediments overlying and eroded into an upper-distributary-mouth bar. Geologic hammer for scale. (From Hemish and Suneson, 1997, fig. 52.)

tion at Stop 8 are interpreted to be distal-marine deposits. The thin sandstones may represent flood or storm events.

[Additional interpretations of the lower part of the Clonsilla Hill Road section are that unit 2 represents a distributary-mouth-bar sequence, and that the large-scale high-angle cross-stratification in some of thicker sandstone beds is the result of reworking by storm waves in a relatively shallow-marine environment. This conclusion is based, in part, on the apparent coarsening- and thickening-upward nature of unit 2. Also, it is possible that unit 1 may be within the lower part of the Hartshorne Formation; the presence of ripple-bedded sandstones supports this interpretation.]

Measured Section, Stop 8
Hartshorne Formation
Clonsilla Hill Road Section

Location: *S½SE¼NE¼NE¼ sec. 10, T. 5 N., R. 17 E., and N½ NW¼SW¼NW¼ sec. 11, T. 5 N., R. 17 E. (Gowen 7.5′ quadrangle). Measured from crest of high ridge at sharp bend in road, west and south in pasture, southeastward in road ditch, and southward downslope in low ridges enclosed by hairpin bend in road near base of slope. Latimer County, Oklahoma. Section measured by LeRoy A. Hemish.*

	Thickness (feet)
KREBS GROUP:	
HARTSHORNE FORMATION:	
16. Sandstone and silty shale, interbedded; sandstone is moderate yellowish brown (10YR5/4) to grayish orange (10YR7/4) with moderate brown (5YR3/4; 4/4) staining, very fine grained, thin- to medium-bedded; parallel- and wavy-bedded; ripple-marked; includes some ironstone concretions and trace fossils; shale is very pale orange (10YR8/2) to grayish orange (10YR7/4).	23.0
15. Shale, very pale orange (10YR8/2) to grayish orange (10YR7/4), silty.	5.0
14. Sandstone, moderate yellowish brown (10YR5/4) to grayish orange (10YR7/4) with moderate reddish brown (10R4/6) staining, very fine grained, mostly thin-bedded; parallel- and wavy-bedded; internally cross-laminated, ripple-marked; trace fossils abundant on sole of unit; contact sharp.	9.2
13. Shale, light olive gray (5Y5/2) to dark yellowish brown (10YR4/2), weathers grayish orange (10YR7/4) to dark yellowish orange (10YR6/6), silty, sandy, poorly exposed in road ditch.	66.0
12. Sandstone, grayish orange pink (5YR7/2) to moderate brown (5YR3/4; 4/4) to grayish red (5R4/2), very fine grained, locally includes ironstone-pebble conglomerate, thin- to medium-bedded; mostly parallel- and wavy-bedded, but some beds exhibit low-angle cross-stratification; commonly ripple-marked (interference ripples); trace fossils abundant on some soles.	5.0
11. Shale, light olive gray (5Y5/2) to dark yellowish brown (10YR4/2), weathers grayish orange (10YR7/4) to dark yellowish orange (10YR6/6), silty, sandy, poorly exposed in road ditch.	88.0
10. Sandstone, moderate reddish orange (10R6/6) to dark reddish brown (10R3/4) to moderate orange pink (5YR8/4), very fine grained; thin- to medium-bedded, with thick beds locally; mostly parallel- and wavy-bedded; includes some trough cross-bedding in channel fills; some convolute beds with dewatering features; ripple-marked in part; trace fossils abundant on some soles.	8.5
9. Shale, moderate yellowish brown (10YR5/4) to yellowish gray (5Y8/1) with dark yellowish orange (10YR6/6) bands; silty; includes lenticular-bedded, very pale orange (10YR8/2), very fine grained, micaceous, wavy-bedded sandstone with some trace fossils.	36.0
8. Sandstone, grayish orange (10YR7/4) to dark yellowish orange (10YR6/6) to moderate reddish brown (10R4/6), very fine grained, micaceous, very thin to thin-bedded, discontinuously wavy-bedded, bioturbated, trace fossils common on some beds.	0.9
7. Shale, moderate yellowish brown (10YR5/4), silty, poorly exposed in road ditch.	6.0
6. Sandstone and shale, interbedded; sandstone is moderate yellowish brown (10YR5/4) to dark reddish brown (10R3/4), very fine grained, thin- to medium-bedded; parallel- and wavy-bedded; micaceous; trace fossils on soles; shale is moderate yellowish brown (10YR5/4) to dark yellowish orange (10YR6/6); fissile; silty and sandy.	8.0
5. Shale, grayish orange pink (10R8/2) to moderate reddish brown (10R4/6), very sandy, micaceous; includes some 0.5-in.-thick sandstone stringers and lenses.	45.0
4. Sandstone, grayish orange (10YR7/4) to moderate reddish orange (10R6/6) to grayish orange pink (5YR7/2), very fine grained, thin- to medium- to thick-bedded; some beds curved, others planar and parallel with pitted surfaces; contains some deformed beds and large rolled masses; east of hairpin bend in road, the unit is channel-form (massive in part, with ironstone-pebble conglomerate and pitted face at base), laterally trough cross-bedded; shaly at top and base of unit; locally, the basal contact is irregular, with load and slump features as well as inclusions of the underlying shale unit.	21.4
3. Shale, pale yellowish brown (10YR6/2) with moderate reddish brown (10R4/6) weathered streaks and bands, silty.	13.0

2. Sandstone, very light gray (N8), weathers light brown (5YR5/6) to moderate brown (5YR3/4; 4/4), very fine grained, thin- to medium- to thick-bedded; low-angle, trough cross-bedding common; some plane-parallel beds with parting lineations; interference-rippled beds common in upper part; some surfaces pitted; some beds wavy with internal cross-laminations; interbedded with shale near base of unit; base sharp. 41.0

ATOKA FORMATION(?):

1. Shale, light gray (N7), pale yellowish brown (10YR6/2), moderate yellowish brown (10YR5/4), and dark yellowish orange (10YR6/6), silty; includes several 0.4–2.0-ft-thick grayish orange (10YR7/4), thin- to medium-bedded, wavy- to plane-parallel-bedded, very fine grained, ripple-marked, micaceous, bioturbated sandstone beds spaced about 5–10 ft apart vertically in the sequence; base of unit covered. .. 54.0

Total thickness of section 430.0

TABLE 4. – Section of Hartshorne Sandstone and Overlying Beds along Road at Center of Sec. 8, T. 5 N., R. 20 E.
(from Hendricks, 1939, p. 266)

	Feet
McAlester shale (basal part of formation only):	
Shale, bluish gray, clayey, with ferruginous concretions	20.0
Shale, gray, sandy; grades upward into overlying shale	15.0
Sandstone, fine-grained, beds ⅛ in. thick	3.0
Shale, gray, sandy, with ferruginous concretions; grades upward into sandstone above	20.0
Shale, black, carbonaceous and flaky	1.5
Coal, clean (Upper Hartshorne)	2.7
Shale, poorly exposed, brownish and sandy	15.0
Total	77.2
Hartshorne Sandstone:	
Sandstone, medium-grained, ashy white; weathers buff; beds about 2 ft thick	15.0
Shale, poorly exposed, gray and sandy	150.0
Coal (Lower Hartshorne)	3.0
Shale, poorly exposed, buff and sandy	5.0
Sandstone, medium-grained, ashy white; weathers rusty-colored; medium-bedded, with sandy shale partings	20.0
Total	193.0
Shale (Atoka), poorly exposed.	

STOP 9

Panola Measured Section

Directions: From U.S. Highway 270 in Panola, turn south on county road, pass school and church on west. Road turns west in about 0.5 mi. In another 0.3 mi, at fork in road, take left (south) fork. Drive 0.3 mi to large borrow pit on west side of road.

Map reference: Hemish and others (1990a).

Geologic reference: Hendricks (1939, p. 266).

This is the only outcrop of the Hartshorne Formation in the southern part of the Arkoma basin in which both the Lower and Upper Hartshorne coals and the Atoka-Hartshorne and Hartshorne-McAlester contacts are exposed (Fig. 37). Thus, it is the only outcrop of the Hartshorne in the Arkoma basin at which most of the formation is exposed and measurable.

Based on topographic expression, this outcrop is probably representative of much of the Hartshorne Formation in Latimer County. In general, the ridge underlain by the Hartshorne Formation is well defined and moderately steep; locally, however, the ridge is low, narrow, and poorly defined, and at other places it is very steep to vertical (e.g., Stop 10B).

Hendricks (1939, p. 266) measured this outcrop of the Hartshorne Formation and included the Upper Hartshorne coal in the McAlester Formation. His measured section is given in Table 4.

Hendricks (1939) indicated that the Lower and Upper Hartshorne coals are separated by 180 ft. The measured section shown in Figure 37 indicates that the coals are separated by 103 ft. Logs from wells directly to the north indicate that the coals are separated by about 50 ft. It is possible that Hendricks' measurement was in error and that the Upper Hartshorne Member does thicken from north to south.

Hendricks (1939, pl. 27) also shows numerous abandoned slope mines in the Lower Hartshorne coal directly west of this outcrop. The extensive dump on the east side of the creek indicates that the coal was also mined adjacent to the road (Fig. 38). Records from the Oklahoma Department of Mines show that the Gore-Hoover Coal Co. operated the mine, probably sometime just before 1944. The thickness of the Lower Hartshorne coal as measured in the Hailey-Ola Coal Co. No. 12 mine, about 1 mi to the west, is about 5 ft (Hendricks, 1939, pl. 34).

Figure 39 is an electric log from the Tenneco No. 1-29 Pierce well, drilled about 3.25 mi north of the measured section. Several units observed at the surface (Fig. 37) can be correlated with log intervals (Fig. 39). The Upper Hartshorne Member at Stop 9 consists of a fine-grained interval about 40 ft thick (unit 8 and probably unit 7), abruptly overlain by sandstone (unit 9). These strata correlate with the interval 3,808–3,846 ft on the log, which is interpreted as marine shale overlain by delta-fringe sandstone. On the log, the sandstone is overlain by a thin shale(?) interval, whereas covered interval 10 (probably mostly shale) in the measured section is considerably thicker. The log signature closely resembles what would be expected from the exposed strata.

In some cases, the correlation between the outcrop (Fig. 37) and log (Fig. 39) is less obvious. For example, the outcrop of the upper part of the Atoka Formation and the Lower Hartshorne Member at Stop 9 consists of two coarsening-upward sequences that represent two bar-transition to lower-distributary-mouth-bar to upper-distributary-mouth-bar sequences. These coarsening-upward sequences are not clearly represented on the log but may be the intervals 3,866–3,888 and 3,922–3,930 ft.

An important aspect of this measured section and representative well log is the nature of the Atoka–Hartshorne contact. The contact is clearly gradational at the outcrop and is defined by the lowest of several relatively thin (1-ft), discontinuous sandstone beds. The contact at Stop 9 is similar in this respect to the contact at Stops 6 and 10A. In contrast, the log character of the contact shows a more abrupt transition from shale in the Atoka Formation to sandstone in the Hartshorne Formation, albeit over several feet. This contrasts with the log character of the contact in the wells described at Stops 6 and 10A, in which the contact is gradational over intervals of varying thickness. In all cases, however, the depositional environment of the upper part of the Atoka is clearly related to that of the lower part of the Hartshorne.

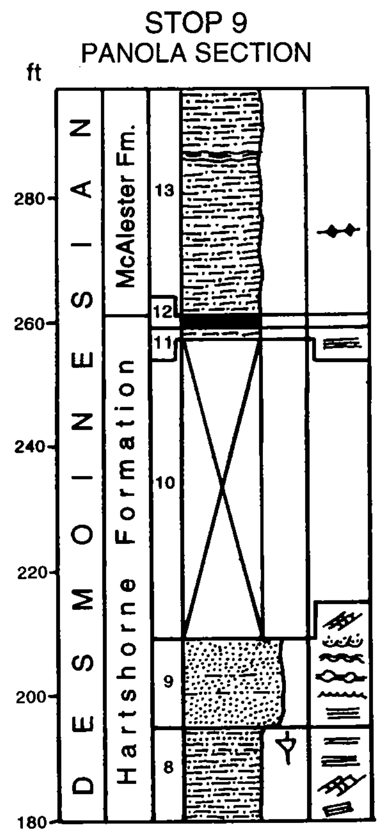
Measured Section, Stop 9

Top of Atoka Formation, Hartshorne Formation, Base of McAlester Formation

Panola Section

Location: C W½E½ sec. 8, T. 5 N., R. 20 E. (Panola 7.5′ quadrangle). Borrow pit and road cut along county road about 0.5 mi south of Panola. Latimer County, Oklahoma.

	Thickness (feet)
KREBS GROUP:	
McCurtain Shale Member, MCALESTER FORMATION:	
13. Shale, silty, dark yellowish brown (10YR4/2). Basal 2–3 ft grayish brown (5YR3/2) to dark gray (N3) with thin streaks and blebs of coal. Most of unit splintery to spheroidal weathering, uniform lithology. Rare 1-in.-thick ironstone beds. Macerated plant material rare, but a single 1-in.-long fragment observed.	36.0
HARTSHORNE FORMATION:	
12. Coal (Upper Hartshorne coal). Locally with thin, black organic shale layers. Weathers blocky to papery.	2.0



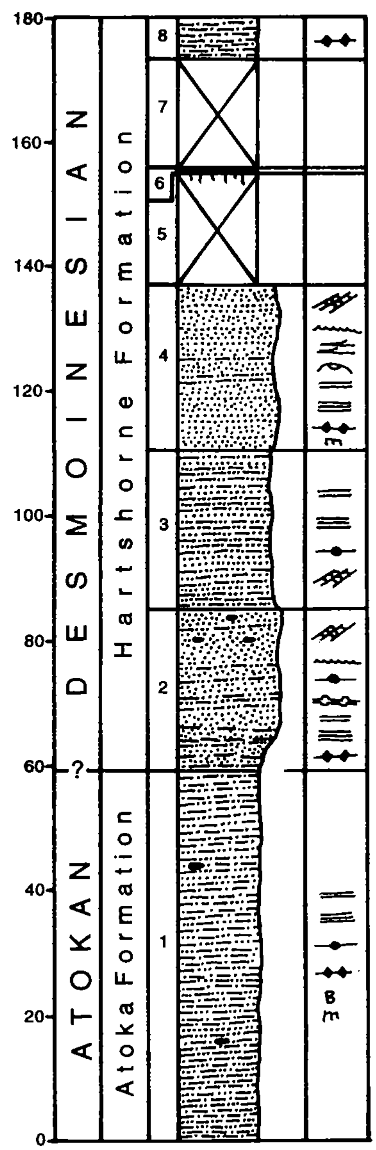


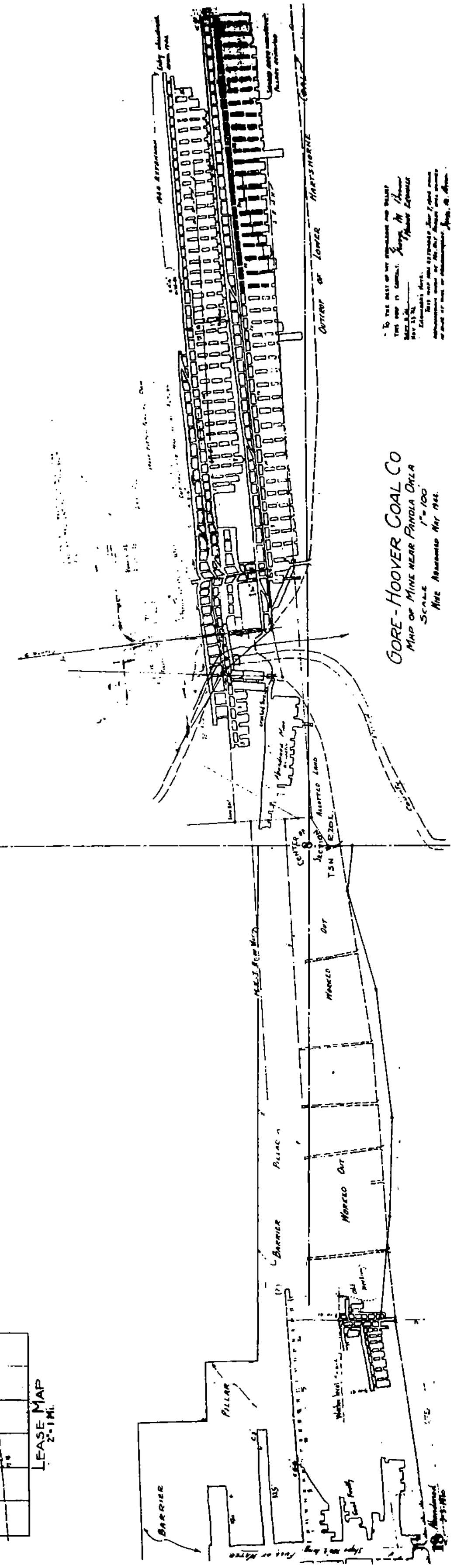
Figure 37. Graphic columnar section of Hartshorne Formation, upper part of Atoka Formation, and lower part of McCurtain Shale Member of McAlester Formation exposed at Stop 9 (Panola section). This is the only outcrop in the southern part of the Arkoma basin at which the Lower Hartshorne coal, Upper Hartshorne coal, basal contact of the Hartshorne Formation, and upper contact of the Hartshorne Formation are exposed. Explanation of symbols in Appendix 2.

11. Shale, dark gray (N3). Sooty, fissile. Contains streaks of coal. Weathers papery. 2.0
10. Covered. .... ~48.0
9. Sandstone, very fine grained, light gray (N7); and minor siltstone. Sandstone as tabular beds 3 in. to 2 ft thick, but with some large-scale thickening and thinning (Fig. 40). Locally steep, wavy-bedded. Sandstone interbedded with thin, fissile siltstone and ripple-bedded flaggy sandstone. Some moderate-scale trough cross-stratification in flaggy sandstone. Base of sandstone beds planar. Sandstone micaceous. 14.0
8. Shale, silty, light olive gray (5Y5/2) to moderate yellowish brown (10YR5/4). Plane-parallel-laminated, fissile. Uniform rock type throughout all but upper 1.5 ft of unit. Locally with carbonized plant fossils as long as 1 in. Upper part includes platy, cross-stratified, very fine grained sandstone. 22.0
7. Covered. 17.0
6. Coal (Lower Hartshorne coal), with poorly exposed underclay. .... (probably low) ~1.0
5. Covered. .... ~18.0
4. Sandstone, very fine grained, light gray (N7); and minor siltstone, moderate yellowish brown (10YR5/4). Sandstone ripple-bedded, cross-stratified, flaggy (Fig. 41). Sandstone contains rare flaser-bedded bands of organic-rich siltstone. Locally parted with thin films of shale. Ripple marks common. Unit capped by 3-ft-thick sandstone, ripple-bedded to faintly parted, with large, low-angle cross-stratification. Siltstone plane-parallel-bedded, platy to fissile. Abundant mica. 26.5
3. Siltstone, fissile, moderate yellowish brown (10YR5/4) to light olive gray (5Y5/2); and minor sandstone, very fine grained, light olive gray (5Y6/1) (Fig. 41). Siltstone plane-parallel-laminated, draped over sandstone lenses. Sandstone lenticular-bedded, cross-stratified. Poorly exposed, mostly float. 25.0
2. Sandstone, very fine grained, light gray (N7); minor siltstone, plane-parallel-stratified, moderate yellowish brown (10YR5/4); and shale. Sandstone ripple-bedded and lenticular-bedded. Abundant macerated carbonized plant material and mica on laminations. Thicker sandstone beds with plane-parallel-stratified lower part, cross-stratified upper part. Tops of beds with ripple marks. Thinner sandstone beds cross-stratified throughout. Rare shale rip-up clasts. One 2-in.-thick sandstone bed with thin, coaly lamination and locally abundant macerated organic material. Siltstone platy, fissile, interbedded with lenticular-bedded very fine grained sandstone that shows much thickening and thinning. Contact with underlying Atoka Formation arbitrary, gradational over about 2 ft. Shown as lowest sandstone lens, which thickens and thins (Fig. 42). 26.0

ATOKA FORMATION:

1. Siltstone, moderate yellowish brown (10YR5/4); shale, silty, olive gray (5Y4/1); and minor very fine grained sandstone. Siltstone and shale well parallel-laminated, fissile. Sandstone lenticular-bedded. Rare ironstone beds. Locally bioturbated. Macerated plant material on bedding planes; abundant mica. 59.5

Total thickness of section 297.0



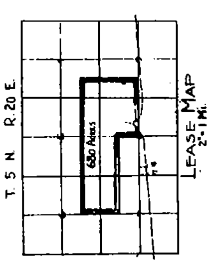


Figure 38. Map of the Gore-Hoover Coal Company mine in the Lower Hartshorne coal near Stop 9. The Panola section was measured along the county road shown in the center of the map. (Map courtesy Oklahoma Department of Mines.)

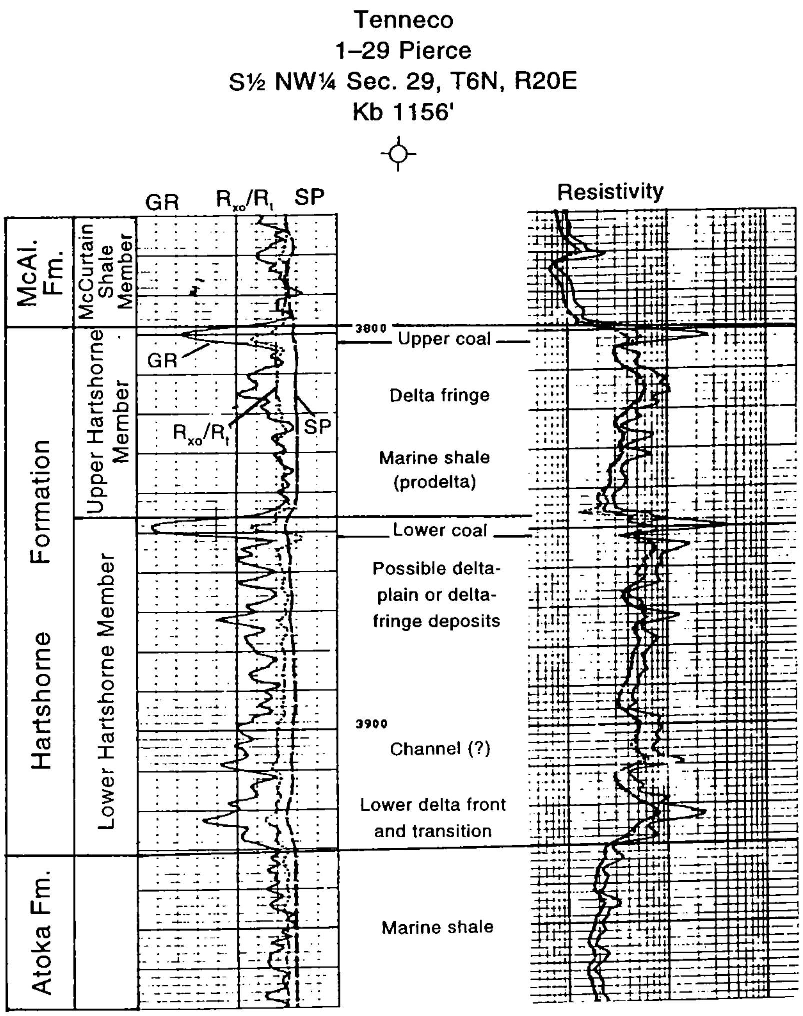


Figure 39. Part of log from the Tenneco No. 1-29 Pierce well, showing the Hartshorne Formation. The Upper Hartshorne Member on the log appears to be similar to that at the Panola section, although thicknesses vary. The Lower Hartshorne Member on the log is interpreted by R. Andrews (personal communication, 1998) to consist mostly of delta-plain and delta-front deposits, whereas the same section at Stop 9 consists only of delta-front strata. *GR* = gamma ray, R_{xo} = resistivity of flushed zone, R_t = resistivity of uninvaded zone ("true resistivity"), *SP* = spontaneous potential.

Figure 40. Unit 9, Panola section. This sandstone is probably an upper-distributary-mouth-bar or storm-reworked deposit. Geologic hammer for scale.

Figure 41. Contact between units 3 (bottom of photograph) and 4, Panola section, showing coarsening-upward character typical of a progradational distributary-mouth bar. Flaggy, ripple-bedded nature of strata is also characteristic of a distributary-mouth bar. Geologic hammer for scale.

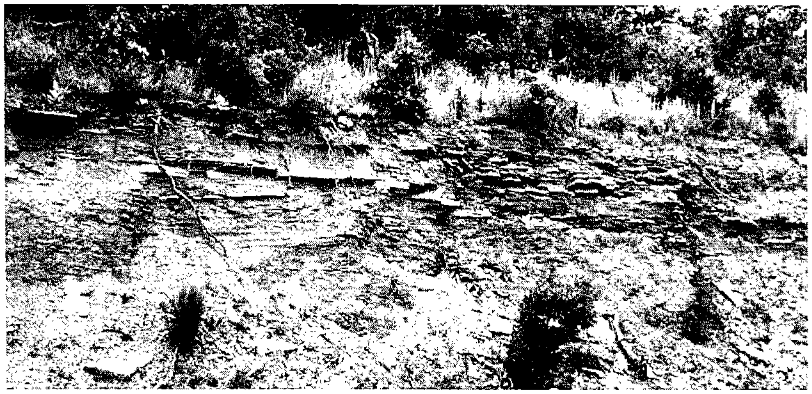


Figure 42. Atoka Formation (unit 1, lower part of photograph) and Hartshorne Formation (unit 2), Panola section, showing gradational nature of the contact. Contact is arbitrarily chosen at lowest continuous sandstone, which may not be regionally mappable.

STOP 10A

Craven Road Measured Section

Directions: From the intersection of the county road to Stop 9 and U.S. Highway 270 in Panola, drive 3.9 mi east on U.S. 270 to Craven Road. Turn right (south) on Craven Road. Drive 1.5 mi south on Craven Road; road turns left (east). Drive 0.2 mi east; road turns right (southwest) and ascends north-dipping dip slope of Hartshorne Formation. Drive 0.4 mi southwest just over top of ridge to large borrow pit on right (north).

This borrow pit (Stop 10A) and Stop 10B are on private property. For permission to visit these outcrops, please contact Larry Boggs, c/o Abbott Ranch, P.O. Box 831, Wilburton, OK 74578-0831; telephone (918) 465-3310.

Map reference: Hemish and others (1990a).

Geologic reference: Hemish and Suneson (1997, p. 62–63).

This outcrop (Fig. 43) and that at Stop 10B have been visited on several recent field trips (Suneson and Hemish, 1994, stop 8; Hemish and Suneson, 1997, stops 11A and 11B). The following description is modified from Hemish and Suneson (1997, p. 62–65).

The contact between the Atoka Formation (below) and the Hartshorne Formation (above) is well exposed at this stop. The contact appears to be gradational (Fig. 44), and its placement probably will elicit some discussion.

The criteria for placing the contact at the base of unit 4 (Fig. 43) are (1) the change from a heterolithic unit of siltstone, sandstone, and shale to a comparatively thick package of thin-bedded shaly sandstone; and (2) the presence of tabular and locally lensoid sandstone beds, locally with erosional bases, at the base of the sandstone unit. At some places along Red Oak Ridge, the sandstone clearly fills channels, and a pebble conglomerate is present at the base of the Hartshorne Formation (e.g., this guidebook, Stops 10B and 13).

A short hike through the woods to the east along Red Oak Ridge reveals a pronounced change in character of the basal part of the Hartshorne Formation (see Stop 10B). Our interpretation of this outcrop is that it is a large distributary channel in a deltaic environment and that the borrow-pit outcrop is marginal to the channel. Stops 10A and 10B are examples of the abrupt lateral facies change that typifies exposures of the Hartshorne Formation along its outcrop belt, particularly in this area and to the east. (See discussion at Stop 10B for an alternate interpretation of that outcrop.)

Based on the mapped location of the Lower Hartshorne coal (Hemish and others, 1990a), the Craven Road section is about 50 to 75 ft below the coal, which makes this section of the Hartshorne Formation unusually thin. The Hartshorne is also unusually thin in

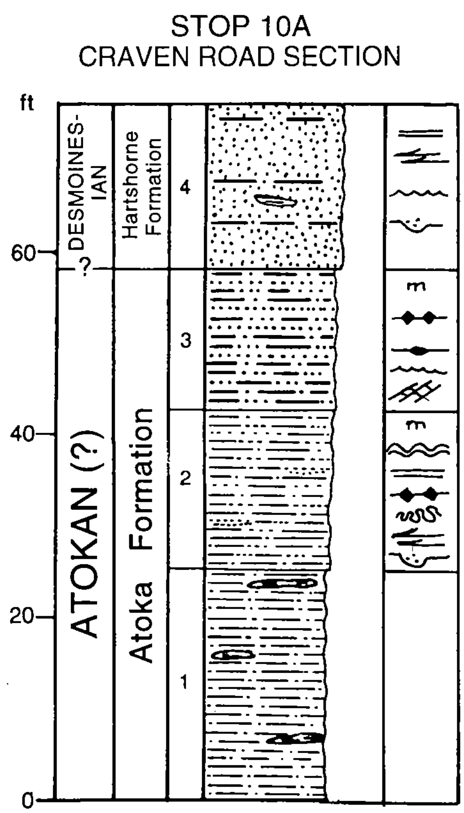


Figure 43. Graphic columnar section of lower part of Hartshorne Formation and upper part of Atoka Formation exposed at Stop 10A (Craven Road section), showing the gradational, coarsening-upward character of the contact. Explanation of symbols in Appendix 2. (From Hemish and Suneson, 1997, fig. 54.)

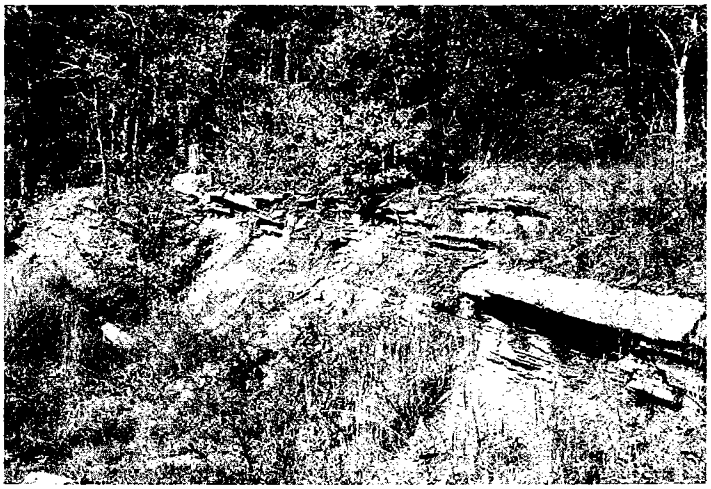


Figure 44. Outcrop of Atoka and Hartshorne Formations in borrow pit at Stop 10A, showing interbedded siltstone, sandstone, and shale overlain by parallel-bedded shaly sandstone. Prominent sandstone bed on right is about 1 ft thick and marks the base of the Hartshorne Formation. The nature of the Atoka-Hartshorne contact at Stop 10A is similar to that at Stop 9 (Fig. 42). (From Suneson and Hemish, 1994, fig. 37.)

the log of the Kaiser-Francis No. 1 Miranda well (Fig. 45), drilled about 1.3 mi to the north. A likely outcrop-to-log correlation is that the base of unit 4 (base of Hartshorne Formation in Fig. 43) is at 1,472 ft in the log. Excluding the sharp gamma-ray spikes at 1,506 and 1,513 ft, the interval 1,460–1,520 ft is a coarsening-upward sequence, similar to that observed at the surface. The depositional environment interpreted from log-character (Fig. 45) and outcrop observations is also similar and represents a progradation from a bar-transition environment to a lower-distributary-mouth bar.

As discussed at Stops 6 and 9, the placement of the Hartshorne-Atoka contact based on surface mapping differs from that based on log interpretation. The Hartshorne is mapped (e.g., Hemish and others, 1990a) on the basis of the stratigraphically lowest sandstone observed in outcrop (Figs. 43,44). In contrast, subsurface workers typically map the base of the Hartshorne as the lowest deflection in gamma-ray or resistivity logs away from a shale baseline (Fig. 45). The interval separating the highest marine shale and lowest mappable sandstone varies greatly in thickness and can lead to substantial confusion among surface mappers and log interpreters. However, this interval, which typically is mostly minor shale, siltstone, and thin, very fine grained sandstone, is depositionally closely related to the underlying shale and overlying sandstone-dominated units.

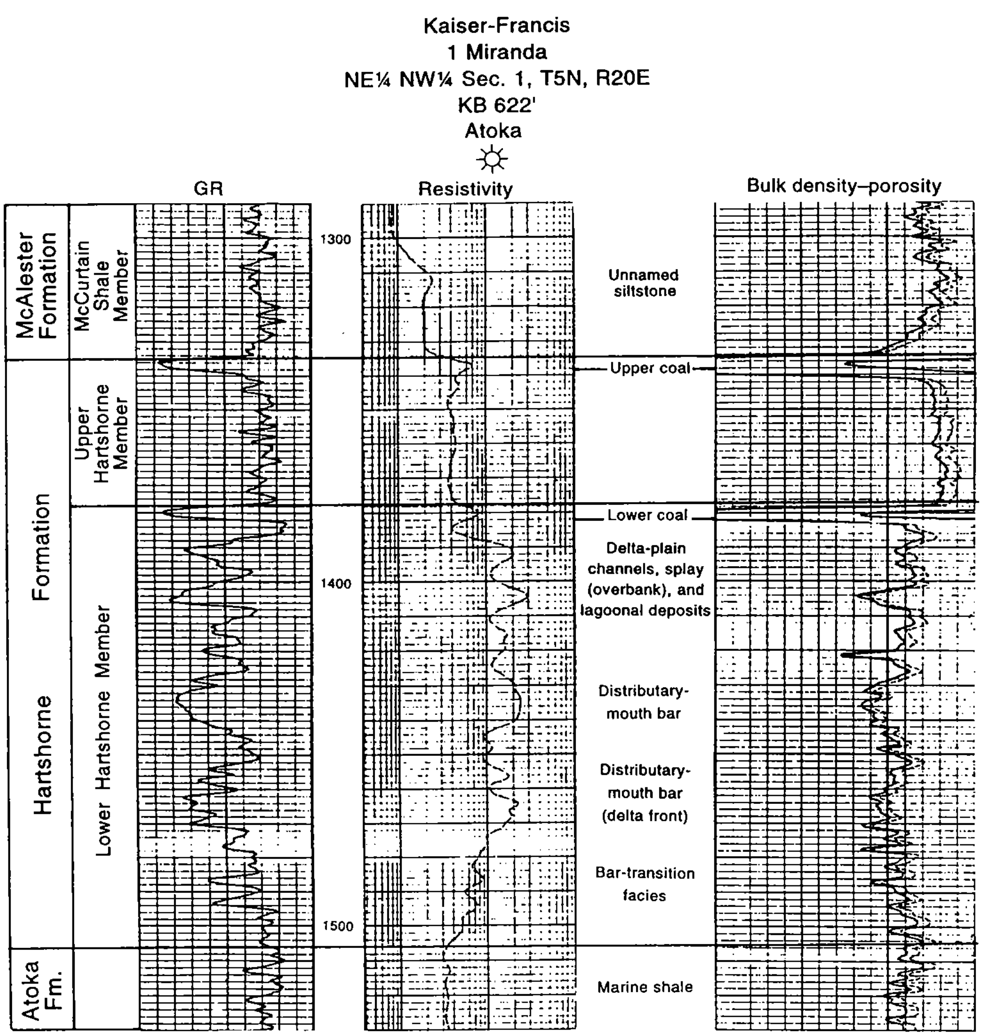


Figure 45. Part of log from the Kaiser-Francis No. 1 Miranda well, showing the Hartshorne Formation (log interpretation from R. Andrews, personal communication, 1998). The outcrop (Stop 10A) (Fig. 43) most likely correlates with the bar-transition to distributary-mouth-bar part of the log. Note that the Atoka-Hartshorne contact on the log is shown as the top of an interpreted marine shale based on the resistivity log (1,506 ft), whereas the contact based on surface outcrops would probably be chosen at the first mappable sandstone (~1,470 ft). See text for a comparison of the Atoka-Hartshorne contact based on subsurface and surface criteria. *GR* = gamma ray.

Measured Section, Stop 10A
Top of Atoka Formation, Hartshorne Formation
Craven Road Section

Location: NE¼NW¼SE¼NW¼ sec. 12, T. 5 N., R. 20 E. (Panola 7.5′ quadrangle). Borrow pit west of road on south slope of Red Oak Ridge ~0.5 mi north of Austin Lake and 4 mi east of Panola measured section (Stop 9). Latimer County, Oklahoma. Section measured by LeRoy A. Hemish. The following description is modified from Hemish and Suneson (1997, p. 63, stop 11A).

	Thickness (feet)
KREBS GROUP:	
HARTSHORNE FORMATION:	
4. Sandstone, moderate brown (5YR4/4) to light brown (5YR5/6) to grayish orange (10YR7/4), very fine grained, noncalcareous, thin- to medium-bedded, mostly parallel-bedded, blocky; contains abundant small-scale, low-angle cross-bedding; surface ripple-marked; in places contains sparse ironstone pebbles; lower bed thins laterally, in places fills small channels cut into underlying unit; shale partings common, with sandstone beds generally ~1 ft thick; basal contact conformable but locally disconformable.	18.0
ATOKA FORMATION:	
3. Siltstone, sandstone, and shale, interstratified, moderate yellowish brown (10YR5/4) to grayish orange (10YR7/4), micaceous, noncalcareous; contains abundant black comminuted plant material on stratification surfaces; mostly lenticular-bedded; very thin bedded to laminated, parallel-bedded; sandstone units cross-bedded and ripple-marked; sandstone layers more abundant in upper half of unit; entire unit is heterolithic; base gradational.	15.5
2. Siltstone, brownish gray (5YR4/1) to grayish red (10R 4/2), interlaminated with light gray (N7), very fine grained sandstone and dark gray (N3) shale; very thin bedded, wavy- and parallel-bedded; micaceous; black comminuted plant material common; horizontal trace fossils abundant on bedding planes; low-angle cross-laminations common; includes scattered grayish orange (10YR7/4), very fine grained sandstone lenses about 6–12 in. thick and 6–10 ft wide that fill channels cut into underlying heterolithic units; basal contact gradational.	17.6
1. Shale, olive gray (5Y4/1) to dark gray (N3), with moderate brown (5YR3/4) to dark yellowish orange (10YR6/6) iron-stained layers; includes minor siltstone and sandstone laminae as well as clay ironstone stringers; base covered.	25.0
Total thickness of section	76.1

STOP 10B

Red Oak Ridge Measured Section

Directions: From Stop 10A, walk east along top of ridge about 600 ft to vertical sandstone bluff.

This outcrop is on private property. See Stop 10A for information about obtaining permission to visit.

Map reference: Hemish and others (1990a).

Geologic reference: Hemish and Suneson (1997, p. 63–65); Suneson and Hemish (1994, p. 56–57).

This outcrop (Fig. 46) was visited in 1997 as part of the same American Association of Petroleum Geologists field trip described for Stop 10A. At that time,

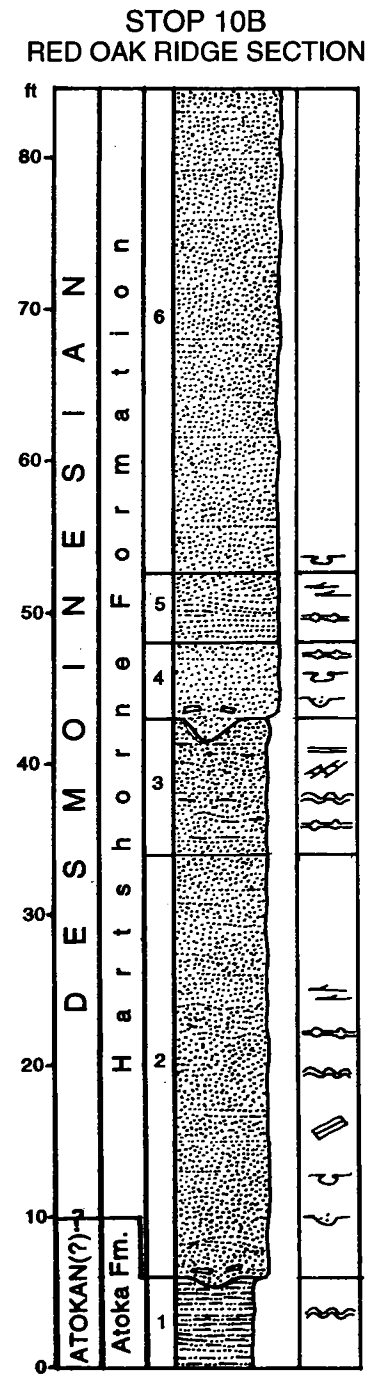


Figure 46. Graphic columnar section of the uppermost part of the Atoka Formation and the lower part of the Hartshorne Formation exposed at Stop 10B (Red Oak Ridge section). The thick sandstone exposed through most of the section was deposited in an incised fluvial channel. Note that the contact between the Hartshorne and Atoka Formations is abrupt and disconformable. Explanation of symbols in Appendix 2. (From Hemish and Suneson, 1997, fig. 55.)

Hemish and Suneson (1997, p. 63) believed that the massive sandstone exposed at the cliff was a thick distributary channel. As a result of work by Andrews (1998) and discussion with other geologists, I now believe that the massive sandstone fills an incised fluvial channel. The following description of this outcrop from Hemish and Suneson (1997, p. 63) has been modified to reflect this new interpretation.

The top of this outcrop was first visited as part of an OGS-sponsored field trip in 1994. At that time, the section had not been measured, and participants did not descend the cliff. In 1997, the outcrop was revisited as part of another field trip, and some participants elected to descend to the base of the cliff. There is a nearby route to the base of the cliff, and participants on this trip who are confident of their climbing abilities are encouraged to follow the field-trip leaders down "to their deaths" [phrase in quotes added by reviewer].

The Red Oak Ridge section is a superb example of an incised fluvial-channel deposit in the Lower Member

Figure 47. View looking northeast at the cliff-forming incised fluvial-channel sandstone in the lower part of the Hartshorne Formation at Stop 10B. Throughout this part of the southern Arkoma basin, thick, typically channel-fill sandstones in the Hartshorne Formation are expressed as cliffs and steep slopes on ridges. Farther east, channel-fill sandstones form isolated hills in an otherwise topographically unexpressed Hartshorne Formation. (From Hemish and Suneson, 1997, fig. 56.)

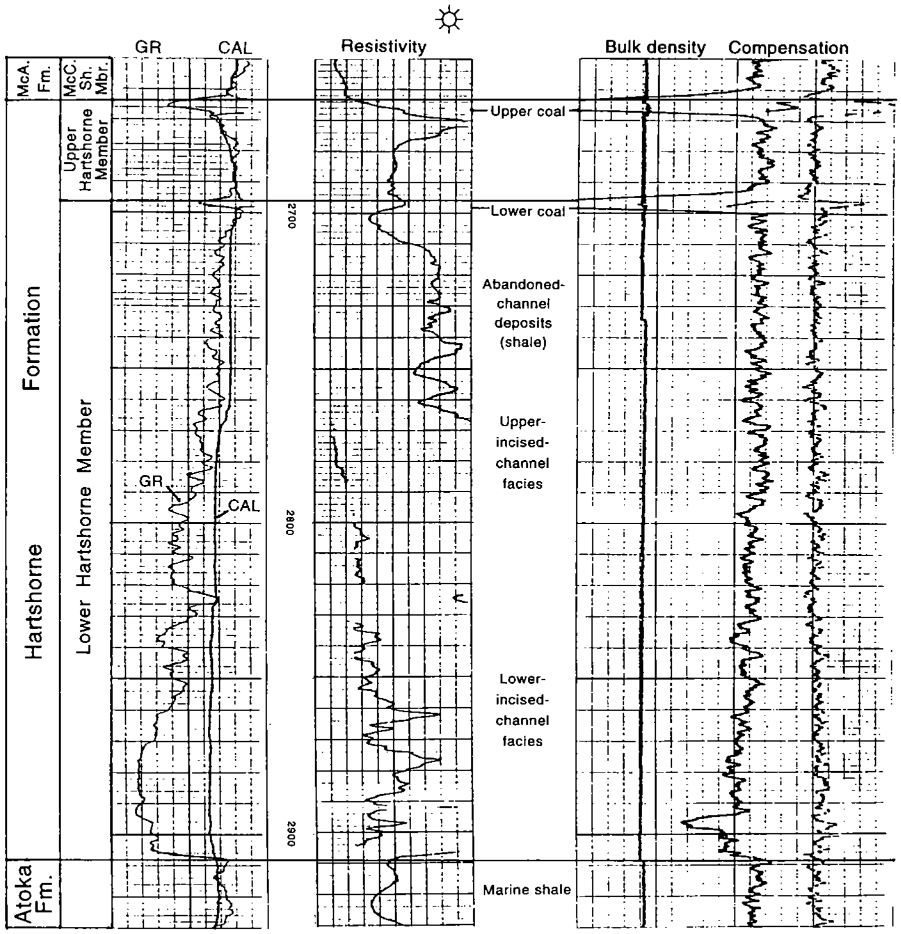


Figure 48. Part of log from the TXO No. 1 Gallagher well. The thick sandstone at the base of the Hartshorne Formation fills an incised valley. The log is representative of the outcrop relations at Stop 10B (Red Oak Ridge Section) (Fig. 46). Log interpetation by R. Andrews (personal communication, 1998). *GR* = gamma ray, *CAL* = caliper.

of the Hartshorne Formation (Fig. 46). In detail, the deposit consists of a number of stacked channels, and sedimentary features within the different sandstones are highly discontinuous. Perhaps the most characteristic feature of the channel deposit is the scarcity of sedimentary features except at the bases of individual sandstones. In addition, the amalgamated character of the channel deposits results in a "false" base (base of unit 4) of the Hartshorne Formation.

The orientation of the channel, in all likelihood, is oblique to the cliff face, which is approximately east-west at this locality. Based on well-log data north of Red Oak Ridge, the channel trends east-northeast (Andrews, 1998, pl. 1). We have identified several channel deposits along Red Oak Ridge; in many cases—where a ridge locally becomes higher and/or steeper (Fig. 47) (both of which occur at Stop 10B)—these channels can be readily identified on topographic maps. An example is Buzzards Roost (Rolling Stop 12, this guidebook).

Figure 48 is part of the log from the TXO No. 1 Gallagher well, drilled about 5.5 mi northeast of Stop 10B. The log is an excellent representation of what the channel sandstone at Stop 10B would look like in the subsurface, despite the fact that the channel in outcrop is at least 70 ft thick, whereas the lower channel sandstone in the well is about 50 ft thick. In both cases (outcrop and log), the thick channel sandstone of the Hartshorne Formation overlies the Atoka Formation.

Figure 49. Large-scale trough cross-stratification in fluvial-channel sandstone, lower part of Hartshorne Formation (unit 5) at Stop 10B. Geologic hammer for scale. (From Hemish and Suneson, 1997, fig. 57.)

Figure 50. Base of Hartshorne Formation (unit 2) at Stop 10B. Geologic hammer rests on sandstone with abundant shale rip-up clasts. The top of the Atoka Formation is directly below this sandstone. Note the blocky-weathering, mostly featureless character of the sandstone. (From Hemish and Suneson, 1997, fig. 58.)

Measured Section, Stop 10B
Top of Atoka Formation and Hartshorne Formation
Red Oak Ridge Section

Location: SW¼NE¼ sec. 12, T. 5 N., R. 20 E. (Panola 7.5′ quadrangle). Latimer County, Oklahoma. Top of unit 6 is at top of vertical cliff ~400 ft S. 35° E. of water tower. Units 3 and 4 measured at base of cliff directly below top of unit 6. Unit 1 measured ~200 ft east of units 3 and 4. Unit 2 measured between unit 1 and units 3 and 4. Unit 5 measured partway up access route down cliff just east of units 3 and 4.

	Thickness (feet)
KREBS GROUP:	
HARTSHORNE FORMATION:	
6. Sandstone. Fine-grained, well-sorted, dark yellowish orange (10YR6/6). Massive, mostly unstratified, locally well-parted. Small load casts at base.	32.0
5. Sandstone. Fine-grained, well-sorted, very pale orange (10YR8/2). Slabby to flaggy with common large-scale trough cross-stratification (Fig. 49), pinch-and-swell structure. Appears to grade into massive sandstone similar to units 4 and 6.	0–4.5
4. Sandstone. Fine-grained. Massive, mostly unstratified, locally has widely spaced anastomosing partings, possibly representing pinch-and-swell structure. Locally contains shale rip-up clasts in zones parallel to bedding planes. Base eroded 2 ft into unit 3, locally marked by small load casts.	3.0–7.0
3. Sandstone. Fine-grained, silty, pale yellowish brown (10YR6/2) to grayish orange (10YR7/4). Mostly parallel-stratified, locally cross-stratified to gently wavy bedded. Minor pinch-and-swell structure. Appears to grade into top of unit 2.	9.0
2. Sandstone. Fine-grained, moderate yellowish brown (10YR5/4). Massive, mostly unstratified, faintly parallel-stratified (Fig. 50). Basal 3 ft locally wavy-bedded with minor pinch-and-swell structure and large-scale cross-stratification. Base locally eroded 6 in. into underlying siltstone and marked by small load casts. Base locally contains eroded shale rip-up clasts as large as 1 ft and plant compressions commonly 2 ft long, one as long as 8 ft.	28.0
ATOKA FORMATION:	
1. Siltstone and sandstone. Sandstone very fine grained. Slightly wavy-bedded. Poorly exposed.	6.0
Total thickness of section	78.0–86.5

STOP 11

Highway 82 Measured Section

Directions: From intersection of U.S. Highway 270 and State Highway 82 just east of Red Oak, Oklahoma, drive 1.6 mi south on Highway 82. Road turns right (southwest) and ascends north-dipping dip slope of Hartshorne Formation. Drive 0.3 mi to top of ridge and park. Measured section is directly south of top of ridge.

Map reference: Hemish and others (1990b).

Geologic reference: Suneson and Hemish (1994, p. 59–60).

Stop 11 is about 4 mi east of Stops 10A and 10B and is generally similar in many respects to Stop 10A. The Highway 82 section (Fig. 51) is in the upper part of the Atoka Formation and the lower part of the Hartshorne and consists of two upward-coarsening sequences (units 1 to 5 and units 6 to 7) representing the progradation of two distributary complexes into the Arkoma basin. The lower sequence consists of prodelta shale (unit 1), overlain by bar-transition sediments (unit 2), lower-distributary-mouth-bar sediments (unit 4), followed by upper-distributary-mouth-bar sandstone (unit 5). Unit 3 is likely a storm deposit. The upper sequence was deposited as a distributary-mouth bar; unit 6 is the lower part, and unit 7 the upper part.

To a large extent, the Highway 82 section is well illustrated on the log of the Kaiser-Francis No. 1 Miranda (Fig. 45), which shows two coarsening-upward distributary-mouth-bar sequences overlying the Atoka Formation. Like several previous stops, the Hartshorne-Atoka contact is gradational and represents sedimentation in closely related depositional environments.

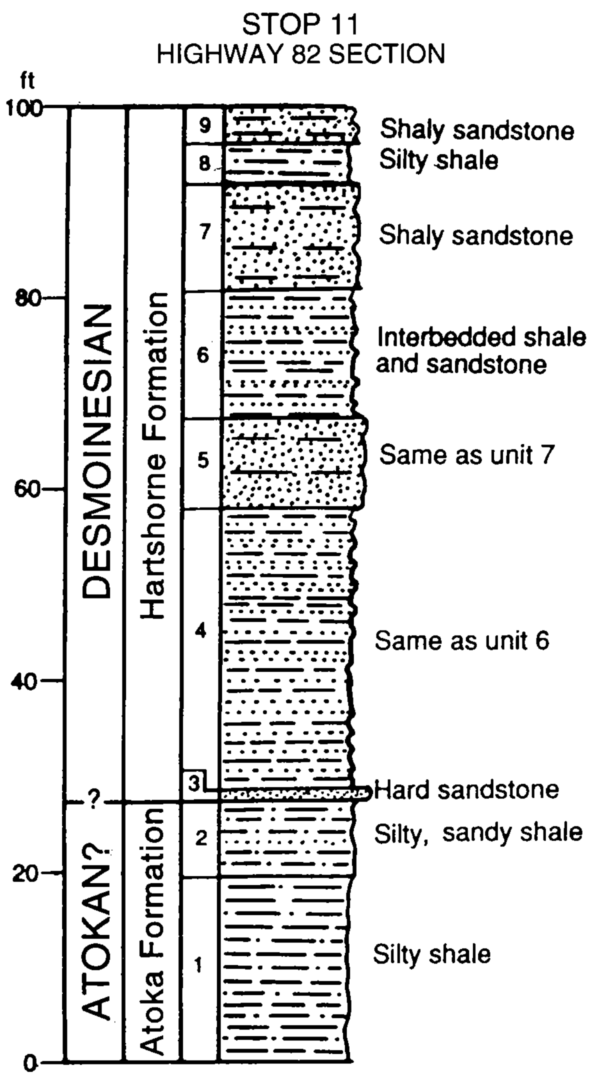


Figure 51. Graphic columnar section of the upper part of the Atoka Formation and the lower part of the Hartshorne Formation exposed at Stop 11 (Highway 82 section). (From Suneson and Hemish, 1994, fig. 43.)

Measured Section, Stop 11

**Top of Atoka Formation and Hartshorne Formation
Highway 82 Section**

Location: SE¼NW¼NW¼ sec. 10, T. 5 N., R. 21 E. (Red Oak 7.5′ quadrangle). Road cut along State Highway 82 on south flank of Red Oak Ridge, about 1.5 mi south of Red Oak. Latimer County, Oklahoma. Section measured by LeRoy A. Hemish. The following description is modified from Suneson and Hemish (1994, p. 59).

	Thickness (feet)
KREBS GROUP:	
HARTSHORNE FORMATION:	
9. Sandstone, moderate reddish orange (10R6/6) to grayish orange (10YR7/4), very fine grained, noncalcareous, well-indurated, burrowed, thin- to medium-bedded; shaly, with low-angle cross-laminations in lower 8 in.	4.0
8. Shale, medium light gray (N6) with moderate red (5R 4/6) mottling, silty, noncalcareous, weathers light brown.	4.2
7. Sandstone, light gray (N7), weathers moderate reddish orange (10R6/6) to dark reddish brown (10R 3/4), very fine grained, noncalcareous; irregularly thin- to medium-bedded, cross-bedded and rippled in part; includes some thin shaly layers; trace fossils abundant on soles of some beds; contains scattered pebbles of clay-ironstone and clay galls in places; fossil-plant material common; contact with underlying unit sharp.	11.5
6. Shale and sandstone, interbedded, very pale orange (10YR8/2) to grayish orange (10YR7/4), wavy-bedded and thin-bedded, noncalcareous, micaceous; contains abundant trace fossils; locally includes lenses of very fine grained, cross-laminated sandstone as thick as 10 in.	13.0
5. Sandstone (same description as unit 7).	9.3
4. Shale and sandstone, interbedded, poorly exposed (same description as unit 6).	30.0
3. Sandstone, light olive gray (5Y5/2), very fine grained, noncalcareous, very hard, contains low-angle, small-scale cross-stratification; contact with underlying unit sharp.	0.7

ATOKA FORMATION:

2. Shale, medium gray (N5) to pale yellowish brown (10YR6/2), silty and sandy, noncalcareous, bioturbated, includes abundant dusky brown (5YR2/2) staining on stratification surfaces; rippled in places; finer grained downward; grades into underlying unit.	8.0
1. Shale, medium dark gray (N4) with dark reddish brown (10R3/4) staining, silty, micaceous in places, noncalcareous; includes some sandstone-filled burrows and black (N1) plant fragments.	19.3
Total thickness of section	100.0

ROLLING STOP 12

Buzzards Roost

Directions: From intersection of U.S. Highways 270 and 271 between Fanshawe and Wister, Oklahoma, drive 2.1 mi southwest on Highway 271. Turn left (east) just before crossing causeway over Wister Lake. Drive 3.6 mi east. Road enters abruptly from right (south). Turn right (south). Drive 0.8 mi and enter Wister Lake State Park. Continue driving east another 0.9 mi to bridge over small arm of Wister Lake and park.

Location: Sec. 34, T. 6 N., R. 24 E. (Summerfield 7.5′ quadrangle). Cliff face north of west road into Wister Lake State Park, about 5 mi east of junction of park road with U.S. Highway 271. Le Flore County, Oklahoma.

Map reference: Hemish and Mazengarb (1992).

Photo and discussion stop only. Section not measured.

Figure 52. View of Buzzards Roost, showing typical outcrop of thick channel-fill sandstones. Note numerous buzzards (turkey vultures) circling above cliffs.

The Hartshorne Formation crops out almost continuously along the southern edge of the Arkoma basin in Latimer and Le Flore Counties. However, its topographic expression varies from barely perceptible, low ridges to vertical cliffs many tens of feet high. Most high, steep ridges and cliffs similar to that at Buzzards Roost mark where the Hartshorne is mostly sandstone; in general, the depositional environment of the Hartshorne in these areas is either an incised fluvial channel (here) or a distributary channel. Stop 10B (Red Oak Ridge) is also an example of an incised fluvial channel in the Hartshorne Formation that forms a vertical cliff (Fig. 52). (This outcrop and that at Red Oak Ridge are parts of the same channel complex that trends east-northeast to northeast into Arkansas; Andrews, 1998, pl. 1.) Directly west of Stop 17 (Green Country Stone Quarry), the Hartshorne Formation is not expressed topographically; but at the quarry (interpreted as a distributary channel), the Hartshorne forms a well-defined ridge. At several other localities in the southern part of the basin, channel facies in the Hartshorne are expressed topographically.

STOP 13

Wister Ridge Picnic Area Measured Section

Directions: From Rolling Stop 12, continue east on main park road for 2.0 mi. Just before road makes a sharp bend to left (north) over relatively low-lying Hartshorne ridge, turn right (east) into picnic area (Picnic Area 2) and drive about 0.2 mi to end of loop. Park and walk to end of point jutting into Wister Lake.

Map reference: Hemish and Suneson (1993).

Geologic reference: Hemish (1993, p. 19).

Hemish (1993) described the outcrop at Stop 13 and interpreted the prominent sandstone that forms the ridge to be the base of the Hartshorne Formation. Most of the section consists of silty shale, siltstone, and very silty sandstone (Fig. 53) and probably represents relatively distal marine sediments. Hemish (1993) suggested that the prominent sandstone at the base of the formation (Fig. 54) was a distributary-channel deposit and, indeed, many of the sedimentary structures in the unit (Fig. 55) are similar to those seen in channels. An alternative explanation is that the sandstone represents a storm event and is possibly a partly reworked slump deposit. This interpretation is consistent with the presence of the sandstone in mostly finer-grained strata.

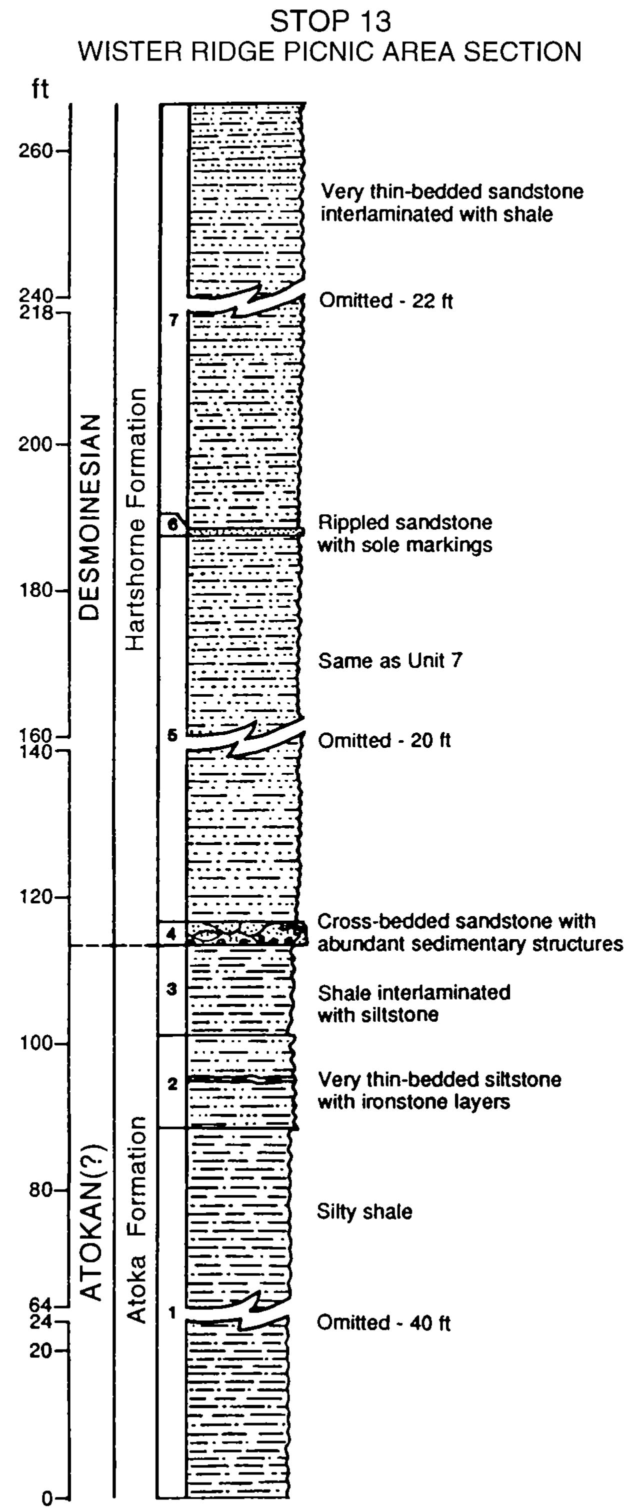


Figure 53. Graphic columnar section of the upper part of the Atoka Formation and the lower part of the Hartshorne Formation exposed at Stop 13 (Wister Ridge Picnic Area section). Note the overall gradual coarsening-upward sequence interrupted by the storm and/or slump deposit of sandstone (unit 4). (From Hemish, 1993, fig. 25.)

Figure 54. Bar-transition or prodelta deposits of Atoka Formation (unit 3), overlain by storm or slump sandstone bed (unit 4) at base of Hartshorne Formation at Stop 13. (From Hemish, 1993, fig. 26.)

Figure 55. Block of Hartshorne sandstone shown at upper right in Figure 54, Stop 13. Sandstone is mostly massive with obscure, thick, trough cross-bedding. Note shale rip-up clasts marking erosional contact. Geologic hammer for scale. (From Hemish, 1993, fig. 27.)

Measured Section, Stop 13

Hartshorne Formation, Top of Atoka Formation
Wister Ridge Picnic Area Section

Location: *NW¼SW¼SW¼ sec. 36, T. 6 N., R. 24 E. (Wister 7.5′ quadrangle). Measured on east point of Wister Ridge, just east of picnic area, starting about 250 ft north of resistant ridge of sandstone, and ending south of ridge at an east-west line extending through large boulder exposed offshore in Wister Lake. Le Flore County, Oklahoma. Section measured by LeRoy A. Hemish. The following description is modified from Hemish (1993, p. 19).*

Thickness (feet)

KREBS GROUP:

HARTSHORNE FORMATION:

7. Sandstone interlaminated with shale, light olive gray (5Y5/2) to pale yellowish brown (10YR6/2), weathers light brown (5Y5/6) to moderate brown (5YR3/4); sandstone is very fine grained, very silty, very

thin bedded, wavy- to parallel-bedded, noncalcareous, micaceous, weakly bioturbated, fissile, iron oxide stained; contact gradational. 77.6

6. Sandstone, light olive gray (5Y5/2) to pale yellowish brown (10YR6/2), weathers light brown (5YR5/6) to moderate brown 5YR4/4), very fine grained, noncalcareous, micaceous, thin- to medium-bedded; wavy-, parallel-bedded; trace fossils on surfaces and soles of beds; includes large, bulbous load casts in places; surface marked by interference ripples; forms thin, resistant rib on slope; base sharp. 1.2
5. Sandstone interlaminated with shale (same description as unit 7). 70.6
4. Sandstone, light gray (N7) to very pale orange (10YR 8/2), weathers light brown (5YR5/6) to moderate brown (5YR4/4); very fine to fine-grained, but includes a ferruginous pebble-lag conglomerate of variable thickness (generally about 1 ft thick) at base; thick-bedded; curved, nonparallel-bedded; trough cross-bedded to massive in places (Fig. 55); contains soft-sediment-deformation features such as flow rolls and load casts; includes abundant fossil-plant impressions in places, some surrounded by coalified zones; trace fossils common, especially on bedding surfaces; surface ripple-marked in some places and honeycombed by weathered-out pebbles in others; base sharp and disconformable; thickness of unit variable—increases westward to >20 ft about 160 ft northeast from picnic shelter house. Measurements on asymmetric ripples indicate that depositing currents flowed S. 20° W. 3.2

ATOKA FORMATION:

3. Shale, medium gray (N5), weathers moderate yellowish brown (10YR5/4) to moderate brown (5YR4/4) and dusky yellowish brown (10YR2/2), interlaminated with siltstone, fissile, wavy-bedded, weakly bioturbated, base gradational. 12.3
2. Siltstone, light olive gray (5Y5/2), weathers moderate brown (5YR3/4), shaly, laminated to very thin bedded; slightly wavy- to parallel-bedded; includes some thin lenses of very fine sandstone; micaceous; contains some black (N1) comminuted plant fragments on bedding planes; includes some resistant, 1-in.-thick ironstone layers; more resistant than underlying unit; contact gradational. 13.0
1. Shale, olive gray (5Y4/1) to medium dark gray (N4), weathers light brown (5YR5/6) to moderate brown (5YR4/4, 5YR3/4), silty, noncalcareous, fissile, exhibits concretionary structure, iron oxide stained; base of unit not exposed. 88.2

Total thickness of section 266.1

STOP 14

Quarry Isle Measured Section

Directions: From the entrance to the picnic area at Stop 13, continue on the main park road west 0.6 mi down the Hartshorne dip slope. The road turns back to the east. Continue east on main park road 2.2 mi to the intersection with U.S. Highway 270. Turn right (west) on Highway 270. Drive 0.3 mi; road turns left (south) and begins to cross Wister Dam. Drive 0.3 mi, turn right (west) onto Quarry Isle, which is an "island" underlain by the Hartshorne Formation. Drive west past store and cabins to end of "island," about 0.6 mi. Measured section is along shore of Wister Lake on west end of Quarry Isle.

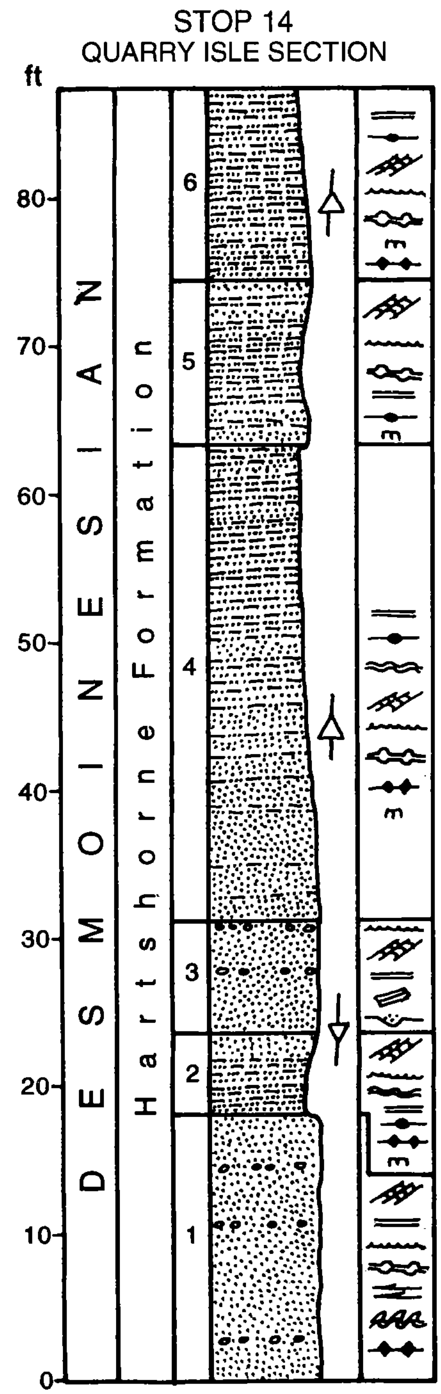


Figure 56. Graphic columnar section of part of Hartshorne Formation exposed at Stop 14 (Quarry Isle section). The sedimentary structures and rock types throughout most of the section are typical of distributary-mouth-bar deposits. Explanation of symbols in Appendix 2.

Alternate directions: From intersection of U.S. Highways 271 and 270 in Wister, Oklahoma, drive south on Highway 270 through Wister toward town of Heavener. Drive 0.9 mi; cross Caston Creek. Continue on Highway 270 for 1.3 mi; road turns to right (north, then west). Drive 0.2 mi and intersect park road to right (referred to in directions above). Drive 0.3 mi; road turns left (south) and begins to cross Wister Dam. Drive 0.3 mi; turn right (west) onto Quarry Isle and follow directions given above.

Map reference: Hemish and Suneson (1993).

The Quarry Isle section (Fig. 56) overlies the Hartshorne section previously described at Wister Ridge Picnic Area (Stop 13), but by how much is impossible to determine because the two are separated by an arm of Wister Lake. It is also impossible to determine how far below the Lower Hartshorne coal the Quarry Isle section lies, because the coal is poorly exposed in this area.

Based only on topographic expression, the Quarry Isle section is in an area of distinct change in the Hartshorne Formation. To the west, the Hartshorne generally forms a continuous ridge, albeit steeper at some places than at others. The steep slopes and local vertical cliffs of the Hartshorne ridge typically mark thick sandstones that fill incised fluvial channels. East of Quarry Isle, the topographic expression of the Hartshorne consists of isolated hills separated by low ridges or nearly flat areas. Most likely, the hills are underlain by relatively thick, resistant sandstones that fill distributary channels in the Hartshorne (discussed at Stop 17). There is little evidence that the thick, incised-valley-fill sandstones similar to those at Stops 10B and 12 are present east of Quarry Isle. This is supported by Andrews' (1998, pl. 1) analysis of subsurface data east of this stop.

Figure 57. Unit 5, Quarry Isle section. Most of unit 5 is well stratified, relatively fine grained, and partly covered (as here). These strata are typical of lower-distributary-mouth-bar deposits. The three prominent sandstones may represent distal storm deposits from which the fine fraction has been removed. Stratigraphic top is toward right. Geologic hammer for scale.

Unlike most of the measured sections of the Hartshorne Formation to the west, the Quarry Isle section consists of at least two fining-upward sequences and two relatively thick sandstones characterized by large-scale high-angle cross-stratification (Fig. 56). In many respects, however, the strata at Stop 14 are similar to those in sections to the west and consist of well-stratified, rippled, very fine grained sandstone and siltstone. Sandstone units 1 and 3 are of particular interest, because they show evidence for rapid deposition by relatively strong currents. Whereas most of the section (units 4, 5, and 6) was deposited in a lower-distributary-mouth-bar environment, units 1 and 3 appear to be upper-distributary-mouth-bar deposits that were reworked by shallow-water processes, possibly storm waves. Unit 2 may represent a thin lower-, overlain by an upper-, distributary-mouth-bar deposit.

Measured Section, Stop 14
Hartshorne Formation
Quarry Isle Section

Location: NE¼SE¼SW¼ sec. 36, T. 6 N., R. 24 E. (Wister 7.5′ quadrangle). West point of Quarry Isle along shore of Wister Lake, Wister Lake State Park, about 0.25 mi east of Wister Ridge Picnic Area measured section (Stop 13). Le Flore County, Oklahoma.

Thickness (feet)

KREBS GROUP:

HARTSHORNE FORMATION:

6. Siltstone, dark yellowish brown (10YR4/2); and minor sandstone, very fine grained, pale yellowish brown (10YR6/2). Siltstone plane-parallel-laminated, interbedded with very thin wisps and lenses of lenticular-bedded sandstone. Sandstone ripple- and cross-bedded, also plane-parallel-laminated. Minor thickening and thinning of some beds. Ripple marks common. Mica conspicuous, macerated plant debris uncommon on bedding planes. 13.0
5. Siltstone and sandstone, very fine grained, light gray (N7). Similar to unit 6 but with several sandstone beds as thick as 10 in. (Fig. 57). Some sandstone beds thicken and thin; others are of constant thickness. Cross-stratified. Trace amount of macerated organic debris on bedding planes. 11.0
4. Siltstone, dark yellowish brown (10YR4/2); and sandstone, very fine grained, medium light gray (N6) to light gray (N7). Siltstone mostly plane-parallel-laminated, also wavy-bedded and/or cross-stratified on a very small scale with very thin lenticular-bedded sandstone (Fig. 58). Mica and carbonized macerated plant debris conspicuous on bedding planes. Ripple-bedded sandstone less common, typically with ripple marks on tops of beds. Sandstone beds continuous but show minor thickening and thinning. 32.5
3. Sandstone, very fine grained, light brownish gray (5YR6/1). Locally with large-scale high-angle cross-stratification, some slightly convex upward; other beds show tabular cross-stratification (Fig. 59). Some beds plane-parallel-laminated. One high-angle cross-stratified bed eroded into underlying plane-parallel-bedded sandstone. Ripple bedding common. Ripple marks common; bases

of sandstone beds flat or undulatory, reflecting underlying ripples. One bed with trough cross-bedding shows paleocurrent direction toward S. 30° W. Locally contains shale rip-up clasts concentrated parallel to cross-stratification. Large plant impressions on top of highest sandstone bed. Weathers flaggy and slabby to blocky.................. 7.5

2. Sandstone, very fine grained, light gray (N7); and siltstone. Base mostly wavy- and plane-parallel-bedded siltstone and sandstone, and lenticular-bedded sandstone. Top mostly flaggy, ripple-bedded sandstone with very thin draped siltstone partings. Parting lineations on one bed trend east-west. Mica and macerated organic debris common on bedding planes. 5.5
1. Sandstone, fine-grained, light gray (N7). Plane-parallel-stratified and high- and low-angle cross-stratified. Several beds with abundant shale rip-up clasts at base, parallel to cross-beds. Cross-stratification convex upward and tabular. Thick, slabby-weathering beds interbedded with flaggy, ripple-bedded sandstone. Some thickening and thinning of beds give appearance of large megaripples. Tops of beds typically rippled. Rare soft-sediment-deformation features. 18.0

Total thickness of section 87.5

Figure 58. Unit 4, Quarry Isle section, showing parallel- and cross-stratified siltstone and lenticular-bedded sandstone typical of lower-distributary-mouth-bar deposits. Stratigraphic top is toward top of photograph. Geologic hammer for scale.

STOP 15

Heavener Road Cut Measured Section

Directions: From the intersection of U.S. Highways 59 and 270 just north of Heavener, Oklahoma, drive 2.7 mi south on U.S. Highway 59/270 to large road cut on both sides of road. Measured section is on west side.

Map reference: Mazengarb and Hemish (1993).

Geologic reference: Donica (1978, p. 125–128); Suneson and Hemish (1994, p. 100–102).

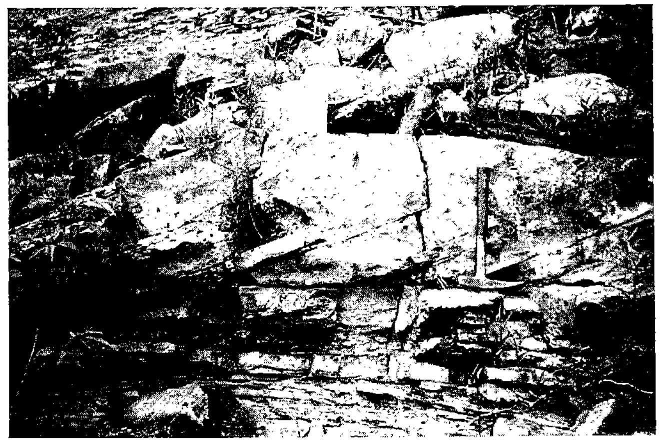


Figure 59. Large-scale tabular cross-stratification in unit 3, Quarry Isle section, indicating deposition under high-energy conditions. The association of such deposits with distributary-mouth-bar sediments suggests that this is a storm deposit. Stratigraphic top is toward top of photograph. Geologic hammer for scale.

This outcrop of the Hartshorne Formation (Fig. 60) probably has been visited by more geologists than all the other Hartshorne outcrops in the State combined. Although truly spectacular and an excellent example of delta-plain sediments (Fig. 61), it is atypical of most exposed Hartshorne strata in the southern part of the Arkoma basin. As discussed at previous stops, most of the Hartshorne consists of delta-front sandstone, siltstone, and shale. This outcrop, perhaps more than any other in Oklahoma, probably has caused geologists to think of the Hartshorne Formation in terms of a delta model.

The following description of this outcrop is modified slightly from Suneson and Hemish (1994, p. 100–102), which, in turn, was based on a detailed study of the outcrop by Donica (1978).

The Atoka and Hartshorne Formations at the Heavener road cut were described in detail by Donica (1978). He placed the contact between the two formations at the base of the lowest sandstone (Fig. 60). This sandstone is 10–40 ft above two thin (0.5-ft-thick) coal beds. Hendricks' (1939, p. 267) measured section of the Hartshorne Formation at Petry's Cut along the railroad 0.9 mi to the east showed the Atoka-Hartshorne contact at the base of a 1.5-ft-thick sandstone that is directly below the lower of the two thin coals at Petry's Cut. Donica (1978, p. 16) suggested that the sandstone used by Hendricks (1939) to mark the base of the Hartshorne is discontinuous and is not the more extensive Hartshorne sandstone that typically is used to mark the base of the Hartshorne. An equally likely explanation is that Hendricks (1939, p. 264) believed that the Atoka Formation did not contain any coal beds; therefore, he placed the two thin coals in the Hartshorne Formation. Briggs and others (1975, p. 93) briefly described the strata at the Heavener road cut and apparently included the entire exposed sequence in the Hartshorne Formation.

The strata exposed in the Heavener road cut (Fig. 61) were deposited in interdistributary marshes and swamps in a delta-plain environment (Donica, 1978; Briggs and others, 1975). Coal beds represent periods of peat accumulation with little or no sediment influx; shale intervals represent periods of slightly greater clastic sedimentation; and the sandstones are overbank and/or crevasse-splay deposits that probably represent periods of flooding. Unlike the Hartshorne exposure at Stop 10B, the Heavener road cut exposes no fluvial-channel deposits. The "alluvial channel" in the lower Hartshorne Formation shown by McDaniel (1961, fig. 8) may refer to the "channel sandstone" pictured by Hendricks (1939, pl. 29A); however, the sandstone pictured by Hendricks (1939) is in the upper part of the Hartshorne. Similar, but thicker, channels in the upper part of the Hartshorne Formation near Heavener are on Lost Mountain (SE¼ sec. 12, T. 5 N., R. 25 E.) and on the hill in the NE¼ sec. 5, T. 5 N., R. 25 E. (L. A. Hemish, unpublished field observations).

A reexamination of the Atoka Formation at the Heavener Road Cut section by R. Andrews and me for this field trip allows some additional interpretations to be made. Units 1 through 5 and 6 through 10 (Fig. 60) appear to represent two fining-upward transgressive sequences. The lower parts of both sequences are laminated sandy siltstones; these grade upward into black organic-rich shales with abundant siderite nodules, which are overlain by zones with abundant coal. Our interpretation of these sequences is that the lower part of each was deposited in a delta-margin environment, possibly at the outer fringe of an interdistributary bay. The sandy siltstones may be distal crevasse-splay deposits. These are overlain by lagoonal shales, which, in turn, are overlain by and/or interbedded with probable marsh deposits (coals). As correctly interpreted by Donica (1978), the overlying units are upper-delta-plain bay-fill shales and crevasse-splay sandstones or possibly flood-plain deposits.

Figure 62 is part of the electric log from the Mobil No. 1 Ann Lyons well, drilled ~7.1 mi north-northeast of the Heavener Road Cut section. A comparison of the measured section (Fig. 60) and the log (Fig. 62) shows several similarities. In both, the Lower Hartshorne coal is underlain by shale; the thin coal beds in the shale strongly suggest that the unit (unit 24 in Fig. 60) represents lagoonal–bay-fill sediments. Below the shale is a series of delta-plain (probably lagoonal, bay-fill, and crevasse-splay) shale and sandstone units (units 13–23) that range from about 0.5 to 13 ft thick; these are represented on the log in the interval from about 1,102 to 1,158 ft. The highly irregular gamma-ray log is characteristic of such delta-plain deposits. The log suggests that one or two slightly fining-upward delta-plain sequences constitute the lower part of the Hartshorne in this area, but this is not obvious at the outcrop.

Some significant differences are apparent between the outcrop (Fig. 60) and log (Fig. 62). The Atoka For-

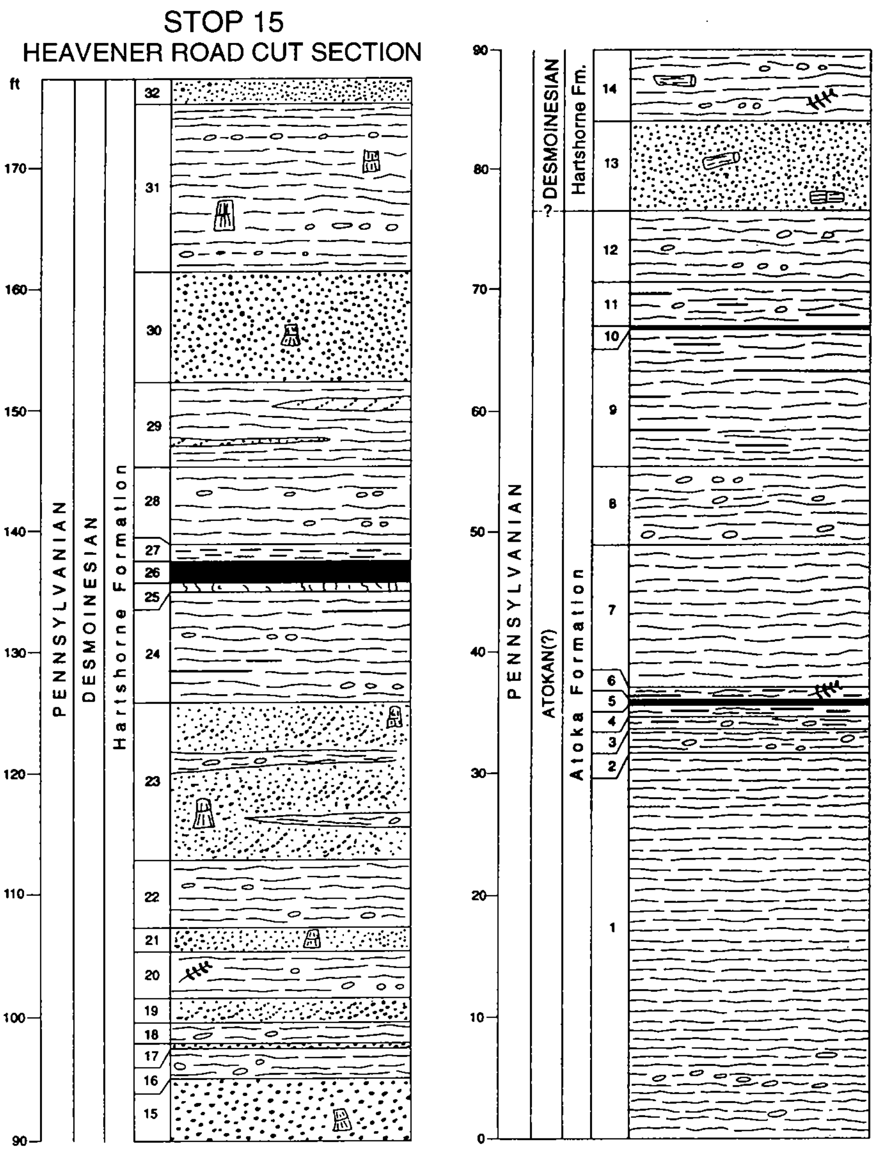


Figure 60. Graphic columnar section of the upper part of the Atoka Formation and the lower part of the Hartshorne Formation exposed at Stop 15 (Heavener Road Cut section). Note the presence of several thin coal beds in the Atoka Formation and upright (growth position) *Calamites* in the Hartshorne Formation. Such features are diagnostic of a delta-plain environment. (From Suneson and Hemish, 1994, fig. 67.)

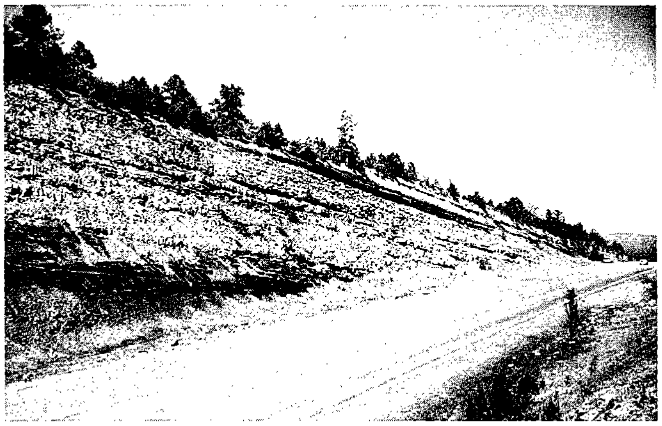


Figure 61. Northwest side of Heavener road cut, Stop 15. Dark-colored strata on left were identified by Donica (1978) as mostly shale in the Atoka Formation, but they appear to include a significant amount of sandy siltstone (R. Andrews' and the author's observations); lighter colored strata above are in lower part of Hartshorne Formation. Upper Hartshorne sandstone exposed at top of road cut, underlain by conspicuous black band of Lower Hartshorne coal. (From Suneson and Hemish, 1994, fig. 68.)

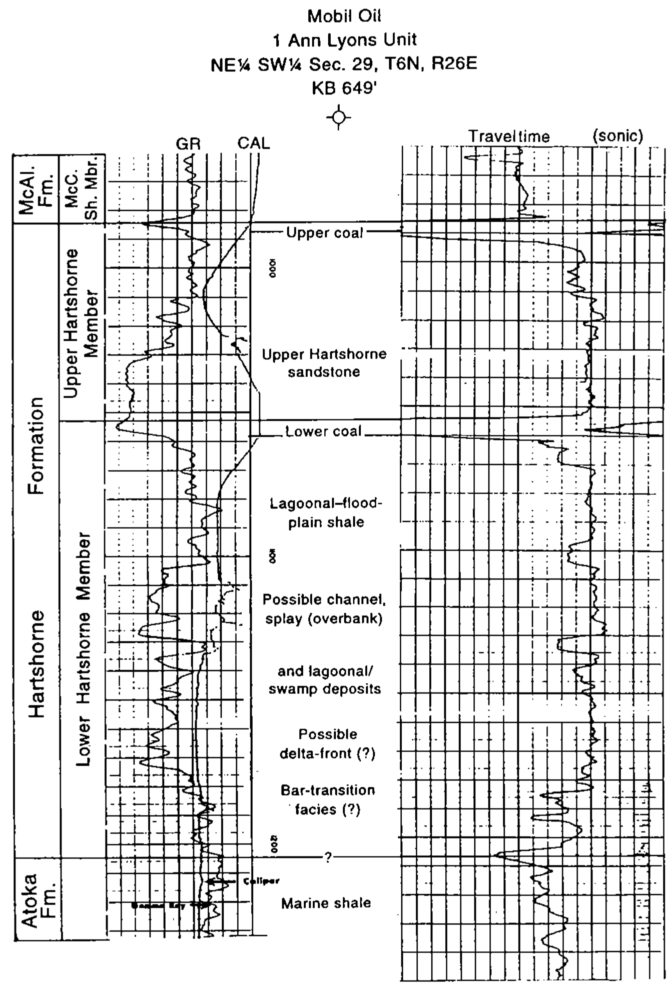


Figure 62. Part of log from the Mobil No. 1 Ann Lyons well. Log pattern of upper and middle parts of Lower Hartshorne Member is characteristic of delta-plain deposits (R. Andrews, personal communication, 1998). Lower part of Hartshorne Formation (bar transition) and upper part of Atoka Formation (marine) on log are different from those exposed at Stop 15. *GR* = gamma ray, *CAL* = caliper.

mation at the Heavener Road Cut section consists of a thick seqence of bay-fill shale and minor coal. This is the only outcrop of the upper part of the Atoka Formation in the southern part of the Arkoma basin that is not made up of marine, prodelta, or distal-delta-fringe strata. The marine shale and shoreface-transition strata interpreted on the log of the No. 1 Ann Lyons well are typical of most Atoka–basal Hartshorne strata in the Arkoma basin. Also, the strata above the Lower Hartshorne coal on the log are sandstone and probably fill a channel, whereas those above the coal in the outcrop are interbedded shale and sandstone. These differences are probably due to the distance between the measured section and the well.

Measured Section, Stop 15

Upper Part of Atoka Formation and Hartshorne Formation

Heavener Road Cut Section

***Location:** NW¼SE¼NW¼ sec. 36, T. 5 N., R. 25 E. (Hontubby 7.5' quadrangle). Road cut along U.S. Highway 59/270 about 1.5 mi south of Heavener. Le Flore County, Oklahoma. Section measured by David R. Donica. The following description is modified from Donica (1978).*

	Thickness (feet)
KREBS GROUP:	
HARTSHORNE FORMATION:	
32. Sandstone, gray, weathers buff (top of section).	2.0
31. Shale, interlaminated gray and brown, containing siderite nodules and upright *Calamites*.	4.0
30. Sandstone, gray, fine-grained, containing upright *Calamites*.	9.0
29. Shale, gray, interbedded with cross-bedded sandstone.	6.8
28. Shale, gray, thinly laminated, containing siderite nodules.	6.8
27. Shale, black, carbonaceous.	1.2
26. Coal (Lower Hartshorne).	1.9
25. Underclay, rooted.	0.5
24. Shale, gray, fissile, containing siderite nodules and streaks of coal.	9.4
23. Sandstone, gray, cross-bedded, containing upright *Calamites*, interbedded with gray shale containing siderite nodules.	12.8
22. Shale, gray, containing siderite nodules.	5.8
21. Sandstone, gray, fine-grained, containing upright *Calamites*, one of which is 1.8 ft tall. The sandstone is variable in thickness.	1.7
20. Shale, gray, finely laminated, with siderite nodules containing plant impressions.	4.2
19. Sandstone, gray, fine-grained, cross-bedded.	1.9
18. Shale, gray, thinly laminated, containing siderite nodules.	1.6

17. Sandstone, gray, very fine grained, cross-bedded. ... 0.5
16. Shale, gray, thinly laminated, containing siderite nodules. ... 2.5
15. Sandstone, gray, very fine grained, containing upright *Calamites*. ... 5.2
14. Shale, gray, finely laminated, with siderite nodules containing *Calamites* and numerous leaf impressions. ... 5.7
13. Sandstone, gray, fine-grained, containing *Calamites*. 7.5

ATOKA FORMATION:

12. Shale, gray, thinly laminated, containing siderite nodules. ... 5.7
11. Shale, carbonaceous, containing thin coal streaks and siderite nodules. ... 3.7
10. Coal. ... 0.5
9. Shale, black, carbonaceous, with numerous coal streaks. ... 11.3
8. Shale, gray, containing siderite nodules. ... 6.5
7. Shale, gray. ... 11.5
6. Shale, sideritic, overlying shale, black, carbonaceous, containing thin coal streaks and numerous plant impressions. ... 1.2
5. Coal. ... 0.5
4. Shale, black, with coal streaks. ... 0.9
3. Shale, black, containing siderite nodules. ... 0.9
2. Shale, gray, containing siderite nodules. ... 2.0
1. Shale, gray, thinly laminated, with interbedded sideritic shale (base of section). ... 31.8

Total thickness of section 177.5

STOP 16

Williams Measured Section

Directions: From intersection of State Highways 112 and 120 south of Pocola, Oklahoma, drive south just over 0.5 mi on Highway 112 and turn right (west) on county road. Drive 1.4 mi; road turns to left (south). Drive another 0.5 mi to large outcrop on left (east) side of road. Park at intersection with road to right (west). Measured section is mostly of road cut but also includes borrow pit northwest of road intersection.

Map reference: Knechtel (1949).

Geologic reference: Houseknecht (1983, p. 90, 97).

The Hartshorne Formation in this area typically forms small isolated hills separated by low ridges or flat areas. This suggests that most of the Hartshorne consists of siltstone and shale, which is rarely exposed. The hills are underlain by slightly thicker accumulations of sandstone, which probably are distributary channels similar to those exposed at Stop 17 or shallow-marine bars formed by reworking of distributary-mouth-bar deposits.

This outcrop (Fig. 63) was visited on a field trip sponsored by the Society of Economic Paleontologists and Mineralogists in 1983 and was described by Houseknecht (1983, p. 90). The following is modified from his description.

Despite its unspectacular appearance, this is the most complete outcrop section displaying Hartshorne facies deposited in an interdistributary location. These strata, which dip 15° to the south, represent prodelta facies coarsening upward into tidally influenced delta-front facies. The delta-front sandstones, displaying a myriad of ripple-generated sedimentary structures and small-scale trough cross-bedding, were deposited in an interdistributary area well removed from any fluvial influence.

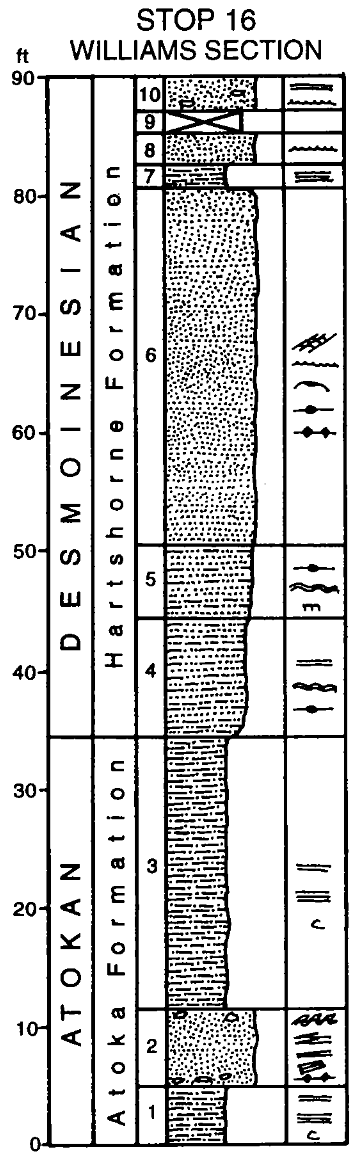


Figure 63. Graphic columnar section of upper part of Atoka Formation and lower part of Hartshorne Formation exposed at Stop 16 (Williams section). The sandstone in the lower part of the section (unit 2) appears to be an allochthonous channel deposit that is a slide block within the prodelta marine shales of the Atoka Formation. Units 3 through 6 exhibit a classic coarsening-upward sequence, reflecting the progradation of a distributary-mouth bar over prodelta shales. Explanation of symbols in Appendix 2.

Above the delta-front sandstone, but not exposed at this location, are interdistributary-bay shales and the Lower Hartshorne coal, which has been mined from small drifts just to the south.

Because most natural and man-made outcrops are in sandstone-rich Hartshorne sequences, this exposure gives a rare opportunity for examining a sandstone-poor Hartshorne progradational sequence.

Several aspects of Houseknecht's (1983) description require clarification. The sequence does exhibit an overall coarsening-upward character, from probable prodelta shale in the Atoka Formation (units 1 and 3, Fig. 63) to shoreface transition and/or lower-distributary-mouth-bar siltstone and sandstone (units 4 and 5) to upper-distributary-mouth-bar sandstone (unit 6). These strata were not deposited in an "interdistributary location," which would more likely be bay-fill shales and crevasse-splay sandstones. Also, there is no evidence that the sediments reflect a tidal influence. Based on Knechtel's (1949) map showing the location of the Lower Hartshorne coal, the top of the Williams section is about 115 ft below the coal. While it is likely that at least some delta-plain sediments occur beneath the coal, there is no surface evidence in this area for any.

Several blocky-weathering sandstone beds as thick as 4 ft crop out several hundred feet to the east in the woods. Their exact position within the measured section is difficult to determine, but they probably are within unit 6. They exhibit some thickening and thinning and large, low-angle cross-stratification. These beds may represent storm-reworked sandstones or shallow-marine bars within the distributary-mouth-bar sequence.

Of particular interest at this outcrop is the large sandstone block in the borrow pit on the west side of the road (Fig. 64). This sandstone is about 20 ft below the top of the Atoka Formation. Although several features suggest that the sandstone fills a channel within the shale (particularly the shale rip-up clasts at the base), the sandstone is probably a submarine slide block. Features supporting this interpretation include (1) the highly irregular nature of the basal contact of the sandstone, (2) deformed shale that appears to have been "squeezed" into fractures and between bedding planes in the sandstone, and (3) soft-sediment-deformation features within the sandstone. In addition, the large

Figure 64. Sandstone slide block (unit 2) in upper part of Atoka Formation, Williams section. Geologic hammer for scale.

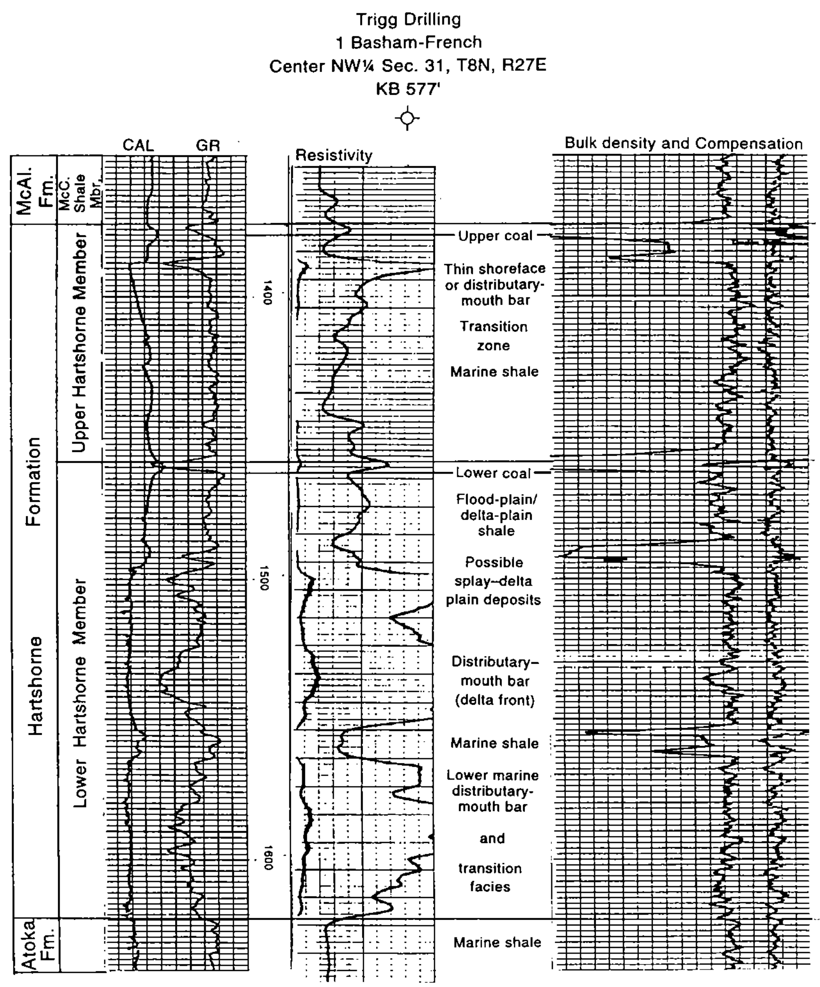


Figure 65. Part of log from Trigg Drilling No. 1 Basham-French well, showing the Hartshorne Formation. The lower part of the Hartshorne on the log shows a coarsening-upward character typical of bar-transition and lower-distributary-mouth-bar deposits. Although the thicknesses of the coarsening-upward sequence on the log and in outcrop at Stop 16 differ, the log pattern probably reflects strata similar to those observed at the surface. *CAL* = caliper, *GR* = gamma ray.

plant impressions in the sandstone suggest a very shallow-water origin in contrast to the probable relatively deep-marine origin of the surrounding shale.

Figure 65 is part of the electric log from the Triggs Drilling No. 1 Basham-French well, drilled ~3.5 mi south-southeast of the measured section. The position of the Hartshorne-Atoka contact relative to the Lower Hartshorne coal on the log and in outcrop (based on mapping by Knechtel [1949] and assuming a constant dip of the outcrop) is about the same. Similarly, the lower part of the log (1,575–1,620 ft) and the outcrop show upward-coarsening sequences of similar thicknesses that are typical of a prograding distributary-mouth-bar complex. The strata exposed at the surface are consistent with this interpretation.

Figure 66. Ripple-bedded sandstone in unit 6, Williams section. The ripple-bedded character of the sandstones and the paucity of siltstone and shale suggest that this sequence was deposited in an upper-distributary-mouth-bar environment. Unlike outcrops at Stops 6, 8, and 10, there is no evidence for reworking by storm waves. Geologic hammer for scale.

Measured Section, Stop 16

Hartshorne Formation, Top of Atoka Formation
Williams Section

Location: SW¼SW¼SW¼ sec. 12, T. 8 N., R. 26 E., and SE¼SE¼ SE¼ sec. 11, T. 8 N., R. 26 E. (Spiro 7.5′ quadrangle). Road cut along county (section-line) road, about 1.75 mi east-northeast of Williams. Le Flore County, Oklahoma. Section measured by David W. Houseknecht; modified by Neil H. Suneson.

	Thickness (feet)
KREBS GROUP:	
HARTSHORNE FORMATION:	
10. Sandstone, fine-grained, grayish orange (10YR7/4). Poorly exposed. Slightly ripple-bedded, generally plane-parallel-bedded. Shale rip-up clasts in bottom 6 in.	3.0
9. Covered, possibly shale similar to unit 7, based on float.	~2.0
8. Sandstone, pale yellowish brown (10YR6/2). Tops ripple-marked.	2.5
7. Silty shale, olive black (5Y2/1). Weathers fissile to chippy, possibly organic-rich. Poorly exposed.	~2.0
6. Sandstone, very fine to rarely medium-grained, light brownish gray (5YR6/1) to light olive gray (5Y5/2); and minor siltstone. Sandstone ripple-bedded (Fig. 66), rarely flaser- and lenticular-bedded toward top because of increasing amount of siltstone. Trace amount of organic material on bedding planes. Weathers flaggy. Contact with unit 5 slightly erosional.	30.0
5. Silty sandstone, very fine grained, olive gray (5Y4/1); and siltstone. Sandstone wavy- to lenticular-bedded. Siltstone with conspicuous mica parallel to laminations.	6.0
4. Shaly siltstone, moderate brown (5YR4/4); and minor sandstone, very fine grained. Siltstone mostly parallel-bedded, poorly exposed. Sandstone lenticular-bedded and faintly wavy-bedded.	10.0
3. Silty shale, olive black (5Y2/1). Parallel-laminated, fissile. Very fine mica parallel to laminations. Weathers to light brown (5YR5/6) to dark yellowish brown (10YR4/2).	23.0
2. Sandstone, fine-grained, medium light gray (N6); and minor shale (Fig. 62). Sandstone blocky weathering, plane-parallel partings. Large-scale low-angle tabular cross-stratification causes some thickening and thinning of beds. Shale locally highly deformed, appears "squeezed" into sandstone. Sandstone locally detached, surrounded by shale. Base and top of sandstone contain shale rip-up clasts. Top of sandstone with abundant plant impressions and carbonized fragments as long as 1.5 ft.	6.5
1. Silty shale. Similar to unit 3. Top directly below unit 2 is highly deformed locally. Lower part not shown in Figure 63.	~16.0
Total thickness of section	101.0

STOP 17

Green Country Stone Measured Section

Directions: From intersection of State Highways 112 and 120 south of Pocola, Oklahoma, drive east 2.5 mi on Highway 120. Entrance to Green Country Stone Quarry is on the right (south). Drive into quarry.

Permission to visit the exposures of the Hartshorne Formation in the Green Country Stone Quarry has been given to us, courtesy of Mr. Robert Thompson, owner. Individuals wishing to revisit the quarry should contact Mr. Thompson, c/o Green Country Stone, 47275 East 807 Street, Poteau, Oklahoma 74953; telephone (918) 654-3627; fax (918) 654-3779.

Map reference: Knechtel (1949).

The outcrop at the Green Country Stone Quarry (Fig. 67; Pl. 1) is on the south flank of the Backbone anticline. Strata in the quarry dip about 10° south. Knechtel (1949, pl. 1) shows this outcrop as a relatively thick sandstone in the lower part of the Hartshorne that thins and/or divides to the west. This thinning is reflected in the topographic expression of the Hartshorne; near the quarry, the Hartshorne underlies a ridge with >100 ft of relief. To the west, the Hartshorne either is not expressed topographically or underlies isolated elongate hills (e.g., Stop 16). Knechtel (1949) also mapped a sandstone bed in the upper part of the Hartshorne Formation that overlies the stratigraphic interval of the Lower Hartshorne coal. This bed pinches out entirely just west of the quarry.

The Lower Hartshorne coal is present about 0.5 mi west of the quarry but is absent between the quarry and the Arkansas State line (Knechtel, 1949, pl. 1). It is possible that the Lower Hartshorne coal either (1) was not deposited where the sandstone in the lower part of the formation was the thickest, perhaps because the sand did not compact and form a topographic low as readily as surrounding mud and silt, or (2) was deposited but subsequently eroded by later channels that filled with sand. The Upper Hartshorne coal, in contrast, is present along the entire south flank of the Backbone anticline.

Most of the exposures in the Green Country Stone quarry are upper-distributary-mouth-bar deposits (Pl. 1). Equally, if not more impressive, are two distributary channels that eroded into the bars (Pl. 1; Fig. 68). Sandstone fills most of the channels and occurs as a series of nested, highly cross-stratified deposits. The azimuth of the channels is about N. 20° E.–S. 20° W. The dip of large foreset beds within the channels suggests that the current direction was toward the north.

Figure 68. Upper-distributary-mouth-bar deposits (horizontally bedded strata at base of exposure), overlain and eroded into by distributary channel (units 2 and 3), Green Country Stone section. Erosive base of channel near geologist's head.

Other interesting features to note are the faults and "pop-up" ridges on the quarry floor caused by unloading as a result of quarrying and removal of flagstones.

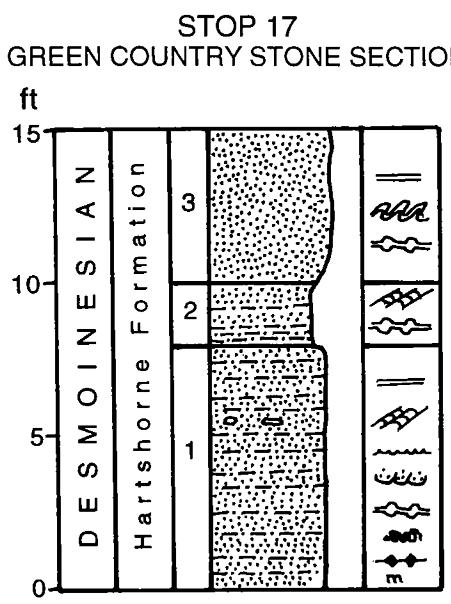


Figure 67. Graphic columnar section of part of Hartshorne Formation exposed at Stop 17 (Green Country Stone section). Explanation of symbols in Appendix 2.

Measured Section, Stop 17

Hartshorne Formation

Green Country Stone Section

Location: *NW¼NW¼ sec. 10, T. 8 N., R. 27 E., and NE¼NE¼ sec. 9, T. 8 N., R. 27 E. (Hackett 7.5′ quadrangle). Flagstone quarry operated by Green Country Stone, just south of State Highway 120, about 2 mi west of Hackett, Arkansas. Le Flore County, Oklahoma.*

	Thickness (feet)
KREBS GROUP:	
HARTSHORNE FORMATION:	
3. Sandstone, fine-grained, very pale orange (10YR8/2) to grayish orange (10YR7/4). Massive, unstratified to faintly plane-parallel-stratified to very soft-sediment-deformed. Base of unit sharp, abrupt (Fig. 68). Distributary-channel deposit.	5.0
2. Sandstone and shale. Generally similar to unit 1, except sandstone beds are lenticular, showing significant thickening and thinning. Beds dip in opposite direction from those of outcrop. Occurs in base of channel.	2.0
1. Sandstone, fine-grained, medium light gray (N6); and minor silty shale, grayish black (N2). Sandstone beds 1.5 in. to 1 ft thick, mostly faintly plane-parallel-laminated or unstratified, some tabular cross-stratified. Trough cross-bedding indicates paleocurrent direction to the north. Most beds of constant thickness; some show minor thickening and thinning. Tops of beds slightly ripple-marked. Trace fossils (long trails in bedding planes) rare. Minor, very small shale rip-up clasts. Shale beds 0.5 to 1.5 in. thick, mica conspicuous on bedding planes. Macerated plant debris rare.	8.0
Total thickness of section	15.0

STOP 18

Bokoshe Measured Section

Directions: From Bokoshe, Oklahoma, drive west on State Highway 31. About 1.5 mi west of town, the highway passes just south of a conspicuous dam that forms Bokoshe Lake. Turn south 0.7 mi west of dam on a section-line road. Stop 18 is the low ridge 0.4 mi south of the highway.

Map reference: Knechtel (1949).

This outcrop lies on the south flank of the Milton anticline, the axis of which is slightly less than 1 mi north of here. The strata dip gently to the south.

Although the section of the Hartshorne Formation exposed at this stop is relatively thin (Fig. 69), it is the best outcrop of easily accessible Hartshorne strata for many miles. In general, the Hartshorne on the southeast flank of the Milton anticline forms a low ridge much like this one, or else is not expressed topographically. The same is true for the northwest flank of the anticline. Most of the Hartshorne outcrops on the Milton anticline examined on a reconnaissance field trip to prepare for this guidebook were less than 10 ft thick.

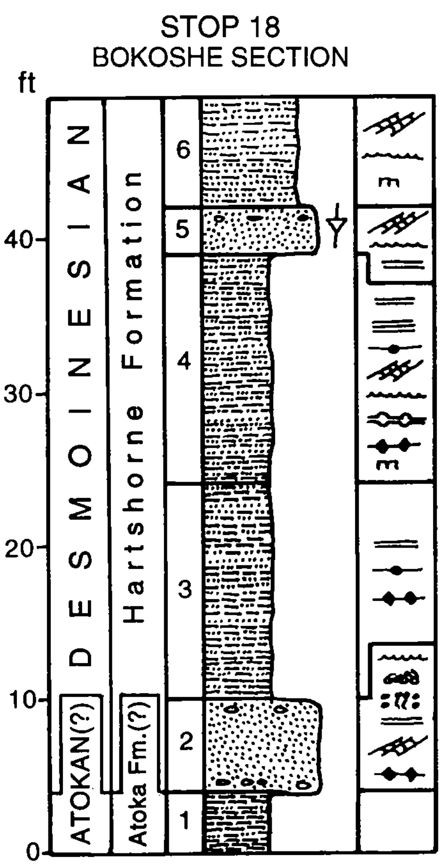


Figure 69. Graphic columnar section of the upper part of the Atoka Formation and the lower part of the Hartshorne Formation exposed at Stop 18 (Bokoshe section). The overall fine-grained character of the rocks at Stop 18 is probably typical of most of the Hartshorne Formation in this part of the Arkoma basin. Explanation of symbols in Appendix 2.

This outcrop is also just west of the crest of the Backbone anticline. Based on Knechtel's (1949) map, the Hartshorne forms no topographic expression on the north flank of the Backbone anticline and therefore probably consists mostly of shale and siltstone. On the south flank, the Hartshorne generally forms a low ridge similar to that at Stop 18, although locally (e.g., SW¼ sec. 18, T. 8 N., R. 25 E., about 6 mi east of here) it underlies a steep slope and undoubtedly consists of a greater amount of sandstone than is typical for this area.

Although good sections of the Hartshorne are rare, the Hartshorne coal has been extensively mined throughout the area. In addition, the coal-split line passes close to this outcrop; there is one Hartshorne coal to the west (3–5 ft thick) and two coals (Upper and Lower) to the east, separated by as much as 2.5 ft of shale (Knechtel,1949, table 3). An enigmatic occurrence of igneous and metamorphic cobbles in the Lower Hartshorne coal was noted by Knechtel (1949, p. 46):

> In the Gillie mine [on the south side of Bokoshe, about 2 mi northeast of Stop 18], well-rounded erratic cobbles have occasionally been found by the miners in the upper part of the Lower Hartshorne coal bed. One of these is reported by Prof. Ray L. Six of Oklahoma A.&M. College to be composed of igneous rock tentatively identified as quartz monzonite. Another, which was given to the writer by Mr. Paul Rees of Bokoshe, is of dark-gray quartzite. The cobbles were supposedly transported here from distant sources, as no bedrock that could have furnished the materials composing them is known to occur nearby. Such well-worn rock fragments must have travelled considerable distances as constituents of gravel. At first they must have been impelled along stream beds by fairly strong currents of water, but their presence in a coal bed suggests that there were no strong currents where they were finally deposited. They may therefore have been finally rafted into the coal-forming environment during floods, either attached to the roots of floating trees or embedded in ice floes.

At the present time, I have no explanation for the origin of the cobbles in the Hartshorne coal.

The significance of this outcrop is that it may represent much of what the Hartshorne Formation is like in the subsurface to the south and to the north of the northern outcrop belt on the Milton anticline. Most of the section is fine-grained, very well stratified, and contains some evidence for currents (Fig. 69). In addition, the presence of abundant macerated organic debris suggests a significant terrestrial component to the sediments. Most likely, these units (3, 4, and 6) were deposited in a distal-delta-fringe or a lower-distributary-mouth-bar environment. The presence of shale rip-up clasts in the sandstones (units 2 and 5) supports a storm origin, particularly considering that the sandstones are directly underlain and overlain by relatively deep-marine strata.

The depositional environment of the Atoka Formation is questionable, because it is so poorly exposed. It appears to be finer grained than the Hartshorne at this outcrop and may consist of prodelta deposits.

Measured Section, Stop 18

Upper Part of Atoka Formation and Hartshorne Formation

Bokoshe Section

Location: W side SW¼NW¼NW¼ sec. 18, T. 8 N., R. 24 E. (Bokoshe 7.5′ quadrangle). Along section-line road between sec. 18, T. 8 N., R. 24 E., and sec. 13, T. 8 N., R. 23 E. Le Flore County, Oklahoma.

	Thickness (feet)
KREBS GROUP:	
HARTSHORNE FORMATION:	
6. Sandstone, silty, very fine grained, light olive gray (5Y5/2); and siltstone. Sandstone platy, ripple-bedded, cross-stratified, micaceous. Poorly exposed. Siltstone mostly covered.	7.0
5. Sandstone, very fine grained, pale yellowish brown (10YR6/2). Bed thickness increases upward from platy to flaggy to massive and unstratified. Basal part ripple-bedded with ripple marks on tops of beds to plane-parallel-stratified. Upper part contains shale rip-up clasts.	3.0
4. Siltstone; sandy shale; and sandstone, very fine grained, pale yellowish brown (10YR6/2). Siltstone flaggy, plane-parallel-stratified and cross-stratified, abundant mica and macerated plant material on laminations. Shale platy to fissile. Sandstone ripple-bedded, cross-stratified, relatively continuous, although some thickening and thinning. Sandstone locally lenticular-bedded in siltstone.	15.0
3. Siltstone; shale; and sandstone, very fine grained. Siltstone platy. Shale clayey, light gray (N7). Sandstone locally with macerated plant material. Unit poorly exposed, partly covered. Description based on float. Probably similar to unit 4, but with more shale.	14.0
2. Sandstone, very fine grained. Faintly cross-stratified to well parallel-laminated. Top with ripple marks and abundant vertical burrows and horizontal trace fossils. Base contains small shale rip-up clasts. Trace amount of macerated plant material. Jumbled blocks at outcrop. Forms ledge in field to west. Contact with underlying Atoka Formation abrupt, but not exposed.	6.0
ATOKA FORMATION:	
1. Shale and minor siltstone. Unexposed; description based on float.	4.0
Total thickness of section	49.0

STOP 19

McCurtain Measured Section

Directions: From intersection of State Highways 26 and 31 in McCurtain, Oklahoma, drive 2.6 mi east on Highway 31 to section-line road, which is also the Haskell–Le Flore county line. Drive north 1.2 mi on section-line road to top of low ridge.

Map reference: Oakes and Knechtel (1948); Knechtel (1949).

This outcrop of the Hartshorne Formation (Fig. 70) is the northwesternmost on this field trip. The strata are on the northwestern flank of the Milton anticline and dip about 14° to the north. The Hartshorne Formation is exposed on the crest of the Milton anticline at the town of McCurtain about 3 mi west-southwest of this stop, and the Hartshorne coal was strip mined at two localities about 1 mi west of town. The Hartshorne

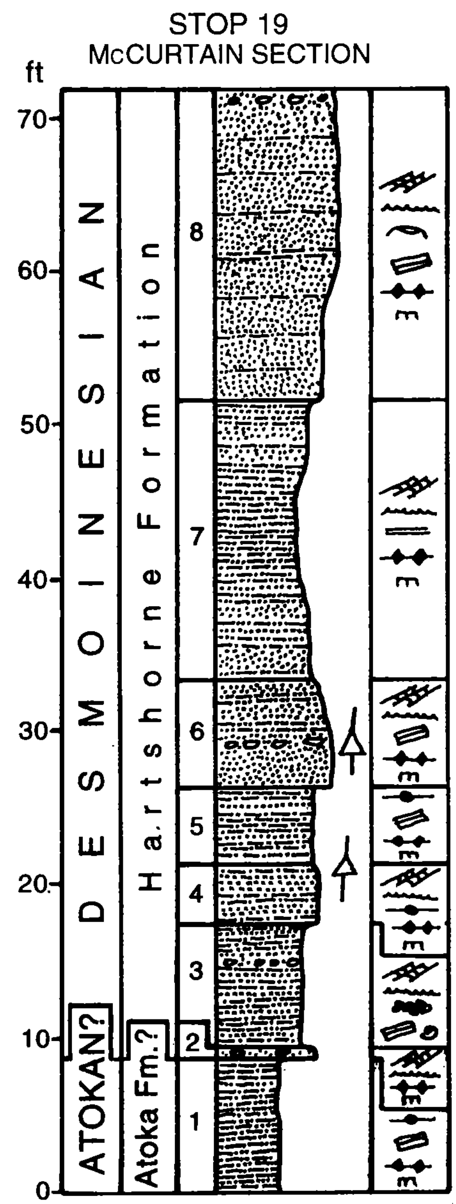


Figure 70. Graphic columnar section of the upper part of the Atoka Formation and the lower part of the Hartshorne Formation exposed at Stop 19 (McCurtain section). Note the presence of marine invertebrate fossils in unit 3. Explanation of symbols in Appendix 2.

Formation is not exposed west of the mines; it is present, however, in the subsurface throughout the basin.

Oakes and Knechtel (1948, pl. 1) show several strip mines in the Hartshorne directly north of McCurtain, and Knechtel (1949, pl. 1) shows several coal prospects in the coal directly northeast of here. The 1968 McCurtain 7.5′ topographic map (photorevised in 1982) shows that the entire outcrop belt of Hartshorne coal on the north flank of the Milton anticline has been strip mined. Based on drill-hole data, Knechtel (1949, table 3) estimated the Hartshorne coal just north of Stop 18 to be 3.9 ft thick. Oakes and Knechtel (1948, table 3) measured 3 ft 4 in. of coal separated by a 2-in. shale parting in a drill hole north of Stop 18; they suggested that the parting represented a break between the Upper and Lower Hartshorne coals.

Perhaps the most important aspect of this stop is its location. It is the northwesternmost well-exposed outcrop of the Hartshorne Formation in this part of the Arkoma basin. An outcrop described by Oakes and Knechtel (1948, appendix) on the south side of Round Prairie, about 10 mi to the north, included only the uppermost 2 ft of the Hartshorne Formation. The next Hartshorne outcrop to the north, on the northwest side of the Stigler syncline, is in northern Haskell County and is about 20 mi from this stop.

The origin of the Hartshorne Formation at Stop 19 is enigmatic. The occurrence of crinoid fragments in unit 3 clearly indicates a marine origin. The presence of large amounts of organic debris, including coal laminations between ripples (unit 2) and unmacerated plant material in the directly subjacent Atoka Formation (unit 1), suggests a nearby source of terrestrial debris. Organic debris, including relatively large and well-preserved pieces, is also common in units 4 through 8. Although in many respects the strata resemble distributary-mouth-bar sequences, the characteristic upward coarsening is not obvious in outcrop. A preferred explanation for this outcrop is that it represents a tidal flat or estuary, but the poor quality of the exposures makes a more precise interpretation impossible.

Measured Section, Stop 19

Hartshorne Formation and Top of Atoka Formation McCurtain Section

Location: C W side NW¼NW¼ sec. 18, T. 8 N., R. 23 E. (McCurtain 7.5′ quadrangle). Along section-line road between sec. 18, T. 8 N., R. 23 E., and sec. 13, T. 8 N., R. 22 E., about 3 mi east-northeast of McCurtain. On boundary between Haskell and Le Flore Counties, Oklahoma.

Note: Units 1–3 are exposed in bar ditch on west side of road in Haskell County. Units 4–6 are exposed in road cut on east side of road in Le Flore County. Units 7 and 8 are exposed in road and in bar ditch on west side of road in Haskell County.

	Thickness (feet)
KREBS GROUP:	
HARTSHORNE FORMATION:	
8. Sandstone, very fine grained, light olive gray (5Y5/2) to moderate olive brown (5Y4/4); minor siltstone; and silty shale. Sandstone flaggy, ripple-bedded, with ripple marks on top, micaceous, locally with abundant macerated organic debris on bedding planes. One 1-in.-long plant fossil observed. Sandstone rarely flaser-bedded. Rounded shale rip-up clasts rare. Siltstone and shale mostly covered or poorly exposed.	~20.0
7. Silty sandstone, very fine grained, moderate olive brown (5Y4/4); siltstone; and silty shale. Sandstone flaggy, locally ripple- and cross-bedded, micaceous, with abundant carbonized macerated plant debris on bedding planes. Siltstone and shale planar-laminated and platy with conspicuous coalified laminations. Poorly exposed.	~18.0
6. Silty sandstone, fine-grained to very fine grained, pale yellowish brown (10YR6/2); and minor siltstone. Sandstone platy to flaggy, ripple- and cross-bedded, locally with abundant, rounded and flattened shale rip-up clasts as long as 2 in. Some beds with ripple marks. Mica and macerated organic debris common. Locally contains coalified plant debris as long as 1.5 in.	7.0
5. Silty shale, olive black (5Y2/1); and sandstone, very fine grained, light olive gray (5Y5/2). Sandstone beds 0.125 to 2 in. thick; thinner beds lenticular-bedded, thicker beds flaggy, ripple-bedded. Mica and well-preserved carbonized plant debris common on bedding planes. Sandstone hard, silica-cemented. Poorly exposed.	5.0
4. Sandstone, very fine grained, light brownish gray (5YR6/1); and silty shale. Sandstone flaggy, beds 4 in. to 1 ft thick. Ripple marks common. Interbedded with ripple-bedded strata similar to unit 5. Trace fossils on thinner beds. Mica, macerated organic debris common.	4.0
3. Sandstone, very fine grained, dark yellowish brown (10YR4/2); siltstone; and silty shale, olive gray (5Y3/2). Unit includes 1-in.-thick ripple-bedded sandstone; interlaminated ripple-, lenticular-, and/or cross-bedded siltstone and silty to sandy shale; platy silty shale. Sandstone cross-stratified, locally with small trace fossils and relatively large carbonized plant fossils. Rounded siltstone and medium-grained sandstone rip-up clasts and broken crinoid fragments present in one sandstone bed about 4 ft below top of unit. Shale typically draped over ripples in sandstone and siltstone.	8.0
2. Sandstone, fine-grained, light olive gray (5Y5/2). Flaggy, ripple- and cross-bedded, shale rip-up clasts throughout. Thin coal laminations locally between ripples. Contact with unit 1 gradational.	0.5
ATOKA FORMATION:	
1. Siltstone; and silty shale, pale yellowish brown (10YR 6/2) to light brown (5YR5/6). Shale contains abundant mica and whole (unmacerated) to macerated carbonized organic debris and is interlaminated with lenticular-bedded siltstone. Poorly exposed, weathered, limonite-stained, soft.	9.0
Total thickness of section	71.5

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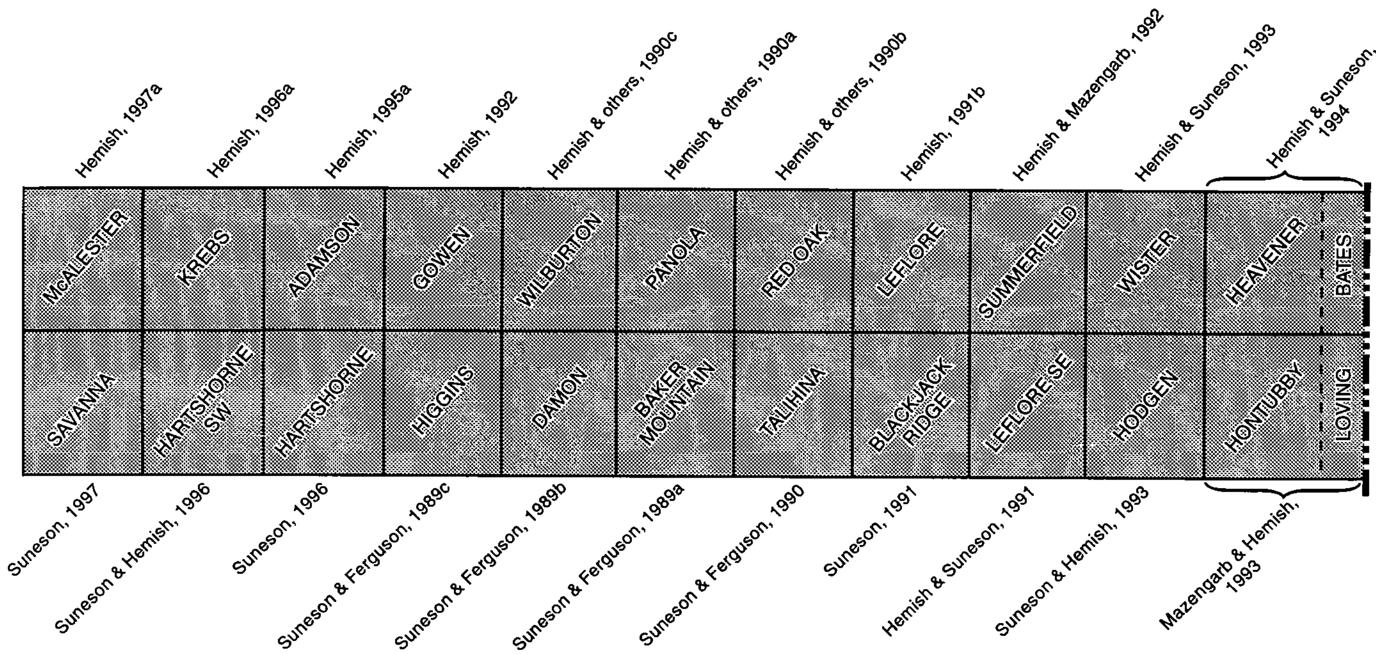
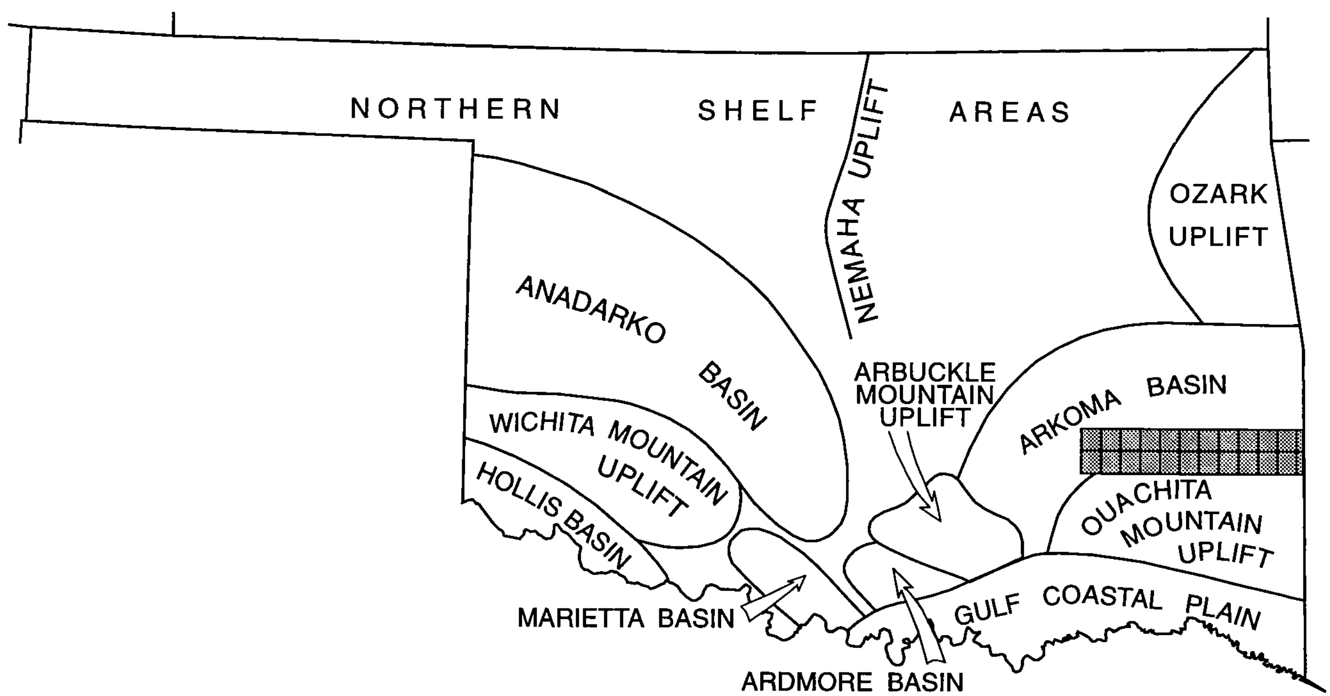
APPENDIX 1
Geologic Maps Published as Part of COGEOMAP and STATEMAP Projects





APPENDIX 2
Explanation of Symbols Used in This Guidebook

- Sandstone
- Sandstone (includes ironstone pebbles and shale clasts)
- Sandstone, conglomeratic
- Sandstone, siltstone, shale, interbedded
- Siltstone
- Siltstone, shaly
- Shale
- Shale, silty, sandy
- Shale, black
- Ironstone
- Coal
- Underclay
- Covered interval

SEDIMENTARY FEATURES

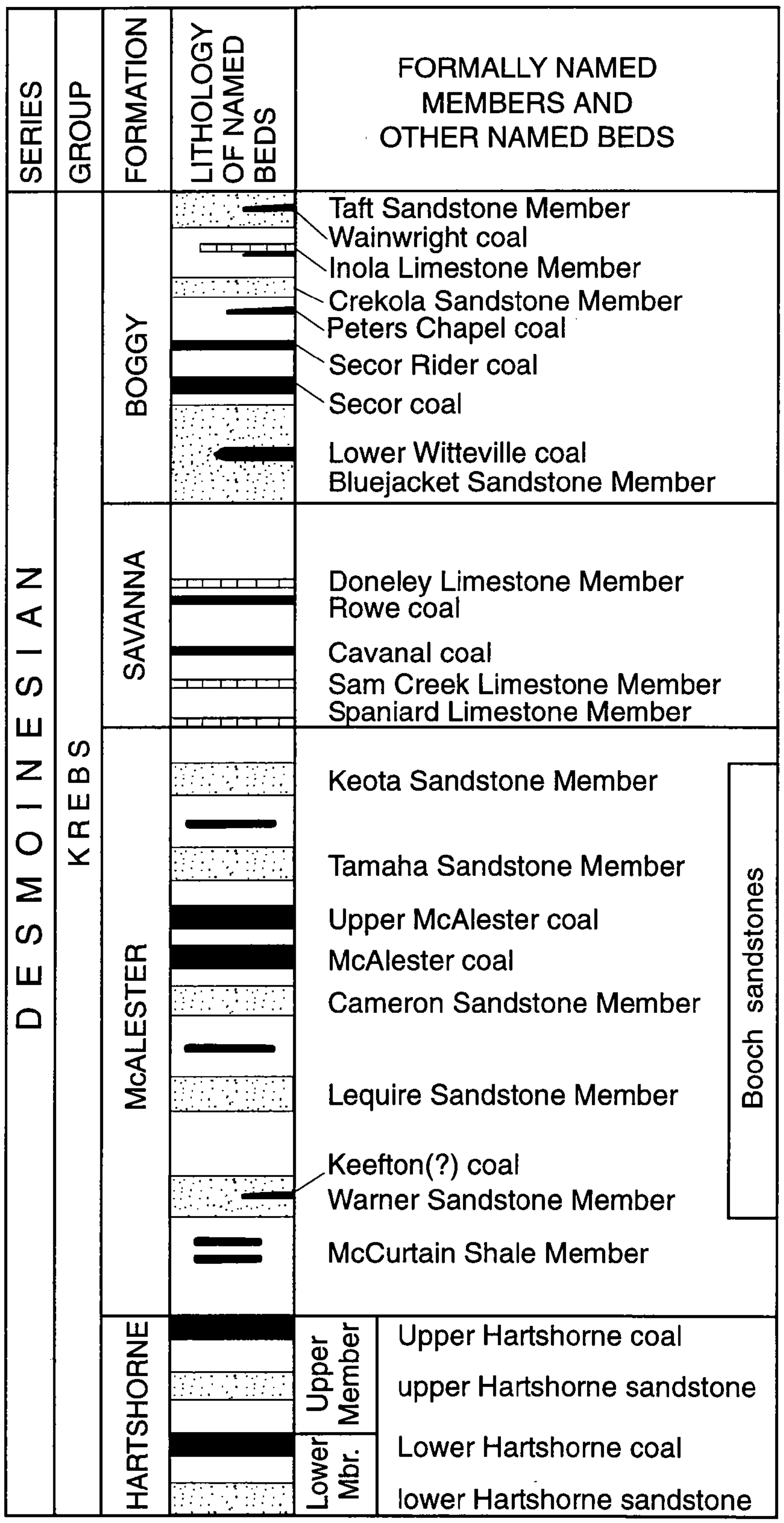
- Plane, parallel stratification
- Trough cross-stratification
- Cross-stratification, large and small scale
- Low-angle cross-stratification
- Wavy bedding
- Lenticular bedding
- Flaser bedding
- Swaly bedding, curved bedding
- Pinch-and-swell features
- Convolute, slumped, or contorted bedding
- Parting lineation
- Ripple marks
- Scour and fill, channeling
- Flow rolls, ball-and-pillow structures
- Siltstone nodules
- Load structures
- Boxwork weathering
- Dewatering structures or dish and pillar
- Fissile
- Plant fossils
- Macerated plant material
- Trace fossils
- Burrows, borings
- Invertebrate fossils
- B Bioturbated
- C Calcareous
- L Liesegang banding
- m Micaceous
- P Pitted to cavernous
- Fining-upward sequence
- Coarsening-upward sequence

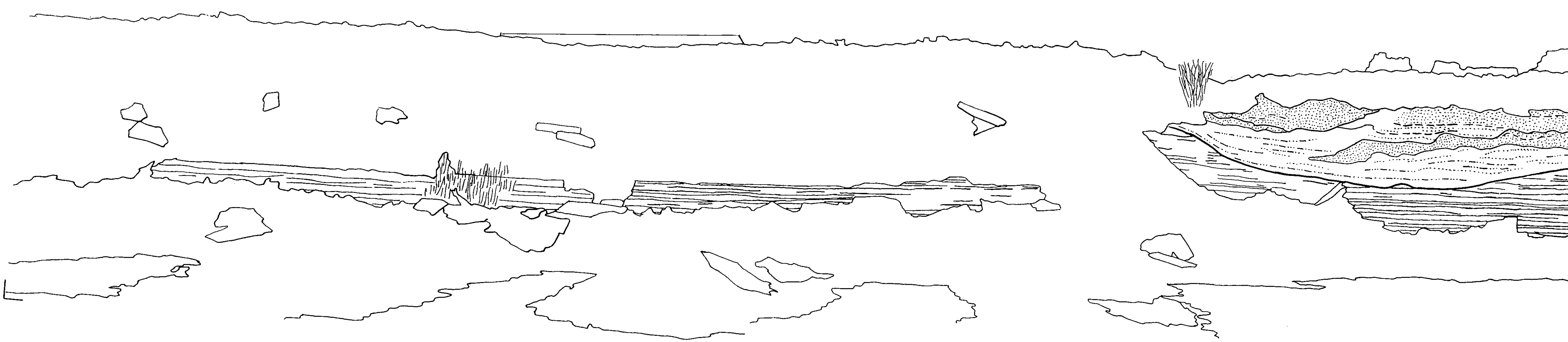
Stratigraphy in Field-Trip Area

	SERIES		FORMATION
PENNSYLVANIAN	Desmoinesian	Krebs Group	Boggy Formation
PENNSYLVANIAN	Desmoinesian	Krebs Group	Savanna Formation
PENNSYLVANIAN	Desmoinesian	Krebs Group	McAlester Formation
PENNSYLVANIAN	Desmoinesian	Krebs Group	Hartshorne Formation
PENNSYLVANIAN	Atokan		Atoka Formation
PENNSYLVANIAN	Morrowan		Wapanucka Limestone ☼
PENNSYLVANIAN	Morrowan		Union Valley Limestone Cromwell sandstone ☼
MISSISSIPPIAN	Chesterian		"Caney" Shale
MISSISSIPPIAN	Meramecian		"Caney" Shale
MISSISSIPPIAN	Osagean		"Caney" Shale
MISSISSIPPIAN	Kinderhookian		"Caney" Shale
DEVONIAN	Upper		Woodford Shale
DEVONIAN	Lower	Hunton Group	Frisco Limestone Bois d'Arc Limestone Haragan Limestone
DEVONIAN / SILURIAN	Lower / Upper	Hunton Group	Henryhouse Formation
SILURIAN	Upper, Lower	Hunton Group	Chimney Hill Subgroup
ORDOVICIAN	Upper		Sylvan Shale
ORDOVICIAN	Upper	Viola Group	Welling Formation Viola Springs Formation
ORDOVICIAN	Middle	Simpson Group	Bromide Formation Tulip Creek Formation McLish Formation Oil Creek Formation Joins Formation
ORDOVICIAN	Lower	Arbuckle Group ☼	West Spring Creek Formation Kindblade Formation Cool Creek Formation McKenzie Hill Formation Butterly Dolomite
CAMBRIAN	Upper	Arbuckle Group	Signal Mountain Limestone Royer Dolomite Fort Sill Limestone
CAMBRIAN	Upper	Timbered Hills Group	Honey Creek Limestone Reagan Sandstone
PRECAMBRIAN			Granite and rhyolite

		THURMAN FORMATION (CABANISS GROUP)
KREBS GROUP	BOGGY FORMATION	Secor Rider coal ⚒
KREBS GROUP	BOGGY FORMATION	Secor coal ⚒
KREBS GROUP	SAVANNA FORMATION	Cavanal coal ⚒
KREBS GROUP	McALESTER FORMATION	Upper Booch sandstone ☼
KREBS GROUP	McALESTER FORMATION	Upper McAlester coal ⚒
KREBS GROUP	McALESTER FORMATION	McAlester coal ⚒
KREBS GROUP	McALESTER FORMATION	Middle Booch sandstone ☼
KREBS GROUP	McALESTER FORMATION	Lower Booch sandstone ☼
KREBS GROUP	HARTSHORNE FORMATION	Upper Hartshorne coal ⚒
KREBS GROUP	HARTSHORNE FORMATION	Lower Hartshorne coal ⚒ ☼
KREBS GROUP	HARTSHORNE FORMATION	Hartshorne sandstone ☼
ATOKA FORMATION		Red Oak sandstone ☼
ATOKA FORMATION		Spiro sandstone ☼

Stratigraphy of Krebs Group in Field-Trip Area





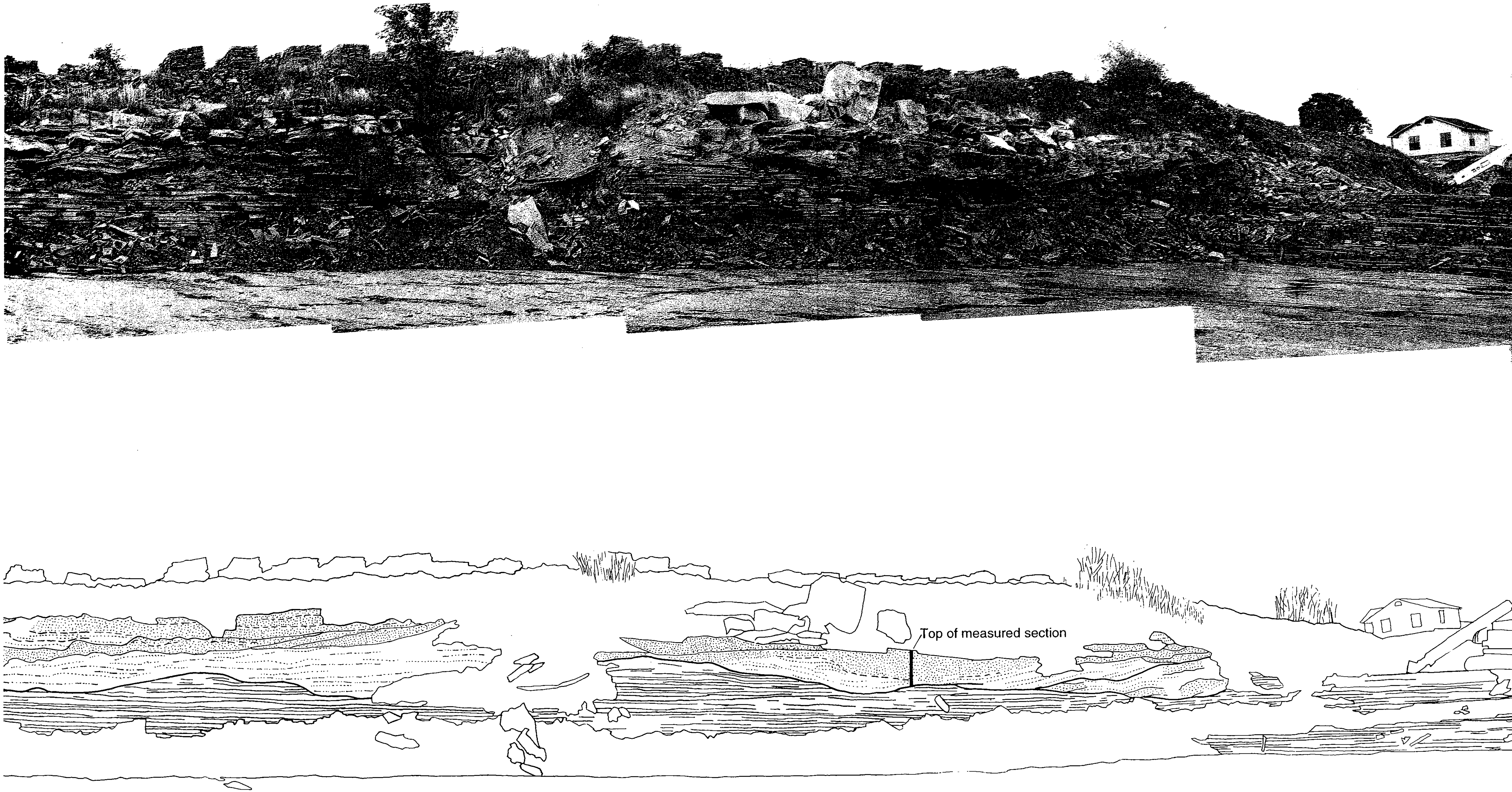
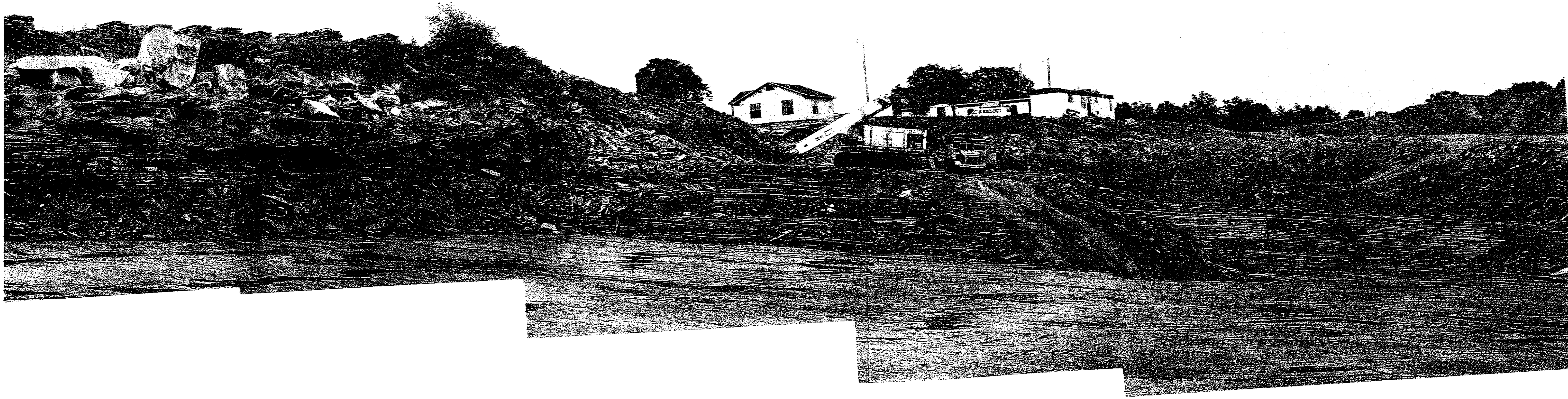
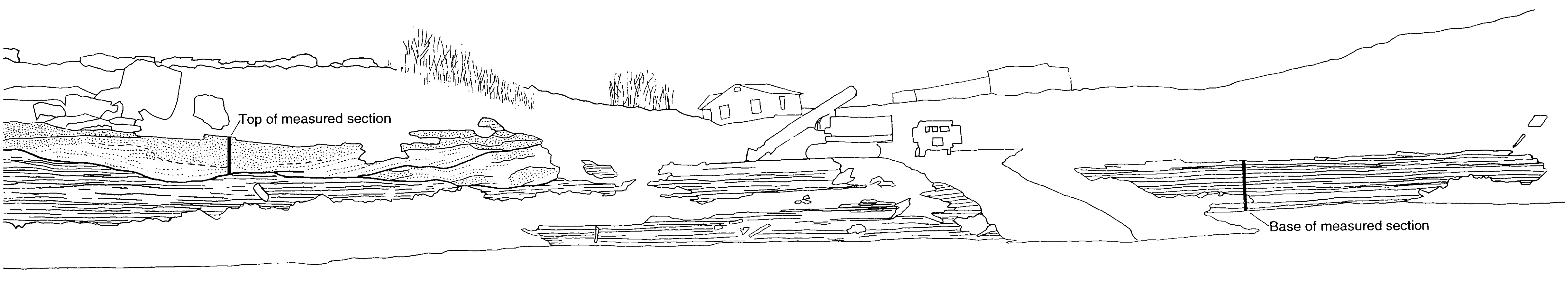


PLATE 1. DISTRIBUTARY CHANNEL IN HARTSHORNE FORMATION, GREEN COUN





NNEL IN HARTSHORNE FORMATION, GREEN COUNTRY STONE QUARRY