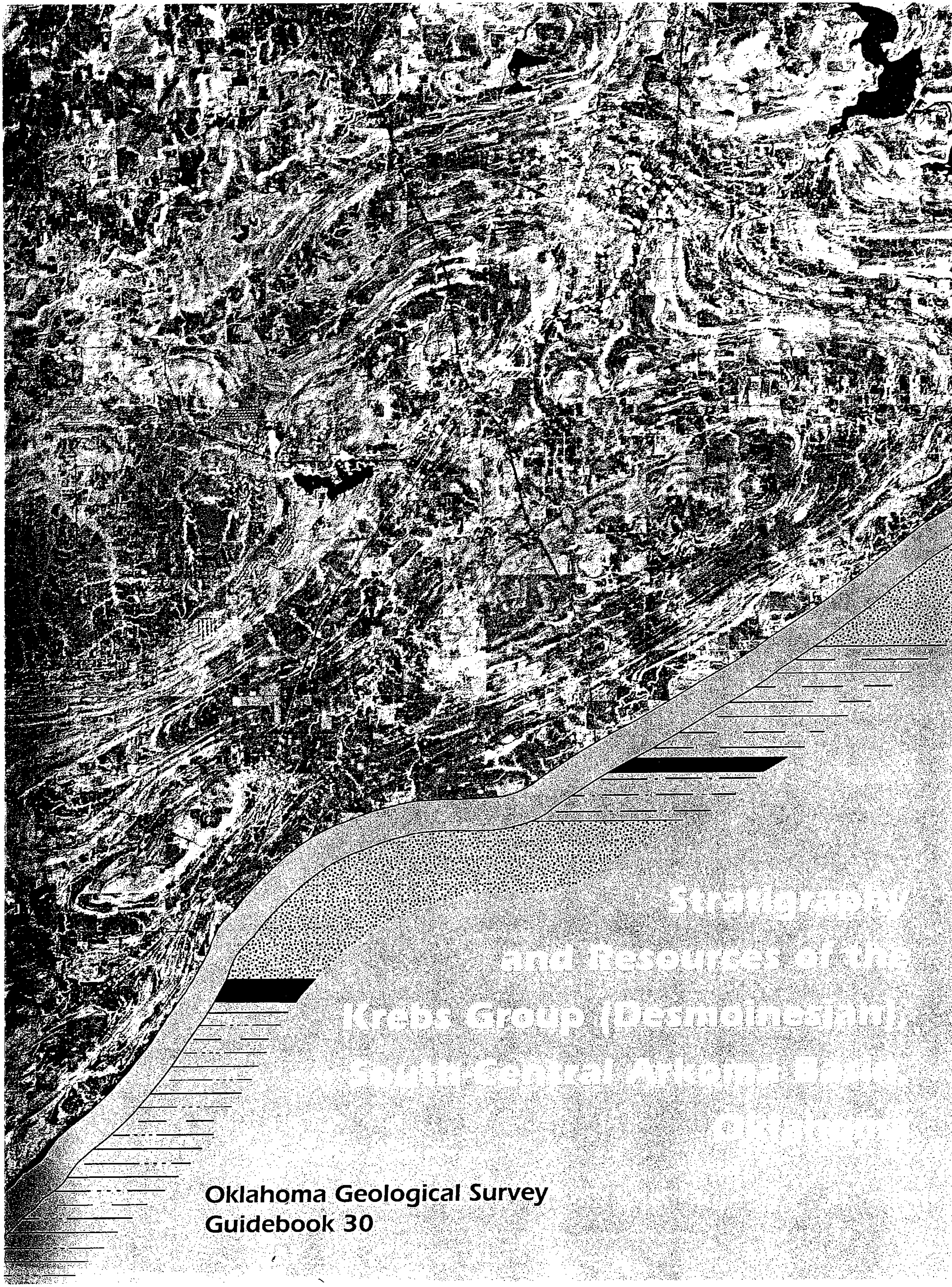

Stratigraphy and Resources of the Krebs Group (Desmoinesian), South-Central Arkoma Basin, Oklahoma

Oklahoma Geological Survey
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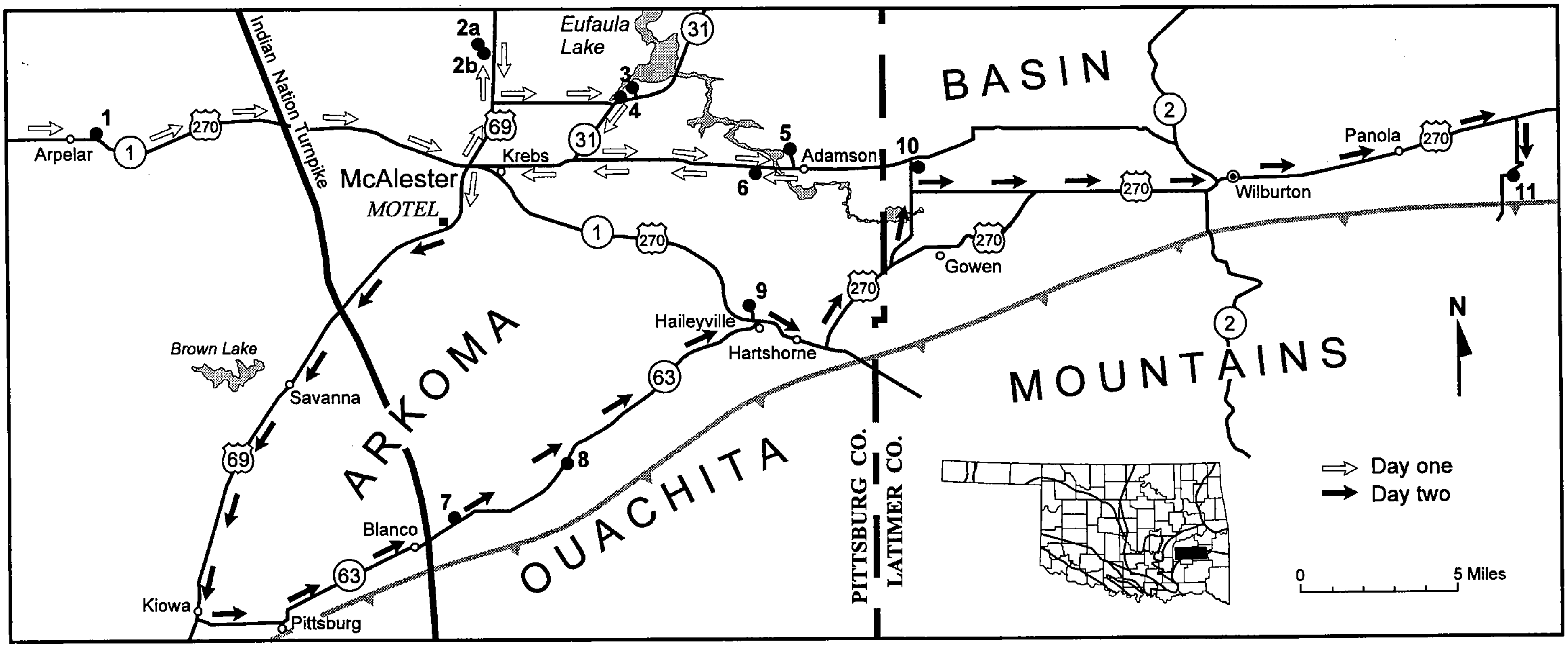
MAP OF FIELD-TRIP STOPS



Oklahoma Geological Survey
Charles J. Mankin, *Director*

Guidebook 30

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Stratigraphy and Resources of the Krebs Group (Desmoinesian), South-Central Arkoma Basin, Oklahoma

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Prepared for
American Association of Petroleum Geologists
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Oklahoma City, Oklahoma

Field Trip No. 1
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The University of Oklahoma
Norman

1997

DEDICATION

LAH dedicates this book to Dr. V. J. Ansfield, the University of South Dakota, whose consummate teaching skills and enthusiasm for earth science, in both the classroom and in the field, inspired me to pursue a career in geology, which has been one of the most rewarding endeavors of my life.

NHS dedicates this book to Dr. Ivo Lucchitta, U.S. Geological Survey, Flagstaff, Arizona. Ivo instilled in me a love for field geology and taught me the simple beauty of a geologic map.

Front Cover

Side-looking radar (SLAR) image of the southern part of the Arkoma basin near McAlester, Oklahoma.

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. 700 copies have been prepared at a cost of $3,083 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) Guidebook 29, "Geology and Resources of the Eastern Frontal Belt, Ouachita Mountains, and Southeastern Arkoma Basin, Oklahoma," which provided information on the area to the east and southeast of the area covered in this volume. OGS Guidebook 30 reports on the stratigraphy and resources of the south-central part of the Arkoma basin. Recent detailed field mapping of lower Desmoinesian strata in the vicinity of McAlester, Oklahoma, provides an opportunity for detailed examination and stratigraphic analysis of numerous outcrops of rocks comprising the Krebs Group in the area. This guidebook was prepared for a two-day field trip (September 13–14, 1997) conducted in conjunction with the American Association of Petroleum Geologists Mid-Continent Section meeting held in Oklahoma City, Oklahoma, September 14–16, 1997.

Coal and natural gas have long been the principal energy resources in this part of the Arkoma basin. Oil is produced from areas just to the north and northwest, along the margin of the Arkoma basin. A recently developed resource is coal-bed methane. It is hoped that the field trip will promote interest in the resource potential of the Krebs Group and provide occasion for discussion of its depositional environments.

Most of the field-trip area has been mapped recently at a scale of 1:24,000 by the authors. These maps are available as uncolored, author-prepared open-file reports from the OGS. They are the most recent in a series of maps that are part of a 12-year-long mapping project in the Ouachita Mountains and Arkoma basin. Appendix 1 is an index map showing the locations of the 7.5′ quadrangles and the names of the authors who completed the geologic mapping. This mapping project was funded by the OGS and the U.S. Geological Survey (USGS), Department of the Interior, as part of the COGEOMAP (Cooperative Geologic Mapping) and STATEMAP programs. Most of the geologic mapping that forms the basis for this guidebook was supported by the USGS under assistance awards 1434-HQ-96-AG-01512, 1434-95-A-01376, and 1434-94-A-1249. It should be noted that the views and conclusions contained in this report are those of the authors and should not be interpreted as necessarily representing the official policies, either expressed or implied, of the U.S. Government.

We would like to thank Brian Cardott, Ken Johnson, Bob Northcutt, and Pat Sutherland for reviewing an early draft of this guidebook. We are grateful to Christie Cooper, OGS editor, and her staff (particularly Frances Young, technical editor, and Tracy Peeters, associate editor), and to T. Wayne Furr, manager, OGS Cartographic Section, and his staff (particularly Jim Anderson), for their efforts in helping with the production of this guidebook. We 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.

LEROY A. HEMISH AND NEIL H. SUNESON
Field-Trip Leaders

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PART I

Summary Papers

Stratigraphy and Resources of the Krebs Group (Desmoinesian), South-Central Arkoma Basin, Oklahoma

INTRODUCTION

THE ARKOMA BASIN

The Arkoma basin is an elongate, arcuate, structural and depositional basin lying just north of the Ouachita Mountains fold-and-thrust belt. It extends from the Arbuckle Mountains of Oklahoma on the west to just northeast of Little Rock, Arkansas, where it is covered by sediments of the Mississippi embayment. It is bounded on the south by the Choctaw fault (in Oklahoma), and by the Ross Creek fault (in Arkansas). The Ozark Mountains and the northeastern Oklahoma shelf (also known as the Cherokee platform) bound the basin on the north (Fig. 1).

The southern part of the Arkoma basin adjacent to the Ouachita Mountains is described by Arbenz (1984) as a compressional fold belt of Pennsylvanian age. The surface geology of the area covered by this guidebook is dominated by broad synclines and relatively tight anticlines. Much of the area, particularly the southern part, is underlain by north-directed thrust faults, many of which are parallel to bedding planes, as well as south-directed backthrusts and "out-of-the-syncline" faults. Structurally, the area forms a classic triangle zone, which is typical of many foreland basins immediately adjacent to fold-and-thrust belts.

Prior to the Atokan, the Arkoma basin was part of an epicontinental shelf on which a relatively thin sequence of shallow-water carbonates and clastics was deposited (Fig. 2). In the middle Atokan, the Arkoma basin developed into a rapidly subsiding, major foreland basin that began receiving deep-water clastic sediments. This thick sequence of dominantly marine beds (Atoka Formation) is generally conformably (but locally disconformably) overlain by deltaic sandstones, siltstones, and coals of the Hartshorne Formation (Krebs Group). The overlying formations in the Krebs Group probably were deposited as prograding deltas and in shallow-marine environments similar to those of the Hartshorne, but the sediments were derived from different source areas.

All of the Morrowan, Atokan, and early Desmoinesian strata preserved in the Arkoma basin were deformed by folding and faulting associated with formation of the Ouachita tectonic belt. Deformation ceased at the end of the early Desmoinesian.

KREBS GROUP (DESMOINESIAN)

The Krebs Group (Desmoinesian) was named by Oakes (1953, p. 1523) for the town of Krebs, in T. 5 N., R. 15 E., central Pittsburg County, Oklahoma. The Krebs Group comprises (in ascending order): the Hartshorne, McAlester, Savanna, and Boggy Formations (Fig. 3). It includes all the strata between the top of the Atoka Formation (below) and the base of the Cabaniss Group (above).

The Krebs Group is overlain by the Thurman Formation, locally the lowest formation of the Cabaniss Group (Fig. 2). The Thurman is overlapped by the Stuart Formation beneath surficial deposits associated with the Canadian River (Oakes, 1953, p. 1525); the Stuart Formation, in turn, is overlapped by the Senora Formation in southwestern Muskogee County.

In Oklahoma, the Krebs Group crops out from the northeast flank of the Arbuckle Mountains northeastward to the Kansas state line, and eastward in the Arkoma basin to Arkansas (Oakes, 1953). The southern limit of the Krebs Group in Oklahoma is immediately north of the Choctaw fault (Fig. 1). Rocks of the group are dominantly dark gray to olive shales, interbedded with sandstones, siltstones, and rare conglomerates. The sandstones typically form resistant ridges, which give the impression that there is more sandstone in the group than actually is present. The Krebs Group also contains some thin, lenticular limestone beds, as well as all of the important commercial coal beds in the

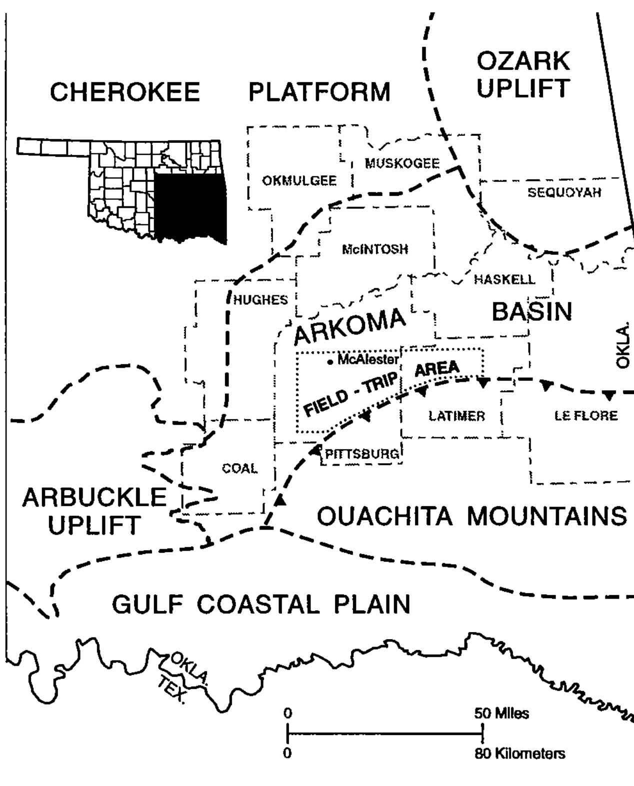


Figure 1. Map of eastern Oklahoma showing field-trip area and major geologic provinces (modified from Northcutt and Campbell, 1996). Choctaw fault shown with sawtooth pattern; other province boundaries shown as dashed lines.

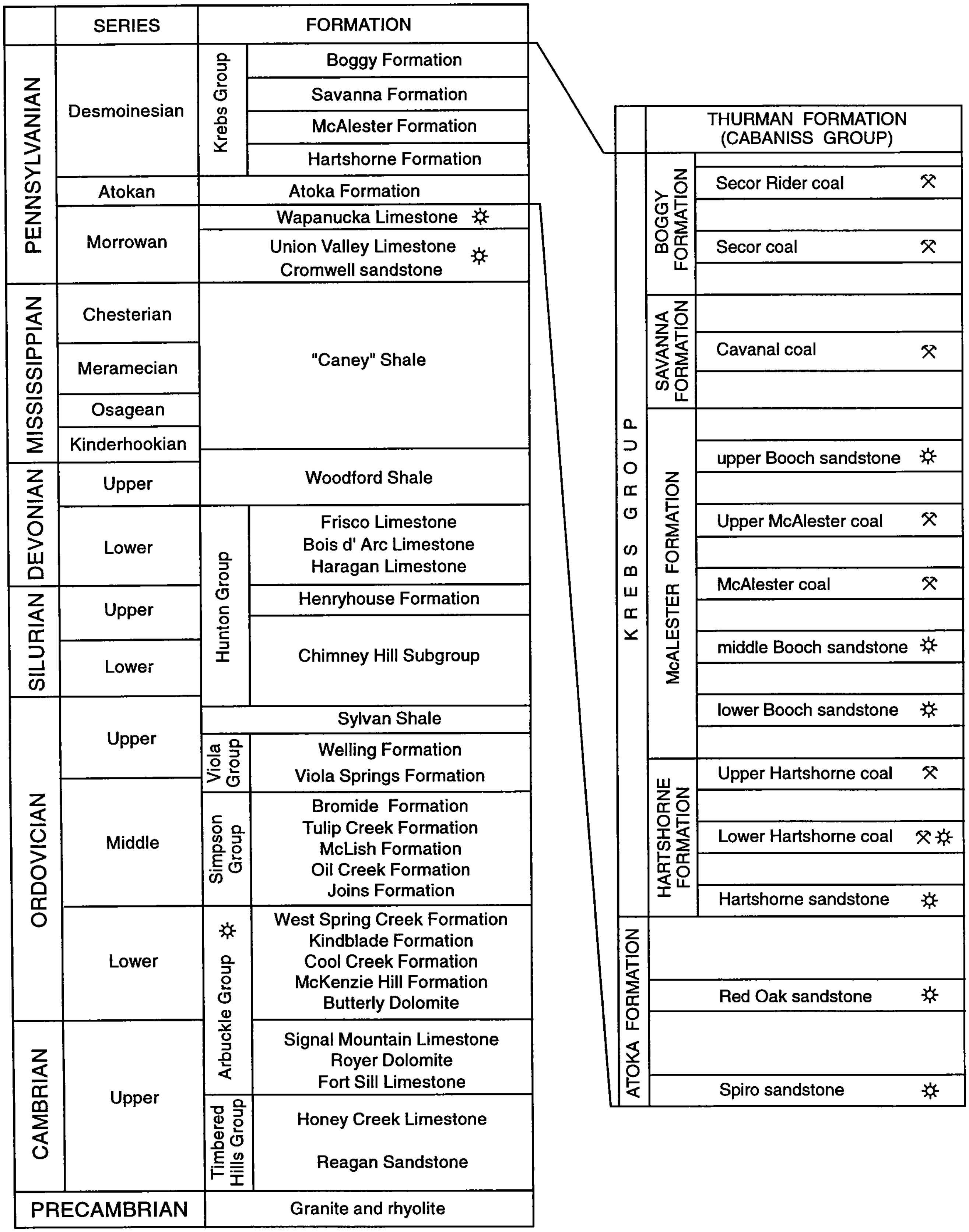


Figure 2. Stratigraphic chart for the Arkoma basin in the field-trip area showing principal coal beds and petroleum-producing units. Left column (from Johnson, 1988) shows detailed stratigraphy of lower and middle Paleozoic units present only in the subsurface. Right column shows relative position of principal gas reservoirs (☼) and coal beds (⚒). (Note: The positions of the Booch sandstones relative to the McAlester coal are uncertain over the field-trip area.)

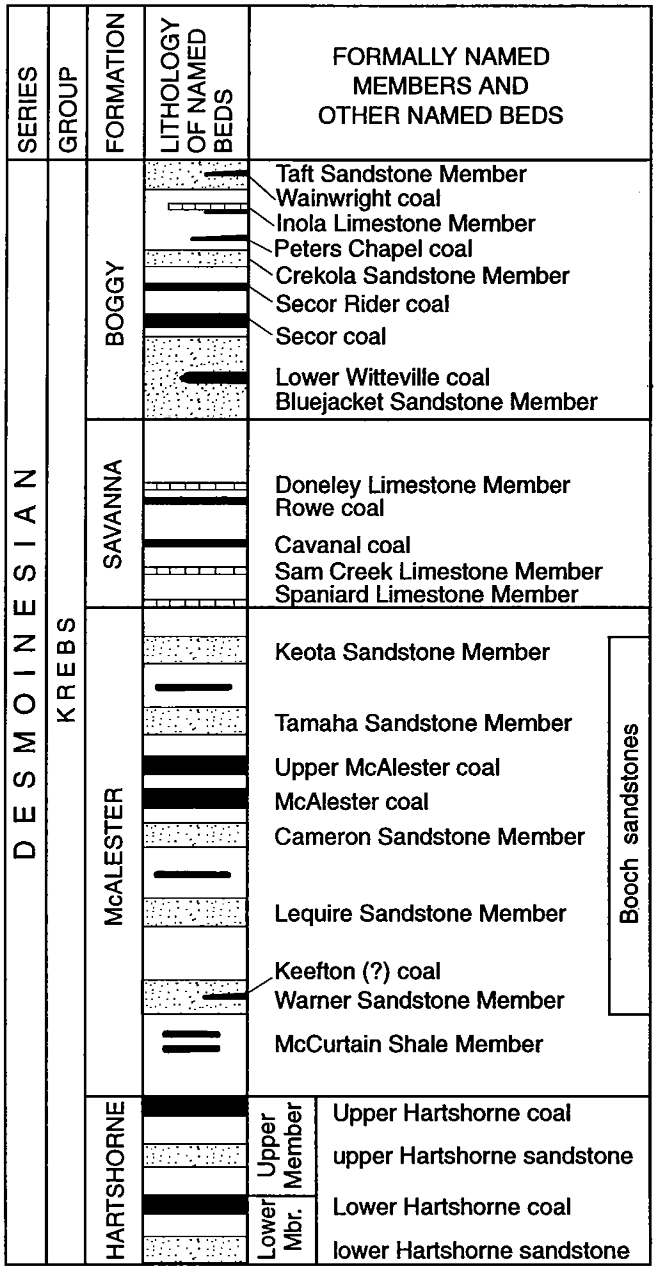


Figure 3. Generalized stratigraphic column of the Krebs Group showing the relative position of formally named members, names of coal beds, and other informally named beds. Discontinuous, unnamed sandstones are omitted from the column. (See note, right column, this page, for discussion of capitalization and formally described units.)

Arkoma basin (except for limited reserves of the Croweburg coal [Senora Formation, Cabaniss Group] in the extreme northwestern part of the basin).

The Krebs Group is ~6,000 ft thick west of McAlester. It thickens in the eastern part of the Arkoma basin, and is >8,000 ft thick near Poteau. The Krebs Group is much thinner southwestward, along the flanks of the Arbuckle Mountains. It is also thinner northward, being only 340 ft thick along the Kansas-Oklahoma line (Oakes, 1953).

The Krebs and Cabaniss Groups in Oklahoma are approximately equivalent to the Cherokee Group of southeastern Kansas, which comprises the Krebs and Cabaniss Formations (Brady and others, 1994). However, some of the lower units of the Krebs Group in Oklahoma are older than the Cherokee rocks of Kansas, where they probably are not present or are too thin to be identifiable (Oakes, 1953). The Krebs Formation of Kansas lies unconformably on the Mississippian erosion surface just north of the Oklahoma border (Brady and others, 1994).

REGIONAL RESOURCES

Natural gas is the principal geologic resource of the Arkoma basin. Coal, aggregate, building stone, and coal-bed methane are currently minor resources; in the past, coal was a major resource, and coal-bed methane has the potential to become a significant resource.

Natural gas has been exploited in the vicinity of McAlester since the early 1900s. The most recent peak in drilling activity occurred from the late 1980s to the early 1990s. The major gas reservoirs in the field-trip area range in age from Ordovician to Pennsylvanian (Desmoinesian) and include (from oldest to youngest): Arbuckle Group carbonates, Cromwell sandstone, Wapanucka Limestone, Spiro sandstone, Red Oak sandstone, Hartshorne sandstone, and Booch sandstones (Fig. 2).

Several workable Desmoinesian coal beds are present in the Arkoma basin. The most important ones (from oldest to youngest) are: Lower Hartshorne, Upper Hartshorne, McAlester, Upper McAlester, Cavanal, Secor, and Secor Rider (Fig. 2). Historically, coal mining has been an important part of the economy of the McAlester area, since the coming of the railroads into Indian Territory; today, the industry is dormant in the south-central part of the Arkoma basin. However, several active mines are producing coal in the eastern part of the Arkoma basin of Oklahoma. The bulk of that production is used to supply the needs of the AES Shady Point co-generation power plant north of the City of Poteau.

Note: Correct use of stratigraphic nomenclature is important, particularly because three of the four formations in the Krebs Group were named in the field-trip area. In this guidebook, both formal and informal names are used for surface and subsurface units. Only those units that have been formally described from surface outcrops (e.g., the Warner Sandstone Member) are capitalized. Informal surface units are not capitalized, even if the unit is widespread, easily recognized, and the name is commonly used (e.g., the Spiro sandstone and the Hartshorne coal). Similarly, names used for subsurface units (e.g., the Booch sandstone) are not capitalized.

In some cases, the name of a formation has been changed or raised (e.g., the originally defined Hartshorne sandstone is now recognized as the Hartshorne Formation). In this book, only the currently accepted name (Hartshorne Formation) is capitalized, even though the original term (Hartshorne sandstone) was recognized for many years.

Locations in this guidebook use standard section-township-range abbreviations. Rock-color terms are those shown on the rock-color chart (Rock-Color Chart Committee, 1991).

HARTSHORNE FORMATION (DESMOINESIAN), ARKOMA BASIN, OKLAHOMA

GENERAL

The Hartshorne (pronounced HARTS-horne) Formation is the basal Desmoinesian (middle Pennsylvanian) unit in the Arkoma basin of Oklahoma and Arkansas (Figs. 2, 3). It is the oldest formation in the Krebs Group, which includes (from oldest to youngest) the Hartshorne, McAlester, Savanna, and Boggy Formations. 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. 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 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.

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

In the southern part of the Arkoma basin, 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.

The different rock types in the Hartshorne Formation vary in thickness. The lower Hartshorne sandstone is relatively continuous, but it varies from many tens of feet thick to barely identifiable. The Lower Hartshorne coal is also relatively continuous, but it thins over those areas where the lower sandstone is thickest or where channels filled with the upper sandstone have eroded it (Houseknecht and Iannacchione, 1982). The upper Hartshorne sandstone is discontinuous and varies from zero to a few tens of feet thick. 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 upper Hartshorne sandstone in northern Le Flore County, and Rieke and Kirr (1984) reported the Hartshorne coal locally consists of three separate beds in the McAlester district.

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 immediately 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."

> 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. (Branson, 1956, p. 96)

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.

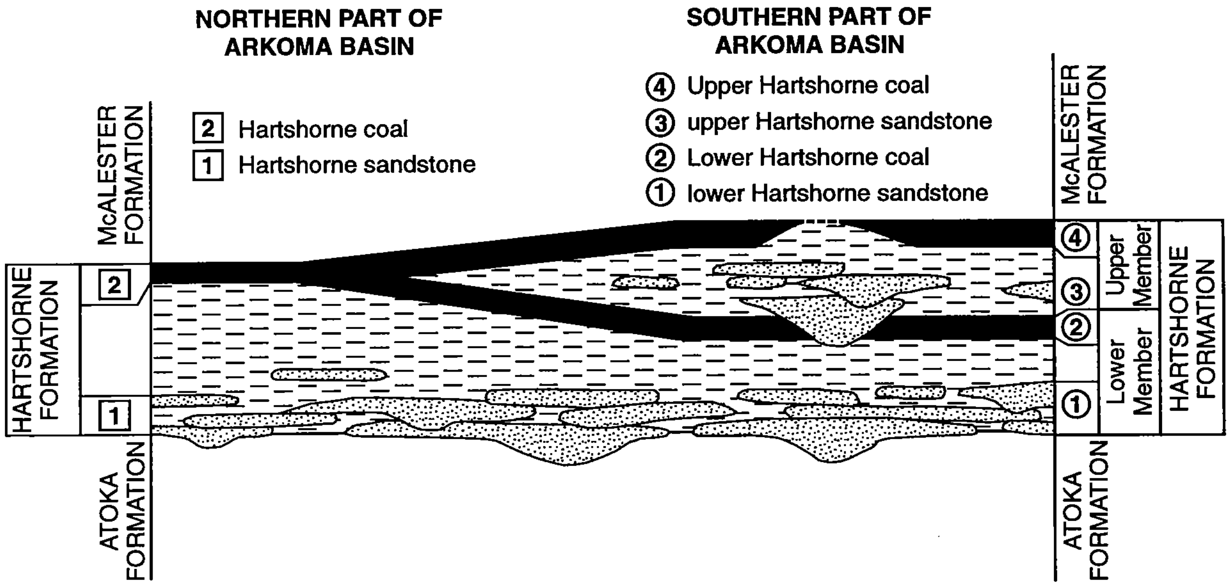


Figure 4. General relationship of different stratigraphic units (formal and informal) that constitute the Hartshorne Formation in the northern and southern part of the Arkoma basin in Oklahoma. Note: Locally (including areas within the field-trip area) the Upper Hartshorne coal merges with the Lower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

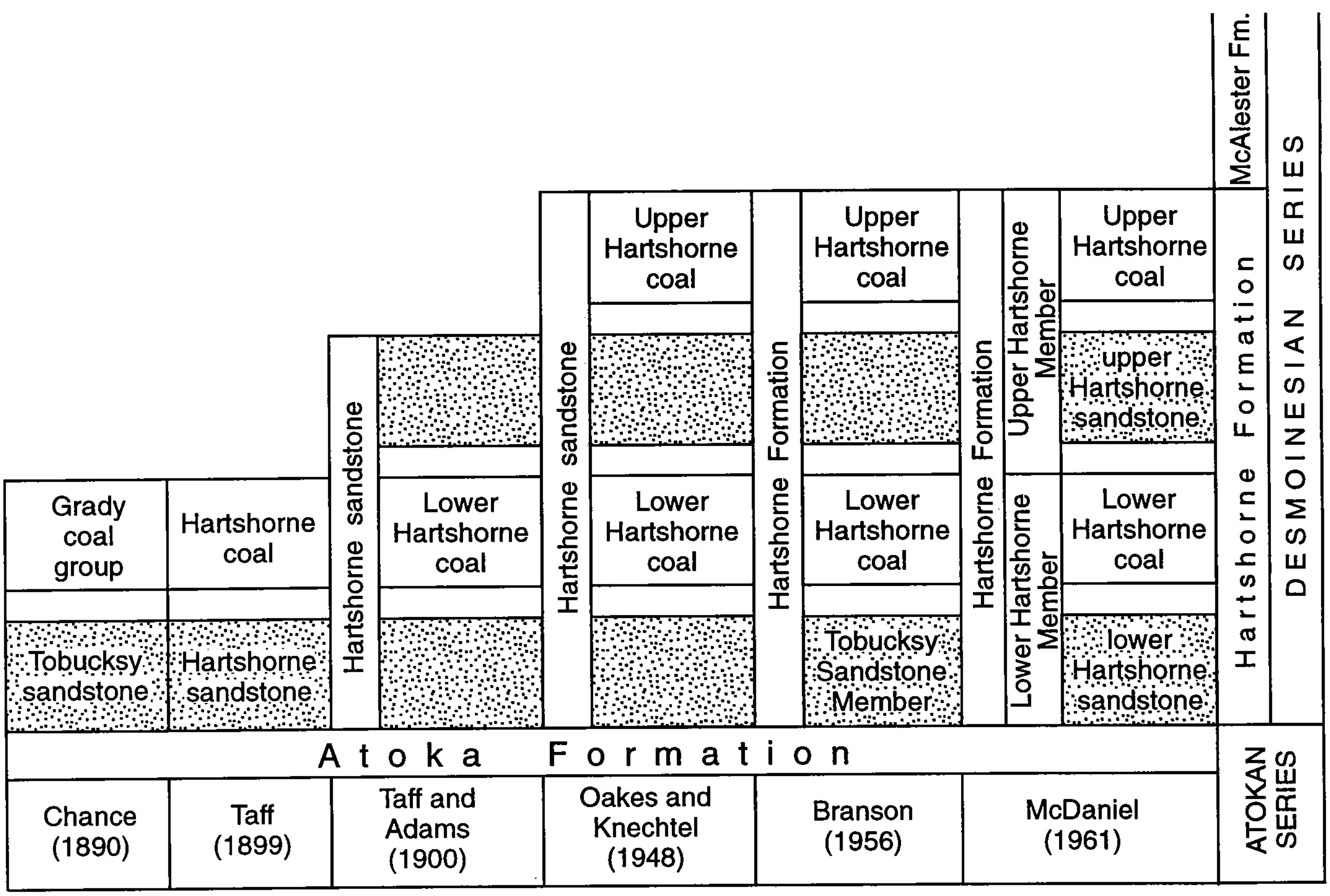


Figure 5. History of nomenclature and definitions of the Hartshorne Formation, 1890–1961. (Modified from Suneson and Hemish, 1994, p. 58.) This report follows the terminology proposed by McDaniel (1961).

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 locally divided. 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 suggested 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 coal (Fig. 5). Branson (1956) 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. (Branson, 1956, p. 96)

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 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 AND THICKNESS

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 center part of the basin occur on the flanks or 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 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 Hartshorne. 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, 1961b). 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 ft 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 ft 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.

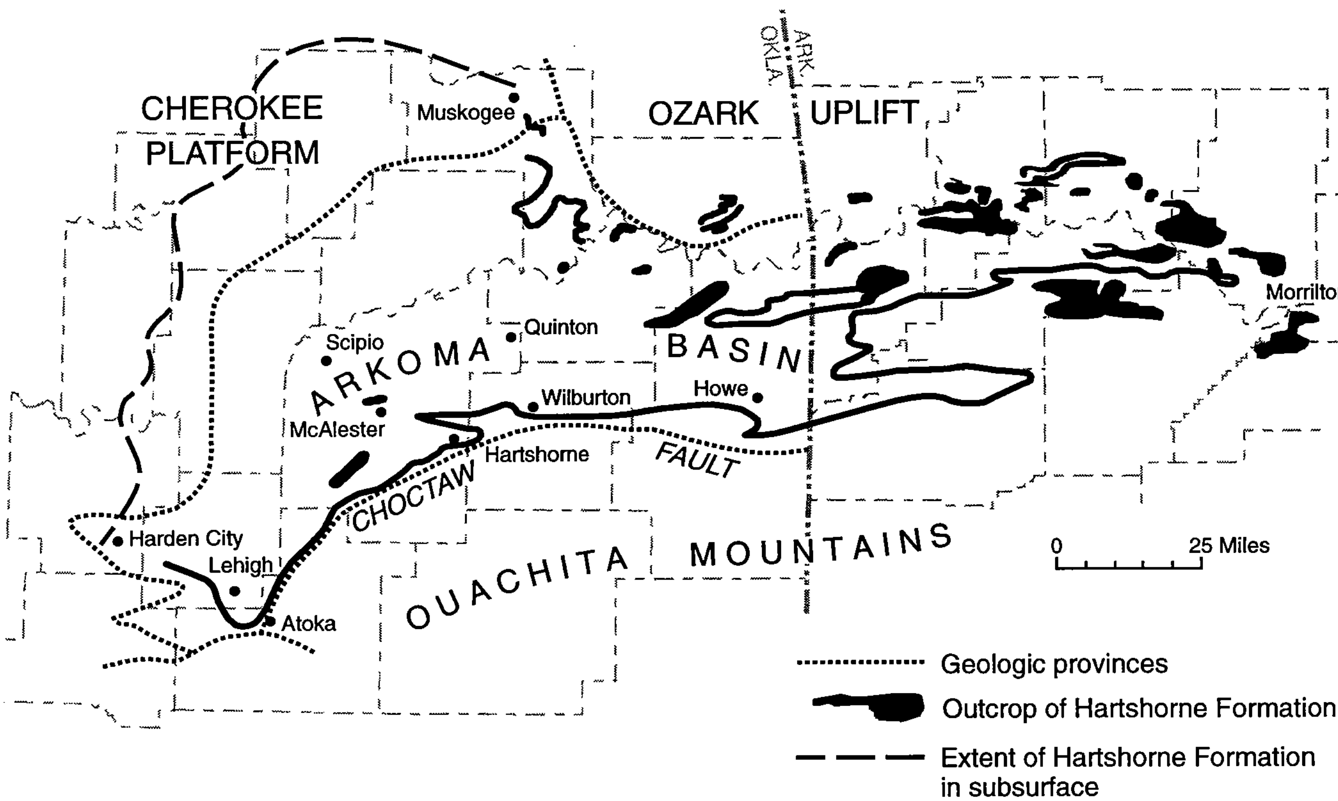


Figure 6. Map showing outcrop pattern of the Hartshorne Formation in Arkansas and Oklahoma. Dashed line is western extent of Hartshorne based on well penetrations reported on Oklahoma Corporation Commission form 1002-A. Dotted lines are margins of geologic provinces in Oklahoma, based on Northcutt and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

In Oklahoma, the contact between the Hartshorne Formation and the underlying Atoka Formation is conformable to disconformable. The overlying McAlester Formation mostly conformably overlies the Hartshorne (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, it appears that the McAlester paraconformably overlies the Atoka. 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 Formation. 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). 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 to be 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 heterogenous 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 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 ft and 5.6 ft, respectively, in the McAlester district and ~7 ft 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 of >1,500 ft in northern Le Flore County. Coal analyses are reported by Hendricks (1937a) and Hendricks (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

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 the 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 suggested to them 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, and they suggested that it probably represents 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. (Scruton, 1950, p. 420)

> The site of deposition was a region where a river, or group or [sic] 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. (Scruton, 1950, 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 immediately 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, channel-form 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 channel-form 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 Atoka Formation has been 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.

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. 7), and Houseknecht and others (1983) and Houseknecht and others (1984) mapped the subsurface distribution of the different Hartshorne lithofacies throughout the Arkoma basin. 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 (1961b) 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 suggested 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 have 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.

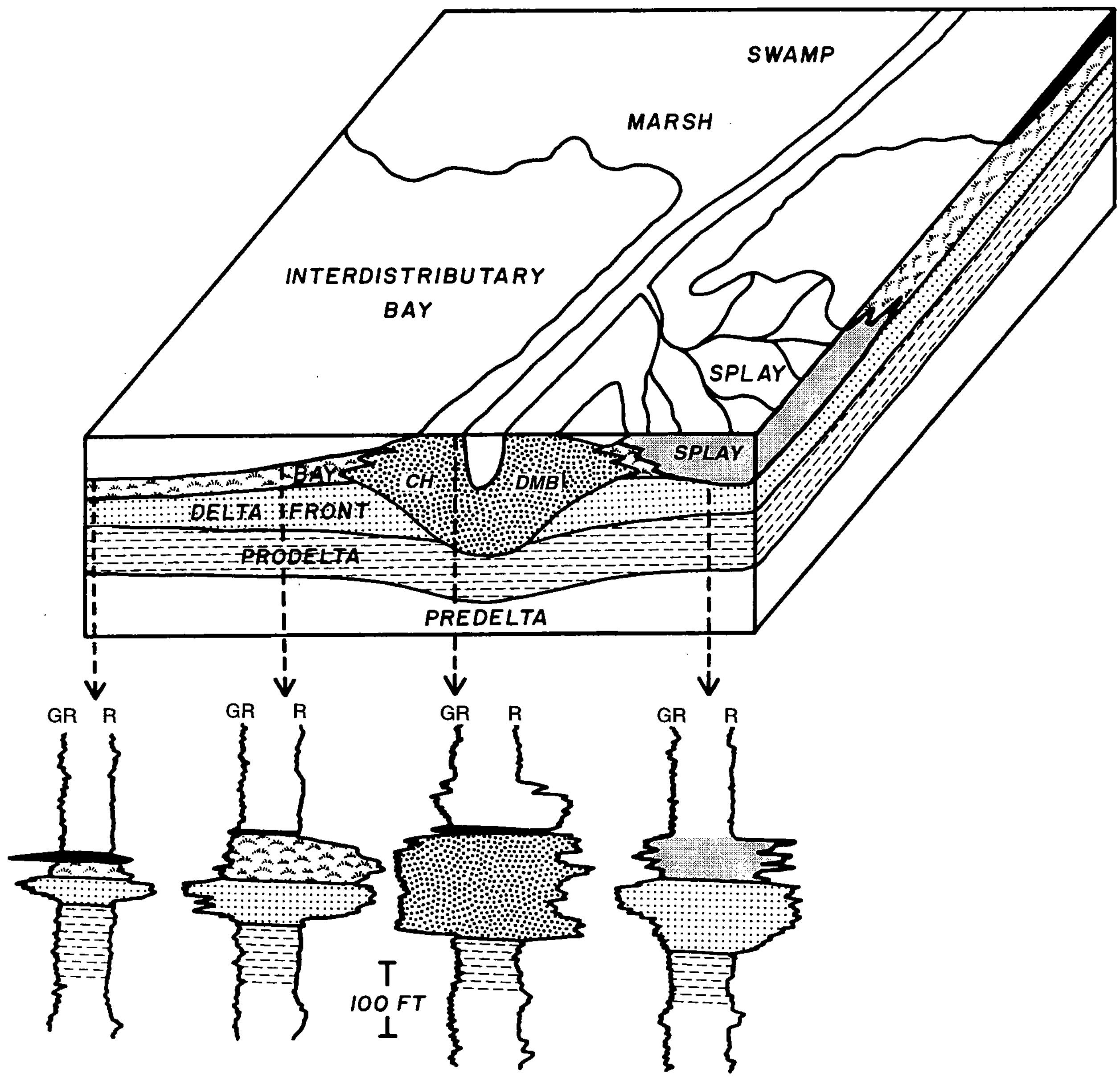


Figure 7. Idealized block diagram of Hartshorne deltaic environments and facies showing typical gamma-ray and resistivity log responses. (From Houseknecht and others, 1983, p. 59; reproduced courtesy Midcontinent SEPM.)

RESOURCES

Coal

Although coal in Oklahoma was first reported on 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 have been published by the U.S. Geological Survey (Hendricks, 1937a; Hendricks, 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 have been described by Hemish (in press, a). 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 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 1 shows the total

TABLE 1. — HARTSHORNE COAL MINED AND LOST IN MINING[1] (thousands of short tons)

County	Lower Hartshorne	Upper Hartshorne	Hartshorne[2]
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

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

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 were produced from the Lower Hartshorne coal and 43,804 short tons from the Hartshorne coal (S. A. Friedman, unpublished data, 1996). This represents ~20% of Oklahoma's total coal production for that year. The Hartshorne coal was produced only in Le Flore County in 1995.

Friedman (1991) (based on Friedman [1974]) estimates the Hartshorne coal bed 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.

Coal-Bed Methane

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 1.6 MMcf of methane in 24 hours. Methane emission reached 400 Mcf/day 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.

The first production of coal-bed methane from the Hartshorne coal occurred 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 coal-bed-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 coal-bed-methane wells in the Arkoma basin and the number of wells they have drilled are: Amoco (18), Aztec Energy (12, includes one McAlester well), Bear Production (39), Continental Resources (11), CWF Energy (8), OGP Operating (18), ONEOK (6, includes three McAlester wells), and Redwine (43). (Note: The Amoco and ONEOK totals are unconfirmed as exclusively coal-bed-methane wells.)

Figure 8 shows the location of most of the Hartshorne coal-bed-methane development in the Arkoma basin. Production rates vary from about 25 Mcf/day to 250 Mfc/day with little or no water (Forgotson and Friedman, 1993). There is no apparent relation between coal-bed-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 coal-bed-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 Bcf methane. They considered this estimate 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 Tcf 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 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 methane at 500–3,000-ft depths, and an additional 1.2 Tcf methane at 3,000–7000-ft depths. Based on a revised estimate of Hartshorne coal resources, Gossling (1994) identified 3.1–3.5 Tcf methane in the Hartshorne coals in the eastern and central parts of the Arkoma basin in Oklahoma.

Natural Gas

The discovery of gas in sandstones in the Hartshorne Formation occurred in 1910 in Le Flore County. The discovery well for the Poteau-Gilmore field is 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, there were 59 producing wells in the 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 1,300–1800-ft depths (Knechtel, 1949, p. 57). Gas in the Hartshorne was discovered in the nearby Gilmore field by the Le Flore County Gas and Electric Co. No. 9 Tucker, located 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. 9): 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,

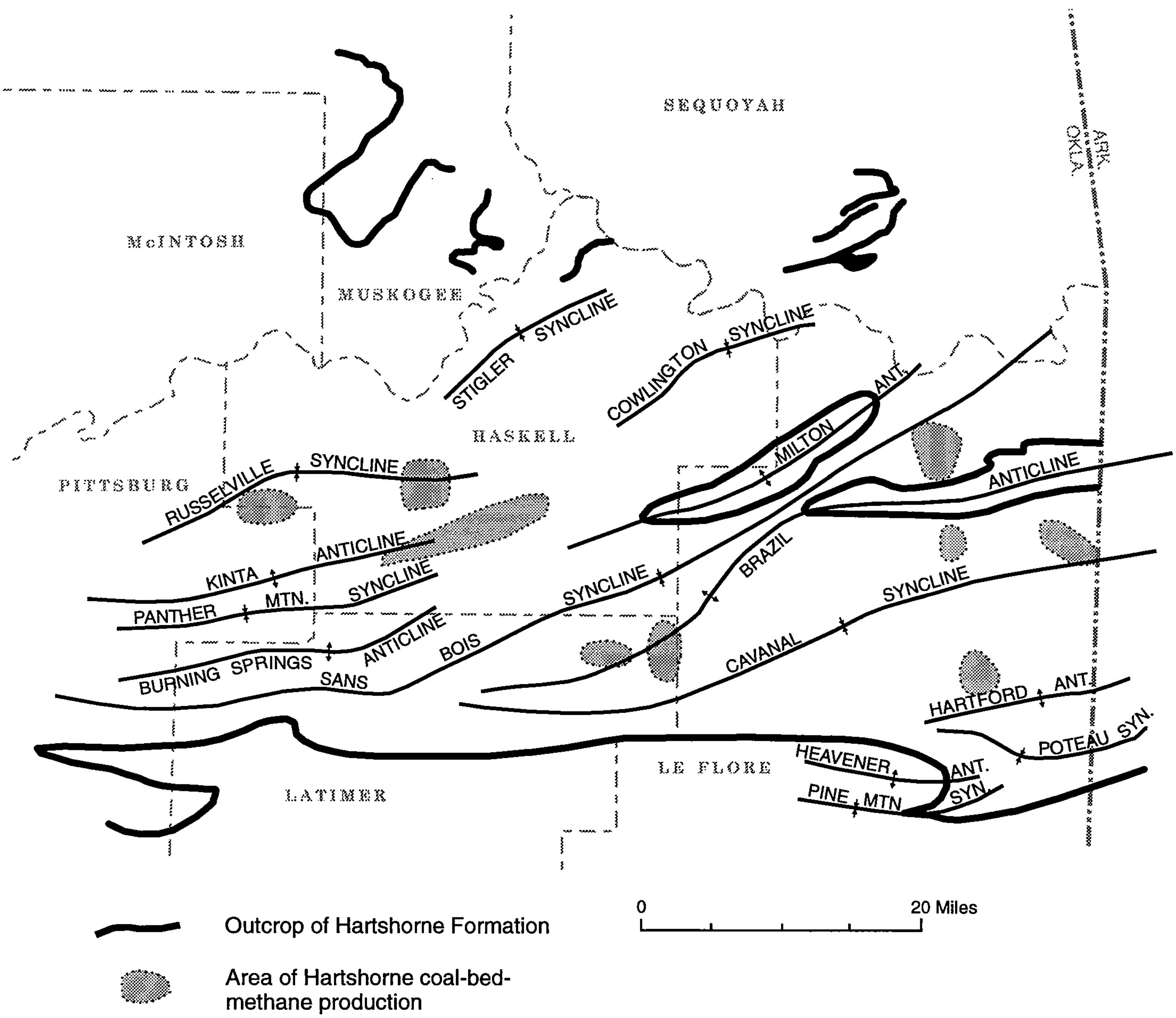


Figure 8. Map showing major surface folds and locations (pattern) of coal-bed-methane production from the Hartshorne Formation. Also shown are surface exposures (heavy line) of the Hartshorne.

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 the South Pine Hollow field by the Carter No. 1 Morris (sec. 24, T. 5 N., R. 12 E.) in 1959 and subsequent analysis by McDaniel (1968) showed that distributary-channel sandstones 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 suggested that most production from sandstones in the Hartshorne Formation occurs where the relatively thick distributary-channel sandstones cross anticlines in the Arkoma basin. Fields (1987) noted that gas production in the Southeast Reams field is from an east-west-trending distributary channel where it crosses the crest of the Flowery Mound anticline. The West McAlester field produces from where an east-west-trending Hartshorne channel crosses the McAlester anticline, and the Northeast Savanna field produces from

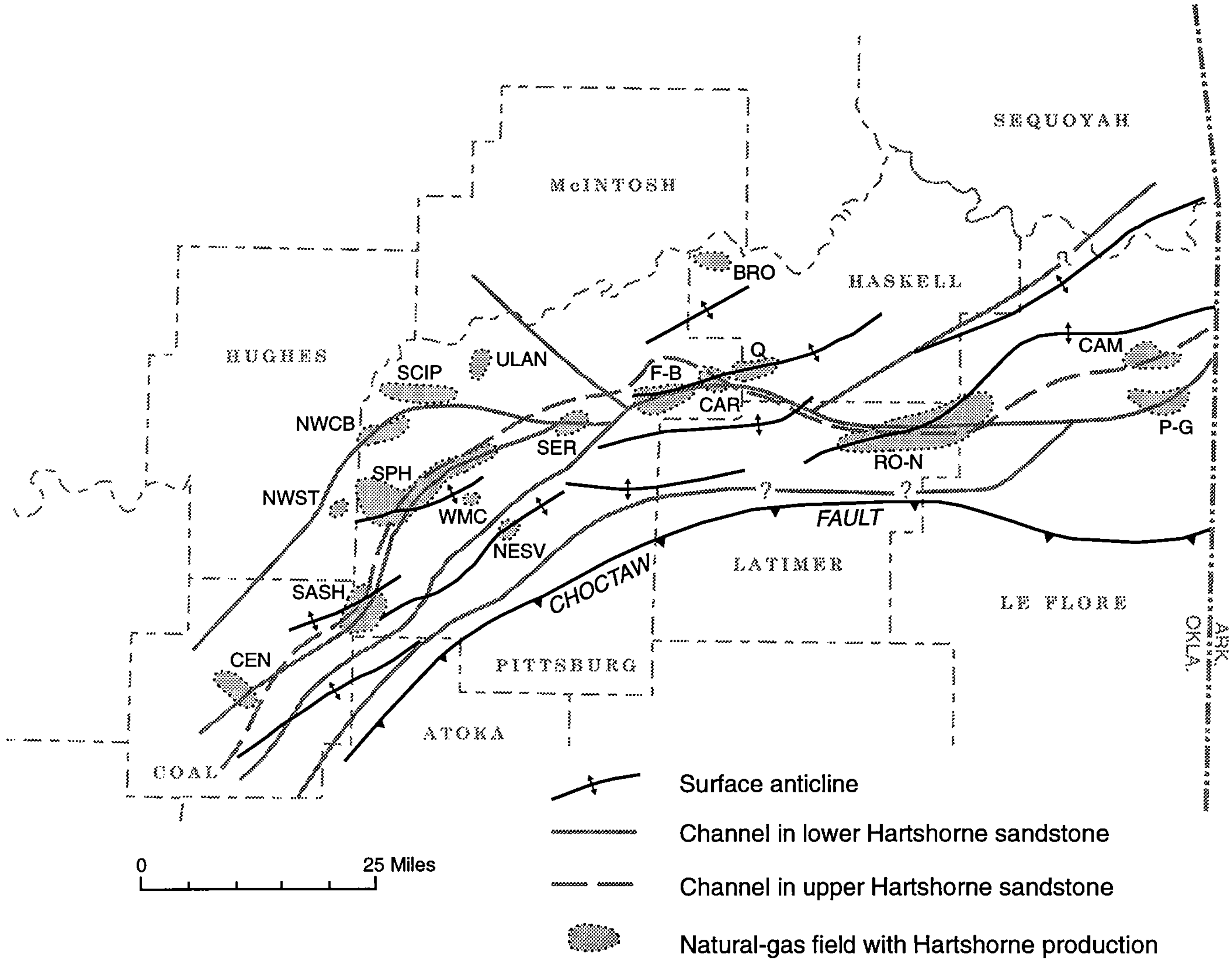


Figure 9. Map showing: (1) **major surface anticlines** (black lines with divergent arrows) (from Arbenz, 1989, pl. 8); (2) **major distributary channels in the Hartshorne Formation** (lower Hartshorne sandstone = solid gray line; upper Hartshorne sandstone = dashed gray line) (from Houseknecht and others, 1983, fig. 12); and (3) **gas fields with Hartshorne production** (patterned areas) (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) are: 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.

where a northeast-southwest channel crosses the Savanna anticline.

Fields (1987) also noted that the Hartshorne produces from crevasse-splay deposits. Gas fields where this occurs are Northwest Scipio (updip pinch-out), Ulan (structural high), and Northwest Cabaniss (updip pinch-out).

There are several possible sources for the natural gas in the Hartshorne sandstones: 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 the Cameron and Poteau-Gilmore fields was derived from the coal; in contrast, the gas in the Quinton field was derived from organic material in the adjacent shales, possibly with some gas coming from the coal (Iannacchione and Puglio, 1985).

McALESTER FORMATION (DESMOINESIAN), ARKOMA BASIN, OKLAHOMA

GENERAL

The McAlester Formation is the second oldest of the four formations that make up the Desmoinesian Krebs Group in the Arkoma basin of Oklahoma and Arkansas. It mostly conformably overlies the Hartshorne Formation and conformably underlies the Savanna Formation (Fig. 3). In general, the base of the McAlester is mapped at the top of the Upper Hartshorne coal or at the top of the Hartshorne coal, where the Upper and Lower coals have merged. The top of the McAlester Formation is at the base of the lowest massive sandstone of the Savanna Formation. In most places, the contact with the Savanna is gradational and conformable; locally, however, the basal sandstone unit of the Savanna Formation is deposited in channels eroded into the McAlester. Where this occurs, the contact is a paraconformity.

Most of the McAlester Formation consists of poorly exposed shale; as a result, the McAlester typically forms valleys between ridges or mountains underlain by the sandstone-rich Hartshorne and Savanna Formations. The formation also includes several moderately to poorly exposed sandstone beds of varying thickness, extent, and continuity, which generally form low ridges or hills in what would otherwise be a relatively flat valley floor. In the extreme southern part of the Arkoma basin, chert conglomerate beds are present. Several coal beds are also present and, like the sandstones, vary greatly in character. The thickest and most continuous coal bed has been mined locally.

The McAlester Formation is divided into six named members (from bottom to top): the McCurtain Shale, the Warner Sandstone, the Lequire Sandstone, the Cameron Sandstone, the Tamaha Sandstone, and the Keota Sandstone (Fig. 3). The sandstone members are separated by unnamed intervals that consist mostly of shale. The members are discontinuous to varying degrees, locally merge (e.g., Warner-Lequire), and locally split (e.g., upper and lower Warner Sandstones). The McAlester Formation in the Arkoma basin also contains three named coal beds: the Keefton(?) coal is within the Warner Sandstone Member; the McAlester (Stigler) coal immediately overlies the Cameron Sandstone Member; and the Upper McAlester (Stigler Rider) overlies the McAlester (Stigler) coal. The McAlester also contains many thin, discontinuous coal beds. There are more named coals in the McAlester Formation on the Cherokee platform area north of the Arkoma basin, but that area is beyond the scope of this report.

In the subsurface, some of the McAlester sandstones are referred to as the Booch sands or sandstones (Fig. 3). In most places, the Warner (or Warner-Lequire, where the two have merged) is called the lower Booch and the Cameron is called the upper Booch. Locally, however, the Cameron is called the middle Booch and the Keota is called the upper Booch. The Booch sands are important oil- and gas-producing units in the Arkoma basin and eastern Cherokee platform. In this paper, the names "Warner," "Cameron," and "Keota" will be used when referring to surface outcrops and "Booch" will be used when discussing subsurface studies.

The sandstone members of the McAlester Formation vary in thickness from several hundred feet to barely identifiable or absent. The McAlester (Stigler) coal is relatively continuous and serves as an important marker bed in the formation.

HISTORY OF NOMENCLATURE

The McAlester Formation was originally named by Taff (1899, p. 437), who called it the McAlester shale (Fig. 10). Taff (1899) divided it into three parts: a lower part dominated by shale and containing the Hartshorne coal at its base, a middle part containing three to four sandstone beds, and an upper part containing mostly shale with the McAlester coal near its base. Presumably, Taff (1899) named the McAlester shale for exposures near the town of McAlester, but it is equally plausible that he named it for the McAlester coal, which was named by Chance (1890). A year later, Taff and Adams (1900) recognized that the Hartshorne coal consisted of two coal beds ("upper" and "lower") and regarded the Upper Hartshorne coal as the basal unit of the McAlester shale.

The southern part of the Arkoma basin was mapped by Hendricks (1937a), Knechtel (1937), and Hendricks and others (1936). These authors accepted the terminology and definition of the McAlester shale as established by Taff and Adams (1900) and included the Upper Hartshorne coal as well as the immediately underlying shale (all rocks above the sandstones in the Hartshorne Formation) at its base (Fig. 10). In addition, Hendricks (1937a) accepted the three-part division of the McAlester described by Taff (1899), but noted that the middle part contained as many as five sandstone "members" and that all parts contained coal beds. Knechtel (1937) reported four widespread and relatively continuous sandstones in the McAlester shale in the Lehigh coal district.

The widely recognized sandstones within the McAlester shale were first "named and assigned member status in 1927 by Thom (1935)" (in Russell, 1960, p. 14), but this work evidently was unpublished. Wilson (1935) and Wilson and Newell (1937), acknowledging Thom's work, recognized the same sandstone members, and named them (from oldest to youngest), the McCurtain Shale Member, the Warner Sandstone Member, the Lequire Sandstone Member, the Cameron Sandstone Member, the Stigler coal, the Tamaha Sandstone Member, and the Keota Sandstone Member. Wilson (1935) and Wilson and Newell (1937), however, included the Tamaha and Keota in the overlying Savanna sandstone and the Upper Hartshorne coal in the McAlester shale (Fig. 10).

Oakes and Knechtel (1948) and Knechtel (1949) formally raised the rank of the McAlester shale to McAlester Forma-

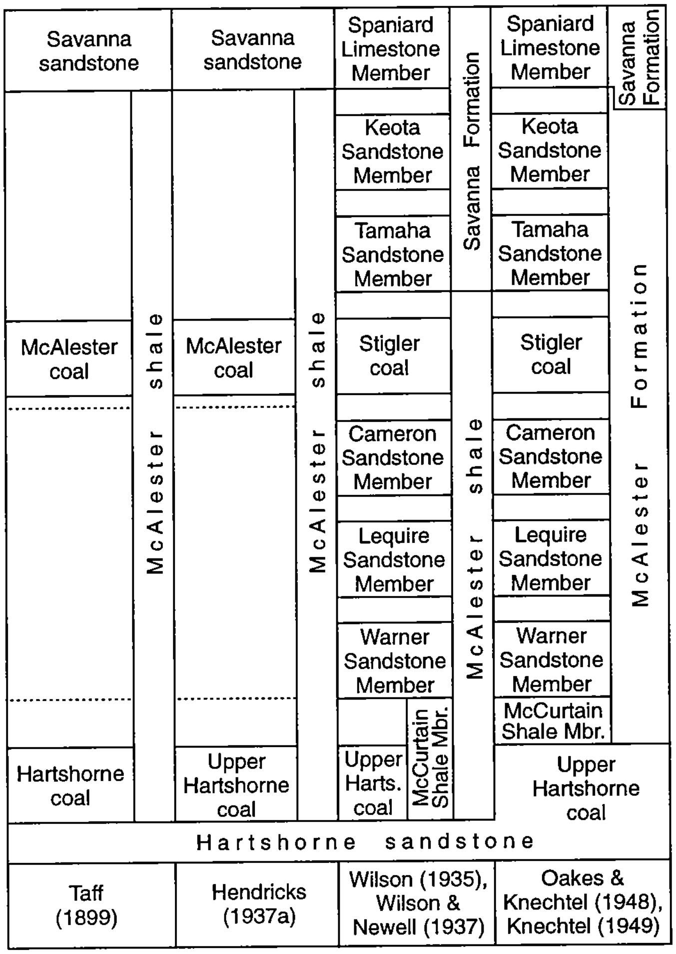


Figure 10. History of nomenclature and definitions of the McAlester Formation, 1899–1949. The definition proposed by Oakes and Knechtel (1948) and Knechtel (1949) is followed in this report.

tion (Fig. 10). They also included the Tamaha and Keota Sandstone Members, as well as the unnamed shale unit immediately overlying the Keota, in the McAlester Formation. This redefinition of the sandstone members of the McAlester Formation was based on new mapping by Oakes and Knechtel (1948), which connected the Muskogee-Porum area studied by Wilson and Newell (1937) with the "type area" originally defined by Taff (1899) and mapped by Hendricks (1937a). At present, most, if not all, geologists working in the Arkoma basin of Oklahoma accept the definition of the McAlester Formation by Oakes and Knechtel (1948, p. 27):

> The base is redefined as the top of the Upper Hartshorne coal....The McAlester-Savanna contact in Haskell County and northern Le Flore County is here defined as the top of the first shale unit above the Keota sandstone member, and over most of these two counties it is equivalent to the contact as mapped by Taff in the vicinity of Savanna, Pittsburg County, and extended by Taff and Adams, and later by Hendricks to the vicinity of Poteau, Le Flore County.

Oakes and Knechtel (1948, p. 48) described the base of the Savanna Formation as follows:

> The actual contact [McAlester-Savanna], equivalent to that in the vicinity of Savanna, is shown approximately on the accompanying geologic map by a dotted line drawn below and essentially parallel to the base of a sandstone unit which is unquestionably in the Savanna and is probably equivalent to the "Spiro" sandstone mapped by Wilson in Muskogee County. Such evidence as we have seems to indicate that the actual contact so indicated falls approximately at the stratigraphic position of the base of the Spaniard Limestone Member of the Savanna, also mapped by Wilson in Muskogee County.

Recent 1:24,000-scale OGS geologic maps of the southern part of the Arkoma basin (Appendix 1) recognize the individual sandstone members of the McAlester Formation: Warner (locally upper and lower), Lequire, Cameron, Tamaha, and Keota. In addition, an "unnamed sandstone" is present locally in the McCurtain Shale Member. In general, the Warner and Cameron Sandstone Members are widespread, the others are discontinuous and less commonly exposed. The McAlester coal has also been recognized throughout much of the southern part of the basin.

An important unit for economic reasons and correlation purposes in the McAlester Formation is the McAlester (Stigler) coal. The McAlester coal was originally named by Chance (1890), presumably because it was mined near the town of McAlester. The name was widely used in the southern part of the Arkoma basin (Hendricks, 1937a; Hendricks, 1939) except for the Lehigh district, where it was called "the Lehigh coal, ...[which] occurs at about the horizon of the McAlester coal bed of the McAlester district" (Knechtel, 1937, p. 134). In the northern part of the Arkoma basin, the mineable coal in the McAlester Formation was referred to as the Stigler coal (e.g., in Haskell County [Oakes and Knechtel, 1948]). Wilson (1935) and Wilson and Newell (1937) first correlated the McAlester and Stigler coals:

> The formation contains the McAlester, or Stigler, coal bed. (Wilson, 1935, p. 507)

> The principal coal beds found are in the McAlester shale (Stigler [McAlester] and upper Hartshorne coals). (Wilson and Newell, 1937, p. 85)

Despite these observations, Hendricks (1939, p. 269) suggested that "about 58 ft above the McAlester coal is a continuous coal bed that is probably the equivalent of the Stigler coal." Friedman (1978) suggested that the upper coal referred to by Hendricks (1939) is probably what is now known as the Upper McAlester, or Stigler Rider, coal. Although the two coals now are widely acknowledged to be correlative, the name McAlester coal is commonly used in Atoka, Coal, Pittsburg, Latimer, and southern Le Flore Counties, whereas the name Stigler coal is commonly used in Haskell, Sequoyah, and northern Le Flore Counties (Friedman, 1982).

As stated previously, the sandstones in the McAlester Formation are generally referred to as the Booch sandstones in the subsurface, although the correlation between surface (Warner, Lequire, etc.) and subsurface (lower, middle Booch, etc.) units is imperfect, at best.

When Northcutt (1995, p. 15) reviewed the origin of Booch sandstone nomenclature, he noted that "the 'Booch' sand is an informal subsurface term, which was used first in 1906 in the Morris field of Okmulgee County, as reported by Clark (1930, p. 64)," whom he quoted:

> In 1906 two gas wells were drilled in the townsite of Morris to the 1,200 foot sand, afterwards called the Booch sand.... Another important well drilled in 1906 was located in the NW¼ sec. 20, T. 13 N., R. 14 E., on the Booch farm and gave the name to the Booch sand, which afterwards became famous for large wells.

Northcutt (1995, p. 15) also quoted Jordan (1957, p. 21), who made reference to the original occurrence of the name "Booch":

> First ref.—Fohs and Gardner (1914), Fuel Oil Jour., Aug. Suppl. Named for Booch farm, 20-13N-14E, Morris field, Okmulgee Co. C[entral] Oklahoma. Equal to Warner ss. At places Upper, Lower, First, Second, Third Booch. At places over 150 feet thick. Equal to Taneha sand. See also Youngstown sand.

DISTRIBUTION AND THICKNESS

Surface exposures of the McAlester Formation extend from ~10 mi southwest of Morrilton, Arkansas, on the east, to Fittstown, Oklahoma, on the southwest, to the Kansas state line on the north (Fig. 11). The McAlester Formation exposed north of Muskogee, Oklahoma, is within the Cherokee platform geologic province of Northcutt and Campbell (1996) and will not be discussed in this report. Strata older than the McAlester 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 McAlester has been eroded from at least parts of these areas. Therefore, the original extent of the McAlester Formation cannot be determined, although most workers assume that its present extent is close to its original extent.

In much of the western part of the Arkoma basin, the McAlester is buried by younger strata. In the Cherokee platform area, the McAlester Formation extends as far west as Seminole County, central Pottawatomie County, and eastern Oklahoma County (Northcutt, 1995, pl. 1).

The McAlester Formation in Arkansas is about 500–2,000 ft thick (Haley, 1961b), although these figures include the Hartshorne coal. In Arkansas (using Oklahoma terminology), the McAlester Formation is about 400–1,900 ft thick. The McAlester thickens from north to south, and isopach lines are approximately parallel to the axis of the Arkoma basin (Haley, 1961b, fig. 180.2). Weirich (1953) mapped the hinge line of the McAlester and Savanna Formations (his lower Cherokee unit) as extending from northern Hughes County northeast to northwestern Muskogee County. Northcutt (1995, pl. 1) located the hinge line of the McAlester Formation slightly to the southeast of Weirich's (1953) (Fig. 11).

In Oklahoma, the thickness of the McAlester Formation varies widely. Along its northern outcrop belt, the following

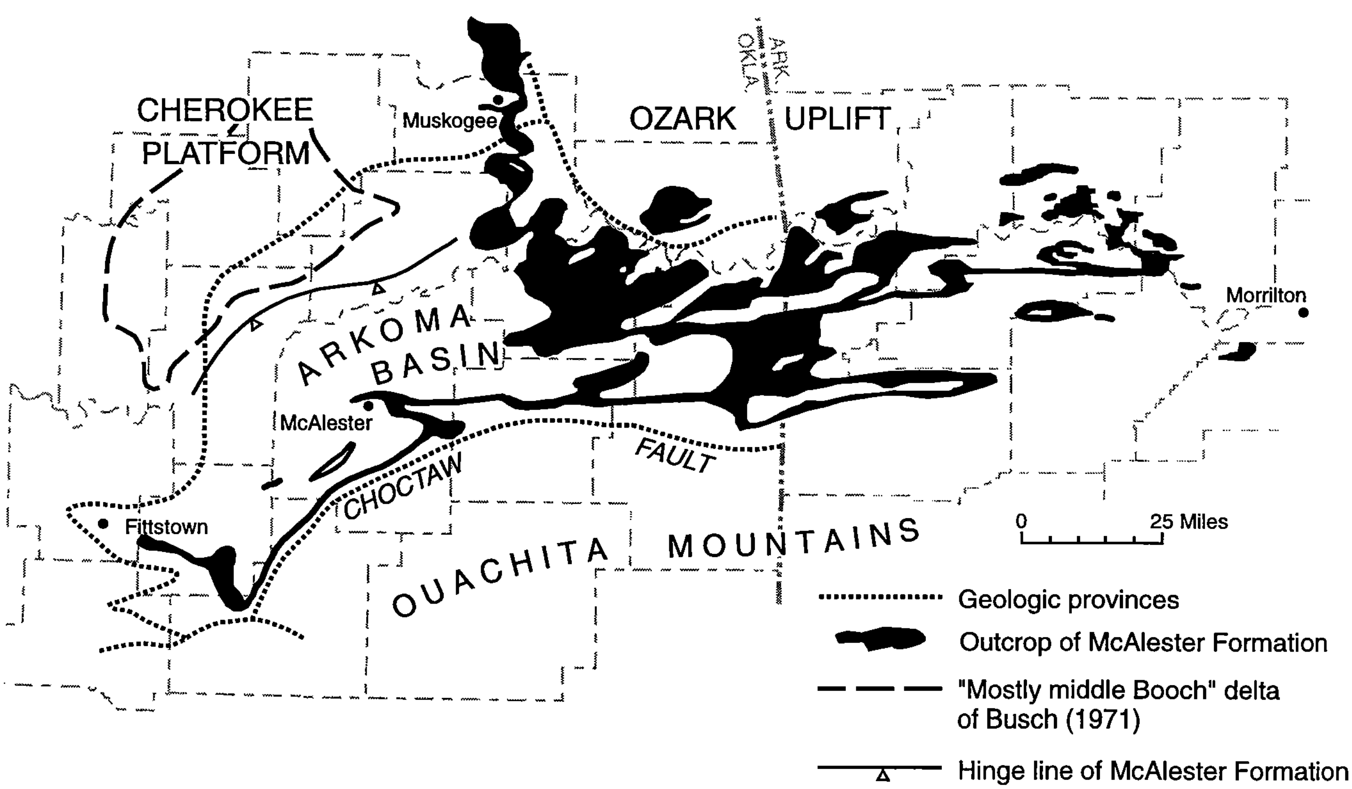


Figure 11. Map showing outcrop pattern (heavy solid line and blackened areas) of the McAlester Formation in Arkansas and Oklahoma. Dashed line is area of the "mostly middle Booch" delta of Busch (1971, p. 1141), which is also shown in Figure 12 (see p. 21). Dotted lines are margins of geologic provinces in Oklahoma (from Northcutt and Campbell, 1996). Solid line with triangles is hinge line of McAlester Formation (from Northcutt, 1995, pl. 1).

thicknesses have been reported: northern Le Flore County, about 1,000–2,500 ft, thins to north (Knechtel, 1949, p. 17); Haskell County, about 700–2,000 ft, thins to north (Oakes and Knechtel, 1948, p. 28); Muskogee County, about 400–150 ft, thins to north (Oakes, 1977, p. 16). The McAlester Formation extends north into Kansas along the west side of the Ozark uplift, but this area will not be discussed in this report.

Along its southern outcrop belt, the following thicknesses have been reported for the McAlester Formation: central LeFlore County, about 2,000–2,400 ft, although locally thins southward to 1,200 ft on the south side of Poteau Mountain (OGS mapping, Appendix 1); Latimer County, about 2,000–2,400 ft (OGS mapping, Appendix 1); Pittsburg County, 1,400–2,400 ft (Hendricks, 1937a; OGS mapping, Appendix 1); Coal County, about 900–1,600 ft, thins to west (Knechtel, 1937, p. 104). The McAlester Formation is very thin on the north flank of the Clarita horst subprovince of the Arbuckle uplift in southern Pontotoc County (Hart, 1974). It is absent in the Franks graben and on the east side of the Lawrence horst subprovinces of the Arkoma basin (Hart, 1974; Naff, 1962), where the Boggy Formation unconformably overlies the Wapanucka Limestone.

In Oklahoma, the contact between the McAlester Formation and underlying Hartshorne Formation generally is conformable. The overlying Savanna Formation conformably overlies the McAlester, although locally the contact is paraconformable. On the Cherokee platform, the McAlester paraconformably overlies the Atoka Formation. In Arkansas, "the Savanna sandstone rests with a somewhat irregular contact on the McAlester shale" (Hendricks and Parks, 1937, p. 199); in other words, the contact probably is a paraconformity.

PETROGRAPHY AND PETROLOGY

The McAlester Formation consists mostly of shale and thin siltstones; it has five named sandstone members and, in the Arkoma basin, three named coal beds. Ironstone concretions are locally abundant in the shales. Locally, the sandstones are discontinuous; in other places, they split. No petrographic studies have been published on the siltstones and shales of the McAlester Formation. Most descriptions focus on the sandstones and coals, which are better exposed and/or have economic value. No studies have differentiated the different sandstone members petrographically, and there do not appear to be any diagnostic sedimentary structures that can be reliably used to distinguish the different members. Invertebrate fossils are extremely rare and of no use for correlation purposes.

Sandstones

Most of the sandstones in the McAlester Formation are described as fine grained, thin bedded, slabby, and characterized by ripple marks. Locally, individual beds are medium or even coarse grained, and Knechtel (1937) noted that pebble conglomerates are present in the sandstones in the extreme southeastern part of the Lehigh coal district. Scruton (1950) studied the Warner sandstone in the northern part of the Arkoma basin in Muskogee County. He identified a "Warner facies" that is characteristic of the Warner sandstone; it is marked by "good sorting, medium grain size, ...rough cut-and-fill structure, cross-lamination, ... rapid lensing, ... [and] wave-type ripple mark[s]" (Scruton, 1950, p. 418–419). This description applies equally well to much of the Warner along its southern outcrop belt.

Karvelot (1973) studied the McAlester sandstones (excluding the Keota) in the eastern part of the Arkoma basin in Oklahoma. He noted that all are similar petrographically and consist of quartz, chert, feldspar, and rock fragments. Calcite cement is present locally. Sedimentary structures in most of the sandstone units are similar. Karvelot (1973) classified the McAlester sandstones as feldspar-rich quartzarenites.

Bissell (1982) studied the petrography of all five McAlester sandstones (surface and subsurface) in the Eufala Reservoir area, Haskell and Muskogee Counties, Oklahoma. He concluded that the sandstones are similar petrographically; they are classified as sublitharenites and, on average, they are composed of quartz (68%), rock fragments (6%), muscovite (4%), feldspar (3%), and detrital matrix (4%). However, Bissell (1982, p. 44) did suggest that the Warner is coarser grained than the other McAlester sandstones. Fields (1987) studied a single core of lower Booch (Warner) sandstone from northern Pittsburg County, Oklahoma, and agreed with Bissell's (1982) suggestion.

In addition to the studies cited above, several other studies have addressed Booch sandstone petrography. Busch (1971, p. 1142), in his classic study of the Booch delta, recognized that petrographic differences in individual Booch sandstones are the result of their deposition in different sedimentary environments.

> There are significant petrographic differences between the distributary channel sandstones and the interdistributary sheet sandstones.... Where channel sandstones exceed 20 ft in thickness, they generally have larger geometric mean grain diameters than those of the interchannel areas.... The channel sandstones also are better sorted than those of the interchannel. In addition to these differences, the sandstones of the interchannel areas have an average clay content of 20 percent, compared with 15 percent in the channels.

(See section on environment of deposition and provenance [p. 20].)

Karvelot (1973) also noted a general decrease in grain size outside the Warner channels. Bissell (1982) and Fields (1987) did not report systematic or facies-related grain-size differences in the Warner.

Coals

The McAlester (Stigler) coals in Oklahoma have been studied extensively because they are thick enough over widespread areas to mine economically. (In this report, the names McAlester and Upper McAlester will be used in preference to Stigler and Stigler Rider because the report focuses on the southern part of the Arkoma basin, where the former terms are used.) The only other coal in the McAlester Formation that has been mined is the Keefton, which was mined in one place in Sequoyah County and one place in Muskogee County (Friedman, 1995). Hendricks (1937a) noted several other minor coal beds in the McAlester Formation in the McAlester district, and recent maps by the OGS (Appendix 1) show the locations of several. Friedman (1978) noted six minor coal beds in the McAlester Formation in different parts of the Arkoma basin and Haley (1961b) reported eight in the Arkansas part of the basin.

The McAlester coal is 1.7–4.2 ft thick in the McAlester district (Hendricks, 1937a) and 1.3–2.8 ft thick in the Howe-Wilburton district (Hendricks, 1939). In the southwestern part of the Arkoma basin (Lehigh district), the McAlester coal is 3.3 ft to ~5 ft thick (Knechtel, 1937). The McAlester has been mined locally in Haskell County, but Oakes and Knechtel (1948) did not report any thicknesses. Karvelot (1973) mapped the McAlester coal in northern Haskell County and showed a maximum thickness of 32 in.; most of the coal is 15–25 in. thick. The coal is 11 in. to 2 ft thick in the Muskogee-Porum district (Wilson and Newell, 1937) and ≤18 in. to 2 ft thick locally in Muskogee County (Oakes, 1977).

Most of the McAlester coal in the Arkoma basin is high-volatile A bituminous or medium-volatile bituminous; however, it is low-volatile bituminous in the eastern part of the basin in Oklahoma (Trumbull, 1957; Karvelot, 1973; Cardott, 1990). The rank generally increases from southwest to northeast. Coal analyses are reported by Hendricks (1937a, 1939) and Knechtel (1937) and are summarized by Trumbull (1957, p. 343) and Friedman (1995). The range of average analyses of the McAlester coal is: sulfur, 0.9–4.5%; ash, 4.2–11.7%; calorific value, 11,590–14,430 Btu; fixed carbon, 44.3–67.3% (from Friedman, 1995, table 2). Karvelot (1973) reported a broad range of sulfur values (<0.5% to >5%) and ash values (2.6–11.6%) in Haskell and Muskogee Counties.

ENVIRONMENT OF DEPOSITION AND PROVENANCE

Hendricks and others (1936) first described the depositional environment of the McAlester Formation. Their interpretation was based on detailed field studies of the Arkoma basin coal districts (Hendricks, 1937a; Knechtel, 1937; Dane and others, 1938; Hendricks, 1939). Hendricks and others (1936) showed that the depocenter of the McAlester is in the southernmost part of the Arkoma basin immediately north of the Choctaw fault. They divided the formation into three parts and made no attempt to describe the depositional environment of the lower two, except to say that conglomerates predominate over sandstones in the middle part in the southwestern part of the basin. The upper part of the McAlester Formation, however, consists "largely of alternating continental and marine shales" (Hendricks and others, 1936, p. 1350); marine shales dominate in the west and continental shales dominate in the east. Their only suggestion as to the origin of the sandstones in the McAlester Formation was that

> the source of the sediments that formed the strata of the [Arkoma] coal basin lies mainly farther south. Much of the material probably came directly from Llanoria, an ancient land mass south of the present Ouachita Mountains, but probably a greater amount of material was supplied to the Hartshorne, McAlester, Savanna, and Boggy formations by the erosion of the Stanley, Jackfork, and Atoka formations of the Ouachita Mountains. (Hendricks and others, 1936, p. 1353–1354)

Most recent work on the Krebs Group shows that the principle source areas were to the east (Hartshorne Formation) or north (McAlester, Savanna, Boggy Formations) of the Arkoma basin (e.g., Sutherland, 1988, and references cited therein). A local source area in the western Ouachita Mountains and/or eastern Arbuckle Mountains is based on the presence of conglomerates throughout the section in the southwestern part of the basin and finer-grained strata to the north and northeast.

Reed (1923) was the first geologist to suggest a deltaic origin for the Booch sandstone. He recognized that the Booch in the Henryetta district (immediately north of the Arkoma basin) had the map pattern and cross-sectional shape of a river channel and noted that the discontinuous nature of many of the sandstones in the district was similar to that reported for modern deltas. However, Reed (1923, p. 55) suggested

> that during much of Pennsylvanian time the region south and east of Henryetta may have been a broad delta, or series of deltas; a subsiding coastal plain over which aggrading rivers wandered. The shore zone doubtless shifted widely, so that marine beds are interbedded with the dominantly fluviatile deposits. North of Henryetta, on the other hand, the beds are, on this hypothesis, dominantly marine.

In other words, Reed (1923) suggested the Booch delta(s) prograded from south to north.

Scruton (1950) was the first geologist to recognize the deltaic and nearshore neritic character of the Warner Sandstone Member of the McAlester Formation. He also suggested that the Ozark Mountains area to the northeast was the source terrane for the sands.

> The Little Cabin (now Warner Sandstone Member), with its subparallel ridges of coarse-grained, cross-laminated, cut-and-fill, fossiliferous...sandstone is the product of the river channel and submarine channel with their near channel associates. (Scruton, 1950, p. 420)

> The site of deposition was a region where a river, or group or [sic] rivers, flowing generally southwest off of the positive Ozark Dome entered the sea. At some place within the area every characterisitic feature of the deltaic environment can be found. (Scruton, 1950, p. 424)

Russell (1960) reported several depositional environments for the Krebs Group, including shallow marine, estuarine, and deltaic. Some of the sandstones represent channel deposits and the coals represent marshes.

Haley (1961b) suggested that the McAlester Formation in the Arkansas part of the Arkoma basin accumulated in a basin with two troughs. He also suggested source terranes to the north and south. A northern source terrane for parts of the Krebs Group was supported by a study of ripple-mark orientation (Agterberg and Briggs, 1963). However, this study did not differentiate sandstones in the McAlester, Savanna, and Boggy Formations.

Karvelot (1973) studied the interval in the McAlester Formation from the base of the Warner Sandstone Member to the top of the Tamaha Sandstone Member in the northern part of the Arkoma basin in Oklahoma. Based on map patterns, sedimentary structures, and petrography, he concluded that the Warner Sandstone Member consists of two sequences: the lower is composed of a series of widely spaced, west-to-east or northwest-to-southeast (down-current), anastomosing channels; the upper sequence is a single, relatively wide, northwest-to-southeast (down-current) channel (Fig. 12). Karvelot (1973) also suggested that the Lequire Sandstone Member shows many of the same characteristics as the Warner and that its origin (channel sand) is similar. He concludes:

> Channels within the lower Warner sequence and the Lequire Sandstone are interpreted as deltaic distributaries. The sandy and silty facies associated with these distributaries are considered to be delta front, delta margin, deltaic plain, interdistributary or natural levee environments. The Lower Warner and Lequire Sandstones represent two sequences of distal delta-lobe progradation eastward from the delta-depocenter represented by Busch's "Booch Delta." ...The upper sandstone facies of the Warner Sandstone is interpreted as an alluvial sequence which probably was deposited during maximum regression. (Karvelot, 1973, p. 117)

In contrast, Karvelot (1973) interpreted the Tamaha and, possibly, the Cameron Sandstone Members to be shallow-marine deposits.

Based on the faunal content and the lithologic characteristics of the shale in the McAlester Formation, Karvelot (1973) suggested that its depositional environment is dominantly shallow marine, and, secondarily, prodelta, interdistributary, marsh, and swamp.

Most of the recent work on the McAlester Formation (including that of Karvelot [1973], discussed above) focuses

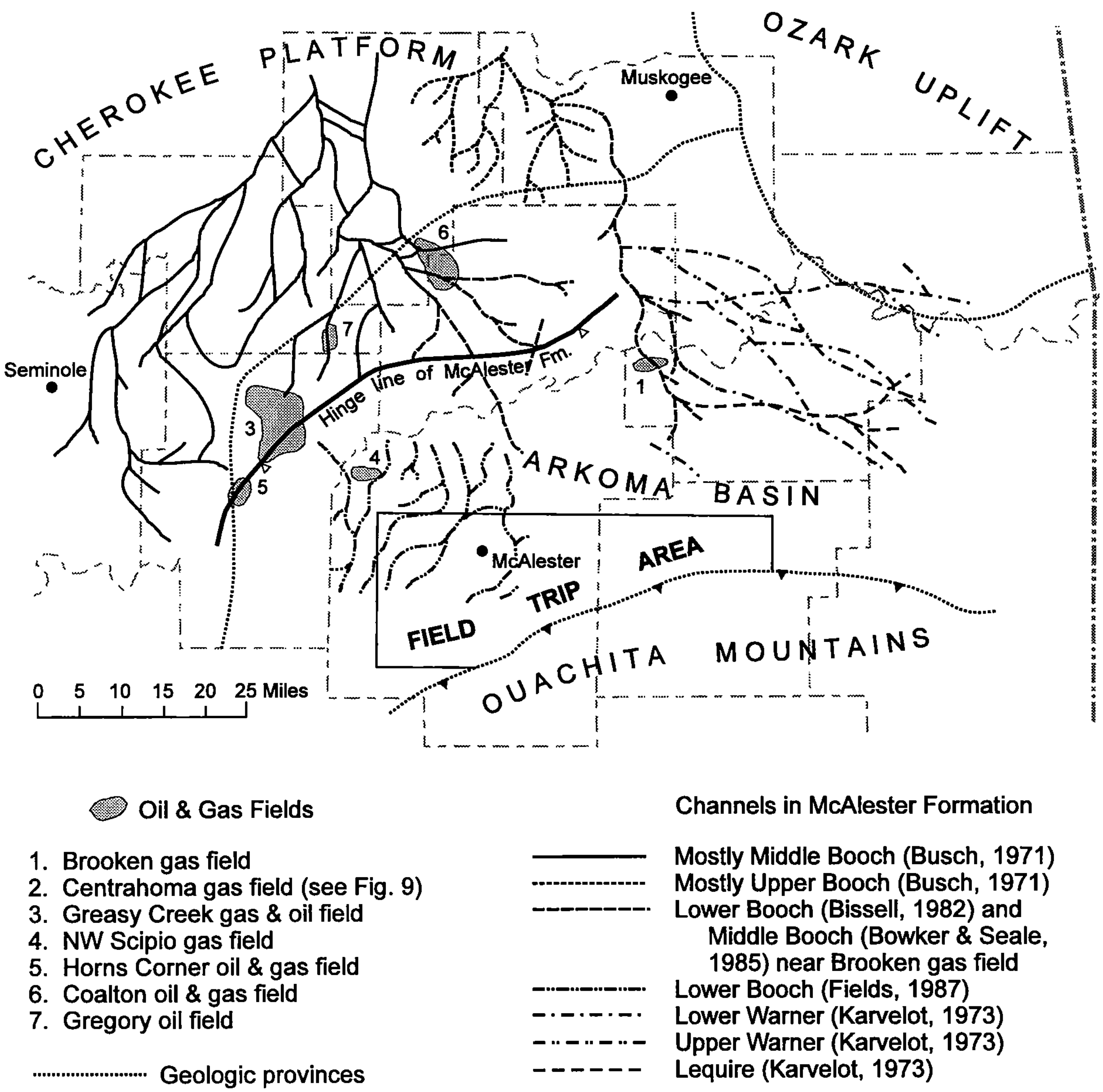


Figure 12. Map showing distribution of Booch (Warner, Lequire) channels in the Arkoma basin and on the Cherokee platform. Also shown is hinge line of McAlester Formation (from Northcutt, 1995, pl. 1), oil and gas fields with Booch production (pattern) (locations from Burchfield, 1985), and the area of field trip. Note: See text (p. 20–22) for discussion of channels mapped by Karvelot (1973).

on the depositional environment of the sandstones and follows up on the classic study of the Booch delta by Busch (1953, 1959, 1971, 1974). Based on isopach maps of the middle Booch sandstone, Busch showed that the unit has the form and character of a series of anastomosing distributary channels (Fig. 12). (It is important to note that Busch's studies focused on the Cherokee platform area of eastern Oklahoma and extended only into the northwesternmost part of the Arkoma basin.) He observed that where the channel sandstones are thickest, the underlying beds had been eroded. He interpreted some of the smaller distributary sandstones to have been deposited in a crevasse-splay environment. Busch also recognized that the upper Booch sandstone locally was deposited in a deltaic environment, but he did not address the origin of the lower or lower middle Booch sandstones. He also did not attempt to correlate the four Booch sandstones with their surface equivalents.

Busch's work on the middle and upper Booch was followed by two studies on the lower Booch (Bissell, 1982; Fields, 1987). Bissell (1982) suggested that the lower Booch represented a regressive sedimentation cycle, which includes "prodeltaic silty-shale, delta-front siltstone, [and] channel or prograded shoreline sandstones" (p. 92). Both studies (done in adjacent areas) concluded that the lower Booch sandstone represents a high-constructive, elongate delta; they also state that the lower Booch is equivalent to the Warner Sandstone Member of the McAlester Formation (Bissell, 1982; Fields, 1987). It is not clear, however, whether the lower Booch of Bissell (1982) and Fields (1987) is the same as that of Busch (1953, 1959, 1971, 1974). Figure 12 shows that some of the "mostly middle Booch" and "mostly upper Booch" channels of Busch (1971, fig. 5) coincide with some of Bissell's (1982) lower Booch channels.

Busch's work may also have inspired the study of the surface exposures of the McAlester sandstones by Karvelot (1973, p. 112), who mapped channels in the Warner and Lequire Sandstone Members, but added:

> Figure 5 is a reconstruction of possible channel distributions in the lower Warner sequence and is not intended to show the exact distribution but is given for comparison with the distribution of other sandstones in the McAlester Formation.

The most recent work on the Booch sandstone is by Northcutt (1995). Based on previous work, Northcutt (1995, p. 14) identified what he considered to be "Booch sediments," which include shales "deposited in marine, delta-front, lagoonal, and coastal-plain environments," as well as sandstones, the greatest thicknesses of which "were deposited in distributary channels on the delta plain." The Booch also includes coals deposited in lagoons on the delta plain. Clearly, the Booch sediments of Northcutt (1995) are equivalent to the McAlester Formation of surface terminology.

Northcutt (1995) also reviewed the history of Booch sandstone studies, combined all published maps of the Booch on the Cherokee platform into a single map showing the Booch delta, and interpreted areas of fluvial, upper delta-plain, and lower delta-plain deposition. But, as in most studies of the Booch, Northcutt's (1995) map covered only the extreme northern part of the Arkoma basin. Northcutt (1995) also did not appear to differentiate any of as many as five individual Booch sandstones.

There are no recent studies on the depositional environment of the Warner Sandstone Member (Booch sandstone) or of any of the other sandstone members of the McAlester Formation in the southern part of the Arkoma basin. Similarly, there have been no attempts to relate the sandstone units of the McAlester Formation, as they crop out on the surface, to the oil-or gas-producing Booch sandstones in the subsurface.

RESOURCES

Coal

The McAlester Formation in the Arkoma basin contains as many as seven coal beds (Friedman, 1974), although Hendricks (1937a, pl. 3) showed many more, most of which are only inches thick. The only coal bed that has been mined to any significant extent is the McAlester (Stigler); the Upper McAlester (Stigler Rider) and Keefton coals have been mined to a much lesser extent. The distribution, thickness, chemistry, and production of the McAlester coal through about 1930 has been published in a series of reports by the U.S. Geological Survey (Hendricks, 1937a, 1939; Knechtel, 1937). Russell (1960) briefly discussed the coal resources of northern Latimer County, and Oakes and Knechtel (1948) and Knechtel (1949) published comprehensive reports on the geology and coal resources (including the McAlester coal) of Haskell and northern Le Flore Counties, respectively. Trumbull (1957) and Friedman (1974) published estimates of McAlester coal production and reserves. Karvelot (1973) discussed the geology, rank, petrology, distribution, chemistry, reserves, and development considerations of the McAlester coal over much of the northern part of the Arkoma basin in Oklahoma.

As with the Hartshorne coals, extensive underground mining of the McAlester coals took place in the latter part of the 19th century; surface-mining began in the early 20th century. The number of underground mines gradually decreased throughout the 1900s, to nearly zero in 1970. The deepest coal to be mined underground in Oklahoma was the McAlester coal in the Carbon No. 5 mine, by Lone Star Steel Company in 1960 (Friedman, 1995).

Currently, S. A. Friedman and B. J. Cardott of the OGS are compiling historical production data for the McAlester coal, county by county. Table 2 shows the total tonnage (short tons) of McAlester coal "mined and lost in mining" through 1973.

The most recent year for which statewide bed-by-bed production is available is 1995, when 240,240 short tons of coal were produced from the McAlester and Upper McAlester coals (S. A. Friedman, unpublished data, 1996). This represents ~13% of Oklahoma's total coal production for that year. The McAlester coal was produced only in Latimer and Haskell Counties in 1995.

Friedman (1995) (based on Friedman, 1974) estimates that the McAlester (including the Stigler) coal contains 1,545 million short tons of remaining resources. Karvelot (1973, table 5) estimates the total recoverable strippable reserves in the northern part of the Arkoma basin at ~51 million tons.

The Keefton coal immediately overlies the lower, more continuous sandstone bed in the Warner Sandstone Mem-

TABLE 2.—MCALESTER COAL MINED AND LOST IN MINING THROUGH 1973[1] (thousands of short tons)

County	lower McAlester[2]	Upper McAlester	McAlester (includes Stigler)
Coal	0	0	68,390
Haskell	0	0	14,815
Latimer	1,129	166	0
Le Flore	9	0	328
Muskogee	0	0	3,147
Pittsburg	0	0	71,640
Sequoyah	0	0	3,224

[1]Based on Friedman (1974).
[2]Informal name; refers to McAlester coal where Upper McAlester has been identified.

ber of the McAlester Formation. It has been mined in Sequoyah and Muskogee Counties, and Friedman (1995) estimates that there are ~4 million tons of strippable identified resources in Muskogee and Sequoyah Counties; an undetermined amount of resources is present in Haskell County.

Coal-Bed Methane

The coal-bed methane resources of the McAlester coal have not been investigated to nearly the same extent as those of the underlying Hartshorne coal. At the present time, seven coal-bed-methane wells have been completed in the McAlester coal (B. J. Cardott, 1997, personal communication). Friedman (1995, p. G-127)) suggests that the McAlester "contains significant coalbed methane resources in places where it is 3 to 5 feet thick."

Natural Gas

The name "Booch" was first used in 1906 in the Morris field, Okmulgee County (Northcutt, 1995). Clark (1930) reports that the producing sand was named for the Booch farm (sec. 20, T. 13 N., R. 14 E.). This area is north of the hinge line of the McAlester Formation (Fig. 11) and is near the upper to lower delta-plain depositional environment of the Booch, as mapped by Northcutt (1995). Jordan (1957) correlated the Booch with the Warner and noted that upper, lower, first, second, and third Booch sands are present locally. As stated above, these subsurface sands probably correlate in some manner with the named surface members of the McAlester Formation (from bottom to top, Warner, Lequire, Cameron, Tamaha, Keota), but precise surface-to-subsurface correlations are not known.

As of 1991, the Booch had produced 172 Bcf nonassociated and associated gas from four major (>10 Bcf) fields in the Arkoma basin; these include the Brooken, Centrahoma, Northwest Scipio, and Greasy Creek (Brown and Parham, 1994) (Fig. 12). In addition, Northcutt (1995) identified 78 oil fields that produce from the Booch sandstone; all but four of these (Coalton, Gregory, Greasy Creek, and Horns Corner) are entirely north or west of the Arkoma basin and are beyond the scope of this report. To date, only two fields in the Arkoma basin with Booch production (Brooken gas field and Greasy Creek oil field) have been described in detail in the published literature.

The Brooken gas field is located in northwestern Haskell County and northeastern Pittsburg County (Fig. 12). The Desmoinesian middle Booch (61 of 83 productive wells) and Hartshorne sandstones (32 wells) are the principal producing formations in the field (Bowker and Seale, 1985):

> The middle Booch sandstone is a white to tan, coarse to fine-grained quartz arenite....Well logs reveal the middle Booch to be a thick, massive sandstone with sharp upper and lower contacts. In cross section the Booch demonstrates very abrupt lateral contacts and thickening at the expense of underlying shales. This geometry is indicative of channeling. (p. 171–172)
>
> Core analysis, regional mapping, and reviews of previous studies support the interpretation that the Booch sandstone was deposited as a deltaic complex on the shelf of the Arkoma basin. The provenance of the siliciclastics that formed the delta was towards the north....The middle Booch at Brooken is interpreted to be composed of a series of stacked distributary channel sandstones that formed one of the deltaic lobes. (p. 172–173)
>
> The upper Booch in the Brooken was deposited in overbank and/or innerdistributary [sic] environments. (p. 174)

Northcutt (1995, p. 44–56) described the geology of the northeastern part of the Greasy Creek oil field, which is located in northern Hughes County. The Greasy Creek field is adjacent to the northwestern margin of the Arkoma basin (Fig. 12). The principal oil reservoir in the northeastern part of the Greasy Creek field is the lower Booch sandstone, which in this area consists of a "stacked channel sequence deposited near the distal end of a distributary channel on the lower delta plain at the hinge line of the McAlester Formation" (Northcutt, 1995, p. 44). The shales beneath the Booch channel (probably equivalent to the McCurtain Shale Member) are marine shales deposited in a prodelta environment. Northcutt (1995) identified three sandstone layers associated with the Booch channel: the lowest layer is thin and discontinuous, the middle layer represents massive channel-fill sandstones, and the upper layer appears to be of relatively great extent and consists of point-bar deposits.

There are several other less-well-studied fields in the Arkoma basin that produce oil and/or gas from the Booch sandstone (Fig. 12). The Northwest Scipio field (T. 7 N., R. 12 E., Pittsburg County) locally produces from a small lower Booch channel that "connects two north-south trending distributaries" (Fields, 1987, p. 100–101). The Ulan field (T. 7 N., R. 13 E., Pittsburg County) locally produces from a narrow, north-south–trending upper Booch channel (Fields, 1987). Oakes and Koontz (1967) reported production from Booch sandstone reservoirs in several fields just north of the McAlester hinge line; for example, Coalton, Southeast Salem, North Hitchita, and Checotah. Some appear to be close to Booch channels mapped by Busch (1953, 1959, 1971, 1974), however, Oakes and Koontz (1967) did not suggest a relation between hydrocarbon accumulation or reservoir quality and channel distribution.

SAVANNA FORMATION (DESMOINESIAN), ARKOMA BASIN, OKLAHOMA

GENERAL

The Savanna Formation overlies the McAlester Formation and underlies the Boggy Formation throughout the Arkoma basin of Oklahoma as well as the Cherokee platform (Figs. 1, 2). Hendricks (1937a, p. 16) was of the opinion that "the Savanna rests unconformably on the McAlester shale." Although minor erosional surfaces can be observed in exposures in the Arkoma basin at the base of the lowest sandstone of the Savanna, the contact with the McAlester is more appropriately described as paraconformable.

The Savanna Formation is in irregular contact with the overlying Bluejacket Sandstone Member of the Boggy Formation. Channeling is evident at some places where the contact is paraconformable; at others the contact is gradational (Oakes and Koontz, 1967, p. 24; Hemish, 1995b, p. 215, 221).

Oakes and Knechtel (1948, p. 44) noted that the Savanna Formation "is a succession of sandstone and shale beds in which shale predominates but sandstone is most conspicuous in outcrops. It contains a minor amount of limestone in thin lenses and beds, and fossils of both marine animals and land plants are present locally." Coal beds have been observed in the Savanna Formation throughout the Arkoma basin and in the Cherokee platform of Oklahoma (Hemish, 1984, p. 163; 1995b, p. 210).

Taff (1899, p. 437) originated the concept of mapping the sandstones of the Savanna Formation based on topographic expression. He observed that "there are five principal sandstone beds, which have different thicknesses, from nearly 50 to 200 feet." Hendricks (1937a, p. 17) referred to "two large bands" of Savanna sandstone in the McAlester area, but later on the same page said that "for convenience in mapping, several sandstones separated by thin shales were mapped together as sandstone groups. Over most of the district four such groups were traceable." Weirich (1953, p. 2031) noted that "individual sandstone beds in the basin are lenticular, but the zones are persistent and may be traced without difficulty throughout the basin."

Hemish and others (1990c), mapping at a scale of 1:24,000, found that seven sandstone "packages" or "groups" were mappable in the Wilburton 7.5′ quadrangle. These seven ridge-forming groups were mapped eastward in adjacent 7.5′ quadrangles to the Arkansas-Oklahoma line, and informally called the Savanna 1–7 sandstones (Hemish and others, 1990a,b; Hemish, 1991b; Hemish and Mazengarb, 1992; and Hemish and Suneson, 1993, 1994). Hemish (1992, 1995a, 1996a, 1997a), mapped the seven sandstone "groups" westward from the Wilburton 7.5′ quadrangle, across the Gowen 7.5′ quadrangle, and into the Adamson 7.5′ quadrangle, but was unable to differentiate the units further west near McAlester in the Krebs and McAlester 7.5′ quadrangles (see Appendix 1 for location of quadrangles).

Interestingly, Hendricks (1939, pl. 33) had earlier mapped seven sandstone units separated by shales in the Savanna Formation on Cavanal Mountain and Poteau Mountain (both near Arkansas), but could not differentiate them in the McAlester and Lehigh areas either.

Hemish (1996c, p. 180) observed that the Savanna Formation consists primarily of clastics in both the Arkoma basin and the Cherokee platform areas. He stated that "the percentage of sandstone decreases from ~16% in the basin to about 2–3% in the shelf area." He also noted that the Savanna thins northward across the Cherokee platform area, from ~1,450 ft in Ts. 5 and 6 N., Rs. 16 and 17 E., within the Arkoma basin of eastern Oklahoma, to ~70 ft just south of the Oklahoma-Kansas border in T. 27 N., R. 20 E.

HISTORY OF NOMENCLATURE

The Savanna Formation (Savanna sandstone, as originally defined) was named by Taff (1899, p. 437–438), presumably from outcrops in the vicinity of the town of Savanna, Pittsburg County, Oklahoma (Fig. 13). He described it as follows:

> Next, above the McAlester shale there is a series of sandstones and shales about 1,150 feet thick. The shaly beds combined are probably thicker than the sandstones, but since the sandstones are better exposed and their presence is so strongly impressed upon the observer in the prominent ridges which they make, sandstone seems the more appropriate term. There are five principal sandstone beds, which have different thicknesses, from nearly 50 to 200 feet, the one at the top and the one at the base being generally thicker than

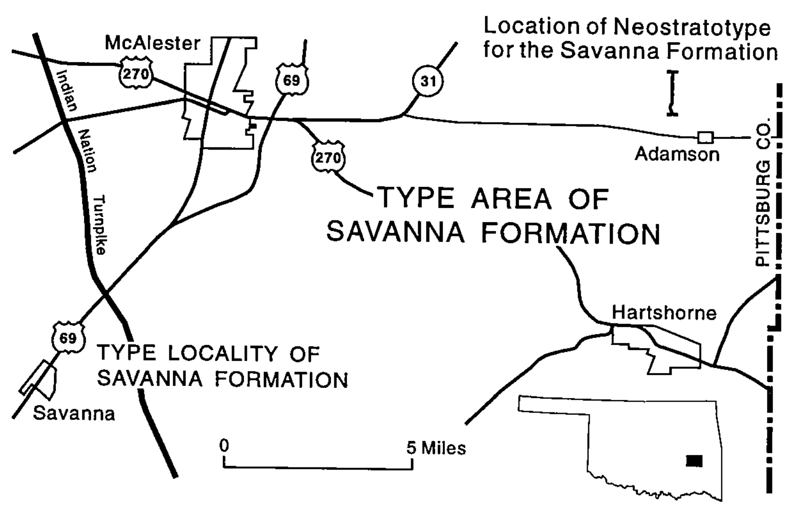


Figure. 13. Map showing the type locality, type area, and location of the neostratotype for the Savanna Formation in central Pittsburg County, Oklahoma. (From Hemish, 1995b, fig. 1.)

the intermediate ones. The sandstones may be distinguished only by their position in the section or their thickness of bedding. They are brown or grayish-brown, fine-grained and compact. Except in the uppermost beds, upon which the town of McAlester is built, the beds are generally thin and in part shaly. The uppermost sandstone occurs in two members, 75 to 100 feet thick, separated by variable blue clay shales. The uppermost beds of this sandstone are found in many places to be massive, and those in contact with the shale are often beautifully ripple-marked. No coal of any value has been found associated with these beds of sandstone in the McAlester district, though a thin bed has been reported to occur in the upper part of the series. (Taff, 1899, p. 437–438)

In the Arkoma basin the Savanna Formation was subsequently investigated and described by Snider (1914), Morgan (1924), Wilson (1935), Wilson and Newell (1937), Hendricks (1937a, 1939), Knechtel (1937, 1949), Dane and others (1938), Oakes and Knechtel (1948), Russell (1960), Vanderpool (1960), Webb (1960), Hemish (1990d; 1991a,b; 1992; 1993a,b; 1994a; 1995a,b; 1996a,b,c,d), Hemish and others (1990a,b,c), Hemish and Mazengarb (1992), and Hemish and Suneson (1993, 1994). Because of the variable nature of individual beds in the Savanna Formation, and because there was no precise measured section defining an upper and lower boundary, various workers have included more or less than the equivalents of the original Savanna of Taff (1899). Figure 14 shows the changing concepts of the McAlester/Savanna and Savanna/Boggy boundaries in Oklahoma.

Thicknesses vary because of incorrectly recognized top and bottom of the formation. Prior to 1954, changes in definitions of the upper and lower boundaries of the Savanna by some of the early workers created the impression of a much thicker or much thinner, formation (Fig. 14). For many years, the thick shale unit at the top of the Savanna Formation (as currently defined) was included in the overlying Boggy Formation. Miser (1954) established the contact between the Savanna Formation and the Boggy Formation at the base of the Bluejacket Sandstone Member of the Boggy in the course of preparation of the Geologic Map of Oklahoma. Miser's (1954) definition of the top of the Savanna Formation is presently used by all geologists working in the Arkoma basin.

The McAlester/Savanna boundary in Oklahoma currently is defined as the base of the Spaniard Limestone, or in its absence, as the base of the first mappable sandstone above the Keota Sandstone Member of the McAlester Formation (Fig. 14). Because the lower, sand-rich part of the Savanna Formation pinches out northward from the central Arkoma basin, where its lower boundary has been defined historically as a resistant sandstone, a change in the definition of the boundary was necessary. Oakes and Knechtel (1948, p. 51, fig. 7) showed that the Spaniard Limestone Member of the Savanna Formation in the vicinity of the Canadian River occupies approximately the same stratigraphic position as does the base of the lowest sandstone of the Savanna in the Arkoma basin to the south. Therefore, in

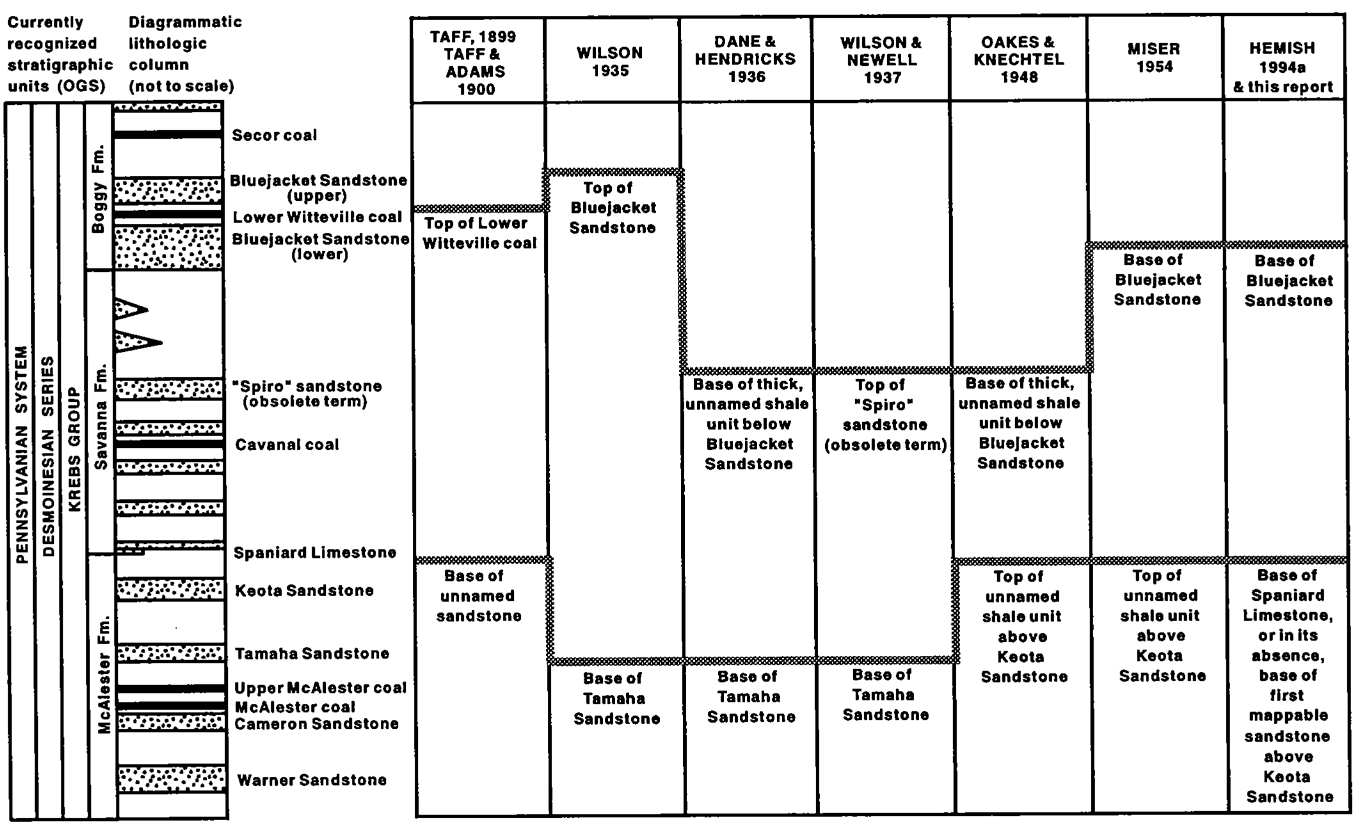


Figure. 14. Concepts of the McAlester/Savanna and Savanna/Boggy boundary positions in Oklahoma. (From Hemish, 1994a, fig. 7.)

the northern part of the Arkoma basin and throughout the shelf, the McAlester/Savanna contact is marked by the base of the Spaniard Limestone (Hemish, 1996c, fig. 2B), which is persistent throughout the entire area (Hemish, 1996c, p. 191).

Although the Savanna Formation is a long- and well-established stratigraphic unit, a formal type section had never been specified, nor had a type locality been stated. Recognizing the need for a standard to serve for definition and recognition of the Savanna, Hemish (1995b) established a principal reference section (neostratotype) within the type area of the formation (Fig. 13). The location of the neostratotype (near Adamson) is sufficiently close to the type locality to preserve this well-established name and maintain stability of Oklahoma's stratigraphic nomenclature. The principal reference section of the Savanna Formation (Appendix 2) will be featured at Stop 5, this field trip.

Hemish (1996c) subsequently established a supplementary reference section for the Savanna Formation in the eastern part of the Arkoma basin near the town of Red Oak. Additionally, a new reference well for the Savanna was established in Mayes County in the Cherokee platform area of Oklahoma (Hemish, 1996c, p. 197).

DISTRIBUTION AND THICKNESS

In Oklahoma, the outcrop belt of the Savanna Formation extends from the Arkansas-Oklahoma line westward in the Arkoma basin to the northern flank of the Arbuckle Mountains and northward to the Kansas-Oklahoma line (Fig. 15). The Savanna Formation also crops out in Arkansas within the Arkoma basin (Fig. 15) where locally it is thicker (maximum thickness, ~2,200 ft [Haley, 1961a, p. 8]) than it is anywhere in Oklahoma. In the Arkoma basin of Oklahoma, the Savanna Formation generally is about 1,100–1,450 ft thick. The thickest reported occurrence of the Savanna in Oklahoma is in the vicinity of Wister, Le Flore County, where it is ~1,750 ft thick (Hendricks, 1939, p. 272). The Savanna Formation thins northward across the Cherokee platform area to ~70 ft just south of the Oklahoma-Kansas border (Hemish, 1996c).

The Savanna Formation is not recognized in Kansas; its stratigraphic equivalents become part of the Krebs Formation (Brady and others, 1994, sheet 1).

CHARACTER

Detailed studies of the petrography of the units comprising the Savanna Formation are notably absent from the literature. Petrology generally is discussed in a cursory manner in most reports dealing with the Savanna, but detailed thin-section work has not been done (or not reported). Taff (1899, p. 437) originally noted that the Savanna sandstones "are brown or grayish brown, fine grained and compact... and in part shaly" and that the sandstones are separated by "variable blue clay shales."

Hendricks (1937a, p. 18) reported on the Savanna Formation in the McAlester district, and observed that the sandstones "are even bedded and fine- to medium-grained."

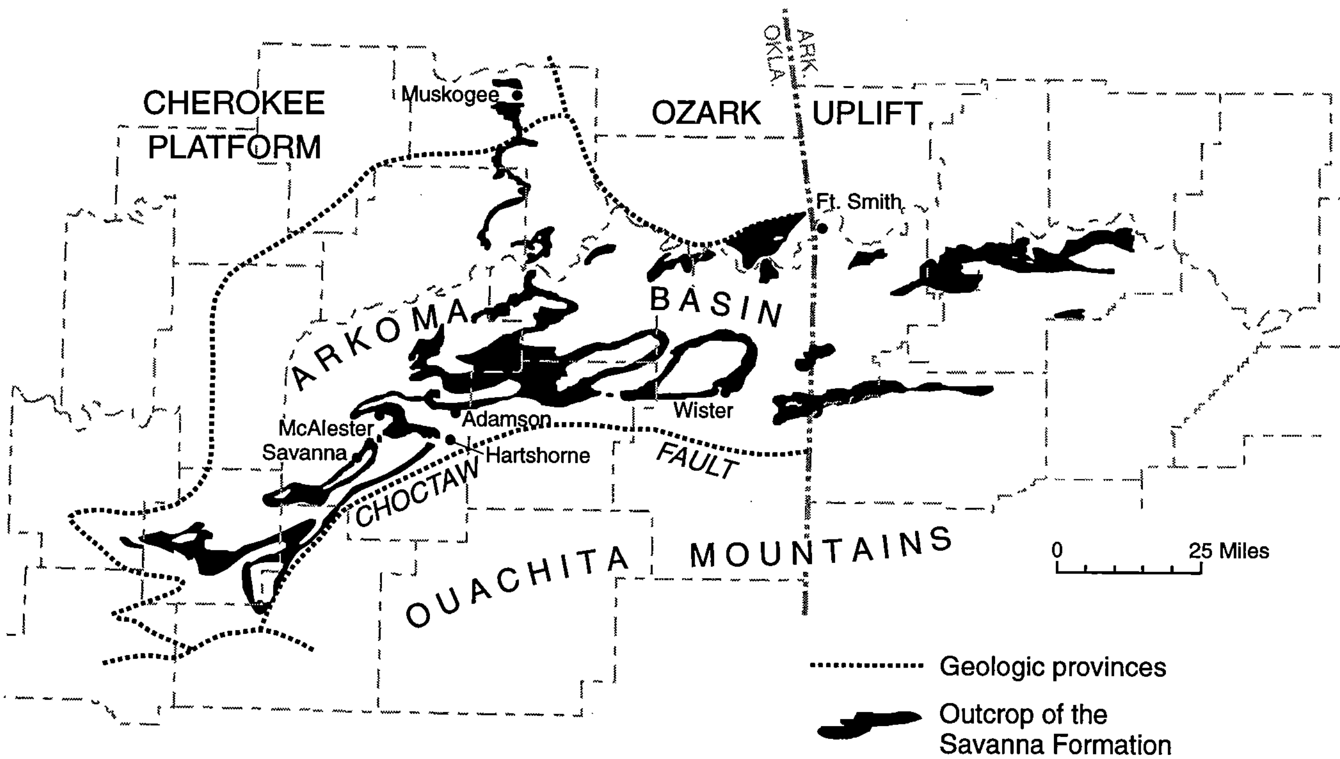


Figure 15. Outcrop belt of the Savanna Formation in the Arkoma basin area of Oklahoma and Arkansas. (Modified from Miser, 1954; Haley and others, 1976.)

Southwest of Blanco, in the southern part of the district, Hendricks (1937a, p. 18) reported several local beds of conglomerate 1–2 in. thick, consisting of pebbles of quartz and chert in a matrix of coarse sand. He noted that "the chert pebbles are angular to subangular and are as much as a quarter of an inch in length, whereas the quartz pebbles are generally well rounded and somewhat smaller" (Hendricks, 1937a, p. 18).

Interbedded with the sandstone is a considerable amount of clayey shale and sandy, silty micaceous shale that locally contains abundant rolled, spheroidal masses of sandstone a few inches to ~2 ft in diameter. Plant debris and flakes of mica follow the curving surfaces of the concentric sheets (Hendricks, 1937a, p. 18). Hendricks (1937a) also reported finding coal beds, plant fossils, and marine invertebrates in the sandstones and interbedded shales of the Savanna. Southwest of McAlester he found several horizons of blocky red and green conglomeratic clay, containing spheroidal pellets of manganiferous clay, angular fragments of coal, angular fragments of sandstone as much as one-fifth of an inch in length, and flat plates of shale one-tenth of an inch in length.

Near the western end of the basin, Morgan (1924, p. 74) reported prominent outcrops of conglomeratic beds in the Savanna Formation that contain "fragments of oolitic and pink-crinoidal limestone from the Chimneyhill Formation. Other limestone fragments included in the conglomerates closely resemble strata from the Viola and Arbuckle."

Hemish (1995b; this report, Stop 4) describes several thin, discontinuous limestones containing invertebrate fossils, as well as a stromatolitic limestone in the field-trip area. Further to the north, just north of the Canadian River, but still in the Arkoma basin, three well-known limestones occur in the Savanna Formation. The one at the base of the Savanna (Spaniard Limestone) was named by S. W. Lowman (1932), who described it as dark gray, fine-grained, brown-weathering, and including dark gray to black, fossiliferous shale, as well as blue gray, calcareous, fossiliferous shale. Lowman (1932) also named the next stratigraphically higher limestone, the Sam Creek Limestone. He described it as a gray, brown-weathering, coquinoidal limestone underlain by gray fossiliferous shales and limestones. The youngest of the three limestones was named the Doneley Limestone by Branson (1954b, p. 192). At the type section, it is a 3-in.-thick calcareous ironstone. Elsewhere, it averages ~0.5 ft thick and is a gray, brown-weathering, richly fossiliferous limestone. The three limestones are stratigraphically equivalent to the subsurface "Brown limes" (Jordan, 1957, p. 28).

In general, the authors of this report find the sandstones in the Savanna Formation to be shades of brown, grayish orange, or (less commonly) red; very fine grained; well cemented by silica and/or limonite; quartzose; and texturally and compositionally mature. The shales generally are shades of olive or gray (or, less commonly, are black); they are silty and, rarely, fossiliferous; they contain abundant sideritic concretions. Limestones are typically impure, silty and sandy; brachiopods and crinoids are common. Where coal beds occur, they often are associated with well-preserved plant fossils.

The petrologic diversity of the Savanna Formation can be observed at Stops 4 and 5 (this field trip) and should provide evidence of changing depositional environments, as well as examples for facies analysis.

DEPOSITIONAL ENVIRONMENTS AND FACIES CHANGES

A comprehensive study of the depositional environments of the Savanna Formation has never been undertaken. Yeakel (undated) showed diagrammatically that the source of the Savanna clastics was from the south in the western part of the Arkoma basin, and from the east in the eastern part. He indicated that deposition occurred in a deltaic environment. His interpretation is suupported by the thickening of the formation eastward into Arkansas (Haley, 1961a), and by the conglomeratic nature of the sandstones in the southwestern part of the basin, which have constituents derived from outcropping formations in the Arbuckle Mountains.

Sutherland (1988, p. 1799) noted that Krebs Group depositional patterns were complex and included several major northwestward transgressions, followed by regressive southward progradations of fluvial deltaic systems across the shelf and into the Arkoma basin. Rocks in the Savanna Formation mapped by the authors in the Arkoma basin suggest deposition in a deltaic complex, as well as in a non-deltaic marine environment in places. Lateral facies changes within this depositional framework are exemplified by contrasting exposures at Stops 4 and 5. (Facies changes at Stop 4 can be seen just by examining outcrops on one side of the road and then the other.)

Repeated vertical sequences in the Savanna Formation indicate recurring depositional events. The term cyclothem was coined by Weller (in Wanless and Weller, 1932, p. 1003) for these repetitive sequences. Figure 16 shows the complete, "ideal" cyclothem, which consists of ten members. Bennison (1979, p. 292) recognized that the "ideal" cyclothem does not fit the cyclic conditions in Oklahoma, and that some of the members commonly are missing. Earlier, Branson (1954a, p. 1) had described his concept of a normal type of cyclothem in northeastern Oklahoma, as follows (member 1 is lowest):

6. shale, clay-ironstone concretions;
5. clay-ironstone, or fusulinid-bearing limestone;
4. coal;
3. underclay;
2. micaceous silty shale; and
1. sandstone.

Bennison (1979, p. 293) presented a different interpretation of a typical northeastern Oklahoma cyclothem. His redefinition is as follows (member 1 is lowest):

7. underclay, or paleosol;
6. weathered siltstone or shaly sandstone with molds of logs;
5. sandstone, cross-bedded;
4. sandy to silty shale, minor sandy limestone;
3. shale, clay-ironstone concretions;
2. limestone and black shale with phosphatic nodules; and
1. coal and carbonaceous shales.

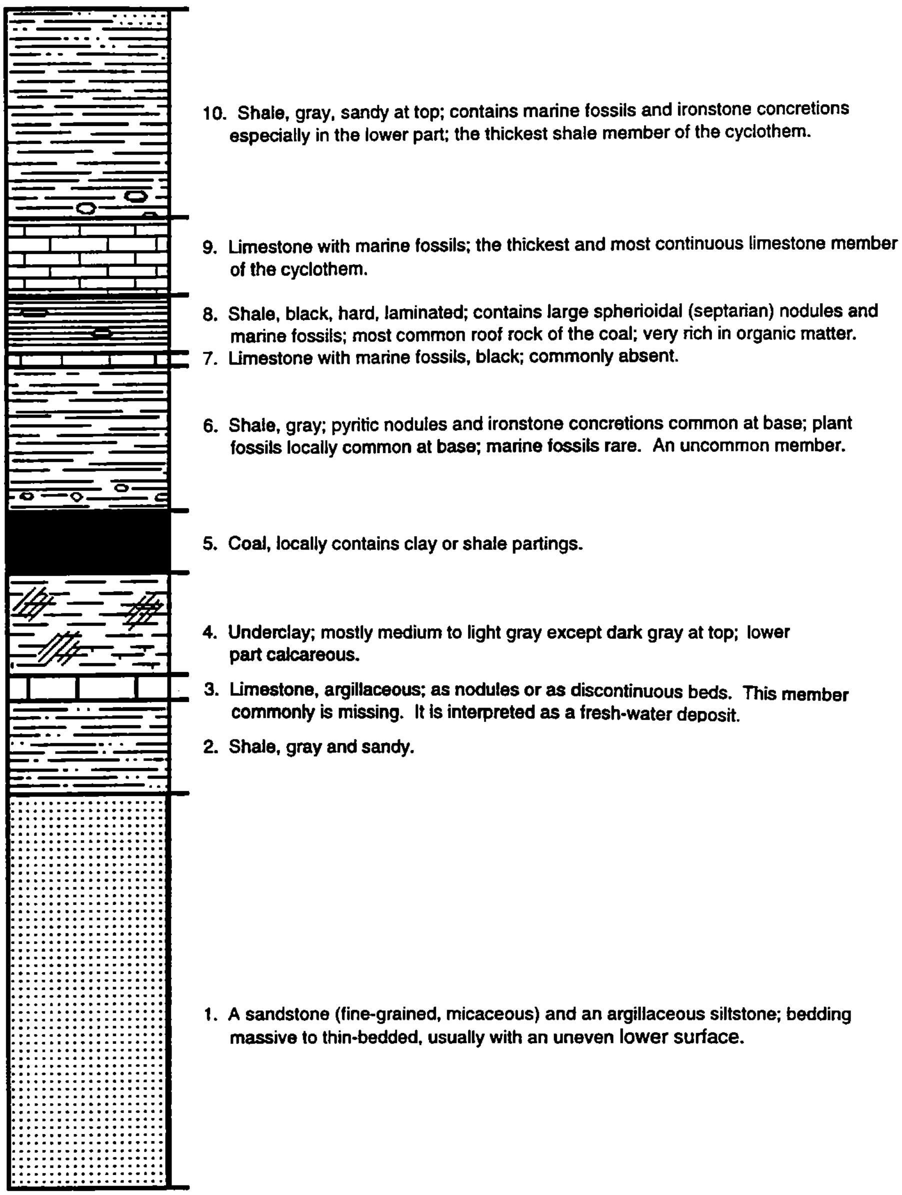


Figure 16. Ideal cyclothem. A cyclothem is a sequence of rock types arranged in a definite order. The rocks were deposited in different depositional environments during a regression and transgression of the sea. The order is similar in adjacent cyclothems. (Modified from Willman and Payne, 1942, fig. 42, p. 86.)

The rationale of Bennison's (1979) interpretation is that the transgression begins with a coal swamp and ends with a soil profile (paleosol). He does not agree that the lowest member is a transgressive sandstone (as interpreted in the others' concepts). Bennison (1979, p. 293) says that, in reality, the sandstone "shows regressive tendencies and is more likely to grade downward through transitional interbeds than any other elements in the coal cycle."

Repeated sequences of rock units similar to those described above have been observed by the authors in the McAlester area, as well as elsewhere in the Arkoma basin; such sequences confirm the cyclic nature of the Savanna Formation. However, the sequences in the Arkoma basin rarely fit the cyclothem models of Willman and Payne (1942), Branson (1954), or Bennison (1979).

Lateral variations in sandstone thicknesses over a short distance, as well as the discontinuous nature of single beds, indicate rapid facies changes. Scour surfaces and thickness irregularities suggest the presence of channels. Wave- and current-rippled siltstones and fine-grained sandstones (that show evidence of burrowing) in a coarsening-upward sequence, suggest deposition in a prodelta environment. Coals, carbonaceous shales, abundant detrital wood fragments, and channel sands indicate deposition in, or close to, the subaerial portion of a delta.

Other lithologic units, such as fossiliferous limestones, indicate marine sedimentary processes. Facies changes, sedimentary features, textural changes, areal patterns of sedimentary units, and the vertical sequence of environmental units all point to the conclusion that the Savanna Formation was deposited in a delta complex.

RESOURCES

Coal

Numerous local coal beds were noted in the Savanna Formation by Hendricks (1937a) in the McAlester district, but only two of the beds are thick enough to be mined. Hendricks (1937a) believed that the older of the two beds lies just above the lowest sandstone group of the Savanna in the vicinity of McAlester (secs. 29, 30, T. 6 N., R. 15 E.), where it has been mined, and it is reported to be ~4 ft thick. Recent mapping by Hemish (1997a) in the same area is not in agreement with Hendricks's map (1937a, pl. 2). Hemish's map is based on detailed field correlations and on thickness trends. (The Savanna Formation should be only ~1,100 ft thick in this area, where it is known to be thinning westward from its principal reference section. Hendricks's map shows the Savanna to be ~1,800 ft thick.) Hemish believes that the sandstone called the lowest sandstone of the Savanna by Hendricks is the Cameron Sandstone Member of the McAlester Formation, and that the 4-ft-thick coal that occurs in a thick shale interval just above the sandstone is in the McAlester Formation (Fig. 14). This coal correlates with the McAlester coal as shown by Hemish's map (Hemish, 1997a). Hendricks (1937a, p. 60) noted that the McAlester coal is 2 ft 5.5 in. to 4 ft 2 in. thick in secs. 31, 32, T. 6 N., R. 15 E., (<1 mi to the south of his misidentified coal).

The younger of the two minable coals occurs in the middle of the Savanna Formation and has been worked at

TABLE 3. — REMAINING COAL RESOURCES IN THE SAVANNA FORMATION[a]
(thousands of short tons)

Coal depth (ft)	Sulfur content (%)	Total Acres	Total Tons	Recoverable reserves (tons)	Net recoverable reserves (tons)
Le Flore County, Oklahoma					
Cavanal (mvb)[b]					
0–100	3.3 (4.8–2.1)	1,412	5,396	4,317	4,317
101–1,100	3.3 (4.8–2.1)	14,617	60,828	30,414	14,010
1,001–2,000	3.3 (4.8–2.1)	9,522	36,512	18,256	4,227
2,001–3,000	3.3 (4.8–2.1)	2,792	9,804	4,902	0
	Total:	28,343	112,540	57,889	22,554
Unnamed Coals above Cavanal; and Lower Cavanal (mvb)[b]					
0–100	—	638	1,973	1,578	1,578
101–1,000	—	4,782	18,205	9,102	83
1,001–2,000	—	4,011	15,589	7,794	0
2,001–3,000	—	1,007	4,094	2,047	0
	Total:	10,438	39,861	20,521	1,661
Pittsburg County, Oklahoma					
Cavanal(?) coal or coal in Savanna Formation (hvb)[c]					
0–100	—	626	2,253	1,802	1,802
101–1,000	—	5,787	20,833	10,416	0
1,001–2,000	—	6,457	23,245	11,622	0
	Total:	12,870	46,331	23,840	1,802

[a]Modified from Friedman (1974, appendix).
[b]Medium-volatile bituminous.
[c]High-volatile bituminous.

a small mine in sec. 18, T. 4 N., R. 16 E. (Hendricks, 1937a, p. 19). This coal was not named, but may correlate with the Cavanal coal and/or one of the coals exposed in the road cut at Stop 4 (this field trip).

The Cavanal coal is a comparatively thick coal bed that occurs at about the middle of the Savanna Formation in the eastern part of the Arkoma basin of Oklahoma (Trumbull, 1957, p. 349) (Fig. 14). It has been mined around Cavanal Mountain, where it is 24–38 in. thick. The bed thins northward and westward into Haskell and Latimer Counties, respectively. Other thinner coals are present in Le Flore County just above and just below the Cavanal coal.

A thin coal (Rowe coal bed), slightly younger than the Cavanal bed, has been mapped in the northern part of the Arkoma basin by Wilson and Newell (1937), and by Hemish (in press, a,b). It averages only about 10–12 in. thick, but has been mined on a small scale in McIntosh and Muskogee Counties, as well as in counties to the north. This coal may correlate with an 11-in.-thick coal mapped by Hemish (1996b) in south-central Haskell County.

Pennsylvanian coals of Oklahoma range in rank from high-volatile C bituminous to low-volatile bituminous. The coals in the Savanna Formation are high-sulfur coals and range in rank from high-volatile bituminous to medium-volatile bituminous (Friedman, 1974). Coal-resource tables from Friedman (1974, appendix) show that in Le Flore County 117 acres and 456,000 short tons of Cavanal coal have been mined or lost in mining, and that 70 acres and 235,000 short tons of the coals just above and just below the Cavanal coal have been mined or lost in mining. Production records are not available for Savanna coals mined in other counties in the central Arkoma basin. Table 3 shows the remaining coal resources in the Savanna Formation in Le Flore and Pittsburg Counties, the only two counties for which Friedman (1974) shows resources in the central Arkoma basin.

In the northern Arkoma basin and McAlester hingeline area (McIntosh and Muskogee Counties), Hemish (in press, a; table 2; in press, b, table 2) listed only one coal bed in the Savanna Formation that has economic potential, the Rowe coal. He listed 709 acres and 1,558,000 short tons of remaining Rowe resources in McIntosh County, but showed no record of any amounts mined or lost in mining (Hemish, in press, a, table 2). In Muskogee County, Hemish (in press, b, table 2) listed, 2,237 acres and 4,453,000 short tons of remaining Rowe resources, and 51 acres and 86,000 short tons mined or lost in mining.

Coal is not being mined from the Savanna Formation in Oklahoma at the present time.

Natural Gas

Sandstones of the Savanna Formation have not been exploited for hydrocarbons in the Arkoma basin, with one known exception. The No. 1 Graham well, located in the center of the SE¼SE¼ sec. 22, T. 7 N., R. 13 E., Pittsburg County, in the Ulan Field (Fig. 9), produces gas from the Savanna sand at a depth of 1,877–1,896 ft (Fields, 1987). The calculated open flow for Savanna initial production was 1,450 thousand cubic ft of gas per day.

BOGGY FORMATION (DESMOINESIAN), ARKOMA BASIN, OKLAHOMA

GENERAL

The Boggy Formation overlies the Savanna Formation in the Arkoma basin and Cherokee platform of Oklahoma (Figs. 1, 2); it is preserved in outliers in Arkansas in only two small areas (Fig. 17). The Boggy extends westward in the subsurface in Oklahoma as far as T. 20 W. (Andrews, 1997, pl. 1). Its sands (Red Fork of subsurface terminology) are prolific hydrocarbon reservoirs in the Cherokee platform, Anadarko shelf, and Anadarko basin areas.

Miser (1954) established the contact between the Savanna Formation and the Boggy Formation at the base of the Bluejacket Sandstone Member of the Boggy in the course of preparation of the Geologic Map of Oklahoma (Fig. 14). The Bluejacket is in irregular contact with the underlying shales and siltstones of the Savanna. The contact is gradational in some places; at others, channeling is evident (Oakes and Koentz , 1967, p. 24).

The upper limit of the Boggy Formation was placed by Taff (1899) at the base of the Thurman Formation. Oakes (1953) thought that there must be an unconformity at the top of the Boggy Formation, based on the following criteria: (1) an abrupt change in the character of the sediments in the Arkoma basin, where coarse quartz sand mixed with chert pebbles in the base of the Thurman abruptly succeed shale and fine-grained sandstone; (2) a distinct paleontological break; and, (3) discordance between the structure of the Boggy and the structure of post-Boggy rocks. Rocks younger than the Thurman successively overlap the next older formation northward. The stratigraphic succession (from oldest to youngest) in the Krebs and Cabaniss Groups goes from Boggy/Thurman/Stuart/Senora from basin to shelf.

The Boggy Formation is predominantly shale, but, like the Savanna, contains a variable number of sandstone "zones" or "groups" that form topographic ridges. Hemish and others (1990a,c) Hemish (1991b; 1992; 1995a; 1996a,b); Hemish and Mazengarb (1992), and Hemish and Suneson (1994) (see Appendix 1) mapped as many as eight ridge-forming groups in the Boggy Formation in the central and eastern parts of the Arkoma basin, and they called them informally Boggy 1–8 sandstones.

HISTORY OF NOMENCLATURE

Taff (1899, p. 438–439) originally named the Boggy shale (Formation), presumably from outcrops in the valleys of Clear Boggy Creek and Muddy Boggy Creek, in Coal, Pittsburg, and Pontotoc Counties, Oklahoma. He did not formally designate a type locality, and to this day the Boggy does not have a type section or any kind of a reference section. In his original description Taff (1899, p. 438–439) wrote of the Boggy in the south-central part of the Arkoma basin:

> There is a mass of shale and sandstone above the Savanna sandstone nearly 3,000 feet thick....In the Boggy shale there are probably not less than sixteen beds of sandstone ranging in thickness from 20 to 150 feet, separated by shale from 100 to 600 feet thick. One coal bed, about 2 feet 6 inches thick, has been located and worked to a small extent, though now abandoned....
>
> The shales of this series are exposed to a very slight extent. In the few hill slopes and stream cuttings where observed the shales are bluish fissile clay containing ironstone concretions, thin wavy sandstone plates, and shaly sandstone strata. The sandstones fall in one general class and vary but little in minor detail of structure. They are generally brownish or gray and some beds are quite ferruginous....All the sandstones are fine grained and were without doubt deposited under very similar conditions.

Four members have been named in the Boggy Formation: (from bottom to top) the Bluejacket Sandstone Member, the Crekola Sandstone Member, the Inola Limestone Member, and the Taft Sandstone Member. The Bluejacket Sandstone Member (Bartlesville sand of subsurface terminology) was named by Ohern (1914, p. 28) from outcrops in the hills west of the town of Bluejacket, Craig County, Oklahoma. Howe (1951, p. 2088) observed that the type section of the Bluejacket Sandstone was not adequately defined. He redefined the Bluejacket in a generalized graphic section of the sequence of beds exposed in the "hills west of Bluejacket, Oklahoma" (Howe, 1951, fig. 1, p. 2089). He did not include a measured section, but he did provide a location for the type section. Chrisman (1951, p. 18, appendix 15) subsequently measured a section in the NW¼NE¼NE¼ sec. 25, T. 27 N., R. 20 E., at the location of Howe's type section. Hemish (1989, p. 77), noting the variability of the lithology of the Bluejacket, as well as the need for detailed descriptions of the overlying and underlying strata, established two reference wells in its type area in northeastern Craig County.

The Crekola Sandstone Member of the Boggy Formation was named by Wilson (1935, p. 510–511) from the village of Crekola, sec. 10, T. 14 N., R. 17 E., Muskogee County. Because of correlation difficulties, the Crekola Sandstone Member generally is not mapped beyond the boundaries of Muskogee County.

The Inola Limestone Member of the Boggy Formation was first mentioned in print by Lowman (1932) who named it from an outlier on a hill east of the town of Inola, Oklahoma (type locality). Tillman (1952, p. 32) measured a section in a road cut ~12 mi north of the type locality, and proposed that it should be the type section for the Inola Limestone. Branson (1954b, p. 192) formally designated Tillman's measured section as the type section of the Inola, but restricted the term Inola to the lowermost limestone of the four that are described by Tillman (1952). Hemish (1990a, p. 4–23) subsequently redefined the type section to include all the beds from the base of the lower limestone to the top of the fourth (stratigraphically youngest) limestone

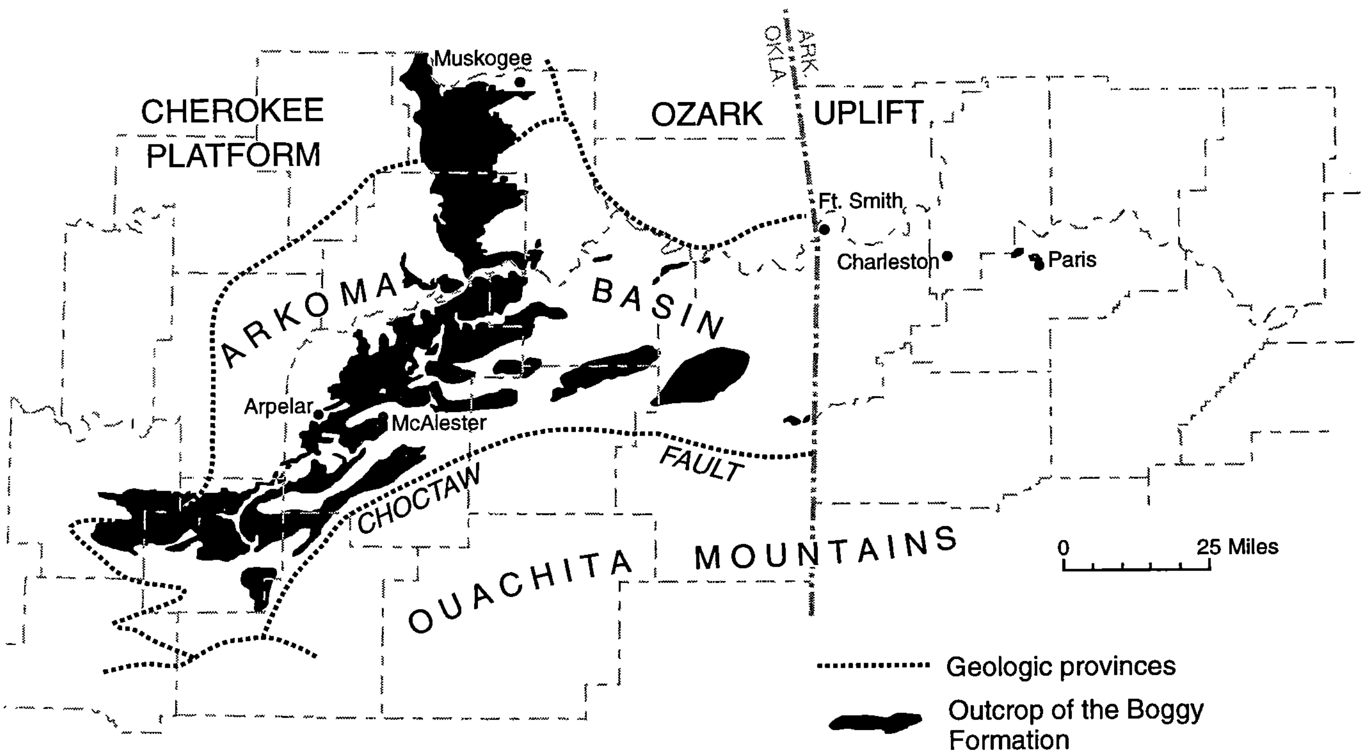


Figure 17. Outcrop belt of the Boggy Formation in the Arkoma basin area of Oklahoma and Arkansas. (Modified from Miser, 1954; Haley and others, 1976.)

described by Tillman (1952). Hemish (1990a) also established a principal reference section on Inola Hill, as well as a subsurface reference section in the vicinity of the type section. The Inola Limestone has been identified in the Arkoma basin, but only as far south as central McIntosh County (Oakes and Koontz, 1967, pl. 1), where it occurs as a single bed < 1 ft thick.

Wilson (1935, p. 510) first used the term "Taft Sandstone," presumably for beds that crop out around the town of Taft, Muskogee County, Oklahoma. Newell (in Wilson and Newell, 1937, p. 56–57) wrote that at "the type locality in T. 15 N., the unit consists of about 20 feet of coarse-grained massive sandstone. The upper third of the division consists of silty to sandy shale." Farther south, some 80 ft of massive sandstones interbedded with shales are present in the Taft escarpment. The limits of the Taft Sandstone Member and correlations have never been adequately established. Therefore it is inadvisable to use the term Taft for the sandstones that crop out in the area of this field trip. These units are referred to informally as "Boggy sandstones" and given number designations where practical.

The Savanna/Boggy boundary positions changed through time (see Fig. 14), mostly because investigators (e.g., Wilson, 1935) included the Bluejacket Sandstone in the Savanna Formation, or included the thick, unnamed shale unit below the Bluejacket Sandstone in the Boggy Formation (e.g., Dane and Hendricks, 1936; Wilson and Newell, 1937; Oakes and Knechtel, 1948). The boundary has been defined at the base of the Bluejacket Sandstone since 1954 when Miser found that horizon to be the only one sufficiently extensive to separate the Savanna Formation (below), from the Boggy Formation (above).

The top of the Boggy Formation has been eroded throughout all but the western part of the Arkoma basin, where the Thurman Formation or the Stuart Formation overlie the Boggy. The top of the Boggy also has been preserved in the Cherokee platform area of Oklahoma, where it is overlain by the Senora Formation. The Thurman Formation can be observed at Stop 1, this field trip, in the Arpelar area. The placement of the upper limit of the Boggy Formation was discussed earlier (p. 30).

DISTRIBUTION AND THICKNESS

Figure 17 shows the outcrop distribution of the Boggy Formation in Oklahoma and Arkansas. Outcrops of the Boggy extend from the north flank of the Arbuckle Mountains northeastward to the Kansas-Oklahoma line. Outcrops of the Boggy are also preserved in the eastern part of the Arkoma basin in Oklahoma and Arkansas, where they are present in synclinal outliers.

The maximum thickness of the Boggy Formation is reported to be ~3,000 ft within the Cavanal syncline on Cavanal Mountain, T. 7 N., R. 24 E., but this does not represent the total thickness of the original deposit (Webb, 1960, p. 25). Hendricks (1937a, p. 24) estimated the Boggy to be ~2,850 ft thick in the McAlester district. The formation thins westward, and in the vicinity of Ada, Morgan (1924, p. 78) found the Boggy to be about 1,300–1,500 ft thick. Northward from the Arkoma basin, the formation also thins. Hemish (1997b) showed the Boggy to be only ~153 ft thick in the area east of Tulsa. Just south of the Kansas-Oklahoma state line in sec. 25, T. 27 N., R. 20 E., Craig County, Hemish (1990b), showed the Boggy to be only ~72 ft thick. About 500 ft of the Boggy Formation is preserved in an outlier south of Charleston, Arkansas, and ~900 ft is present near Paris, Arkansas, in the eastern part of the Arkoma basin (Hendricks and Parks, 1937, p. 200) (Fig. 17).

CHARACTER

In the field-trip area, the Boggy Formation consists of thin sandstones alternating with thick shales, a few coal beds, and a few limestones. The sandstone beds represent only ~7.5% of the entire formation (Hendricks, 1937a, p. 23). The sandstone beds of the Boggy are variable in thickness and character. They are predominantly very fine grained, and they range from thin bedded to massive. Soft-sediment deformation features such as rolled masses and convolute bedding are common. Also common are ripple marks, trace fossils, and fragments of *Stigmaria*, *Sigillaria*, *Lepidodendron*, and *Calamites*. Hendricks (1937a, p. 23) reported finding invertebrate marine fossils in a thin sandstone bed in the northwest corner of sec. 3, T. 3 N., R. 13 E. He also found invertebrate fossils in shales at various horizons within the formation. Recent mapping by the authors in the Savanna quadrangle (Appendix 1) has confirmed the presence of marine fossils in the Boggy. Morgan (1924, p. 80–83) found that the shales of the Boggy Formation carry numerous and well-preserved invertebrate fossil specimens. He identified and listed in a chart nearly 100 different species.

In the western part of the Arkoma basin, coarser-grained clastic beds are present in the upper part of the Boggy. These grade from sandstones and fine-grained conglomerates to coarse limestone conglomerates in Pontotoc County (Morgan, 1924, p. 78).

In northern Pittsburg County, Dane and others (1938, p. 160–161) described the Boggy Formation as predominantly shale, but with "zones of sandstone as much as 100 feet thick....The lenticularity of the individual beds is well established by field observation, and individual beds may reach 20 feet or more in thickness but do not have great lateral extent. Examples of the fusion of two or more beds to form a single thicker bed are also common. Lateral changes in the lithology of the individual beds from thin-bedded and even shaly sandstones to massive and cross-bedded sandstones or to sandstones that exhibit contorted or deformed bedding are the rule rather than the exception."

Oakes (1977, p. 28) contrasted the thicker more massive sandstones of the Arkoma basin (which he called "the basin facies") with the "shelf facies," which he described as finer grained, more shaly, and more lenticular. He also said that the shelf facies contains thin limestones and coal beds that do not extend southward into the basin.

The authors have found from recent mapping that the sandstones in the Boggy Formation north from McAlester and east to the Arkansas-Oklahoma line are predominantly very fine grained, in contrast to the coarser-grained, conglomeratic sandstones to the south and west of McAlester. Andrews (1997) reported exposures of sandstones of the Boggy (Red Fork sand of subsurface terminology) along the western shores of Lake Eufaula, which he interpreted as fluvial in origin. The sand section there is also highly conglomeratic. The authors conclude that the source area for the Boggy sediments south and west of McAlester is different from the source areas for the Boggy sediments of the shelf area and the eastern Arkoma basin.

White (1989, p. 35) reported that the sandstones of the Boggy Formation are sublitharenites to quartz arenites. He found that some of the sandstones contain up to 96% quartz and that the grains are rounder and better sorted than grains in other sandstones of the Boggy. Rock fragments in the Boggy sandstones are predominantly quartz-mica gneiss, quartzite, and argillaceous rocks. Small amounts of feldspar (< 5%) are present. Minor detrital constituents, ranging from trace amounts to 1–2%, include: pyrite, hematite, hornblende, magnetite, rutile, zircon, tourmaline, and mica. Finely particulate plant debris occurs throughout the sandstones as thin carbonaceous partings. Ferruginous, silica, calcite and clay cements can be identified in the various sandstones; ferruginous cement is the most common (White, 1989, p. 36).

In general, the authors have observed that the shales of the Boggy Formation are predominantly sandy, silty, grayish black to olive gray to dark yellowish brown, noncalcareous, locally fissile, carbonaceous in places; locally, they contain invertebrate fossils. The sandstones are generally fine to very fine grained, conglomeratic to the west, predominantly dark yellowish brown to grayish orange to light brown, noncalcareous; they have abundant sedimentary structures, such as ripples, cross-stratification, sole marks, and soft-sediment deformation features. Thin coal beds commonly are associated with plant fossils. Thin limestones and ironstone beds occur locally.

DEPOSITIONAL ENVIRONMENTS

Environmental interpretations of sequences of strata in the Bluejacket (Bartlesville) Member of the Boggy have been made by Weirich (1953) and Visher (1968, 1988). Their maps cover the entire area of the Cherokee platform and much of the Arkoma basin. Vertical sequences, whose members have different depositional origins, are especially well developed in this area and can be observed in many outcrops and quarries. Sedimentary environments represented in the vertical sequences include off-shore marine, upper and lower delta plain, interdelta, and prodelta (Visher, 1968, p. 32).

Any study of the depositional history of sedimentary rocks requires the bringing together of a large amount of data, preferably from an extensive area (Visher, 1988). The availability of numerous cores and many thousands of well logs, as well as almost continuous outcrops for the Bluejacket (Bartlesville) Sandstone, enabled Visher (1968, 1988) to make detailed studies and interpretations of depositional environments represented in the unit. He concluded that the history of deposition of the Bluejacket (Bartlesville) Sandstone can be related to progradation of large deltaic units that developed over tens of thousands of years.

Weirich (1953) showed that the fluvial system that carried clastics into Oklahoma originated north of Kansas City and flowed south-southwestward around the Ozark uplift. The depositional strike is approximately northeast-south-

TABLE 4. — REMAINING COAL RESOURCES IN THE BOGGY FORMATION[a]
(thousands of short tons)

Coal depth (ft)	Sulfur content (%)	Total		Recoverable reserves (tons)	Net recoverable reserves (tons)
		Acres	Tons		
		Haskell County, Oklahoma			
		Secor (hvb)[b]			
0–100	6.5 est.	705	2,648	2,118	2,118
101–1,100	6.5 est.	3,847	14,512	7,256	2,118
	Total:	4,552	17,160	9,374	2,118
		Le Flore County, Oklahoma			
		Secor (mvb)[c]			
0–100	4.1 (4.1)	1,080	4,611	3,689	3,689
101–1,100	4.1 (4.1)	11,204	60,150	30,075	26,392
1,001–2,000	4.7 (4.7)	8,459	46,672	23,336	20,658
2,001–3,000	4.7 (4.7)	6,117	36,826	18,413	0
	Total:	26,860	148,259	75,513	50,739
		Lower Witteville (mvb)[c]			
101–1,000	4.4 (4.4)	5,862	31,789	15,894	14,248
1,001–2,000	4.4 (4.4)	3,744	20,142	10,071	8,885
	Total:	9,606	51,931	25,965	23,133
		Pittsburg County, Oklahoma			
		Coal above Secor (hvb)[b]			
0–100	—	1,092	3,629	2,903	2,903
101–1,000	—	1,491	5,367	2,684	0
	Total:	2,583	8,996	5,587	2,903
		Secor (hvb)[b]			
0–100	5.3 (6.6–3.5)	6,720	29,762	23,738	23,586
101–1,000	5.6 est.	47,499	191,219	95,610	34,540
1,001–2,000	5.6 est.	5,864	21,064	10,532	4,851
	Total:	60,083	241,955	129,880	62,977
		Coal below Secor (hvb)[b]			
0–100	—	125	495	396	396
101–1,000	—	476	1,885	942	0
	Total:	601	2,380	1,338	396

[a]Modified from Friedman (1974, appendix).
[b]High-volatile bituminous.
[c]Medium-volatile bituminous.

west, but changes to east-southeast at the north edge of the Arkoma basin.

In the field-trip area, near McAlester, exposures of the upper part of the Savanna Formation and of the lower part of the Bluejacket Member of the Boggy Formation are interpreted to be prodelta deposits overlain by shallow marine and/or probable tidal-flat deposits. At Stop 3, the subaerial part of the delta complex is represented by coal and shales containing abundant carbonaceous materials. These units formed during late stages of southerly deltaic progradation.

The sandstones in the upper part of the Boggy Formation have not been studied in the field trip area to the same extent as the Bluejacket Member. However, Yeakel (undated) showed diagrammatically that the source of the upper Boggy clastics was from the north. Andrews (1997) showed that the source area for the Red Fork sands of the platform area was to the north of Oklahoma. As the result of years of field mapping and literature review, the authors believe that the fluvial systems that brought upper Boggy clastics southward from the craton discharged into the subsiding Arkoma basin north and east of McAlester, where they were deposited as part of a deltaic/marginal-marine complex. The coarser clastics deposited in the basin south and west of McAlester probably had a different source area to the south or southeast, as indicated by their locally coarse nature.

RESOURCES

Coal

Hendricks (1937a, p. 62) noted the presence of only two coal beds of minable thickness in the Boggy Formation in the McAlester district. The lower of the two occurs ~50 ft above the top of the Savanna Formation in sec. 3, T. 4. N., R. 14 E., where it has been mined. Hendricks (1937a, p. 62) tentatively correlated the bed with the Lower Witteville coal that is ~4 ft thick on Cavanal Mountain, where it also has been mined in the past. The thickness of the coal near McAlester was not listed and is no longer exposed.

TABLE 5. — COAL RESOURCES AND RESERVES IN THE BOGGY FORMATION ACCORDING TO COAL BED[a]
(thousands of short tons)

Coal	Total remaining resources		Mined or lost in mining		Original resources		Reserves	
	Acres	Tons	Acres	Tons	Acres	Tons	Acres	Tons
McIntosh County								
Wainwright	284	535	1	1	285	536	66	95
Peters Chapel	763	2,033	1	3	764	2,036	415	1,003
Secor	7,641	16,857	1,765	4,703	9,406	21,560	1,120	2,119
Lower Witteville	939	1,691	62	235	1,001	1,926	194	368
Muskogee County								
Wainwright	3,436	6,932	50	146	3,486	7,078	1,035	1,823
Peters Chapel	5,598	11,654	42	66	5,640	11,720	1,659	3,192
Secor	7,046	14,582	840	1,637	7,886	16,219	503	815

[a]Modified from Hemish (in press, a, table 2; in press, b, table 2).

The other (upper) coal bed is the Secor coal, which also has been mined in the past in the McAlester district. Hendricks (1937a, p. 62) reported that the Secor lies just above the lowest sandstone of the Boggy Formation and that it is 1.6–3 ft thick where mined. Friedman (1990, p. 194) reported a thickness of 5 ft for the Secor coal ~4 mi southeast of McAlester. The Secor coal is present in the Arkoma basin east of McAlester, although generally it is much thinner than in the McAlester district. It extends north and maintains minable thickness as far north as southern Wagoner County (Hemish, 1986; 1988a,b; 1990c). In Le Flore County, on Cavanal Mountain, the Secor coal is as thick as 4 ft. Currently, it is being mined in two surface pits on the flanks of the mountain, and it is used for generating electricity and CO_2 in the AES Shady Point co-generation plant (Hemish, 1994b, p. 2).

Five coal beds occur in the Boggy Formation in the transition area from the Arkoma basin to the Cherokee platform (Hemish, 1988b, p. 19). In addition to the Lower Witteville and the Secor coals, they are: (1) The Secor Rider coal bed, which occurs from a few inches to 40 ft above the Secor coal. (In 1993, the Secor Rider was being produced in the same mine on Cavanal Mountain, Le Flore County, as the Secor [Hemish, 1994, p. 2].) (2) The Peters Chapel coal bed, which occurs from ~100 ft above the Secor coal in McIntosh County, to ~50 ft above in Muskogee County, to ~30 ft above in Wagoner County. Currently, it is not being exploited. (3) The Bluejacket coal bed is the next stratigraphically higher coal, generally found in association with the Inola Limestone. It is only ~2 in. thick in the northern part of the Arkoma basin, and it has no commercial value.

One other coal bed, the Wainwright coal, which occurs in the upper part of the Boggy Formation, has been identified in the hinge-line and shelf areas. Locally, it is >2 ft thick in southwestern Muskogee County, and it has been mined as recently as the 1970s (Hemish, in press, b).

Like the coals in the Savanna Formation, the Boggy coals range in rank from high-volatile to medium-volatile bituminous in the Arkoma basin (Friedman, 1974). Coal resource tables from Friedman (1974, appendix) show that, in Pittsburg County, 127 acres and 569,000 short tons of the Secor coal have been mined or lost in mining, and 22 acres and 79,000 short tons of the Secor Rider have been mined or lost in mining; in Haskell County, 9 acres and 32,000 short tons of the Secor coal have been mined or lost in mining; in Le Flore County, 83 acres and 522,000 short tons of the Lower Witteville coal have been mined or lost in mining, and 1,020 acres and 6,919,000 short tons of the Secor coal have been mined or lost in mining.

Table 4 shows the remaining coal resources in the Boggy Formation in Haskell, Le Flore, and Pittsburg Counties.

In the northern Arkoma basin and hinge-line areas, Hemish (in press, a, table 2; in press, b, table 2) lists four coal beds in the Boggy Formation that have economic potential: (from lowest to highest) the Lower Witteville, the Secor, the Peters Chapel, and the Wainwright. Resource and reserve data for the coals are shown in Table 5.

Natural Gas

The only known fields where production has been reported from the Boggy (Red Fork) sandstone in the Arkoma basin are in the western part of the area, mainly in Hughes County and eastern Pontotoc County. The fields listed by Andrews (1997, pl. 5) are the Allen District, Greasy Creek, and Holdenville. These are fields that produced ≥5,000 barrels of oil per day or ≥3 Bcf of gas per day from 1979 through June 1996.

PART II

Stop Descriptions

STOP 1

Thurman Formation (Cabaniss Group)

Location: SW¼SW¼SE¼ sec. 32, T. 6 N., R. 13 E., Pittsburg County, north side of U.S. Highway 270 (State Highway 1), 0.6 mi east of Arpelar, Oklahoma

GENERAL GEOLOGY OF THE THURMAN FORMATION

Introduction

The Thurman Formation is the basal formation of the Desmoinesian Cabaniss Group. It is conformably overlain by the Stuart Formation. The nature of its basal contact with the underlying Boggy Formation (Krebs Group) is controversial; some workers maintain that the contact is a paraconformity or disconformity, and others that it is an angular unconformity. This controversy is discussed in more detail below.

The most recent work on the Thurman Formation is by White (1989), who studied the Thurman in northeastern Coal County, southeastern Hughes County, and most of Pittsburg County; much of the following information is summarized from his report. Earlier studies include Hendricks (1937a) in southern Pittsburg County, Dane and others (1938) in northern Pittsburg County, and Weaver (1954) in Hughes County. Govett (1957) mapped the Thurman in the Arpelar area (area of Stop 1); Jones (1957) mapped the Thurman immediately to the south; and Hare (1969) studied the petrography of the Thurman in northern Coal County and southeastern Hughes County. Sutherland (1988) briefly summarized previous studies and attempted to place the deposition of the Thurman in the context of Arkoma basin tectonics.

The outcrop pattern of the Thurman Formation is a broad arc extending from eastern Pontotoc County to north-central Pittsburg County (Fig. 18A). It is ~100 ft thick at its western end (Naff, 1962), thickens to 300 ft in western Pittsburg County (White, 1989), and pinches out to the northeast where the Stuart Formation overlies the Boggy (Oakes, 1948, 1953, 1977). The most common rock types in the Thurman are sandstone and conglomerate; shale is uncommon. Rare beds of fusulinid limestone occur near the base of the Thurman at its western exposures (Naff, 1962).

White (1989) divided the Thurman Formation into three sandstone units, separated by two shales. The sandstone units are generally similar and consist mostly of rippled, trough-cross-stratified sandstones in channels, and conglomerates. The conglomerates contain matrix-supported, subangular chert fragments, shale pebbles, and shale rip-up clasts. Brachiopods and gastropods are present locally. The shale units are silty and locally contain small (<2 mm) chert grains.

White (1989) identified six lithofacies within the Thurman; three represent shallow- or offshore-marine deposition, and three were deposited in a fluvial environment. White (1989, p. 66) also identified what he interpreted to be shoreface sandstones. Fluvial sandstones are predominant in Coal County and shoreface sandstones and marine sandstones, siltstones, and shales predominate in Pittsburg County (Fig. 18A). Hare (1969) recognized fluvial (channel and floodplain), beach, and nearshore facies in the Thurman; his conclusions regarding the locations of the fluvial and marine facies are generally similar to those of White (1989), albeit for a much smaller area. These observations, and the presence of limestone in the Thurman west of White's (1989) study area as noted by Naff (1962), suggest that the middle and thickest part of the Thurman outcrop area represents fluvial-deltaic sediment deposition, whereas the Thurman outcrops in the "flank" areas to the west and northeast represent dominantly marine processes (Fig. 18A).

Dane and others (1938) first proposed that the source terrane for Thurman sediments was different from that for the Boggy sediments. Oakes (1948) suggested a southeastern source for all of the Cabaniss Group, but provided no supporting data. Hare (1969) was the first to show that the source of Thurman sediments was the uplifted Ouachita Mountains to the southeast of the Thurman outcrop area. He based his conclusions on similar clay mineralogy, chert composition, heavy-mineral suite, composition of rock fragments, and paleocurrents. White's (1989) paleocurrent data confirmed a southeastern source area.

Unconformity at the Base of the Thurman Formation

The nature of the Boggy-Thurman contact is controversial. In places, it appears gradational; in other places, it is abrupt; in still other places, it is reported to be marked by structural discordance. Oakes (1953) and Oakes and Koontz (1967) reviewed prior published work on the contact and summarized their view that the contact is an unconformity, based on (1) the abrupt change in the character of sediments (from shale to coarse sandstone and conglomerate) across the contact, particularly south of McIntosh County; (2) the paleontologic break at the top of the Boggy, particularly north of the Arkansas River; and (3) structural discordance, with local differences in strike across the contact of as much as 90°. Similarly, Dane and others (1938, p. 167) noted that "because of the local erosional irregularity at the base, it is believed that the Thurman may rest unconformably on the Boggy shale... [but] angular discordance has not been detected with assurance."

The view that the Boggy-Thurman contact is an unconformity has not been universally accepted, however. Hendricks (1937a, p. 26) stated that the "change from the Boggy shale to Thurman Formation is gradational in the McAlester district." Weaver (1954, p. 33) suggested the Thurman was deposited with "apparent" conformity on the Boggy in Hughes County, but had very little map evidence to prove it. Jones (1957) believed that the contact probably represented a regional unconformity, but was gradational and conformable in the area he mapped. Naff (1962) reported a conformable contact along the western outcrop area of the Thurman.

Map evidence for an angular unconformity is also contradictory. Hendricks (1937a) showed the Thurman to be folded by the Talawanda syncline, as was the Boggy. Similarly, Jones (1957) showed the Thurman to be folded by the Krebs syncline. In contrast, Govett (1957) showed the Lilypad anticline and the Talawanda syncline dying out in the Boggy, but presented no map evidence for an angular unconformity. The structural evidence for an angular unconformity between the Boggy and Thurman is, perhaps, best summarized by Oakes and Koontz (1967, p. 12), in discussing the folds and faults of the Arkoma basin:

> Some of these structures are discernible in the Thurman Formation and younger rocks, but in these younger rocks the amplitude is much smaller.

The Boggy-Thurman contact is probably a paraconformity representing a significant sedimentological break from dominantly fine grained sediments, below, to coarse-grained sediments, above. It also marks the emergence of the Ouachita Mountains above sea level for the first time in this area. However, there is little evidence for an angular unconformity at the top of the Boggy. Ouachita-style deformation appears to have extended through the time of Thurman deposition, albeit in greatly lessened intensity than earlier and to the south. There is no evidence that the overlying Stuart Formation is folded, but it is probable, if not likely, that the present outcrop area of the Stuart is outside the fold belt.

Discussion

The Thurman Formation exposed at the U.S. Highway 270 Arpelar Section (Fig. 18B) is in the lower part of the formation (White, 1989). It is frequently visited by geologists because it is well exposed, easily accessible, and it contains chert-pebble conglomerates. Although the chert fragments are weathered and difficult, if not impossible, to identify as having been eroded from a particular formation, most workers agree on a Ouachita Mountains source terrane. The nearest present-day exposures of chert in the Ouachita Mountains are the Devonian Arkansas Novaculite and Ordovician Bigfork Chert at Black Knob Ridge near Stringtown, ~30 mi to the south. The same formations are also exposed in the Potato Hills, ~40 mi to the east-southeast.

Most of the sedimentary structures in this outcrop support White's (1989) interpretation that the Thurman Formation in this area was deposited in a relatively shallow marine environment. The entire section, however, may represent a shallowing-upward sequence: unit 1 appears to have been deposited below normal wave base but above storm wave base,

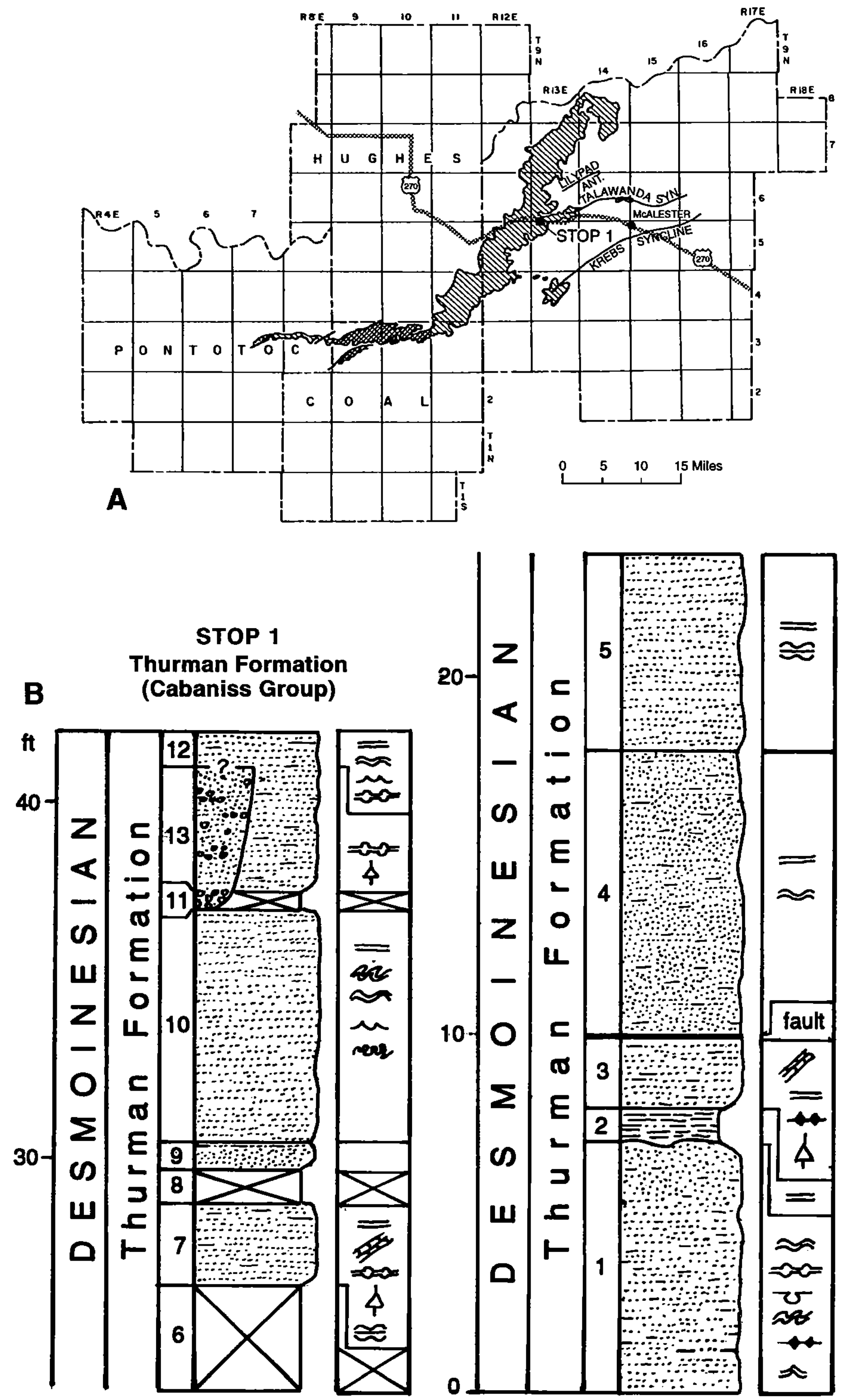


Figure 18. *A*—Map showing outcrop distribution of the Thurman Formation, location of Stop 1, and axes of major folds referred to in text. Single hatched pattern is dominantly marine facies of the Thurman Formation; cross-hatched pattern is dominantly fluvial and/or deltaic facies (based on Naff, 1962; Hare, 1969; White, 1989). (Modified from Hare, 1969.) *B*—Graphic columnar section of the Thurman Formation exposed at Stop 1. Explanation of symbols in Appendix 3.

whereas units 5, 10, and 12 were deposited in a shoreface environment. One interpretation of unit 13 (chert-pebble conglomerate) is that it is a fluvial channel. However, it is eroded into and overlain by shallow-marine sandstones; thus, it appears to be a marine-channel deposit.

Despite a careful search, no marine fossils were observed in the Arpelar section; however, White (1989) found marine invertebrates in the Thurman Formation immediately to the north.

Measured Section, Stop 1

Thurman Formation (Cabaniss Group)

U.S. Highway 270 Arpelar Section

SW¼SW¼SE¼ sec. 32, T. 6 N., R. 13 E., Pittsburg County (Haywood 7.5′ quadrangle). Located 0.6 mi east of Arpeler, on north side of U.S. 270. Section begins in creek bed and continues in bar ditch adjacent to road to top of exposure. (Modified from White, 1989, p. 109–110.) Section measured by Neil H. Suneson.

Thickness (feet)

CABANISS GROUP:

THURMAN FORMATION:

13. Chert-pebble conglomerate, grayish orange (10YR7/4). Most of large clasts are angular to subrounded weathered chert fragments as large as 1.5 in. Rare fragments include iron-oxidized shale rip-up clasts. Chert clasts are matrix-supported in quartzose, coarse-grained sandstone (Fig. 19). Concentration of clasts locally exceeds 50%, particularly at very base of unit. Stratification in sandstone varies from 0.3 to 6 in., and is mostly 0.5–1 in. Locally, conglomerate occurs as wisps and streaks in sandstone. Conglomerate is not graded. Interpretation: marine-channel deposit. Orientation of channel: very approximately N-S.
12. Sandstone, grayish orange (10YR7/4), fine-grained, silty, possibly showing very slight normal grading in some beds. Lower part well-exposed, upper part poorly exposed. Weathers platy to flaggy. Mostly parallel stratified, rarely wavy bedded. Some minor pinch-and-swell. Locally rippled; ripples trend N-S and N. 05° W. All but upper 1 ft eroded into by unit 13; relation of upper 1 ft to unit 13 difficult to determine due to poor exposure. Interpretation: shallow marine, possibly lower shoreface 4.5
11. Covered 0.5
10. Sandstone, dark yellowish orange (10YR6/6), fine-grained, trace silt, appears moderately well sorted. Well-exposed. Lower part weathers platy and flaggy; upper 1 ft weathers to slabs. Mostly parallel stratified with very subtle pinch-and-swell. Individual beds locally with irregular base. Tops locally rippled, symmetric, trend N. 35° W., N. 25° W., and N. 05° W., and with abundant horizontal trace fossils. One area shows soft-sediment deformation. Interpretation: marine sandstone, lower shoreface 6.5
9. Sandstone, siltstone. Sandstone poorly exposed, siltstone fissile.......... 0.8
8. Covered 1.0
7. Sandstone, grayish orange (10YR7/4), fine-grained to medium-fine-grained, slightly silty. Well-exposed. Consists of lower, 1.8-ft-thick flaggy, cross-stratified sandstone showing common pinch-and-swell, and upper, 0.5-ft-thick parallel-stratified sandstone. Upper sandstone appears to drape slightly over wavy top of lower sandstone. Upper sandstone grades upward from medium-fine-grained to fine-grained. Parting lineations trend N. 70° W. Interpretation: shallow-marine offshore bar 2.3
6. Covered. At speed-limit sign and survey marker 3.0
5. Sandstone, very pale orange (10YR8/2), medium-fine-grained, no silt, moderately well sorted. Definitely coarser grained than underlying sandstones. Moderately well exposed. Weathers flaggy to platy, rarely to slabs. Parallel-laminated. Parting lineations trend about N. 80° W. Interpretation: very shallow marine, probably shoreface 5.5
4. Sandstone, dark yellowish orange (10YR6/6), fine-grained. Moderately well exposed, but not continuously; therefore, thickness only approximate. Weathers to large blocks; joints easily mistaken for bedding planes. Unstratified to parallel-laminated, slightly wavy. Interpretation: marine sandstone; paucity of sedimentary structures makes further interpretation difficult 8.0

FAULT, based on high dip of exposed base of unit 4; also low, vertical ledge to north. Unit 3 extremely weathered adjacent to fault. Unknown amount of section missing, probably minor.

3. Sandstone, yellowish gray (5Y7/2), fine-grained, silty, with very abundant carbonized, comminuted plant debris. Moderately well exposed, weathers flaggy to platy. Cross-stratified to parallel-laminated, locally appears to fine upward. Interpretation: relatively shallow marine, possibly near-offshore zone 2.0
2. Shale, very poorly exposed. Interpretation: marine 0.9
1. Sandstone, yellowish gray (5Y7/2) to light olive gray (5Y6/1), fine-grained, silty, poorly sorted, with very abundant carbonized, comminuted plant debris. Well-exposed low cliff just above water level,

Figure 19. Chert-pebble conglomerate (unit 13) near top of U.S. Highway 270 Arpelar Section (Stop 1). Clasts are matrix-supported and show crude stratification. Deposit is interpreted to be a marine-channel deposit. Geologic hammer (13 in. long) for scale.

Figure 20. Wavy-bedded sandstone (unit 1) at base of Highway 270 Arpelar Section (Stop 1). Irregular top of unit may be hummocky cross-stratification (storm deposit). Geologic hammer (for scale) near top of sandstone (just to left of center of photograph).

weathers to blocks, slabs, and flagstones. Wavy- to locally lenticular bedded with some pinch-and-swell (Fig. 20). Rare small load casts, contorted bedding, and dish-and-pillar structures. Top of unit slightly wavy. Includes 4-in.-thick, discontinuous siltstone layer. Interpretation: marine shelf sandstone, deposited above storm-wave base 7.0

Total thickness of section 42.0

STOP 2A

Sandstone of the Boggy Formation

Location: NW¼NW¼NE¼NW¼NE¼ sec. 21, T. 6 N., R. 15 E., along U.S. Highway 69 ~4 mi north of intersection with U.S. Highway 270, Pittsburg County

For permission to visit the quarries at Stops 2A and 2B (private property), please contact Dominic Silva, Box 398, Krebs, OK 74554.

The West Highway 69 Quarry Section, Pit 1, at Stop 2A (Fig. 21) provides an opportunity to examine such sedimentary features as soft-sediment deformation (Fig. 22), ripple marks, possible hummocky cross-stratification, low-angle cross-stratification, and channeling in the Boggy Formation. The strata are well exposed in two walls of an abandoned quarry, and they are easily accessible for close viewing.

Hemish (1996a) informally designated this sandstone as unit Pb4 (see p. 30) of the Boggy Formation. It occurs between unnamed shale units in about the middle of the formation, and is a prominent ridge-former throughout the McAlester area, wherever the Boggy is exposed.

The axis of the Talawanda syncline passes through the quarry (Hemish, 1996a) in an area where its trace bends to the northwest. Subsidiary folds can be observed here, as well as at Stop 2B, where the axis of a minor southwest-plunging syncline passes through another quarry in the same sandstone.

STOP 2A
Sandstone of the Boggy Formation

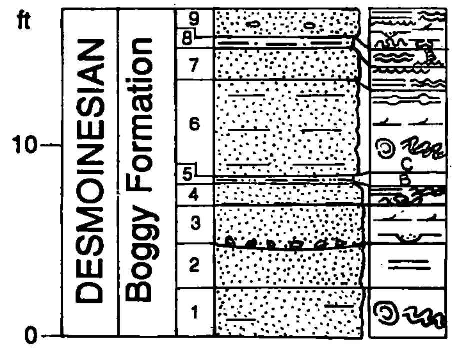


Figure 21. Graphic columnar section of Boggy sandstone unit Pb4 (Hemish, 1996a) exposed in abandoned quarry (pit 1) at Stop 2A. Explanation of symbols in Appendix 3.

Figure 22. Soft-sediment deformation features in the Boggy sandstone exposed in wall of abandoned quarry (pit 1) at Stop 2A.

Measured Section, Stop 2A

Sandstone of the Boggy Formation

West Highway 69 Quarry Section, Pit 1 (Pi-1-97-H)

NW¼NW¼NE¼NW¼NE¼ sec. 21, T. 6 N., R. 15 E., Pittsburg County (Krebs 7.5′ quadrangle). Measured in east and north quarry walls in ravine in pasture west of U.S. Highway 69, ~4 mi north of intersection with U.S. Highway 270. Section measured by LeRoy A. Hemish.

Thickness (feet)

KREBS GROUP:

BOGGY FORMATION:

9. Sandstone, grayish orange (10YR7/4), weathers light brown (5YR5/6) to grayish red (10R4/2), very fine grained, thin- to medium-bedded; plane-, parallel-bedded to discontinuous, wavy-bedded; surface marked by out-of-phase, bifurcating, beveled ripples in part; contains low-angle, curved cross-bedding; locally includes channel forms containing

ironstone-pebble conglomerates; base sharp and irregular with load casts and trace fossils 1.5

8. Shale interbedded with very fine grained sandstone; shale is very pale orange (10YR8/2) and bioturbated; sandstone is grayish orange (10YR7/4) with moderate reddish brown (10R4/6) staining; very thin to thin-bedded; parallel-, wavy-bedded; ripple-marked; thickness variable 0.5
7. Sandstone, moderate reddish orange (10R6/6), very fine grained; thin- to medium-bedded; plane-, parallel-bedded in part to wavy-, parallel-bedded in part; base sharp; surface ripple-marked 1.7
6. Sandstone, shaly in part, grayish orange (10YR7/4) to moderate reddish orange (10R6/6); sandstones show pinch-and-swell features and are cross-bedded; probable hummocky cross-stratification; in the west-facing wall of the quarry, unit includes a 3-ft-thick, deformed section containing concentrically layered, rolled masses—this section wedges out in the northeastern corner of the quarry; in places, the lower 3 ft of unit include small, very light gray (N8) crusts of calcite on parting and joint surfaces; base sharp 5.0
5. Siltstone, dark yellowish orange (10YR6/6), shaly, bioturbated, thickness variable—0.5 in. to 0.5 ft; crumbly 0.3
4. Sandstone, dark yellowish orange (10YR6/6), very thin to medium-bedded; plane-, parallel-bedded to slightly wavy bedded; abundant trace fossils on sole of unit; 1-in.-thick shale at base 1.2
3. Sandstone, dark yellowish orange (10YR6/6) to grayish orange (10YR7/4), very fine grained, medium-bedded, cross-bedded; conglomeratic, with ironstone pebbles and shale rip-up clasts at base of unit; thickness variable—fills channel cut into underlying unit 2.0
2. Sandstone, grayish orange (10YR7/4), very fine grained; plane-, parallel-bedded, blocky; thickness, 1.3–3.2 ft; base sharp 2.3
1. Sandstone, grayish orange (10YR7/4), weathers pale yellowish brown (10YR6/2), very fine grained, contorted beds and rolled masses abundant throughout unit; includes minor shale associated with some rolled masses; base of unit covered 2.5

Total thickness of section 17.0

Note: Units 1–4 described in south-facing quarry wall; other units described in west-facing wall.

STOP 2B

Sandstone of the Boggy Formation

Location: SE¼SW¼NE¼NW¼NE¼ sec. 21, T. 6 N., R. 15 E., ~0.2 mi southeast from Stop 2A, Pittsburg County

This stop is on private property. Please see Stop 2A for information about obtaining permission to visit.

Several different facies of Boggy sandstone unit Pb4 (Hemish, 1996a) are exposed in the walls of West Highway 69 Quarry Section, Pit 2 (Fig. 23). Correlation of individual beds between Stops 2A and Stop 2B is problematical, because of facies changes and structural subtleties. Unit 6

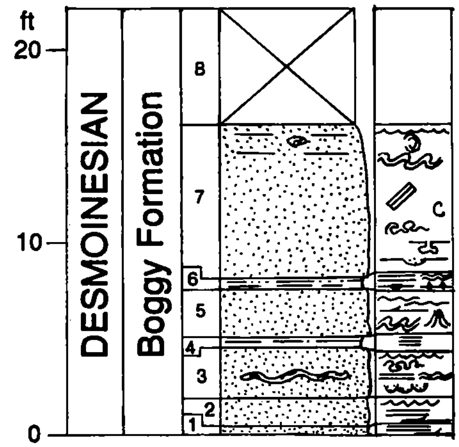


Figure 23. Graphic columnar section of Boggy sandstone unit Pb4 (Hemish, 1996a) exposed in abandoned quarry (pit 2) at Stop 2B. Explanation of symbols in Appendix 3.

(2A) and unit 7 (2B) probably are correlatable; they both contain deformed beds (particularly large, rolled sandstone masses), as well as white, calcite crusts that have similar appearances.

Of particular interest at this stop is the variety of ripple forms, including ladder-back ripples. They are commonly formed in shallow water where wind blows at right angles to current direction, causing a subsidiary set of small, evenly spaced ripples to form in the troughs of more prominent, parallel ripples. Abundant trace fossils can be observed on some ripples; other ripples are scuffed, which suggests tidal-flat sedimentation (Visher, 1968). Plant casts and plant impressions can be found at this stop, although they are not as plentiful here as at other exposures of the Boggy Formation.

Our interpretation of the deposition of the Boggy at Stops 2A and 2B is that the sediments were deposited in a delta-fringe setting, where the water was shallow at times, where minor channelling occurred, and where the influx of sand was sufficiently rapid at times to trigger movement of water-saturated grains.

Measured Section, Stop 2B

Sandstone of the Boggy Formation

West Highway 69 Quarry Section (Pit 2) (Pi-2-97-H)

SE¼SW¼NE¼NW¼NE¼ sec. 21, T. 6 N., R. 15 E., Pittsburg County (Krebs 7.5′ quadrangle). Measured at northeast edge of abandoned sandstone quarry from water level to top of quarry wall, in pasture west of U.S. Highway 69. Section measured by LeRoy A. Hemish.

Thickness (feet)

KREBS GROUP:

BOGGY FORMATION:

8. Covered to top of cut 6.0
7. Sandstone, grayish orange (10YR7/4) to yellowish gray (5Y7/2) with light brown (5YR5/6) to moder-

ate brown (5YR3/4; 4/4) staining, very fine grained; bedding in unit is complex—mostly thin to medium bedded, but contains two zones of convoluted, concentrically layered sandstone masses, each ~2 ft thick (one layer at base of unit); unit laterally includes channel-form structures; large load casts are common on some beds; in the upper 2 ft, unit is shaly and contains sideritic nodules and concretions in rolled masses; upper 0.5 ft displays a variety of ripple forms, including ladder-back ripples; some rippled beds marked by extensive and varied trace fossils; some ripples include very light gray (N8), limey crusts in ripple troughs that appear to contain highly altered, fragmented invertebrate fossils; float at base of unit contains casts of tree rootlets and rare, ribbed plant impressions; ripple-marked top of unit exposed in bench near top of quarry 8.0

6. Shale and siltstone, light olive gray (5Y5/2) to olive gray (5Y3/2); plane-, parallel-laminated to wavy-, parallel-laminated; contains very fine grained sandstone lenses; includes brownish gray (5YR4/1) carbonaceous film in places 0.5
5. Sandstone, grayish orange (10YR7/4) with light brown (5YR5/6) to moderate reddish brown (10R4/6) staining, very fine grained, thin- to medium-bedded; contains discontinuous wavy, nonparallel laminations; includes low-angle cross-stratification; contains dewatering structures and convolute beds; base sharp 2.5
4. Shale, olive gray (5Y3/2) with dark yellowish orange (10YR6/6) and grayish orange (10YR7/4) banding, slightly silty, fissile 0.5
3. Sandstone, grayish orange (10YR7/4), weathers dark yellowish brown (10YR4/2), very fine grained, thin- to medium-bedded, trough-cross-bedded in part; parallel-, wavy-bedded to plane-bedded laterally; includes a concretionary ironstone layer of varying thickness that is irregular-bedded and contorted; ripples exposed at top of unit are mostly straight and symmetric, and extensively marked by horizontal burrows; some ripple crests beveled; soles of ripple marked beds also have trace fossils 2.7
2. Sandstone, grayish orange (10YR7/4) to yellowish gray (5Y7/2), stained dusky brown (5YR2/2) and light brown (5YR5/6), very fine grained; quartzose, with minor clay; medium-bedded, internally parallel laminated with subtle low-angle cross-bedding (hummocky cross-stratification?) truncated by a ripple-marked surface at top of unit; ripples are mostly sinuous, out of phase, and beveled 1.5
1. Sandstone, grayish orange (10YR7/4), very fine grained, quartzose, thin-bedded; parallel-, plane-bedded; internally cross laminated, somewhat silty, exposed just above water level 0.4

Total thickness of section 22.1

STOP 3

Lower Part of the Boggy Formation—Exposed Contact with the Underlying Savanna Formation

Location: SW¼SE¼SE¼NE¼ and NE¼NW¼NE¼SE¼ sec. 30, T. 6 N., R. 16 E., Pittsburg County, along shoreline of Eufaula Lake; access to landing from State Highway 31, ~3 mi north of intersection with road to Adamson

The Highway 31 Landing Section at Stop 3 features the Bluejacket Sandstone Member of the Boggy Formation (Fig. 24). A few feet of silty, sandy, shale in the upper part of the

STOP 3
Lower Part of the Boggy Formation—Exposed Contact with the Underlying Savanna Formation

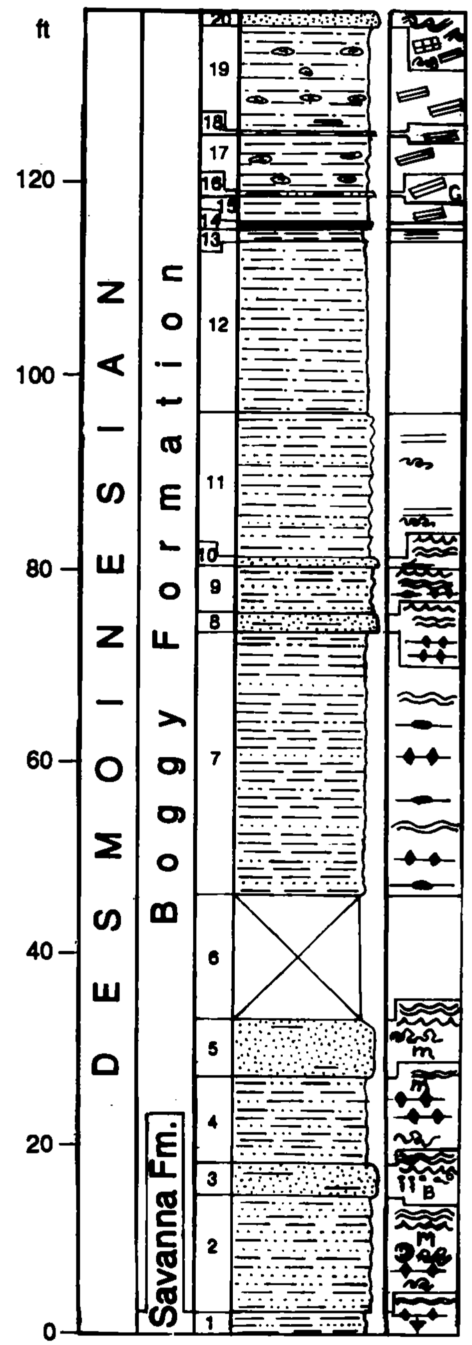


Figure 24. Graphic columnar section of the lower part of Boggy Formation and the upper part of Savanna Formation exposed at Stop 3. Explanation of symbols in Appendix 3.

Savanna Formation is exposed along the beach, just below thin-, wavy-, parallel-bedded, shaly siltstones and sandstones of the Bluejacket (Fig. 25). The contact is conformable and gradational. The sand content increases upward, and the top of the lower unit of the Bluejacket consists of 6 ft of sandstone (unit 5); surfaces show symmetrical and interference ripples, and abundant trace fossils. Unit 5 is underlain by 8.5 ft of shaly, wavy-laminated, micaceous siltstones (Fig. 26).

About 40 ft of poorly exposed, silty and sandy shale separates the lower unit of the Bluejacket Member from the upper unit. The upper unit consists of 22.7 ft of interbedded, wavy-bedded, ripple-marked, thin-bedded, shaly sandstones and siltstones containing abundant macerated plant material (measured section units 8–11).

About 19 ft of poorly exposed, silty shale is present between the upper unit of the Bluejacket Sandstone and the Secor coal bed, which is only ~1 ft thick, and highly weathered where exposed. The Secor coal is an extremely useful marker, as it confirms identification of the Bluejacket Sandstone Member and separates the Bluejacket from the next higher, unnamed sandstone member of the Boggy Formation (unit 20). Unit 20, like most sandstones in the Boggy, is very fine grained and contains abundant plant impressions and casts.

This outcrop probably is near the southern limit of the Bluejacket deltaic complex. The vertical sequence exposed in the lower part of the section is that of prodelta deposits. The upward increase in silt and sand reflects shallowing water, as do the strongly rippled beds. The coal formed in the subaerial portion of the delta, probably in a swamp, as indicated by the abundance of plant fossils in associated beds. The sand at the top of the section is probably a shallow-marine sand formed during a marine transgression across this portion of the delta.

Measured Section, Stop 3

Lower Part of the Boggy Formation—Exposed Contact with the Underlying Savanna Formation Highway 31 Landing Section (Pi-3-97-H)

SW¼SE¼SE¼NE¼ and NE¼NW¼NE¼SE¼ sec. 30, T. 6 N., R. 16 E., Pittsburg County, (Krebs 7.5′ quadrangle). Measured from point formed by resistant sandstone at east side of bay of Eufaula Lake in a southwesterly direction along shoreline to second prominent point. Measured by LeRoy A. Hemish.

Thickness (feet)

KREBS GROUP:

BOGGY FORMATION:

20. Sandstone, grayish orange (10YR7/4) to moderate orange pink (5YR8/4), weathers dark yellowish orange (10YR6/6) to moderate brown (5YR3/4; 4/4) to dark reddish brown (10R3/4), very fine grained, thin- to medium-bedded, slabby to blocky; some blocks exhibit convolute bedding with dewatering features and boxwork ironstone concretions; plant impressions and carbonized plant fragments common—*Stigmaria* present at contact with underlying unit; trace fossils on some soles; base sharp 1.5
19. Shale, light olive gray (5Y6/1), weathers moderate orange pink (5YR8/4) to grayish yellow (5Y8/4); contains numerous horizons of light brown (5YR5/6) ironstone nodules and stringers; silty; plant compressions abundant throughout unit; includes some very thin (0.3-in.) coal stringers near base ... 11.0
18. Ironstone, light brown (5YR5/6) and dark yellowish orange (10YR6/6); occurs as a continuous layer of concretions containing abundant ribbed and partially carbonized plant compressions 0.2
17. Shale, variegated, includes shades of yellowish gray (5Y7/2), light brown (5YR6/4), dark yellowish orange (10YR6/6), very light gray (N8), and pale brown (5YR5/2); contains layers of ironstone concretions light brown (5YR5/6) to dark yellowish orange (10YR6/6) in color; brownish layers are very carbonaceous and contain abundant plant compressions, some of which are partially coalified; unit has the appearance of a paleosol.......... 6.2
16. Siltstone, light brown (5YR5/6) to moderate brown (5YR4/4); ferruginous; ironstone laterally; includes some patchy, very light gray (N8), calcareous crusts in places; contains an abundance of well-preserved fossil seed fern leaves as well as an assortment of other plant material, notably, ribbed fragments, including *Calamites*, that are partially coalified in places 0.2

Note: *Section offset from water's edge ~200 ft along strike to edge of small gully.*

15. Shale, grayish brown (5YR3/2) to brownish black (5YR2/1) with dark yellowish orange (10YR6/6) and pale yellowish orange (10YR8/6) bands in places; contains coal streaks and abundant black, fragmented plant material 2.8
14. Coal, black (N1), impure, highly weathered, finely cleated (Secor coal) 1.0
13. Shale, pale brown (5YR5/2) with dark yellowish orange (10YR6/6) mottling, very carbonaceous, paper-thin fissility 1.0
12. Shale, light brownish gray (5YR6/1) with grayish orange (10YR7/4) streaks, weathers dark yellowish orange; silty, poorly exposed............................ 18.0
11. Siltstone, pale yellowish brown (10YR6/2), weathers grayish orange (10YR7/4), very shaly; plane-, parallel-laminated; includes thin layers (0.7-in.-thick) of very fine grained sandstone with trace fossils on soles; contains some elongated and twisted sandstone nodules ~0.5 in. in diameter and 2–3 in. in length—burrow fillings? (Top of upper unit of Bluejacket Sandstone Member) 15.0
10. Sandstone, grayish orange (10YR7/4) to very pale orange (10YR8/2), very fine grained, thin-bedded, obscurely wavy bedded and ripple-marked, cross-laminated, weathers to thin, broken pieces of various sizes; grades into overlying unit 1.0
9. Siltstone and sandstone, shaly, interlaminated, very pale orange (10YR8/2) to grayish orange (10YR7/4); sandstone-siltstone layers are wavy bedded and ripple marked, with internal lenticular laminations; abundant macerated, carbonized plant material on stratification surfaces; weathers flaky 4.5
8. Sandstone, pale yellowish brown (10YR6/2) to very pale orange (10YR8/2) to dark yellowish orange (10YR6/6), very fine grained, silty, interbedded with shale layers ~0.3 ft thick; very thin bedded, wavy-bedded, ripple-marked; abundant black,

macerated plant material on stratification surfaces; grades into overlying unit (base of upper unit of Bluejacket Sandstone Member) 2.2

7. Shale, interlaminated with siltstone and very fine grained sandstone, medium light gray (N6) with light brown (5YR5/6) staining; wavy-laminated, with lenticular sandstone and siltstone layers; includes abundant black, macerated plant material; grades into overlying unit; weathers to grayish orange (10YR7/4) and dark yellowish orange (10YR6/6) flakes; base of unit covered 27.0
6. Covered interval (estimated from pacing) 13.0
5. Sandstone, grayish orange (10YR7/4) with dusky yellowish brown (10YR2/2) staining, micaceous, thin-bedded; wavy-, parallel-bedded; ripple-marked—predominantly interference ripples but some straight, round-crested, symmetrical types; uppermost bed covered in trace fossils, and trace fossils common throughout unit; some intervals include thin shale layers (top of lower unit of Bluejacket Sandstone Member) 6.0
4. Siltstone, light gray (N7) to grayish orange (10YR7/4), shaly, micaceous, wavy-laminated; includes abundant black, macerated plant material on stratification surfaces; trace fossils on some layers 8.5
3. Sandstone, light brown (5YR5/6; 6/4) to very pale orange (10YR8/2) with moderate red (5R5/4) staining, very fine grained; very thin to medium-bedded; parallel-, wavy-bedded; marked with interference ripples; horizontal borings common; includes two very thin bedded, shaly zones; strongly bioturbated in lower 1 ft 3.3
2. Sandstone and siltstone, pale yellowish brown (10YR6/2) to yellowish gray (5Y7/2), shaly, very thin to thin-bedded; wavy-, parallel-bedded; micaceous; abundant black, carbonized, macerated plant material on stratification surfaces; soft-sediment deformation common in upper and lower parts of unit, with numerous poddy, rolled masses, mostly 2–6 in. in diameter and up to 1.5 ft in length; trace fossils present but uncommon; some surfaces with low-amplitude interference ripples; becomes increasingly shaly in lower half of unit; basal contact gradational (base of lower unit of Bluejacket Sandstone Member) 12.0

SAVANNA FORMATION:

1. Shale, moderate yellowish brown (10YR5/4), interlaminated with very light gray (N8) layers of siltstone and very fine grained sandstone, wavy-bedded; abundant black, carbonized, macerated plant material on stratification surfaces; sequence coarsens upwards, base covered 3.0

Total thickness of section 137.4

Figure 25. Contact (shown by black line) between the sandy, silty shale of the Savanna Formation and the shaly siltstones and sandstones of the Bluejacket Sandstone Member of the Boggy Formation (Stop 3). The contact is gradational. First protruding sandstone layer above the contact is ~3 in. thick.

Figure 26. Contact (shown by black line) between 6 ft of sandstone at the top of the lower unit of the Bluejacket Sandstone Member of the Boggy Formation (unit 5) and 8.5 ft of underlying, wavy-laminated shaly siltstone, also part of the Bluejacket Sandstone Member (unit 4). Geologic pick for scale.

STOP 4

Savanna Formation—Contact with the Underlying McAlester Formation

Location: SW¼SW¼SE¼ sec. 30, T. 6 N., R. 16 E.; and NW¼NW¼NW¼NW¼NE¼, and NE¼NE¼NW¼ sec. 31, T. 6 N., R. 16 E., Pittsburg County, along State Highway 31 just north of intersection with Mud Creek Road

The Highway 31 section at Stop 4 includes 677 ft of the lower part of the Savanna Formation as well as 56 ft of the upper part of the McAlester Formation (Fig. 27). Of particular interest at this outcrop is the evidence for facies changes in the Savanna when units here are compared with lithologic units at Stop 5, the principal reference section (neostratotype) for the Savanna (Adamson section, Appendix 2), located ~5.5 mi to the east. Sandstone units are much thinner and more marine limestones are exposed at Stop 4 than at Stop 5, and several coal beds are present here. The Savanna Formation, as a whole, thins westward, and mapping by Hemish (1996a) shows that the lowest sandstone unit in the Adamson section (Stop 5) pinches out, and the next higher sandstone unit thins to <1 ft in the Highway 31 section (Stop 4). The Savanna Formation is ~1,450 ft thick in the Adamson section (Stop 5), but it thins to ~900 ft

8 mi west of the Highway 31 section (Stop 5) (Hemish, 1997a). Structural complexities in the upper part of the Savanna Formation make an accurate determination of the total thickness at the Highway 31 section (Stop 4) difficult.

The presence of several marine limestones in proximity to coal beds provides evidence for cyclic deposition. The sequence of beds exposed at Stop 4 indicates that a number of regressive and transgressive events occurred during the time the Savanna Formation was deposited, probably in a deltaic environment. Figure 28 shows a *Stigmaria* in growth position in unit 40, and Figure 29 shows stromatolites in unit 15. *Stigmaria* suggest a swamp environment, and stromatolites suggest calm, shallow, marine waters (Blatt and others, 1980, p. 473).

Measured Section, Stop 4

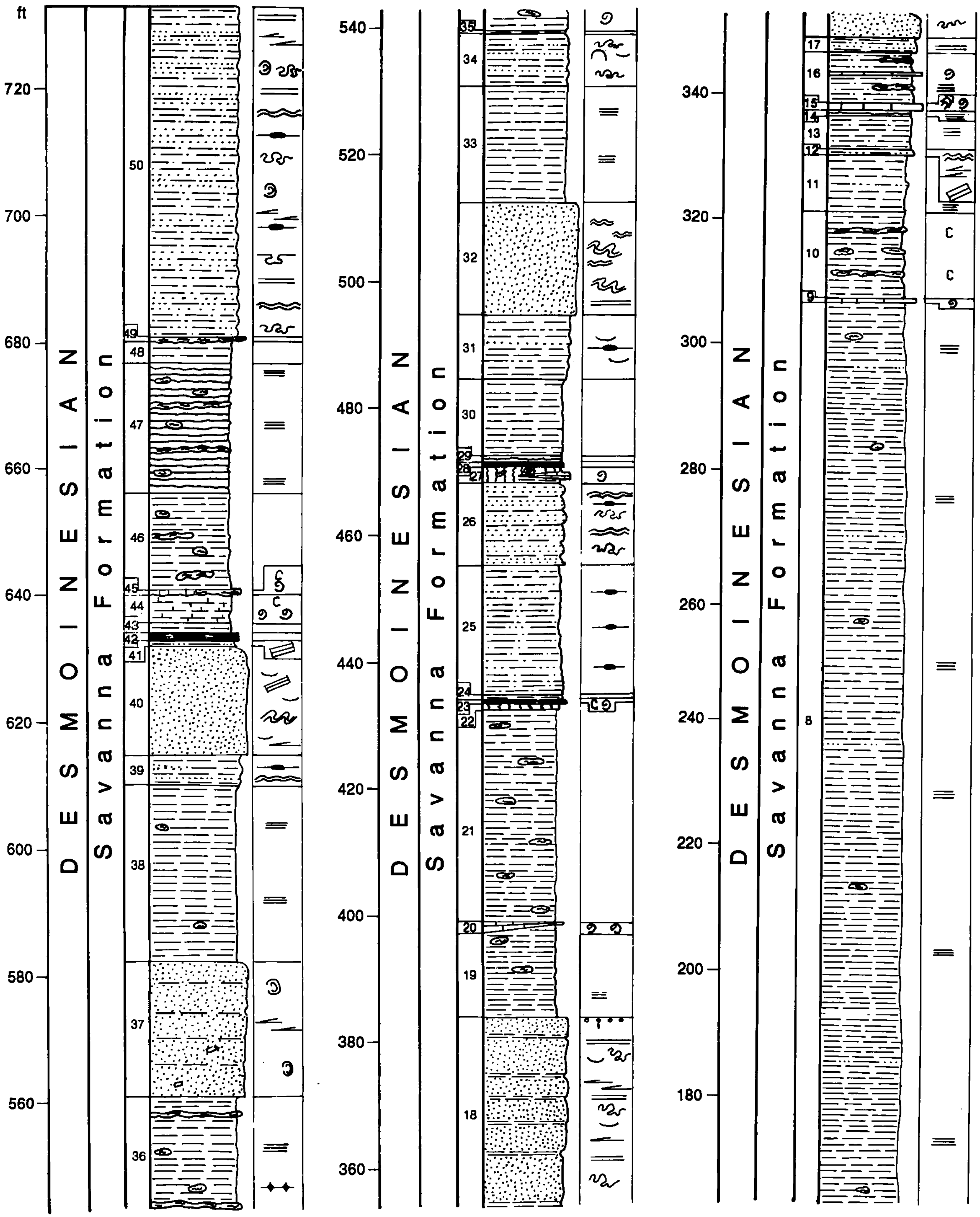
Savanna Formation—Contact with the Underlying McAlester Formation

Highway 31 Section (Pi-1-96-H)

SW¼SW¼SE¼ sec. 30, T. 6 N., R. 16 E.; and NW¼NW¼NW¼ NW¼NE¼ and NE¼NE¼NW¼ sec. 31, T. 6 N., R. 16 E., Pittsburg County (Krebs 7.5′ quadrangle). Measured from concrete culvert under driveway, southeast side of State Highway 31, just south of inlet of Eufaula Lake, in a southwesterly direction, in road cuts on both sides of the highway, to gully just east of north end of guard rail, about 100 ft south of Mud Creek Road. Section measured by LeRoy A. Hemish.

	Thickness (feet)
KREBS GROUP:	
SAVANNA FORMATION:	
50. Shale interbedded with sandstone. Shale is olive gray (5Y4/1) with moderate yellowish brown (10YR5/4) and light brown (5YR5/6) weathered layers; contains siltstone lenses ~0.25 in. thick and 1.5 in. long; sandstone is light olive gray (5Y5/2), weathers dark yellowish brown (10YR4/2), very fine grained, silty, very thin to medium-bedded; parallel-, plane-bedded to discontinuous wavy-bedded; some beds with low-angle cross-bedding; load casts and trace fossils on soles of some beds; unit contains flow rolls	52.5
49. Ironstone, light brown (5YR5/6) and dark yellowish orange (10YR6/6), nodular-bedded	0.2
48. Shale, olive gray (5Y4/1), to grayish orange (10YR7/4) and moderate yellowish brown (10YR5/4), clayey	3.5
47. Shale, olive black (5Y2/1), fissile; contains abundant light brown (5YR5/6) and dark yellowish orange (10YR6/6) ironstone layers up to 0.3 ft thick, as well as scattered ironstone nodules from 0.25 in. in diameter to 0.3 ft in diameter; grades into underlying unit	21.0
46. Shale, pale yellowish brown (10YR6/2), to brownish gray (5YR4/1) with blackish red (5R2/2) and olive black (5Y2/1) layers; contains light brown (5YR5/6) and dark yellowish orange (10YR6/6) ironstone layers and nodules	15.0
45. Ironstone, very dark red (5R2/6) and dark yellowish orange (10YR6/6), calcareous; contains an abundant and diverse fossil assemblage, with brachiopods and crinoids most plentiful; also includes in places fossiliferous layers and concretions of yellowish gray (5Y7/2) and grayish orange (10YR7/4) limestone	0.4
44. Shale, grayish orange (10YR7/4) to moderate yellowish brown (10YR5/4), very calcareous; abundantly fossiliferous, with a diverse assemblage of brachiopods, and crinoid columnals up to 0.8 in. in diameter, as well as other fossil types	5.0
43. Shale, grayish orange (10YR7/4) with grayish yellow (5Y8/4) and pale brown (5YR5/2) streaks, noncalcareous, very clayey at base; grades upward into overlying unit	1.5
42. Coal, brownish black (5YR2/1), very weathered; interbedded with irregular layers of light brownish gray (5YR6/1) clay	1.0
41. Siltstone, very light gray (N8) with pale brown (5YR5/2) streaks, friable; contains small, woody, plant fragments	1.0
40. Sandstone, grayish orange (10YR7/4) with blackish red (5R2/2) staining, very fine grained, thin- to medium- to thick-bedded, nodular-bedded to discontinuous curved-bedded; some convolute beds; some low-angle cross-bedding; in situ *Stigmaria* common in upper part	17.0
39. Shale, yellowish gray (5Y7/2) to light olive gray (5Y5/2); contains lenses and stringers of light olive gray (5Y5/2), very thin bedded, wavy-bedded, silty sandstone	4.8
38. Shale, light olive gray (5Y5/2), contains rare, small, light brown (5YR5/6) ironstone concretions; fissile, weathers to small flakes on the outcrop	28.3
37. Sandstone, light olive gray (5Y6/1), weathers very pale orange (10YR8/2) to grayish orange (10YR7/4), very fine grained, mostly thick to medium bedded; includes rolled masses with concentric bedding, some low-angle cross-bedding, and rare shale clasts; interbedded with medium gray shales of unknown thickness (owing to poor exposure) in places	21.0
36. Shale, light olive gray (5Y5/2), fissile, flaky; includes thin stringers and nodules of moderate reddish brown (10R4/6) and dark yellowish orange (10YR6/6) ironstone concretions, some of which contain calcareous brachiopod valves; others rarely contain black, carbonized plant material	21.0
35. Shale, light gray (N7) to yellowish gray (5Y7/2), clayey; includes an 0.5-in.-thick layer of black (N1), highly carbonaceous shale at both top and base of unit	0.5
34. Shale, light olive gray (5Y5/2); contains light brown (5YR5/6) stringers of ferruginous siltstone; interbedded with 0.1- to 1.0-ft-thick layers of light brown (5YR5/6) (where weathered), light olive gray (5Y5/2) to olive gray (5Y4/1), very fine grained, thin- to medium-bedded, well-jointed sandstone. Trace fossils abundant on tops and soles of beds; upper surface of some sandstones sway, and bases curved in places	8.4
33. Shale, light olive gray (5Y5/2), fissile, flaky	18.4
32. Sandstone, dusky yellow (5Y6/4), weathers grayish brown (5YR3/2), very fine grained, mostly thick bedded; contains discontinuous wavy beds; includes convolute beds, and plane, parallel thin beds near base of unit	18.0
31. Shale and siltstone, dusky yellow (5Y6/4), curved bedding in part; includes some 0.5-ft-thick lenses of very fine grained, silty sandstone	10.0

STOP 4
Savanna Formation—Contact with the Underlying McAlester Formation



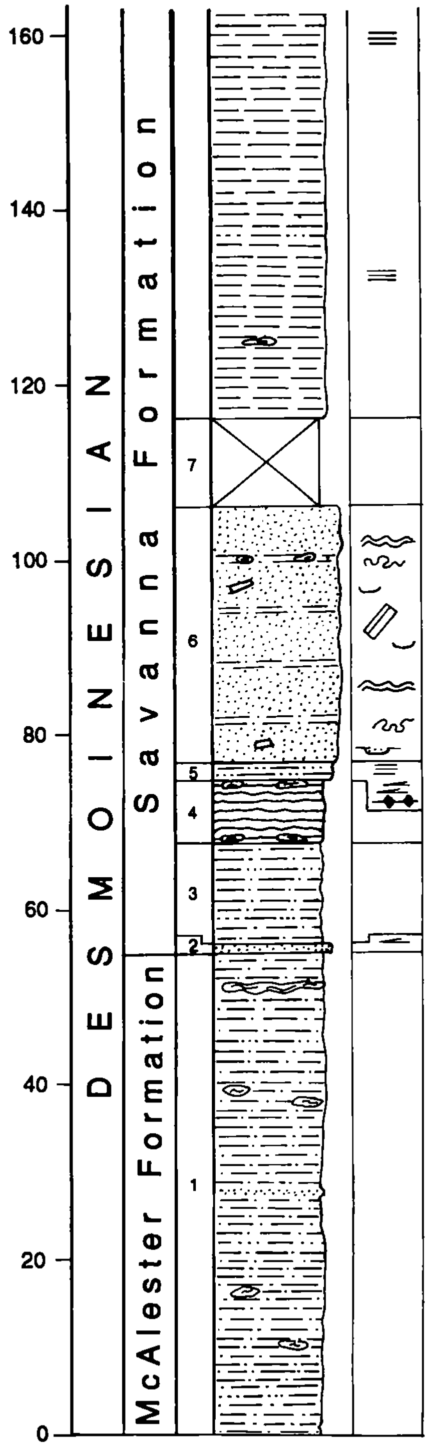


Figure 27 (*facing page and above*). Graphic columnar section of upper part of McAlester Formation and 677 ft of the overlying Savanna Formation (Stop 4). Explanation of symbols in Appendix 3.

30. Shale, light gray (N7) with pale yellowish brown (10YR6/2) and light brown layers; poorly exposed 12.0
29. Shale, black (N1), very carbonaceous 0.2
28. Coal, black (N1), finely cleated, iron oxide staining on cleat surfaces 1.4
27. Underclay, light gray (N7) with light brown (5YR5/6) streaks; includes rare, small ironstone concretions and thin (0.2-in.) brownish black (5YR2/1) carbonaceous shale layers. Note: An 0.8-ft-thick, light brownish gray (5YR6/1) to moderate brown (5YR4/4), highly fossiliferous limestone is exposed 1.0 ft below the base of unit 28 (coal) in this interval in road cut west side of highway. The limestone is underlain by 0.7 ft of grayish orange (10YR7/4) shale 2.5
26. Sandstone, yellowish gray (5Y7/2), to pale yellowish brown (10YR6/2) with light brown (5YR5/6) staining, very fine grained, very thin to thin-bedded; wavy-, parallel-bedded with internal lenticular laminae; shaly; horizontal and vertical trace fossils abundant on bedding planes. Best exposure in west road cut 13.0
25. Shale, medium dark gray (N4), weathers pale yellowish brown (10YR6/2), silty, contains thin lenses of fine-grained siltstone 20.7
24. Shale, pale yellowish brown (10YR6/2) with moderate reddish brown (10R4/6) streaks 0.4
23. Coal, black (N1) with light brown (5YR5/6) staining on cleats, weathered; contains rare, thin lenses (0.7-in.-thick) of fossiliferous carbonaceous limestone. Note: West of the road, the limestone weathers out of the coal and litters the outcrop with 1-in.-thick, very pale orange (10YR8/2) punky fragments. 0.7
22. Underclay, yellowish gray (5Y7/2) with very dark yellowish orange (10YR6/6) streaks; grades into underlying unit 0.8
21. Shale, medium dark gray (N4), weathers moderate yellowish brown (10YR5/4); contains abundant layers of very dark red (5R2/6) and moderate reddish brown (10R4/6) discoidal ironstone concretions 0.1- to 0.2-ft-thick 34.4
20. Limestone, olive black (5Y2/1), weathers light olive gray (5Y5/2), very fine grained, sparsely fossiliferous, brachiopods present, 0.1 ft thick (in east road cut). In west road cut, unit is 1.0–2.0 ft thick, pale yellowish brown (10YR6/2) to grayish orange (10YR7/4) to medium light gray (N6), impure, shaly, thin-bedded, very fossiliferous—brachiopod rich 1.0
19. Shale, olive gray (5Y4/1), weathers to small flakes; includes scattered, calcareous brachiopod valves and dark reddish brown (10R3/4), fossiliferous, calcareous ironstone nodules in upper and middle part of unit, basal contact sharp 13.8
18. Sandstone, medium gray (N5), weathers pale yellowish brown (10YR6/2) to blackish red (5R2/2), very fine grained, thin- to medium-bedded; beds discontinuous curved to irregular to plane-parallel, internally cross laminated; trace fossils common—upper surface extensively burrowed with pinhead-sized trace fossils; interbedded with poorly exposed, dark gray (N3) shales; lower contact sharp to gradational in places 34.0
17. Shale, light olive gray (5Y5/2), interbedded with plane-, parallel-bedded, very fine grained, very thin bedded sandstone and siltstone stringers, basal contact gradational 2.5

16. Shale, dark gray (N3), fissile, flaky, silty; contains abundant, very thin bedded stringers of dark reddish brown (10R3/4), ferruginous siltstone and ironstone concretions; includes an 0.3-ft-thick, very dusky red purple (5RP2/2), fossiliferous limestone layer ~5 ft from base of unit; carbonaceous in lower 0.1 ft; basal contact sharp 8.0

Figure 28. *Stigmaria* in growth position in unit 40, Stop 4. Beds dip ~70° north at this site. Rotate photograph clockwise 70° to restore to original growth position. Geologic pick for scale. (From Hemish, 1997c.)

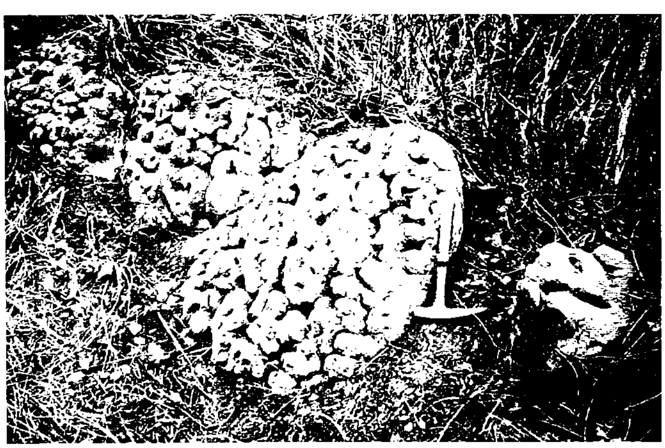


Figure 29. Stromatolitic limestone (unit 15), Stop 4. Top of beds to the left in the photograph. Close lateral linkage of growth forms suggests deposition in relatively calm, shallow, marine waters.

15. Limestone, grayish orange (10YR7/4) to pale yellowish orange (10YR8/6) to dark yellowish orange (10YR6/6), stromatolitic, surface characterized by compound hemispherical mounds that are concentrically layered in cross section; lower 0.2 ft wavy- to plane-bedded with brachiopod fossils common, basal contact sharp 0.8
14. Shale, grayish black (N2), fissile, carbonaceous 0.2
13. Shale, olive gray (5Y4/1), fissile, flaky; contains thin stringers of moderate yellowish brown (10YR5/4) silty shale 7.0
12. Siltstone, light olive gray (5Y5/2) with dark yellowish orange (10YR6/6) and moderate brown (5YR4/4) staining, coarse-grained, sandy, very thin bedded; wavy-, parallel-bedded, cross-laminated; contains small plant impressions 0.5
11. Shale, olive gray (5Y3/2), fissile, flaky; includes an 0.2-ft-thick siltstone layer, similar to unit 13, in about the middle of the unit.............................. 9.5
10. Shale, dark gray (N3), flaky, includes numerous thin stringers and concretionary layers of moderate reddish brown (10R4/6) and dark yellowish orange (10YR6/6) ironstone; some 0.1-ft-thick layers of ironstone are calcareous 14.0
9. Limestone, grayish red purple (5RP4/2), hackly, very fossiliferous—brachiopods predominant...... 0.3
8. Shale, olive black (5Y2/1) to olive gray (5Y4/1), fissile; includes rare siltstone stringers ~0.1 ft thick, as well as rare, dark reddish brown (10R3/4) ironstone concretions up to 0.4 ft in diameter (well exposed in eroded ravine just northeast of Mud Creek bridge) 190.0
7. Covered interval 10.0
6. Sandstone, light olive gray (5Y5/2), weathers very pale orange (10YR8/2) to light brown (5YR5/6), very fine grained; some curved, discontinuous beds; mostly thin to medium-bedded, mostly irregular bedded; wavy-bedded in part; contains rare shale rip-up clasts; some beds include abundant, large plant compressions; some trace fossils; slickensided; interbedded with poorly exposed, medium light gray (N6) to light olive gray (5Y6/1) sandy, silty shales that weather grayish orange (10YR7/4), and contain ironstone nodules in upper part; basal contact sharp and irregular channel-form in places 29.0
5. Siltstone, medium light gray (N6), weathers grayish orange (10YR7/4), very thin bedded, fissile, shaly, contains low-angle cross-bedding in part; includes black (N1), macerated plant material on bedding planes; sharp color change at basal contact......... 2.0
4. Shale, brownish black (5YR2/1), includes a discontinuous layer of 0.1-ft-thick, very dusky red purple (5RP2/2) ironstone concretions at top of unit, as well as a light brown (5YR5/6) discontinuous layer of ironstone concretions at base of unit. Weathers pale yellowish brown (10YR6/2) 7.2
3. Shale, light olive gray (5Y5/2), silty; includes some 1- to 2-in.-thick layers of very fine grained siltstone 11.8
2. Sandstone, light olive gray (5Y5/2) with light brown (5YR5/6) staining; occurs as a single, internally cross laminated bed; upper and lower contacts sharp and irregular (base of Savanna Formation) .. 0.8

MCALESTER FORMATION:

1. Shale, pale yellowish brown (10YR6/2), silty; in-

cludes some light brown (5YR5/6) ferruginous siltstone layers and ironstone concretions, as well as a nodular-bedded, 0.7-ft-thick, very fine grained sandstone layer in about the middle of the unit; base covered 56.0

Total thickness of section 733.0

STOP 5

Principle Reference Section (Neostratotype) for the Savanna Formation

Adamson Section

Location: Section-line road and route of power line between sec. 1, T. 5 N., R. 16 E., and sec. 6, T. 5 N., R. 17 E.; and between sec. 36, T. 6 N., R. 16 E., and sec. 31, T. 6 N., R. 17 E., Pittsburg County, ~0.7 mi northwest of the town of Adamson

Units 39 and 47 are on private property. For permission to enter the pasture to examine the outcrops, please contact Thomas Irwin, Hartshorne, Oklahoma, phone (918) 297-2937.

The principle reference section for the Savanna Formation was established by Hemish (1995b, p. 204–243), and named the Adamson section for its proximity to the community of Adamson. Both the upper and lower contacts are exposed, and there are numerous good exposures of the intervening beds, particularly of the resistant sandstones. The Savanna Formation is ~1,450 ft thick at this location, on the south flank of the Sans Bois syncline.

Time on this field trip does not permit a detailed examination of all the units described in this section, so only selected outcrops will be visited. A complete description, along with graphic columns of the Adamson section, is reproduced in Appendix 2 of this guidebook. For a complete report, with numerous photographs of the various units that comprise the Savanna, the reader is referred to Hemish (1995b, p. 204–243).

At the first stop scheduled, shale beds in the upper part of the McAlester Formation (Fig. 30) are exposed, as are the basal sandstone unit of the Savanna Formation (Fig. 31), several other sandstone units, a fossiliferous sandy limestone, and several shale beds. After viewing the rocks, field trip participants will reload and the vehicle(s) will proceed at right angles to the strike of the beds northward toward the axis of the Sans Bois syncline. The Savanna is exposed along the section-line road and in pastures to the right and left. Time permitting, brief stops will be taken to examine

Figure 30. Silty shale containing abundant clay-ironstone discoidal concretions and layers in the upper part of the McAlester Formation (unit 1, Adamson section), Stop 5, exposed in road cut near base of slope (NW¼SW¼NW¼SW¼ sec. 6, T. 5 N., R. 17 E.). Geologic pick for scale. (From Hemish, 1995b, fig. 4.)

Figure 31. Contact between the McAlester Formation and the Savanna Formation, Stop 5, exposed just east of road at top of thick shale unit (NE¼SE¼NE¼SE¼ sec. 1, T. 5 N., R. 16 E.). Geologic pick (for scale) marks a minor erosional channel in shale at the top of unit 4. (From Hemish, 1995b, fig. 5A.)

Figure 32. Large, rolled sandstone mass (Psv4a sandstone, unit 39) exposed just east of road in pasture on low ridge (SW¼NW¼SW¼NW¼ sec. 6, T. 5 N., R. 17 E.). The mappable sandstones of the Savanna Formation are designated Psv1–7, from lowest (oldest) to highest (youngest); lower case letters (beginning with "a") identify individual sandstone units in the Savanna sandstones. Thus, Psv4a is the lowest sandstone unit in Savanna sandstone 4. Soft-sediment deformation is common in this unit at Stop 5. Geologic pick for scale. (From Hemish, 1995b, fig. 13.)

Figure 33. Flat, parallel-bedded, lower part of Psv5 sandstone (Savanna sandstone 5) (unit 47) exposed in pasture near base of high ridge ~0.1 mi east of road at Stop 5 (SE¼ SW¼NW¼ NW¼ sec. 6, T. 5 N., R. 17 E.). Total thickness of strata shown is ~15 ft. (From Hemish, 1995b, fig. 14.) For explanation of system for designating Savanna sandstones, see caption for Figure 32.

Figure 34. Contact between Savanna Formation and Boggy Formation at Stop 5 (indicated by arrow). Top beds in the Savanna (unit 61) comprise silty shale and lenses of very fine grained sandstone. The overlying lower unit of the Bluejacket Sandstone Member of the Boggy Formation (unit 62) contains flaggy, wavy-bedded, very fine grained sandstone. Contact is exposed in small gully, part way up the bluff north of Buffalo Creek valley (SE¼SE¼NE¼SE¼ sec. 36, T. 6 N., R. 16 E.). Tape measure case is 2 in. wide. (Modified from Hemish, 1995b, fig. 17.)

large, rolled sandstone masses (Fig. 32), and excellent exposures of a flat, parallel-bedded facies of one of the Savanna sandstones (Fig. 33).

A hike across a major stream valley is required to view the Savanna-Boggy contact. The sequence of beds there is the same as the sequence at Stop 3, so that part of the Adamson section will not be seen on this trip. Figure 34 shows the contact between the Savanna Formation and the overlying Boggy Formation.

STOP 6

Warner Sandstone Member of the McAlester Formation

Location: N½SW¼NW¼NW¼ sec. 12, T. 5 N., R. 16 E., ~1.5 mi west of the town of Adamson, along road between Adamson and State Highway 31, Pittsburg County

A complete section of the Warner Sandstone Member (Booch sand) of the McAlester Formation, as well as the contact with the underlying McCurtain Shale Member, is exposed at Stop 6 (Fig. 35). The Warner is ~73 ft thick at this location and consists of three units: a lower sandstone, ~18 ft thick (Fig. 36); a middle shale, ~48 ft thick, which contains a 2-ft-thick coal bed; and an upper sandstone, ~7 ft thick, which is poorly exposed and may be thicker.

The sequence of beds at this stop suggests deposition in a lower deltaic plain, in a series of distributary channels. Low-angle trough-cross-bedded sandstones (Fig. 37) fill channels incised into wavy-, parallel-bedded sandstones, which indicates shallow-water marine sedimentation. The lower shale probably is prodeltaic, and the middle shales represent interdistributary deposits with sufficient subaerial

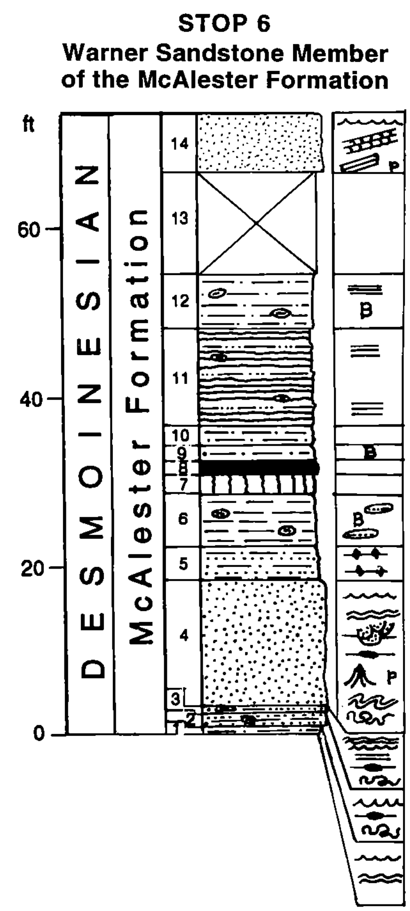


Figure 35. Graphic columnar section of the Warner Sandstone Member of the McAlester Formation exposed at Stop 6. Explanation of symbols in Appendix 3.

exposure to permit the formation of an underclay and a coal bed. The sandstone at the top of the section probably is a marine sand formed during a marine transgression across this portion of the delta.

Measured Section, Stop 6

Warner Sandstone Member of the McAlester Formation

Water Treatment Plant Section (Pi-5-97-H)

N½SW¼NW¼NW¼ sec. 12, T. 5 N., R. 16 E., Pittsburg County (Adamson 7.5′ quadrangle). Measured in steep bluff just south of Adamson Road and just north of water in Gaines Creek arm of Eufaula Lake. Section measured by LeRoy A. Hemish.

	Thickness (feet)
KREBS GROUP:	
MCALESTER FORMATION:	
Warner Sandstone Member:	
14. Sandstone, light brown (5YR5/6) to dark yellowish orange (10YR6/6) to moderate reddish brown (10R4/6), very fine grained, medium-bedded, blocky, ferruginous; disturbed blocks show indistinct ripples, internal cross-laminations, and poorly preserved plant compressions; surfaces pitted (poorly exposed in low ridge just south of Adamson Road, southwest of water treatment plant)	7.2
13. Covered interval	~12.0
12. Shale, medium gray (N5), weathers light brown (5YR6/4), fissile; contains dark yellowish orange (10YR6/6), silty, bioturbated, discoidal ironstone concretions up to 3 in. thick and as much as 1 ft in diameter, lower contact gradational	6.5
11. Shale, black (N1), fissile, weathers to small flakes; contains very thin stringers of light brown (5YR5/6) to dusky red (5R3/4) siltstone, and rare, small, light brown (5YR5/6) ironstone concretions.......	11.4
10. Shale, dark gray (N3), with layers of grayish brown (5YR3/2) interlaminated, carbonaceous shale and siltstone	2.5
9. Shale, light gray (N7); contains numerous very thin bedded stringers of ferruginous, carbonaceous siltstone and sandstone with bioturbation features ...	2.0
8. Coal, black (N1), weathered; contains vertical and horizontal infillings of light brownish gray (5YR 6/1) clay (Keefton coal)	2.0
7. Underclay, light brownish gray (5YR6/1), carbonaceous; includes a 0.25-in.-thick coal stringer; grades into underlying unit	2.0
6. Shale, olive gray (5Y4/1), clayey; contains rare, light brown (5YR5/6) ironstone concretions and medium light gray (N6), bioturbated siltstone nodules	6.0
5. Shale, yellowish gray (5Y7/2) to light brown (5YR6/4), silty; contains light brown (5YR5/6) ironstone concretions, and pale yellowish brown (10YR6/2) very fine grained sandstone masses up to 1 ft in length and 6 in. in diameter that contain abundant black carbonized plant material; interbedded with yellowish gray (5Y7/2), very thin bedded, silty sandstone in upper and lower parts of unit	4.0
4. Sandstone, pale yellowish brown (10YR6/2), weathers light brown (5YR5/6) to moderate yellowish brown (10YR5/4); very fine grained; mostly thin to medium-bedded, but some thick beds; wavy-, parallel-bedded, with ripple-marked surfaces; in places, low-angle trough cross-beds filled channels incised into underlying sandstone beds; some bedding lenticular; some layers display convolute bedding and dewatering features; some soles have abundant trace fossils, others are pitted	15.4
3. Sandstone, pale yellowish brown (10YR6/2), very fine grained, shaly, wavy- to lenticular-bedded, parallel-bedded, ripple-marked; contains elongate (1 ft × 0.2 ft) ironstone concretions; trace fossils abundant; grades into underlying unit	1.0
2. Sandstone and shale, interbedded, medium gray (N5), lenticular-bedded; includes some moderate orange pink (10R7/4) ironstone concretions; ripple-marked; trace fossils abundant; grades into underlying unit	1.5
McCurtain Shale Member:	
1. Shale, medium gray (N5), sandy; contains thin, wavy-bedded, ripple-marked sandstone stringers, base covered	1.0
Total thickness of section	74.5

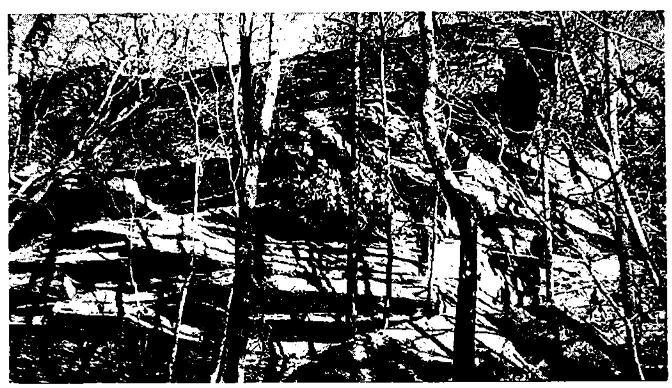


Figure 36. Cliff-forming, wavy-, parallel-bedded lower part of the Warner Sandstone (unit 4) at Stop 6.

Figure 37. Trough cross-bedding in lower part of the Warner Sandstone (unit 4) at Stop 6. Man has hand at base of incised channel.

STOP 7

Cameron Sandstone Member of the McAlester Formation

Location: SW¼NW¼SW¼NE¼ sec. 5, T. 3 N., R. 15 E., bluff overlooking Ti Creek just northwest of State Highway 63, 1.5 mi northeast of Blanco, Pittsburg County

For permission to examine the outcrops at Stop 7 (private property), please contact Doc Coker, Rte. 3, McAlester, OK 74501.

The Ti Creek section at Stop 7 features one of the best and most accessible exposures in Oklahoma of the Cameron Sandstone Member of the McAlester Formation. The beds can be viewed in three dimensions because of erosion associated with Ti Creek. The Cameron is >85 ft thick at this location (Fig. 38) and is predominantly very fine grained sandstone, with rare conglomeratic beds. For the most part, the sandstones are thin- to medium-bedded and parallel-bedded (Fig. 39). Some of the beds exhibit soft-sediment deformation features. Ripple marks are common on some surfaces; beds are wavy in some places and planar in others, with parting lineations.

The depositional environment is thought to have been marginal marine, but interpretations are open for discussion.

Measured Section, Stop 7

Cameron Sandstone Member of the McAlester Formation

Ti Creek Section (Pi-4-97-H)

SW¼NW¼SW¼NE¼ sec. 5, T. 3 N., R. 15 E., Pittsburg County (Hartshorne SW 7.5′ quadrangle). Measured in bluff overlooking Ti Creek, just northwest of Oklahoma State Highway 63. Section measured by LeRoy A. Hemish.

Thickness (feet)

KREBS GROUP:

MCALESTER FORMATION:

Cameron Sandstone Member (Units 3–9):

9. Sandstone, grayish orange (10YR7/4) with dark yellowish orange (10YR6/6) bands, some moderate reddish brown (10R4/6) staining, very fine grained, mostly medium bedded with some thin beds; swaly bedded, with ball-and-pillow structures; surface irregular; convolute bedding just above contact with underlying unit 6.5
8. Sandstone, grayish orange (10YR7/4) to dark yellowish orange (10YR6/6), weathers light brown (5YR5/6; 6/4) to moderate brown (5YR3/4; 4/4), very fine grained, some Liesegang banding, very thin to thin- to medium-bedded; plane-, parallel-bedded; parting lineations common; some wavy-bedded intervals; some soles have groove and flute casts and rare, small trace fossils 25.0
7. Sandstone, pale yellowish orange (10YR8/6) to moderate orange pink (5YR8/4), very fine grained; occurs as single thick-bedded unit with plane beds exhibiting internal cross-laminations; shows ferruginous concretions and parting lineations where broken; wavy-bedded with trace fossils at contact with underlying unit 2.0

STOP 7
Cameron Sandstone Member
of the McAlester Formation

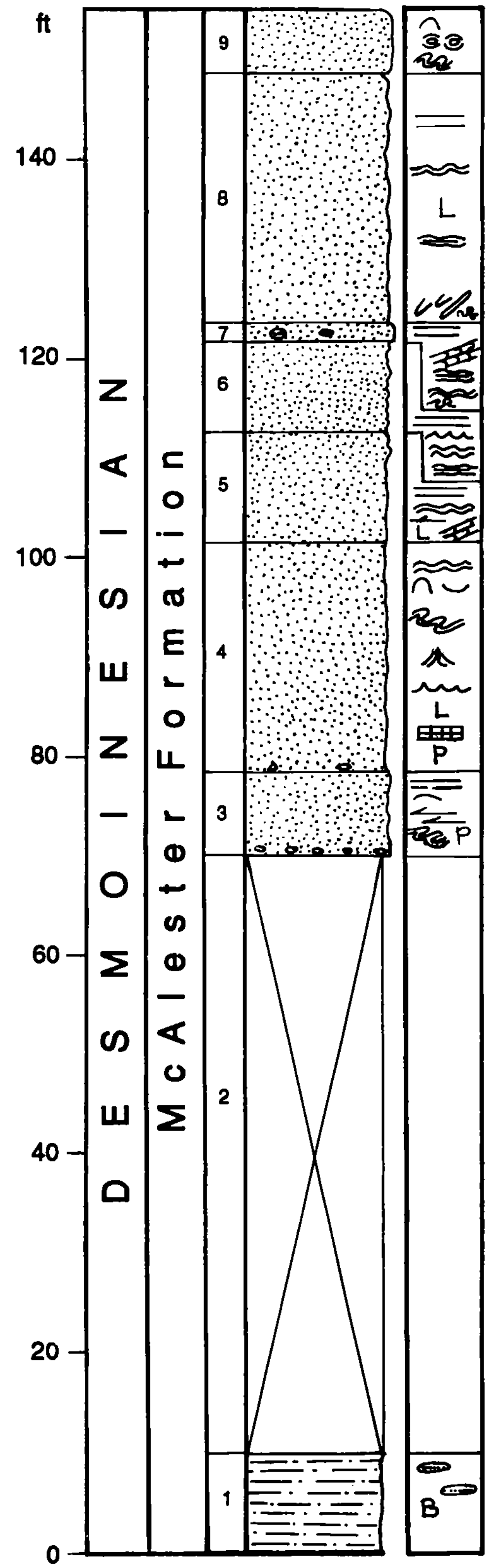


Figure 38. Graphic columnar section of the Cameron Sandstone Member of the McAlester Formation exposed at Stop 7. Explanation of symbols in Appendix 3.

Figure 39. Thin- to medium-bedded, parallel-bedded sandstones in the Cameron Member of the McAlester Formation exposed in bluff east of Ti Creek (Stop 7). Beds dip ~50° to the northwest (left) at this location.

6. Sandstone, grayish orange (10YR7/4) with dark yellowish orange (10YR6/6) banding, weathers light brown (5YR5/6), very fine grained, thin- to medium-bedded; mostly plane, parallel bedded, but some wavy beds and ripple marks; some parting lineations	9.0
5. Sandstone, grayish orange (10YR7/4) to very pale orange (10YR8/2) to dark yellowish orange (10YR6/6), very fine grained; very thin to thin- to medium-bedded; plane-, parallel-bedded in part; wavy-bedded with internal cross-bedding in part; some Liesegang banding	11.0
4. Sandstone, very pale orange (10YR8/2) to grayish orange (10YR7/4) to moderate yellowish brown (10YR5/4), very fine grained, very thin to thin- to medium- to thick-bedded; wavy to swaly beds; many curved beds with 2- to 3-ft-thick convolute beds and dewatering features; ripple-marked on some surfaces; exhibits Liesegang banding and limonite-healed fractures; boxwork and pebble cavities and pits on some soles	23.0
3. Sandstone, grayish orange (10YR7/4) to dark yellowish orange (10YR6/6), very fine grained, mostly medium bedded; bedding discontinuous planar to curved; cross-bedded; some folded, deformed layers; numerous pits on weathered surfaces; includes an ironstone pebble conglomerate near base; thick-bedded in lower part; outcrop of lower 3.5 ft slumped; base covered (lowest exposed unit of Cameron Sandstone Member)	8.5
2. Covered interval (includes contact between Cameron Sandstone Member and McCurtain Shale Member)	60.0
McCurtain Shale Member:	
1. Shale, medium dark gray (N4), flaky, silty, weathers grayish orange (10YR7/4) to dark yellowish orange (10YR6/6); contains abundant moderate yellowish brown (10YR5/4) siltstone nodules exhibiting bioturbation features; ~10 ft exposed in road cut just north of Highway 63; base covered	10.0
Total thickness of section	155.0

STOP 8

Contact Between the Atoka Formation and the Hartshorne Formation

Location: C E½E½ sec. 26, T. 4 N., R. 15 E., and SW¼ SW¼NW¼ sec. 25, T. 4 N., R. 15 E., Pittsburg County. Along State Highway 63, where highway crosses Gardner Creek, ~6 miles northeast of Blanco, Oklahoma

The contact between the Atoka and the Hartshorne Formations at Stop 8 (Gardner Creek section) is gradational and/or arbitrary (Fig. 40). 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 distributary 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 11B, where the contact is clearly disconformable.

The Gardner Creek section represents a regressive sequence. Units 1 (uppermost part of Atoka Formation) and 2 (lowest part of Hartshorne Formation) are interpreted as delta-front distal-bar deposits. The two sandstones at the base of the Hartshorne represent flood events. Units 3 and 4 were deposited in an interdistributary bay or bay some distance from any distributary channels, and unit 5 is a crevasse-splay deposit. The sequence above unit 5 is unexposed, but includes the Upper (and possibly Lower) Hartshorne coal(s). It is likely that much of this sequence includes siltstone and shale; these could be interpreted as bay-fill sediments overlain by marsh-swamp deposits.

The southeast-to-northwest paleocurrent direction of the crevasse-splay deposit (based on the large cross-beds) is somewhat enigmatic. Three explanations seem possible. (1) The Hartshorne Formation extended farther south than its current outcrop distribution, and local paleocurrent directions varied somewhat from the overall east-to-west direction of sediment transport. (2) The Ouachita Mountains to the south served as a local source of sediments. (3) Local paleocurrent directions vary widely and unsystematically. There is no evidence to support the second possible explanation. The third is unsatisfying. The first explanation is preferred, but there is no way to substantiate it.

Measured Section, Stop 8

Atoka Formation and Hartshorne Formation
Gardner Creek Section

C E½E½ sec. 26, T. 4 N., R. 15 E., and SW¼SW¼NW¼ sec. 25, T. 4 N., R. 15 E., Pittsburg County (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. Section measured by Neil H. Suneson.

	Thickness (feet)
HARTSHORNE FORMATION:	
5. Sandstone. Fine-grained, grayish orange (10YR7/4). Cross-stratified, locally with wavy partings. Stacked beds, locally with large-scale cross-stratifications as thick as 2 ft (Fig. 41). Paleocurrent direction, based on large-scale cross-beds, approximately southeast to northwest. Tops symmetrically rippled with approximate N. 40° E. orientation. Weathers to slabs. Interpretation: crevasse-splay deposit	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, shale drapes on ripples (Fig. 42). Locally plane-parallel stratified, lenticular-bedded, and/or	

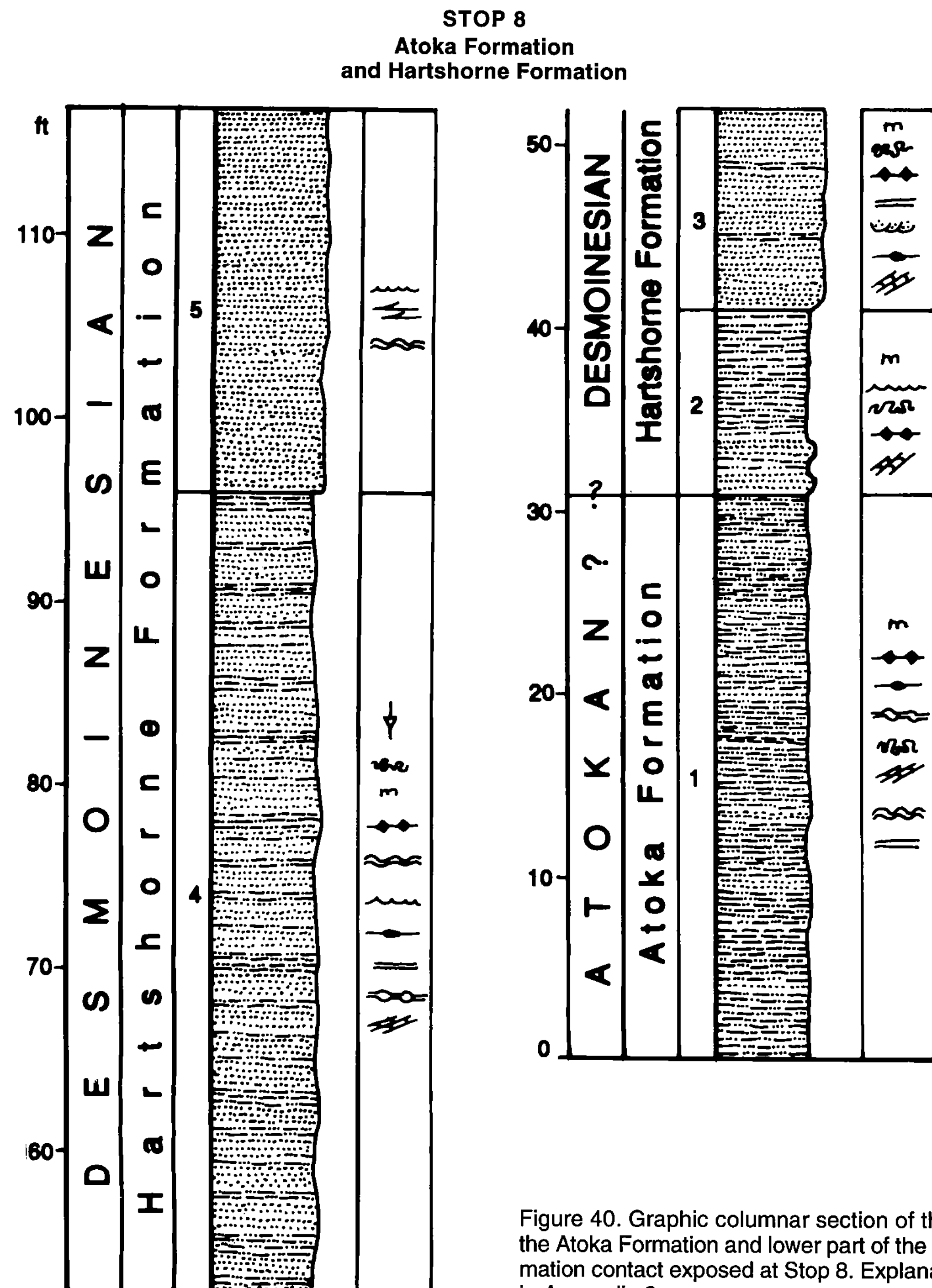


Figure 40. Graphic columnar section of the upper part of the Atoka Formation and lower part of the Hartshorne Formation contact exposed at Stop 8. Explanation of symbols in Appendix 3.

wavy-bedded. Unit contains a 1-ft-thick sandstone that consists of four stacked beds that are interference ripple-marked and 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 upwards slightly. Contact with unit 3 gradational. Interpretation: interdistributary-bay or bay-fill deposit 44.0

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 bottom of beds. Flaggy- and platy-weathering (Fig. 43). Contact with unit 2 gradational. Interpretation: interdistributary-bay or bay-fill deposit, possibly sandy tidal-flat deposit 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. 44). Fine-grained, well-sorted, grayish orange pink (5YR7/2). Cross-stratified, trace shale and organic material on cross-laminations. Base planar, no evidence for erosion, locally contains

Figure 41. Crevasse-splay deposits (unit 5) in Hartshorne Formation at Stop 8. Note faint to well-developed plane-parallel partings and large-scale cross-stratification. Geologic hammer for scale.

Figure 43. Photograph of flaggy-weathering unit 3 at Stop 8. Geologic hammer for scale.

Figure 42. Photograph of lenticular-bedded, highly cross-stratified, fine-grained sandstone and siltstone in unit 4 at Stop 8. Shale drapes on ripples may indicate tidal influence. Geologic hammer for scale.

Figure 44. Contact between Atoka Formation (below prominent sandstone) and Hartshorne Formation (above base of sandstone) in unit 2 at Stop 8. Geologic hammer for scale.

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. Interpretation: delta-front, distal-bar deposit 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 quartz-, mica-, and/or organic-rich layers. Locally lenticular bedded. Sandstone beds show pinch-and-swell, contain trace fossils. About 6 ft below unit 2, 1-5-in.-thick sandstone beds that are fine-grained, silty, contain trace 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. Interpretation: delta-front, distal-bar deposit. 31.0

Total thickness of section 117.0

STOP 9

McCurtain Shale Member and Warner Sandstone Member, McAlester Formation

Location: NE¼NW¼SE¼ sec. 35, T. 5 N., R. 16 E., Pittsburg County. Railroad cut along Arkansas-Oklahoma Railroad, 0.5 mi northwest of Haileyville, Oklahoma

For permission to visit this outcrop (private property), please contact B. David Donoley, President/CEO, Arkansas-Oklahoma Railroad, Inc., 103 South Central, P.O. Box 485, Wilburton, OK 74578; or phone (918) 465-0299.

The Arkansas-Oklahoma Railroad section at Stop 9 (Fig. 45) is the best exposure of the contact between the McCurtain Shale and Warner Sandstone Members of the McAlester Formation in the southern part of the Arkoma basin. The McCurtain Shale Member typically forms valleys and is rarely exposed. Although the Warner Sandstone Member generally is well exposed, most outcrops are lichen covered; thus, subtle (and, in some cases, gross) sedimentary structures commonly are obscured. In addition, the more fine-grained rocks within the Warner Sandstone Member are rarely exposed. In this area, the Warner Sandstone Member is split into lower and upper sandstones; the upper sandstone is very poorly exposed where the railroad cuts through the low ridge ~700 ft northwest of this section. It is not worth visiting.

This section represents two very different sedimentary environments. The McCurtain Shale Member appears to have been deposited in a prodelta environment; the relatively high silt content of the shales, abundance of siltstone and fine-grained sandstone beds, and conspicuous slump features suggest a proximal prodelta setting. In contrast, the Warner Sandstone Member is characterized by a large number of sedimentary structures that suggest deposition in relatively shallow water. The most important of these features are diagnostic and include coal beds (units 10 and 12) and autochthonous plant fossils (units 8 and 16). Any interpretation of the depositional environments of the different units that make up the lower part of the Warner Sandstone Member at this locality should start with these four units.

Part of our interpretation of this section is that unit 8 was deposited in an interdistributary-bay environment; the gradational nature of the contact between units 8 and 7 suggests that unit 7 was deposited in a similar environment. Unit 7 clearly eroded into unit 6 (interpreted to be a prodelta deposit), which suggests that the contact between units 7 and 6 (the Warner Sandstone–McCurtain Shale contact) represents an abrupt lowering of sea level and could mark a sequence boundary.

An important aspect of this section is that there appear to be no sediments associated with distributary channels. Levee, channel-fill, and distributary-mouth-bar deposits are absent in this outcrop.

Measured Section, Stop 9

McCurtain Shale Member and Warner Sandstone Member, McAlester Formation

Arkansas-Oklahoma Railroad Section

NE¼NW¼SE¼ sec. 35, T. 5 N., R. 16 E., Pittsburg County (Hartshorne 7.5′ quadrangle). Section measured on northeast side of cut along Arkansas-Oklahoma Railroad. Section measured by Neil H. Suneson.

Thickness (feet)

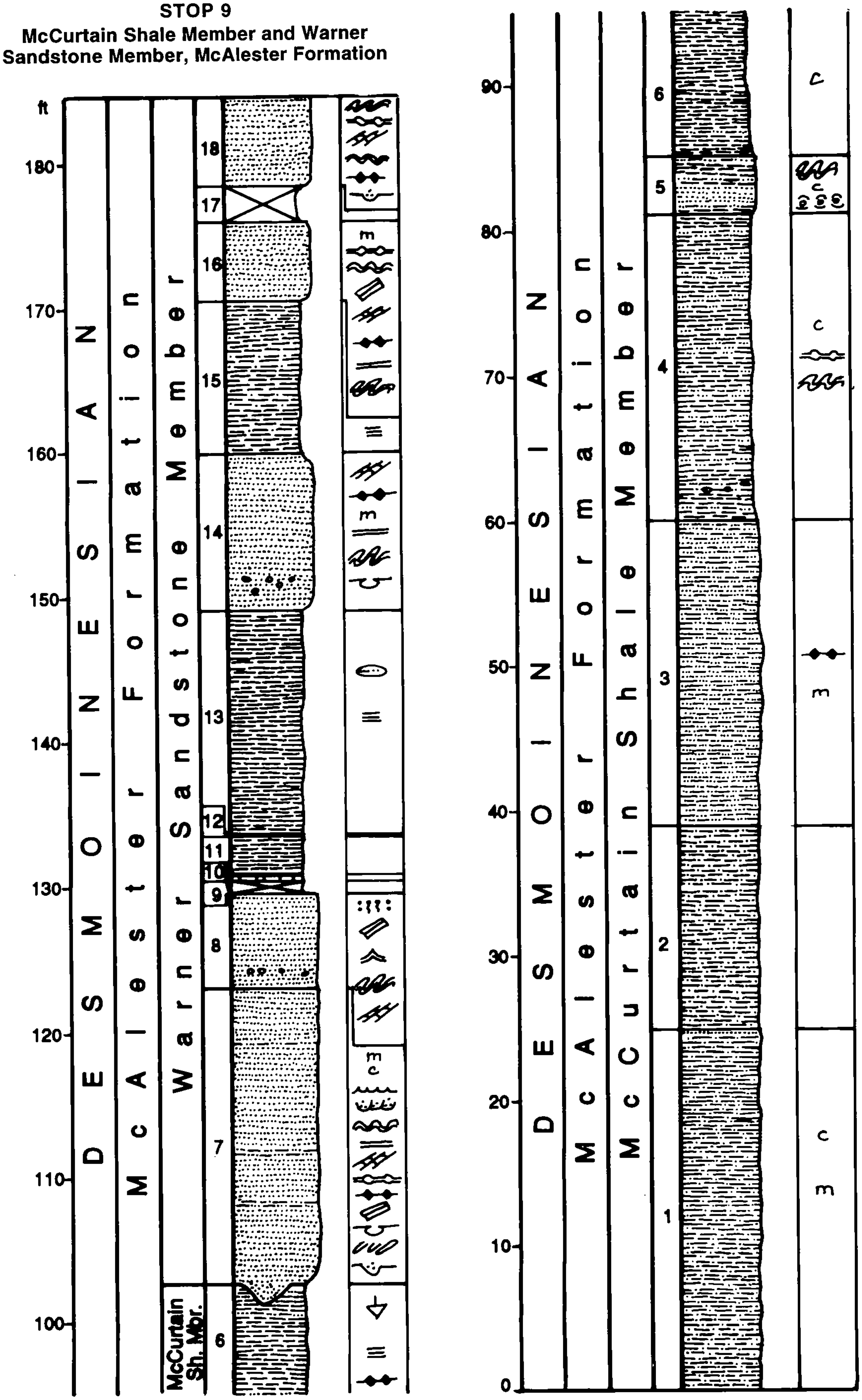
MCALESTER FORMATION:

Warner Sandstone Member:

18. Sandstone. Very fine grained, yellowish gray (5Y 7/2). Abundant organic material on laminations. Slabby, consists of stacked, amalgamated sandstone beds. Cross-beds, pinch-and-swell, soft-sediment deformation features common; scour-and-fill uncommon. Top irregular, wavy-bedded. Interpretation: crevasse-splay sandstone 6.0
17. Covered. Interpretation: interdistributary-bay or bay-fill deposit? 2.5
16. Sandstone. Very fine grained, light gray (N7), conspicuous mica on laminations. Slabby, consists of stacked 0.5–1-ft-thick beds (Fig. 46). Cross-beds, plane-parallel beds, pinch-and-swell, soft-sediment deformation features common. Contains an upright carbonized tree trunk ~3.5 ft tall, 4 in. in diameter, extending through four individual sandstone beds, and with a base in unit 15. Conspicuous carbonized plant compressions, rarely extremely well preserved, on bedding planes. Base abrupt, wavy, slightly undulatory. Interpretation: crevasse-splay deposit ... 5.5
15. Shale. Silty, fissile to platy, poorly exposed. Interpretation: interdistributary-bay or bay-fill deposit 10.5

Figure 45 (*facing page*). Graphic columnar section of the upper part of the McCurtain Shale Member and lower part of the Warner Sandstone Member, McAlester Formation, exposed at Stop 9. Explanation of symbols in Appendix 3.

STOP 9
McCurtain Shale Member and Warner Sandstone Member, McAlester Formation



14. Sandstone. Fine-grained, quartzose, light gray (N7), with conspicuous mica and organic material on laminations. Possible trace glauconite. Mostly plane parallel stratified, rarely cross stratified, locally with soft-sediment deformation features. Abundant rounded shale rip-up clasts ≤3 in. in diameter in zone ~1-ft thick, ~3 ft above base. Base sharp, with abundant load casts. Interpretation: crevasse-splay deposit 11.0
13. Shale. Fissile, grayish black (N2) to olive gray (5Y3/2), appears to be organic-rich. Small coal chips observed in float near lower part of unit, but no coal outcrop observed. Mostly poorly exposed. Rare 0.5–1-in.-thick silica-cemented shale layers appear slightly "boudined." Locally weathers spheroidally. Abundant ironstone concretions near top. Interpretation: marsh-swamp deposit grading upward to interdistributary-bay or bay-fill deposit 15.5
12. Coal. Weathers to 1–2-in. blocks. Interpretation: marsh-swamp deposit 0.2
11. Shale. Very dark colored, sooty, organic-rich. Soft, weathers easily. Yellowish clayey mineral on bedding planes. Poorly exposed. Interpretation: mixed marsh-swamp and interdistributary-bay or bay-fill deposit 2.5
10. Coal and underclay. Coal ~2 in. thick; underclay ~4 in. thick. Coal weathers to 1–2-in. blocks, iron-oxide-stained fractures. Parts well. Interpretation: marsh-swamp deposit 0.5
9. Covered. Probably shale. Interpretation: interdistributary-bay or bay-fill deposit 1.0
8. Sandstone. Very fine grained, quartzose, light olive gray (5Y6/1). Mostly cross bedded and flaser bedded. Cross-beds mostly unidirectional, but locally bidirectional. Locally small-scale soft-sediment deformation and dewatering features. Beds locally lensoid with no evidence for erosion at base (Fig. 47). Upper 4 ft with abundant vertical burrows. Locally contains shale rip-up clasts as large as 2 in. in diameter. Autochthonous 2.5-ft-long *Stigmaria* ~14 in. below top of unit (Fig. 48). Also prone plant cast with slightly carbonized exterior, upright cast at same level. Base gradational with unit 7 (Fig. 49). Interpretation: interdistributary-bay, locally tidal-flat and tidal-channel deposits 6.5
7. Sandstone, minor siltstone, very minor shale. Fine-grained to very fine grained, medium light gray (N6) to light olive gray (5Y6/1). Sandstone includes ripple-marked, wavy-bedded, trough cross-bedded, and flaser-bedded beds 0.5–6 in. thick, interbedded with plane-parallel laminated beds 0.5–3 in. thick. Cross-bedded beds are unidirectional, locally show pinch-and-swell, lensing, pinching-out. Cut-and-fill structures uncommon. Beds generally very continuous across length of outcrop. Cross-bedded beds appear to be most common in lower part of unit; plane-parallel bedded beds most common in middle and upper parts of unit. Unit locally includes some slightly reddish weathering, resistant, calcareous, sandy siltstone layers ~1 in. thick. Very abundant carbonized plant trash on plane-parallel beds, some with ex-

Figure 46. Sandstone of unit 16 (Stop 9), interpreted to be crevasse-splay deposit. Unit 17 is grass-covered slope above unit 16, and unit 18 is exposed at top left of photograph. Unit 15 is mostly covered by large broken blocks eroded from unit 16. Carbonized tree trunk is dark, vertical feature (units 15 and 16) on right side of photograph (arrow). Geologic hammer (left side) for scale.

Figure 47. Sandstone lens (possible tidal channel) in unit 8 (Stop 9) exposed on southwest side of railroad cut. Geologic hammer for scale.

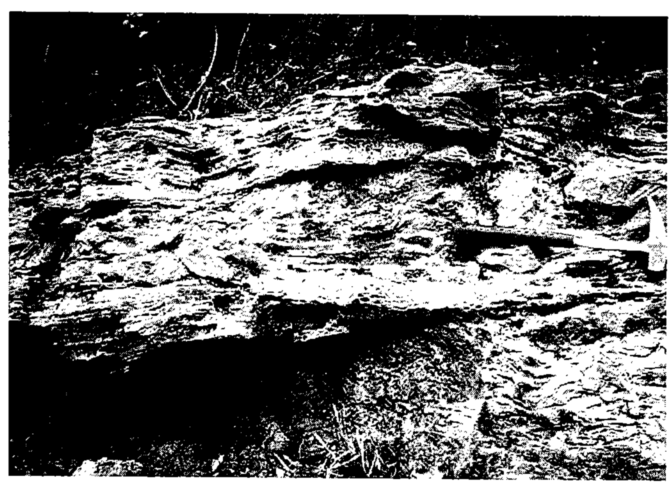


Figure 48. Autochthonous *Stigmaria* near top of unit 8 (Stop 9). Note abundant small-scale soft-sediment deformation features. Float from unit 9 covers top of outcrop. Geologic hammer for scale.

tremely fine detail of plants preserved. Mica conspicuous on bedding planes. Contact with unit 6 sharp, erosional, marked by scoured channels as thick as 2 ft (Fig. 50), locally with groove casts oriented at N. 70°–75° E. and load casts. Shale locally deformed (compressed) beneath channels. Interpretation: interdistributary-bay deposit. If so, represents abrupt lowering of sea level and sequence boundary(?) 20.5

McCurtain Shale Member:

6. Shale and very minor siltstone. Olive black (5Y2/1). Fissile, locally slightly calcareous, abundant carbonized organic debris on bedding planes in upper 1.5 ft. Shale locally exhibits pencil structure. Possibly slightly coarsening upward. Interpretation: proximal prodelta grading upward to possibly distal bar 17.5
5. Siltstone; minor shale; rolled sandstone, siltstone, and shale masses. Sandstone fine-grained, calcareous, locally with soft-sediment deformation features. Rolled siltstone masses with iron oxide stain. Rolled masses range from 2 in. to 3.5 ft long. Unit includes autochthonous, but detached and folded beds. Interpretation: proximal prodelta deposit ... 4.0
4. Siltstone and shale. Shale silty. Rare 1-in.-thick calcareous siltstone layers show pinch-and-swell, locally form alignment of concretions, elsewhere detached and folded. Soft-sediment deformation features common at base. Thickness approximate. Interpretation: proximal prodelta deposit 21.0
3. Siltstone. Sandy, dark yellowish brown (10YR4/2). Platy to chippy, appears highly fractured and weathered. Mica, minor carbonized organic material, iron oxide stain conspicuous on bedding planes. Interpretation: proximal prodelta deposit 21.0
2. Shale. Silty, olive black (5Y2/1). Weathers chippy. Conspicuous 0.25–1-in.-thick iron-oxide-stained beds. Interpretation: proximal prodelta deposit ... 14.0
1. Shale. Silty. Poorly exposed, weathers chippy. Mica conspicuous on bedding planes. 1-in.-thick fine-grained sandstone at top of unit. Hard, quartzose, calcareous cement, discontinuous, locally appears detached and folded. Interpretation: proximal prodelta deposit 25.0

Total thickness of section 184.7

Figure 49. Photograph of northeast side of railroad cut at Stop 9 showing darker-colored unit 7 on right, grading upward to lighter-colored unit 8 in middle. Units 9 through base of 13 are poorly exposed above unit 8, although unit 10 (coal bed) is exposed just below and to the left of the small tree.

Figure 50. Photograph of base of unit 7 (Stop 9), showing channel-form features and erosive nature of contact between units 7 and 6. Geologic hammer for scale.

STOP 10

Lower Part of the Hartshorne Formation

Location: S½SE¼NE¼NE¼ sec. 10, T. 5 N., R. 17 E., and N½NW¼SW¼NW¼ sec. 11, T. 5 N., R. 17 E., Latimer County. Southward from crest of ridge along Clonsilla Hill Road, ~0.75 mi southwest of Drumb, Oklahoma

The Clonsilla Hill section at Stop 10 (Fig. 51) 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 part of the Hartshorne Formation at Stop 10 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, pebble conglomerates, soft-sediment deformation features, and channel-form configuration of some beds (Fig. 52) indicate deposition within a major delta distributary. Figure 52 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-, parallel-bedded with abundant trace fossils and a variety of ripple marks. Such features suggest deposition in a shallow-marine environment.

The shales and interbedded thin sandstones in the upper part of the Atoka Formation at Stop 10 are interpreted to be prodelta deposits. The thin sandstones may represent flood events.

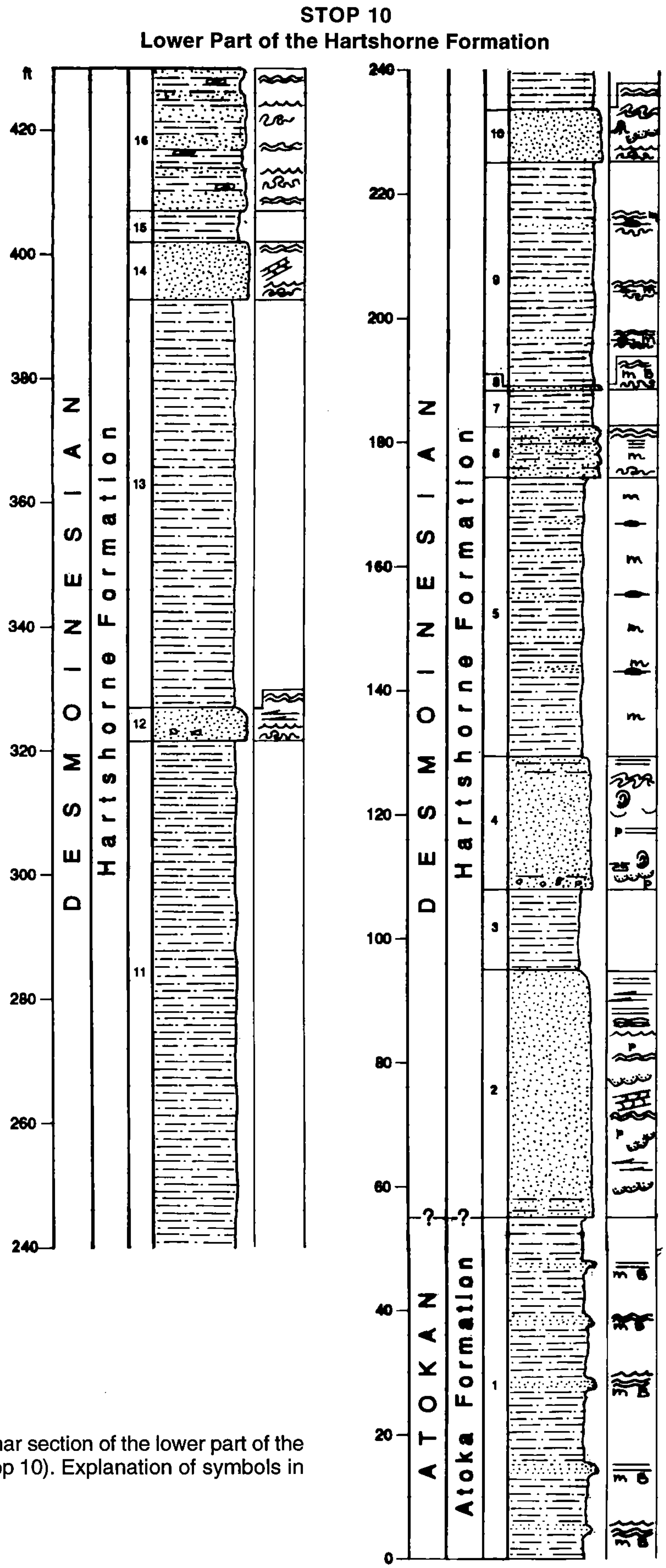


Figure 51. Graphic columnar section of the lower part of the Hartshorne Formation (Stop 10). Explanation of symbols in Appendix 3.

Figure 52. Trough-cross-bedded sandstone filling a channel eroded into underlying plane-bedded sandstone (unit 2, Stop 10). Geologic pick for scale.

Measured Section, Stop 10

Lower Part of the Hartshorne Formation
Clonsilla Hill Road Section (La-1-97-H)

S½SE¼NE¼NE¼ sec. 10, T. 5 N., R. 17 E., and N½NW¼ SW¼NW¼ sec. 11, T. 5 N., R. 17 E., Latimer County (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 down slope in low ridges enclosed by hairpin bend in road near base of slope. Section measured by LeRoy A. Hemish.

Thickness (feet)

DESMOINESIAN SERIES:

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-, 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-, 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-, 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, 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, discontinuous 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-, 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 plane 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

ATOKAN SERIES (?):

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; parallel-, wavy- to plane-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

STOP 11A

Contact Between the Atoka Formation and the Hartshorne Formation

Location: NE¼NW¼SE¼NW¼ sec. 12, T. 5 N., R. 20 E., Latimer County. Immediately south of crest of Red Oak Ridge along west side of Craven Road (which intersects U.S. Highway 270 ~4 mi east of Panola and ~4 mi west of Red Oak, Oklahoma

This borrow pit (Stop 11A) and Stop 11B 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; or phone (918) 465-3310.

[This outcrop was visited in November 1994, as part of a three-day workshop and field trip sponsored by the Oklahoma Geological Survey. The following description of the section is modified slightly from Suneson and Hemish (1994, p. 56–57).]

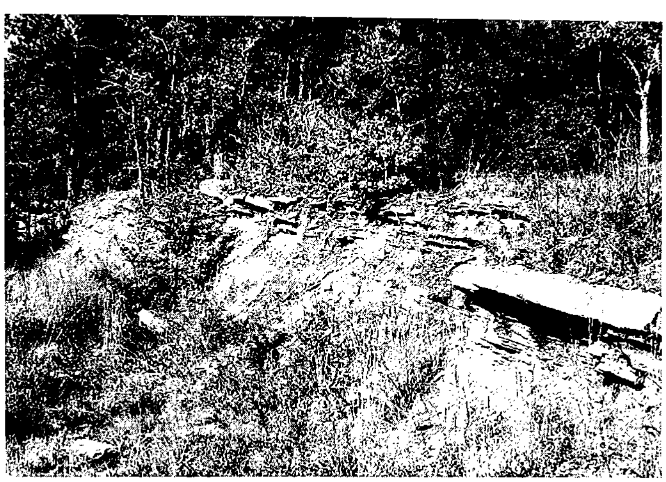


Figure 53. Outcrop of Atoka and Hartshorne Formations in borrow pit at Stop 11A showing interbedded siltstone, sandstone, and shale overlain by parallel-bedded shaly sandstone. Prominent sandstone bed on right is ~1 ft thick. (From Suneson and Hemish, 1994, fig. 37.)

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. 53), and its placement probably will elicit some discussion.

The criteria for placing the contact at the base of unit 4 (Fig. 54) are: (1) the change from a heterolithic unit of siltstone, sandstone, and shale to a comparatively thick package of shaly sandstone; and (2) the presence of local, small channels cutting into the heterolithic unit at the base of the sandstone unit. In some places along Red Oak Ridge, the channeling is much more pronounced and a pebble conglomerate is present at the base of the Hartshorne Formation (Hemish, 1993a, stop 6).

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 11B). Our interpretation of this outcrop is that it is a large distributary channel in a deltaic environment and that the borrow-pit

STOP 11A
Contact Between Atoka Formation and Hartshorne Formation

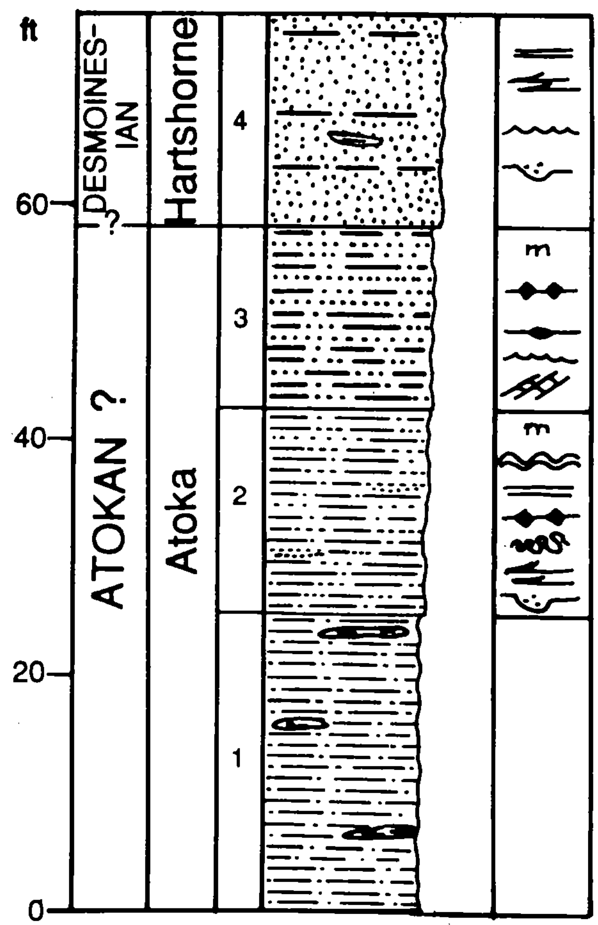


Figure 54. Graphic columnar section of upper part of Atoka Formation and lower part of Hartshorne Formation at Stop 11A. (Modified from Suneson and Hemish, 1994, fig. 38.) Explanation of symbols in Appendix 3.

outcrop is marginal to the channel. Stop 11A,B is an example of the rapid lateral facies change that typifies exposures of the Hartshorne Formation along its outcrop belt, particularly in this area and to the east.

Measured Section, Stop 11A

(Modified from Suneson and Hemish, 1994, p. 56–57, stop 8.)

Contact Between Atoka Formation and Hartshorne Formation

Craven Road Section

NE¼NW¼SE¼NW¼ sec. 12, T. 5 N., R. 20 E., Latimer County (Panola 7.5′ quadrangle). Measured in borrow pit west of road on south slope of Red Oak Ridge. Section measured by LeRoy A. Hemish.

	Thickness (feet)
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 (10R4/2), interlaminated with light gray (N7), very fine grained sandstone and dark gray (N3) shale; very thin bedded, wavy-, 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 11B

Contact Between the Atoka Formation and the Hartshorne Formation

Location: SW¼NE¼ sec. 12, T. 5 N., R. 20 E., Latimer County. About 500 ft east of Craven Road along Red Oak Ridge, southwest of Red Oak, Oklahoma

This outcrop is on private property. See Stop 11A for information about obtaining permission to visit.

The top of this outcrop was visited in 1994 as part of the same OGS workshop and field trip described in Stop 11A. At that time, the section had not been measured, and participants did not descend 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.

The Red Oak Ridge section is a superb example of a distributary-channel deposit in the Lower Member of the Hartshorne Formation (Fig. 55). In detail, the deposit consists of a number of nested 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 nested character of the channel deposits results in a "false" base (base of unit 4) of the Hartshorne Formation.

The orientation of the distributary channel is unknown. In all likelihood, it is oblique to the cliff face, which is approximately east-west at this location. We have identified several distributary-channel deposits along Red Oak Ridge; in many cases—where a ridge locally becomes higher and/or steeper (Fig. 56) (both of which occur at Stop 11B)—these channels can be readily identified on topographic maps.

Measured Section, Stop 11B

Contact Between Atoka Formation and Hartshorne Formation

Red Oak Ridge Section

SW¼NE¼ sec. 12, T. 5 N., R. 20 E., Latimer County (Panola 7.5′ quadrangle). Top of unit 6 is ~400 ft S. 35° E. of water tower at top of vertical cliff. 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 part way up access route down cliff just east of units 3 and 4. Section measured by Neil H. Suneson.

	Thickness (feet)
HARTSHORNE FORMATION:	
6. Sandstone. Fine-grained, well-sorted, dark yellowish orange (10YR6/6). Massive, mostly unstratified, locally well parted. Small load casts at base. Interpretation: distributary-channel deposit	32.0
5. Sandstone. Fine-grained, well-sorted, very pale orange (10YR8/2). Slabby to flaggy with common large-scale trough cross-stratification (Fig. 57), pinch-and-swell. Appears to grade into massive	

STOP 11B
Contact Between Atoka Formation and Hartshorne Formation

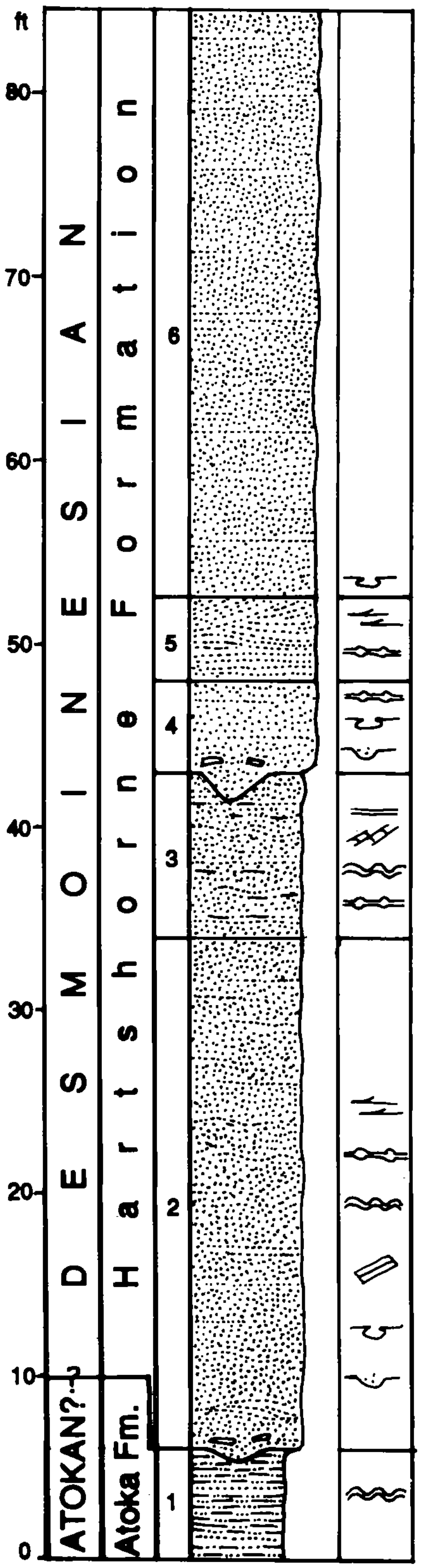


Figure 55. Graphic columnar section of the uppermost part of the Atoka Formation and lower part of the Hartshorne Formation exposed at Stop 11B. Explanation of symbols in Appendix 3.

Figure 56. Photograph looking northeast at the cliff-forming distributary-channel sandstone in the lower part of the Hartshorne Formation at Stop 11B.

Figure 57. Large-scale trough cross-stratification in distributary-channel sandstone, lower part of Hartshorne Formation (unit 5) at Stop 11B. Geologic hammer for scale.

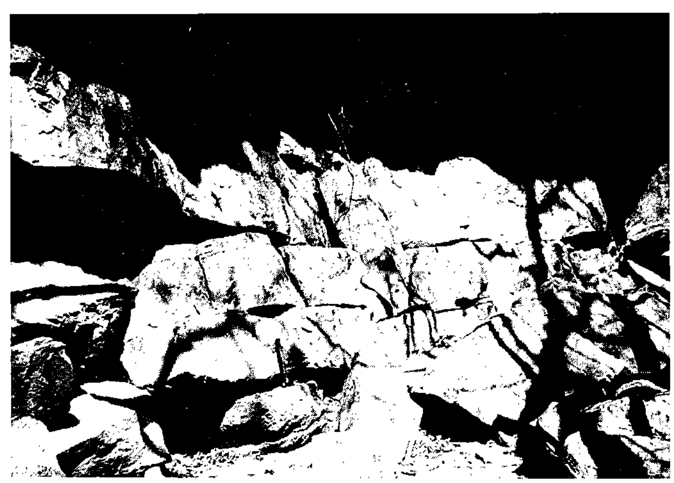


Figure 58. Base of Hartshorne Formation (unit 2) at Stop 11B. Geologic hammer rests on sandstone with abundant shale rip-up clasts. The top of the Atoka Formation is immediately below this sandstone. Note the blocky-weathering, mostly featureless character of the sandstone.

sandstone similar to units 4 and 6. Interpretation: distributary-channel deposit 0–4.5

4. Sandstone. Fine-grained. Massive, mostly unstratified, locally has widely spaced anastomosing partings, possibly representing pinch-and-swell. 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. Interpretation: distributary-channel deposit 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 very gently wavy bedded. Minor pinch-and-swell. Appears to grade into top of unit 2. Interpretation: distributary-channel deposit 9.0

2. Sandstone. Fine-grained, moderate yellowish brown (10YR5/4). Massive, mostly unstratified, faintly parallel stratified (Fig. 58). Basal 3 ft locally wavy bedded with minor pinch-and-swell and large-scale cross-stratification. Base locally eroded 6 in. in to 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. Interpretation: distributary-channel deposit 28.0

ATOKA FORMATION:

1. Siltstone and sandstone. Sandstone very fine grained. Slightly wavy bedded. Poorly exposed. Interpretation: distal delta-front, possibly proximal prodelta deposit....................................... 6.0

Total thickness of section 78–86.5

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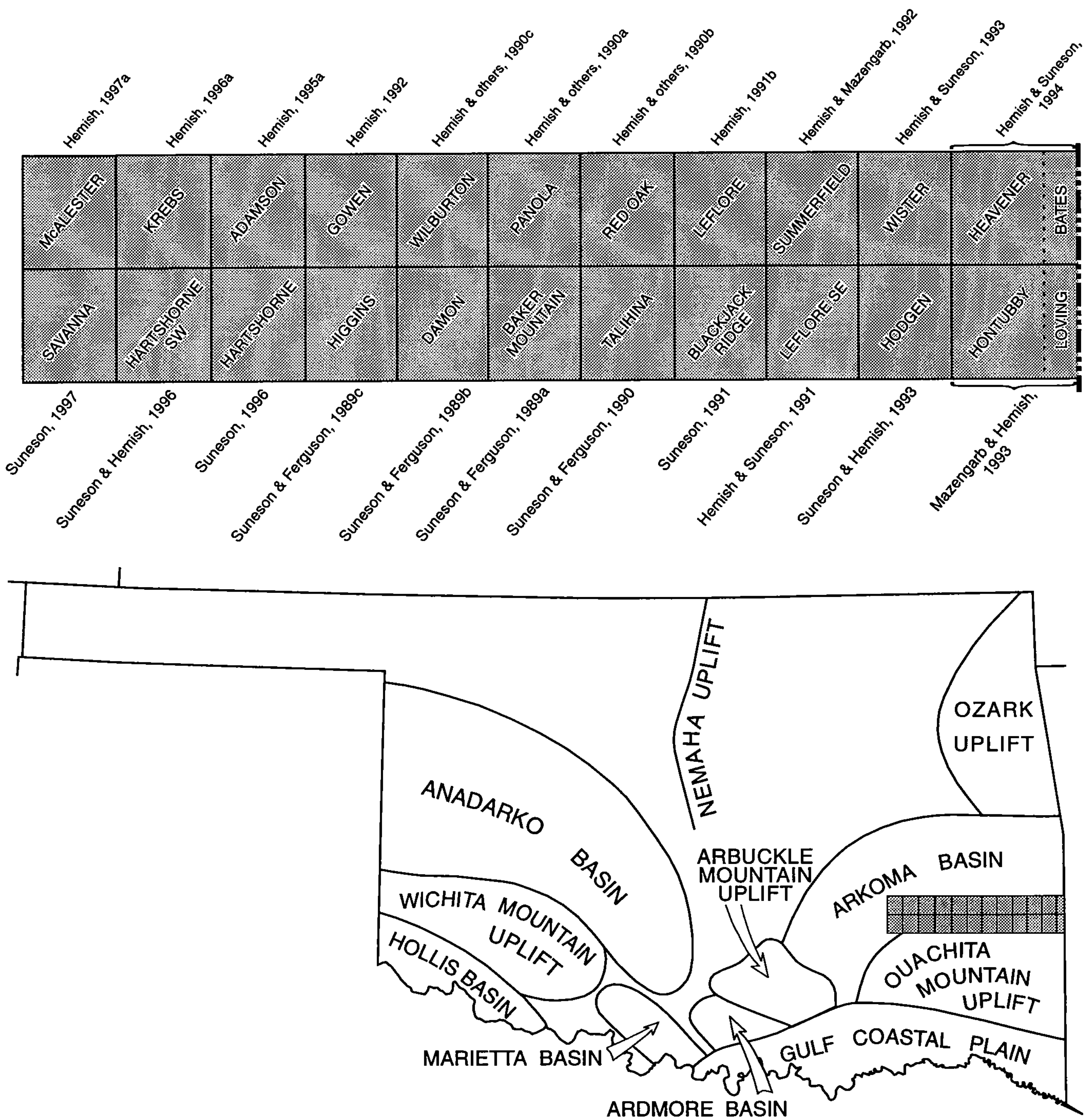
Appendixes

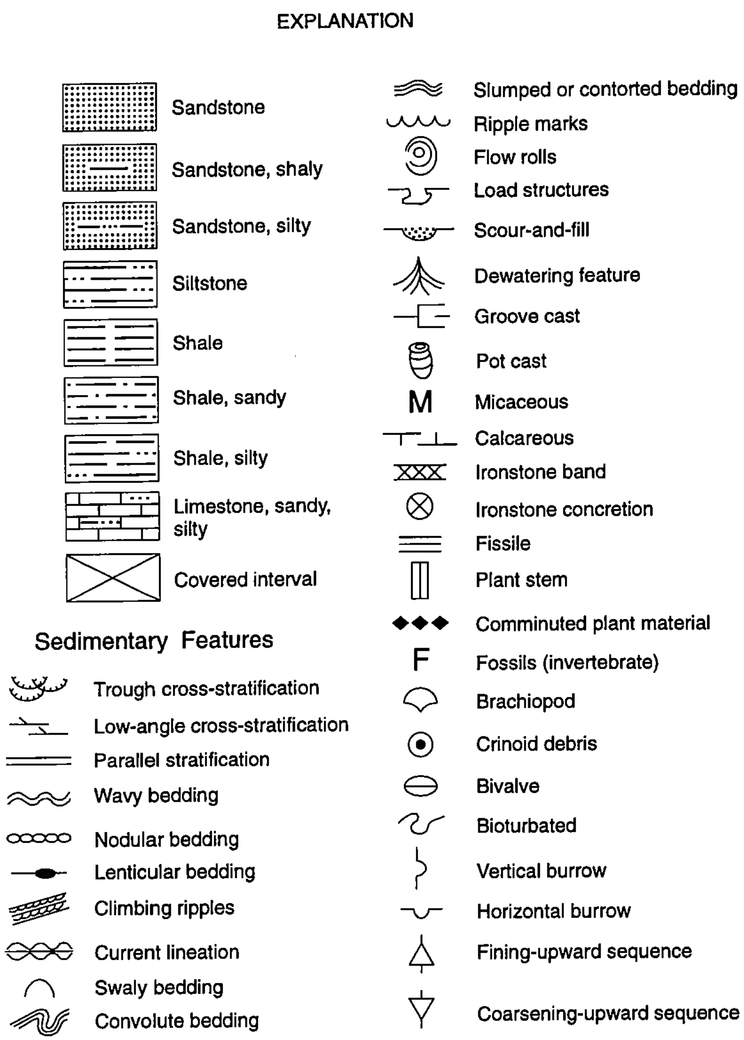
APPENDIX 1

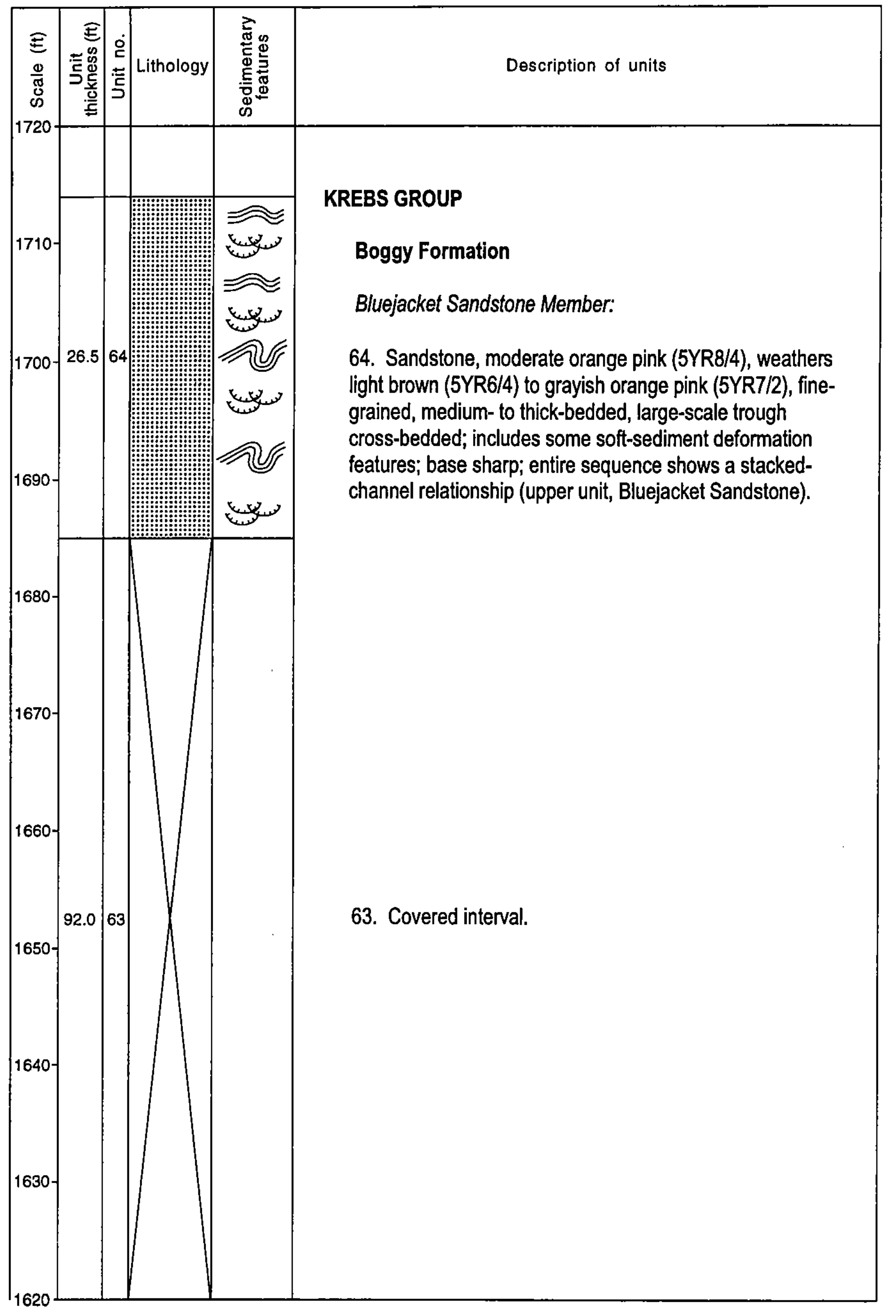
Geologic Maps Published as Part of COGEOMAP and STATEMAP Projects



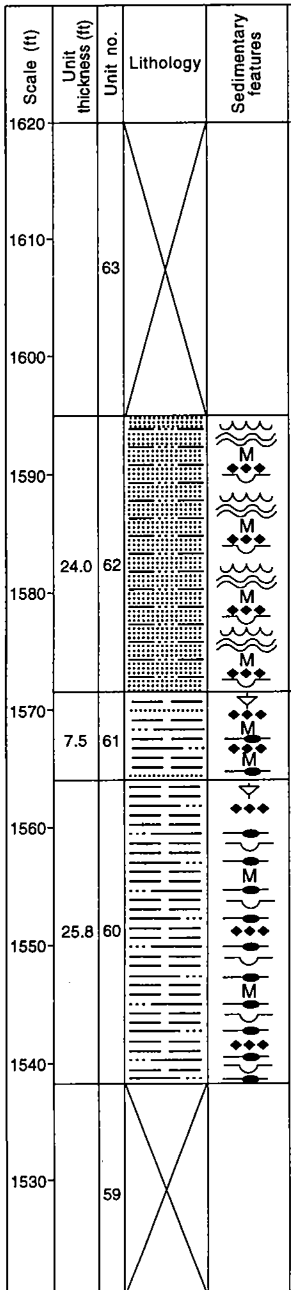
APPENDIX 2: Neostratotype of Savanna Formation (Measured Section Pi-1-94-H—Adamson 7.5′ Quadrangle)

Measured along section-line road and route of power line between sec. 1, T. 5 N., R. 16 E., and sec. 6, T. 5 N., R. 17 E.; and between sec. 36, T. 6 N., R. 16 E., and sec. 31, T. 6 N., R. 17 E., Pittsburg County, Oklahoma; starting at the base of the slope at the road intersection ~0.5 mi northwest of Adamson, and ending at the top of the bluff just north of the flood plain of Buffalo Creek. Section measured perpendicular to east–west strike of beds by LeRoy A. Hemish, October 25–26, 1994. (From Hemish, 1995b.)





APPENDIX 2: Neostratotype of Savanna Formation *(continued)*



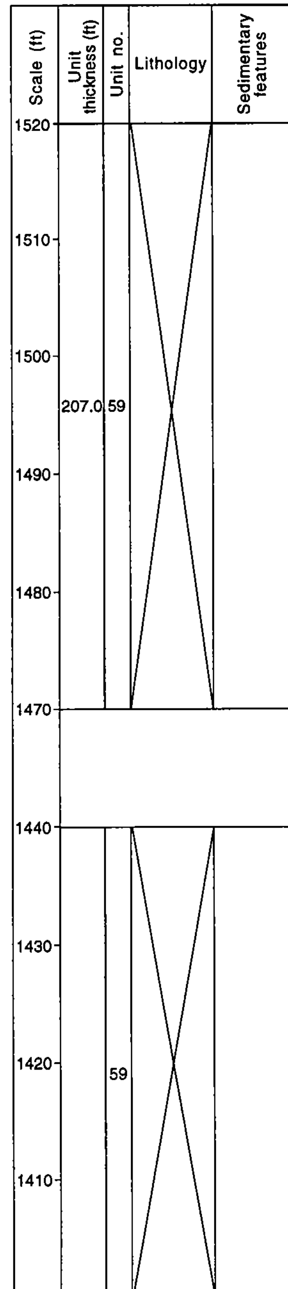
Description of units

62. Sandstone, grayish orange (10YR7/4), very fine grained, silty, shaly, micaceous, very thin to thin-bedded; wavy, parallel-bedded, ripple-marked; black, comminuted plant material on stratification surfaces; trace fossils on soles of beds; basal contact somewhat gradational, but readily defined by change in lithology from predominantly shale to predominantly sandstone (lower unit, Bluejacket Sandstone).

Savanna Formation

61. Shale, moderate yellowish brown (10YR5/4), silty; contains small lenses of very fine grained, micaceous sandstone with black comminuted plant material on stratification surfaces; coarsens upward; base gradational.

60. Shale, olive gray (5Y3/2), weathers yellowish gray (5Y7/2), silty; siltstone laminae are lenticular, micaceous, and have black, carbonized, comminuted plant material on bedding surfaces; unit contains burrows as much as 1 in. long and 0.3 in. in diameter; coarsens upward; base gradational.

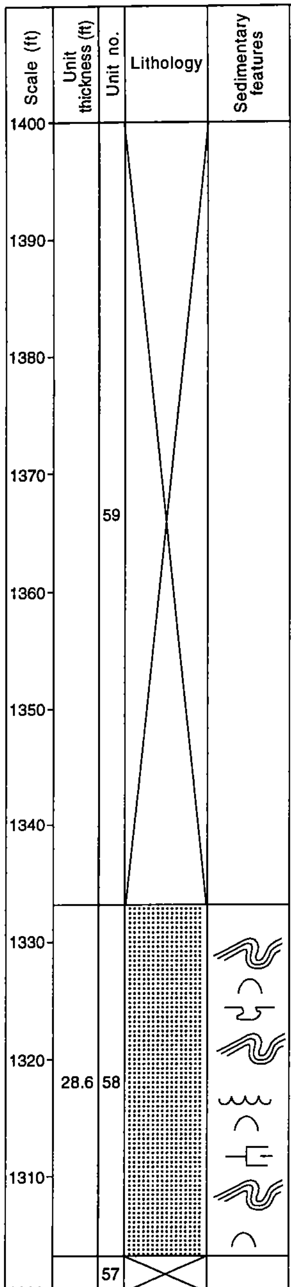


Description of units

59. Covered interval (alluvium in Buffalo Creek Valley).

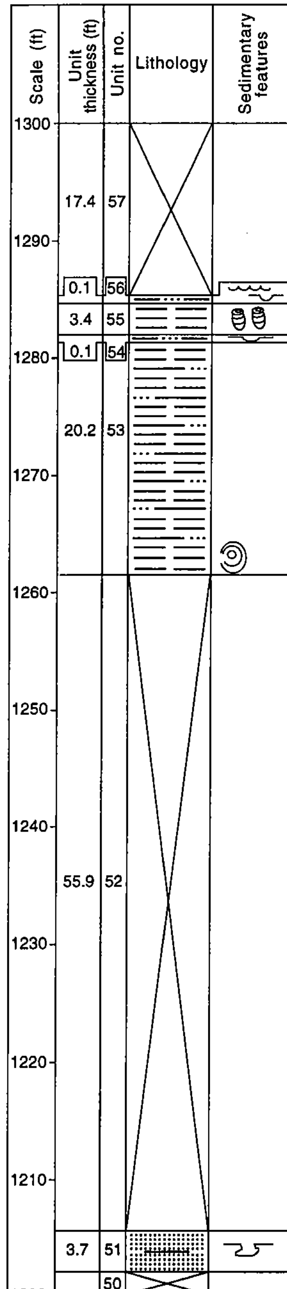
30 feet of unit 59 omitted

APPENDIX 2: Neostratotype of Savanna Formation *(continued)*



Description of units

58. Sandstone, grayish red (5R4/2), weathers very dusky red (10R2/2), ferruginous, very fine grained, thick-bedded, some swaly beds, blocky; many beds show soft-sediment deformation features; exposed mostly as float in steep dip slope south side of Buffalo Creek; some load casts and grooves on overturned float blocks; in situ exposure of sandstone part way down slope is ripple marked; upper part (top?) of unit is exposed at contact with alluvium at edge of flood plain of Buffalo Creek (Psv7).



Description of units

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

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

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

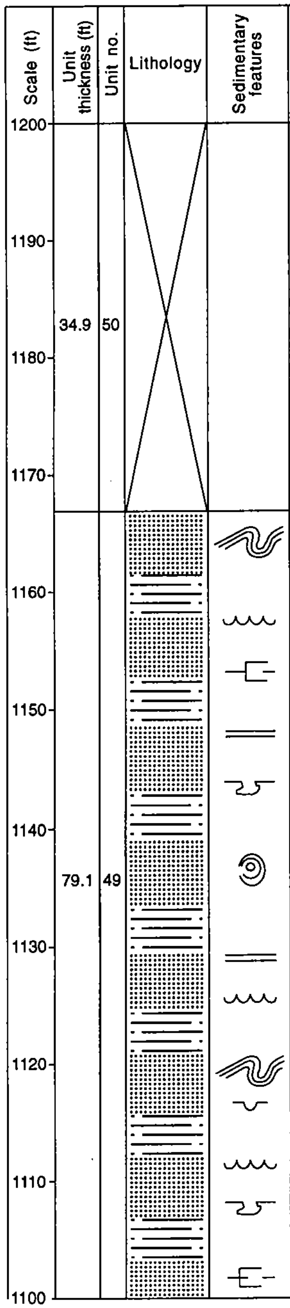
54. Siltstone, dark yellowish brown (10YR4/2) to light olive gray (5Y5/2), weathers dark yellowish orange (10YR6/6) and light brown (5YR5/6), thin-bedded, somewhat wavy-bedded; characterized by a proliferation of trace fossils of many kinds on both top and bottom of bed; base sharp.

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

52. Covered interval.

51. Sandstone, light olive gray (5Y5/2), weathers moderate brown (5YR4/4), very fine grained, shaly, thin- to medium-bedded, irregular-bedded, load casts on some soles, poorly exposed in road bed (Psv6b).

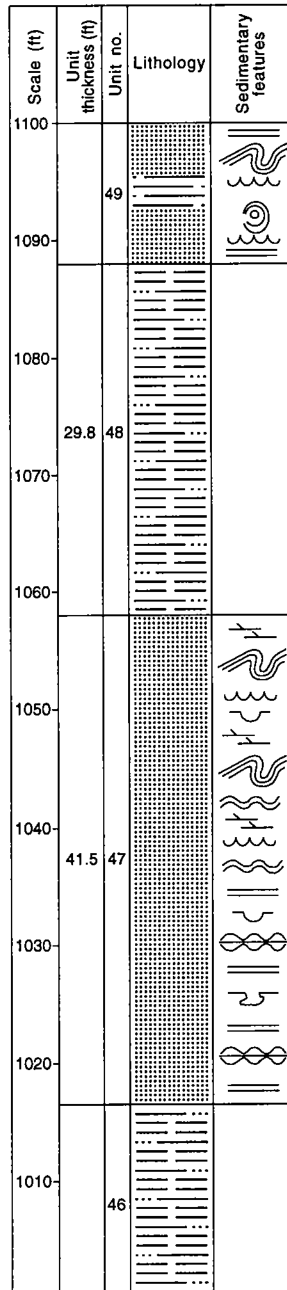
APPENDIX 2: Neostratotype of Savanna Formation *(continued)*



Description of units

50. Covered interval.

49. Sandstone, light olive gray (5Y5/2), weathers light brown (5YR6/4) to moderate reddish brown (10R4/6), to grayish orange (10YR7/4), interbedded with yellowish gray (5Y7/2) and moderate reddish orange (10R6/6) sandy shale; thin- to medium-bedded; some beds are flat and parallel, some are irregular, others are ripple marked; many beds are deformed, showing convolute structures and flow rolls; many beds have good sole markings, including load casts, grooves, and trace fossils; unit is exposed on dip slope in road bed and in ditch (Psv6a).



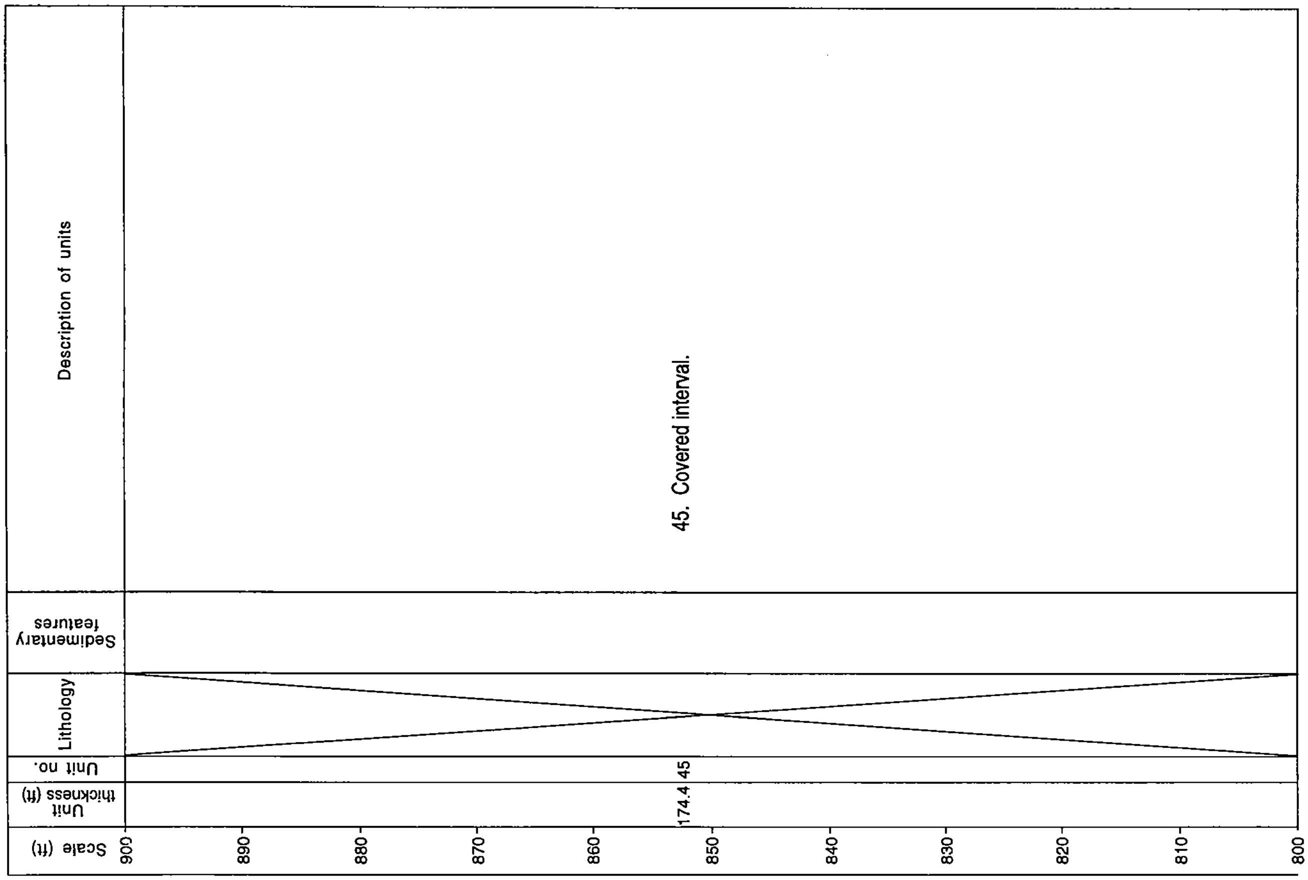
Description of units

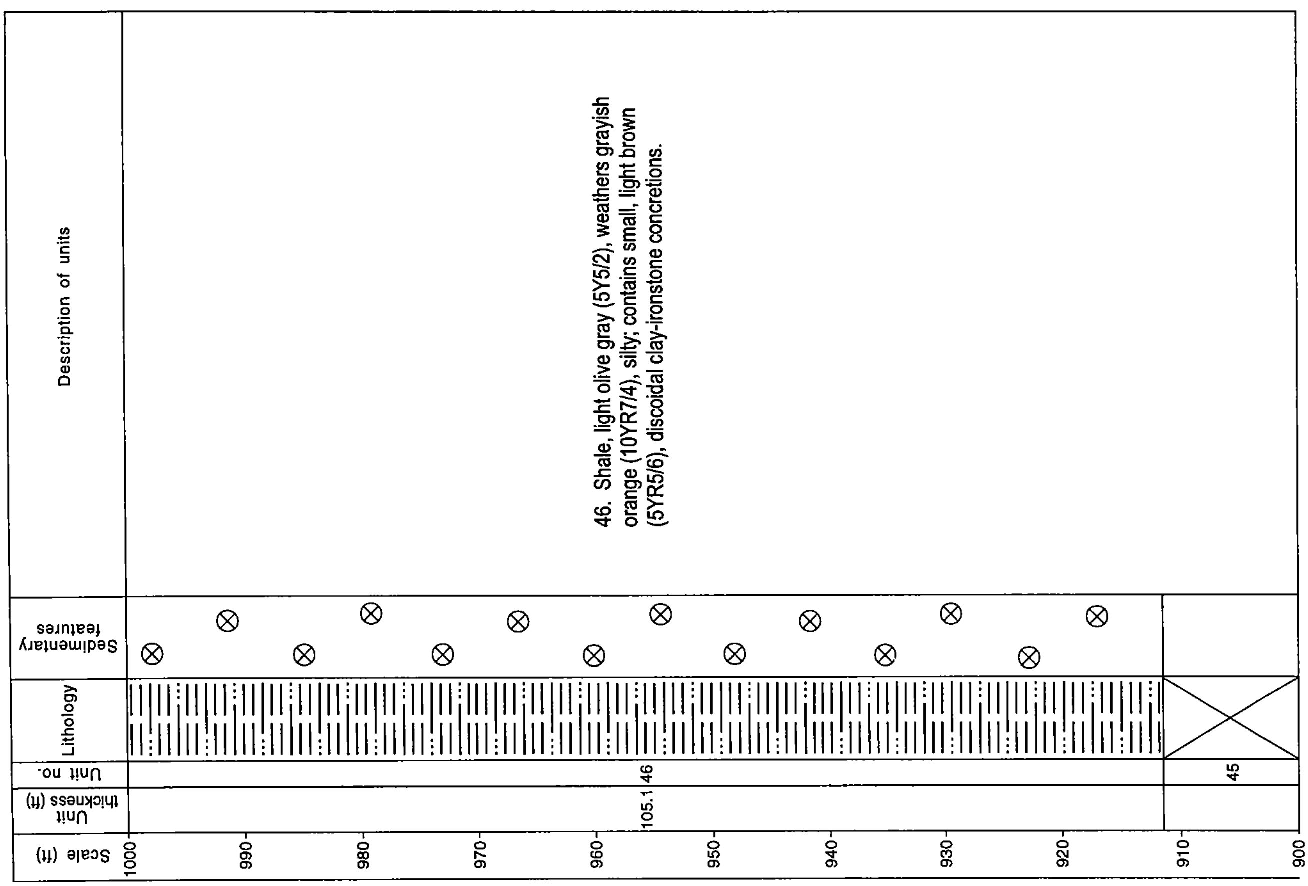
48. Shale, light olive gray (5Y6/1), weathers dusky yellow (5Y6/4), silty; poorly exposed in road ditch, mostly covered.

47. Sandstone, grayish orange (10YR7/4) to moderate brown (5YR4/4) with moderate reddish orange (10R6/6) staining in places, very fine to fine-grained, well-sorted and well-rounded, very thin to thin-bedded, platy; mostly flat, parallel-bedded, but in some places contains large-scale, low-angle cross-bedding; some beds internally wavy-laminated, some have symmetrical ripple marks, others have current lineation features; upper part is mostly pale red (5R6/2), thicker bedded, and displays more low-angle cross-bedding features; also shows some channeling relationships in upper part, as well as soft-sediment deformation features.

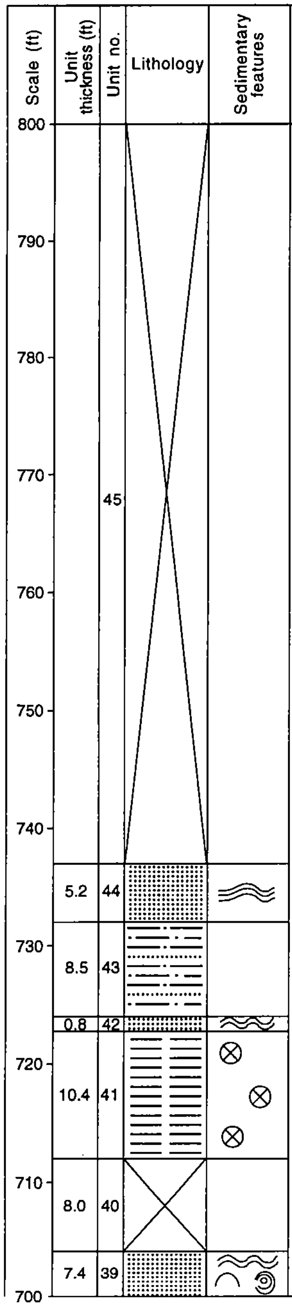
Note: Section was measured along excellent outcrops in pasture, east of road on high ridge. Overturned blocks show numerous sole markings such as load casts and trace fossils in this same area. Base sharp (Psv5).

APPENDIX 2: Neostratotype of Savanna Formation *(continued)*





APPENDIX 2: Neostratotype of Savanna Formation *(continued)*



Description of units

44. Sandstone, yellowish gray (5Y7/2), very fine grained, thick-bedded; exposed surface has a hummocky, "wrinkled," and pitted appearance, poorly exposed in road bed and ditch (Psv4c).

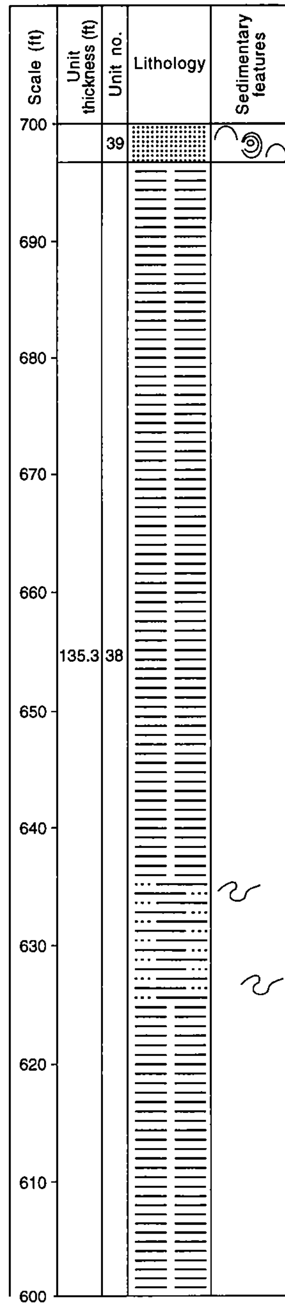
43. Shale, light gray (N7), weathers dusky yellow (5Y6/4), very sandy; contains scattered, very fine grained sandstone stringers, base sharp.

42. Sandstone, grayish orange (10YR7/4), very fine grained, thin-bedded, obscurely wavy-bedded, base sharp (Psv4b).

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

40. Covered interval.

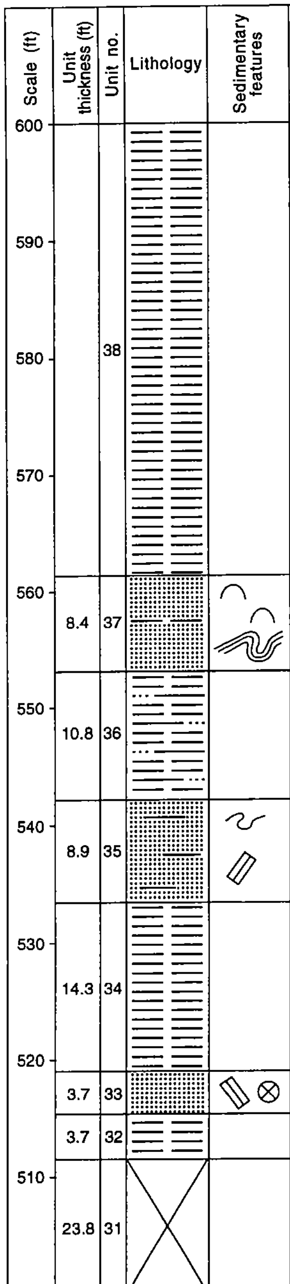
39. Sandstone, grayish orange pink (5YR7/2) to various hues of brown, such as light brown (5YR6/4), pale brown (5YR5/2), and moderate brown (5YR3/4, 5YR4/4); very fine grained; mostly massive; some swaly beds; large flow rolls and other soft-sediment deformation features characterize the unit; well-exposed in pasture just east of road (Psv4a).



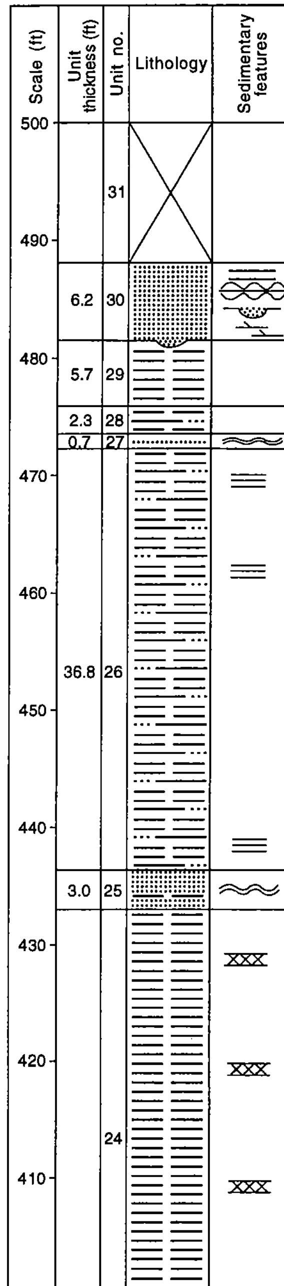
Description of units

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

APPENDIX 2: Neostratotype of Savanna Formation *(continued)*

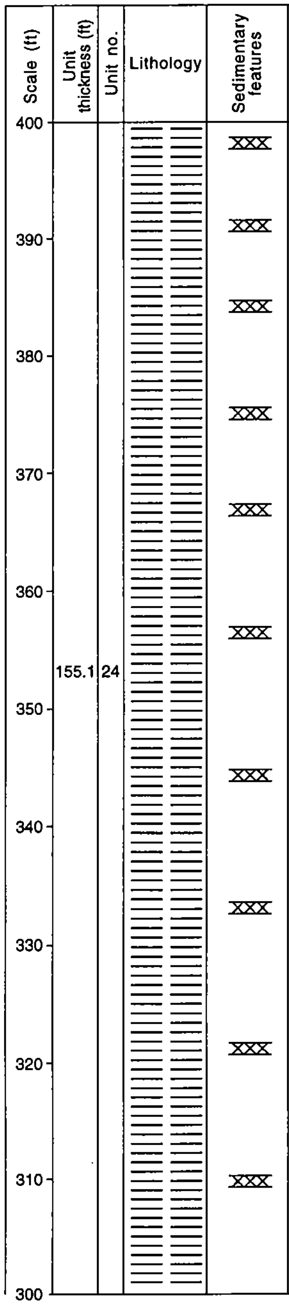


Unit thickness (ft)	Unit no.	Description of units
	38	
8.4	37	37. Sandstone, grayish orange (10YR7/4), dark yellowish orange (10YR6/6), and very pale orange (10YR8/2), very fine grained, irregularly medium bedded; includes some thin swaly beds, soft-sediment deformation features common; includes a 1-ft-thick shale bed in middle of unit; base sharp (Psv3f).
10.8	36	36. Shale, light olive brown (5Y5/6), silty, weathers light olive gray (5Y5/2), poorly exposed in east road ditch.
8.9	35	35. Sandstone, grayish orange (10YR7/4), very fine grained, thin-bedded, bioturbated; contains fossil plant casts; interbedded with dusky yellow (5Y6/4) shale; breaks into small, irregular-shaped blocks; base gradational (Psv3e).
14.3	34	34. Shale, light olive gray (5Y5/2), weathers dark yellowish orange (10YR6/6); poorly exposed in ditch east of road, base sharp.
3.7	33	33. Sandstone, grayish yellow (5Y8/4) to grayish orange (10YR7/4), weathers light brown (5YR5/6), very fine grained, thick- to medium-bedded, irregular-bedded; contains fossil plant casts and a thin discontinuous layer of ironstone pebbles; poorly exposed in road bed and ditch (Psv3d).
3.7	32	32. Shale, olive gray (5Y4/1), weathers grayish orange (10YR7/4), base covered.
23.8	31	31. Covered interval.



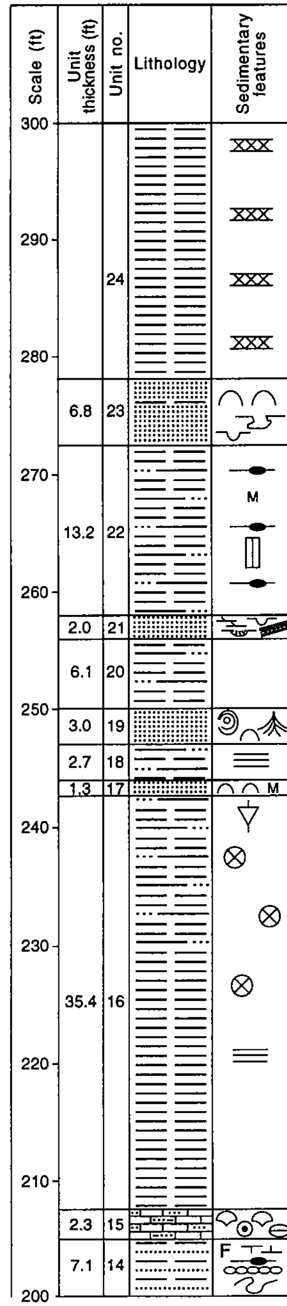
Unit thickness (ft)	Unit no.	Description of units
	31	
6.2	30	30. Sandstone, grayish orange (10YR7/4), weathers moderate yellowish brown (10YR5/4), very fine grained, thin- to medium-bedded at top of unit; cut-and-fill near base, with low-angle cross-bedding; other beds flat and parallel with current lineation features; well-exposed at crest of high ridge; base sharp; channels into underlying shale (Psv3c).
5.7	29	29. Shale, light gray (N7), weathers grayish orange (10YR7/4) and dark yellowish orange (10YR6/6), base gradational.
2.3	28	28. Shale interbedded with siltstone, dark yellowish orange (10YR6/6), weathers grayish orange (10YR7/4), blocky, base gradational.
0.7	27	27. Sandstone, moderate yellowish brown (10YR5/4) to grayish orange (10YR7/4), very fine grained, silty, thin-bedded, obscurely wavy bedded, base sharp (Psv3b).
36.8	26	26. Shale, olive gray (5Y4/1), weathers pale yellowish brown (10YR6/2), silty, breaks into small flakes on the outcrop; includes some light olive gray (5Y5/2) siltstone layers as much as 0.6 ft thick.
3.0	25	25. Sandstone, moderate olive brown (5Y4/4), weathers light olive gray (5Y5/2), very fine grained, thin-bedded, interbedded with shale in lower part, obscurely wavy laminated; basal contact exposed in ditch, east side of road; top part medium-bedded, blocky; base sharp (Psv3a).
	24	

APPENDIX 2: Neostratotype of Savanna Formation *(continued)*



Description of units

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



Description of units

23. Sandstone, dusky yellow (5Y6/4) with light brown (5YR5/6) and dark yellowish orange (10YR6/6) staining, very fine grained, irregularly thick to medium bedded, blocky, swaly bedded in places; overturned beds in pasture have trace fossils and load structures on some soles; a 5-ft-thick, mottled, light olive gray (5Y5/2) and grayish orange (10YR7/4) clayey shale layer is present ~2.5 ft below top of unit; exposed where road turns north along section line (Psv2d).

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

21. Sandstone, grayish orange (10YR7/4), weathers moderate yellowish brown (10YR5/4), very fine grained, shaly, micaceous, thin-bedded; contains low-angle cross-laminations, climbing ripples, and scour-and-fill features; trace fossils on bedding soles; top and base gradational (Psv2c).

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

19. Sandstone, yellowish gray (5Y7/2) to light olive gray (5Y5/2), weathers moderate brown (5YR3/4, 5YR4/4), very fine grained, thick-bedded, blocky; contains flow rolls, dewatering structures, and swaly beds, base sharp and irregular (Psv2b).

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

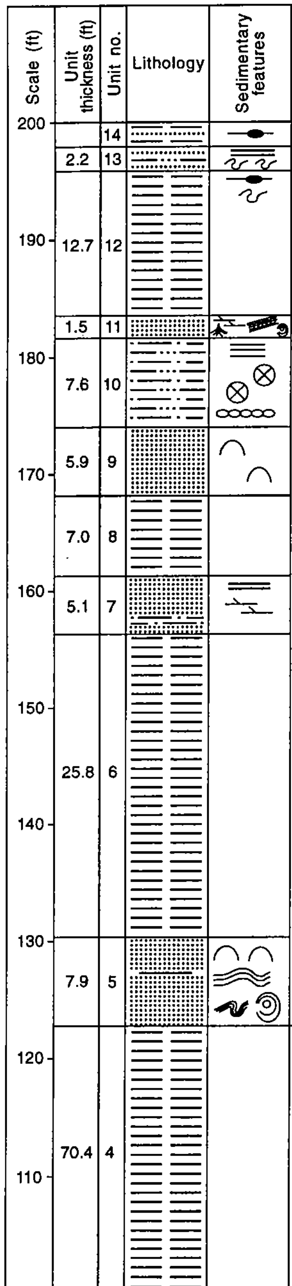
17. Sandstone, dusky yellow (5Y6/4) to light olive gray (5Y5/2), weathers pale yellowish brown (10YR6/2) with grayish brown (5YR3/2) staining, very fine grained, micaceous, medium-bedded, contains low-amplitude swaly bedding, base sharp and curved (Psv2a).

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

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

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

APPENDIX 2: Neostratotype of Savanna Formation *(continued)*



Description of units

13. Sandstone, dusky yellow (5Y6/4) to light olive gray (5Y5/2), weathers moderate yellowish brown (10YR5/4), very fine grained, silty, thin- to medium-bedded, parallel-bedded; strongly bioturbated; similar in appearance to limestone ~7 ft above, but is noncalcareous; base sharp (Psv1e).

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

11. Sandstone, pale yellowish brown (10YR6/2) to light olive gray (5Y5/2) with dark yellowish orange (10YR6/6) and light brown (5YR5/6) staining; very fine grained, medium-bedded; upper part contains low-angle cross-stratification, climbing ripples, and small-scale dewatering features; basal part consists of rolled, pillow-like, sandstone masses (flow rolls) extending downward into underlying shale with sharp but irregular contact (Psv1d).

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

9. Sandstone, grayish orange (10YR7/4), weathers moderate brown (5YR4/4), very fine grained, massive, blocky; includes some low-amplitude, swaly beds in places; base sharp, irregular (Psv1c).

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

7. Sandstone, grayish yellow (5Y8/4) to dusky yellow (5Y6/4), weathers moderate brown (5YR3/4), very fine grained; medium-bedded, parallel-bedded; contains obscure, low-angle cross-stratification; unit includes a 1.5-ft-thick, light olive gray (5Y5/2) sandy shale layer ~1.3 ft from bottom; basal contact sharp and irregular (Psv1b).

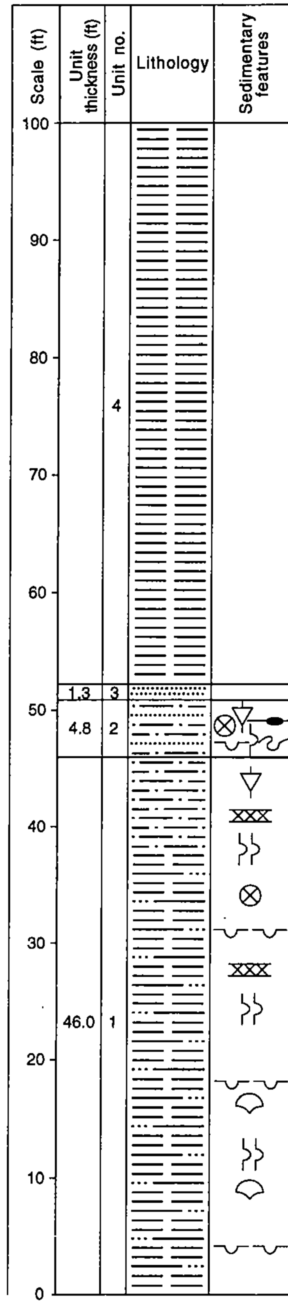
6. Shale, light olive gray (5Y5/2), weathers yellowish gray (5Y7/2), highly weathered, poorly exposed.

5. Sandstone, grayish orange (10YR7/4), light brown (5YR5/6), and moderate brown (5YR3/4, 5YR4/4), very fine grained, massive; soft-sediment deformation features common, such as convolute beds, ball structures, and swaly beds; includes minor shale interbeds in places; basal contact sharp, irregular and disconformable, unit fills shallow channels in underlying shale (Psv1a).

Note: Total thickness of Savanna Formation is 1449.1 ft.

McAlester Formation

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



Description of units

Keota Sandstone Member:

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

Keota Sandstone Member:

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

1. Shale, olive gray (5Y4/1), weathers grayish orange (10YR7/4) to moderate yellowish brown (10YR5/4), silty; contains leached, ferruginous, brachiopod-rich, very fine grained sandstone lenses 2–3 in. thick in lower part of unit; also contains siltstone-filled burrows about 0.25–0.5 in. in diameter, generally on bedding planes, but also cutting across stratification; in upper part includes discoidal, dark reddish brown (10R3/4) to light brown (5YR5/6) clay-ironstone concretions ~0.6 in. in diameter and 1–2 in. thick, as well as clay-ironstone layers ~1 in. thick; becomes sandy upwards and grades into overlying unit; base of unit covered.

APPENDIX 3

Explanation of Symbols Used in this Guidebook*

Sandstone

Sandstone, conglomeratic (includes ironstone pebbles and shale clasts)

Sandstone, shaly

Sandstone, siltstone, shale, interbedded

Siltstone

Siltstone, shaly

Shale

Shale, silty, sandy

Shale, calcareous

Shale, black

Limestone

Ironstone

Coal

Underclay

Covered interval

SEDIMENTARY FEATURES

Plane, parallel stratification

Trough cross-stratification

Cross-stratification

Low-angle cross-stratification

Wavy bedding

Lenticular bedding

Swaly bedding, curved bedding

Convolute, slumped, or contorted bedding

Pinch-and-swell features

Parting lineation

Ripple marks

Scour -and fill, channeling

Flow rolls, ball-and-pillow

Siltstone nodules

Load structures

Flute and groove casts

Box work weathering

Dewatering structures or dish and pillar

Fissile

Stromatolites

Plant fossils

Macerated plant material

Trace fossils

Burrows, borings

Invertebrate fossils

B Bioturbated

C Calcareous

L Liesegang banding

m Micaceous

p Pitted

Fining-upward sequence

Coarsening-upward sequence

*Note: This explanation of symbols does not apply to Appendix 2. See page 74 for the explanation for Appendix 2.

STRATIGRAPHY IN FIELD-TRIP AREA

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

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

STRATIGRAPHY OF KREBS GROUP IN FIELD-TRIP AREA