GUIDEBOOK TO THE GEOLOGY OF THE CROMWELL SANDSTONE AND EQUIVALENT UNITS IN THE LAWRENCE UPLIFT, ARKOMA BASIN, OUACHITA MOUNTAINS, AND OZARK UPLIFT OF EASTERN OKLAHOMA

With Notes on Historic and Modern Coal Mines

by

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Prepared for a field trip lead by

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November 12 and 13, 2003

Co-Sponsored by the

Oklahoma Geological Survey and
Petroleum Technology Transfer Council

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INTRODUCTION

Exploration and Production History

The Cromwell Sandstone ("sand" in much of the literature) is a prolific oil and gas producer in the Arkoma Basin and the southeastern part of the Cherokee Platform. It was named for Joe Cromwell of the Cromwell Oil and Gas Company who discovered oil in the NW¼NE¼SW¼ sec. 15, T. 10 N., R. 8 E., on October 2, 1923 near the town of Cromwell (also named after Joe Cromwell). The well, the Cromwell Oil and Gas No. 1 Bruner, initially flowed 312 bopd from a sandstone at a depth of 3467 to 3475 ft and is the discovery well of the Cromwell field. In March 1924, the T.B. Hoffer Oil Corp. No. 1 Stidham recorded an initial production of 4000 bopd at a depth of 3510 ft (Rison and Bunn, 1924). In less than a year, 75 wells produced 62,391 bo weekly from the Cromwell. Although the sandstone and field were named for the discoverer of oil in the area, gas had been discovered a year earlier by the Cosden Oil and Gas Company a year earlier. Rison and Bunn (1924) first named the Cromwell Sandstone ("sand zone").

Early production from the Cromwell Sandstone focused mostly on oil from relatively shallow reservoirs (3000 to 4000 ft) in the western part of the Arkoma Basin (Andrews, 2003). Starting in the early 1960's, exploration for gas from the Cromwell extended to the deeper (15,000 ft) parts of the basin. Since its discovery, 120 mmb oil and 835 bcf gas have been produced from the Cromwell (data courtesy IHS Energy); this does not include Cromwell production from commingled zones and Andrews (2003) estimates that an additional 20 to 30 mmb oil and 30 to 40 bcf gas could be added to the ultimate recovery from the unit.

History of Nomenclature

Despite the importance of the Cromwell Sandstone to Oklahoma's petroleum industry, (or perhaps *because* of its importance to the industry), the Cromwell and, more generally, the Morrowan stratigraphy of the western Arkoma Basin area has a complicated history. Along the north flank of the Arbuckle Mountains where the units crop out, Taff (1901) and Morgan (1924) mapped a single Mississippian and lower Pennsylvanian black shale unit (Caney Shale) below the Wapanucka Limestone. Hollingsworth (1933) divided the lower part of the Pennsylvanian section into four members of the Wapanucka Formation: (from bottom to top) Lower Wapanucka Shale, Union Valley Sandstone, Upper Wapanucka Shale, Wapanucka Limestone. (The lowest three members correlated with Morgan's (1924) Pennsylvanian part of the Caney Shale.) He further recognized that the Union Valley Sandstone Member was the same as the Cromwell Sandstone in many oil and gas fields in the area. Hyatt (1936) divided the Pennsylvanian shale beneath the Wapanucka Limestone into the Pennsylvanian Caney and a shale in the lower part of the Wapanucka Formation; these shale units were separated by the Union Valley Formation which consisted of an upper limestone and a lower sandstone. Withrow (1969) elevated the name Union Valley to formation, renamed the lower sandstone the Cromwell Sandstone Member, and named the upper limestone the Union Valley Limestone Member.

Elias (1954) summarized most of the earlier literature and suggested that the Caney Shale in the northern Arbuckle Mountains was Mississippian and equivalent to the Goddard Shale in the southern Arbuckle Mountains. He also suggested that the Caney was unconformably overlain by the Pennsylvanian Rhoda Creek Formation; this probably is equivalent to Hollingsworth's (1933) Lower Wapanucka Shale and Hyatt's (1936) Pennsylvanian Caney. (Adding to the confusion was Elias' (1954) use of the Springer or Springeran Series to separate the Mississippian Chesterian from the Pennsylvanian Morrowan Series. Fortunately, few workers accepted this new series.) Grayson (1990) essentially repeated Elias' (1954) stratigraphy but, more importantly, documented the conformable nature of the Mississippian – Pennsylvanian boundary within the Rhoda Creek Formation and the Morrowan conodont zonation. Grayson's (1990) suggestion that the base of the Union Valley Formation be placed at the lowest occurrence of *Idiognathoides sinuatus* and that its top be placed at the lowest occurrence of *Idiognathodus sinuosus* allows recognition of the Union Valley/Cromwell Sandstone interval in areas where sandstone is absent and/or well-log correlation is difficult.

Throughout this guidebook, every attempt has been made to distinguish formally named geologic units from informally named units. In general, formally named units are exposed (somewhere) on the surface and are capitalized (e.g., Cromwell Sandstone Member of the Union Valley Formation). (An exception to this rule is the name of coal beds, for example, the McAlester coal.) Informal names generally are used by the petroleum industry to refer to subsurface reservoir units and are shown with lower-case letters (e.g., Red Oak sandstone). In many cases reservoir units crop out; but unless they have been formally described and given a type section, they retain a lower-case letter (e.g., Spiro sandstone). In other cases the same unit has different names on the surface and in the subsurface (e.g., surface Bluejacket Sandstone Member of the Boggy Formation, subsurface Bartlesville sandstone). To simplify what may be a somewhat ponderous formal nomenclature, many names are shortened (but retain the proper capitalization) (e.g., surface Warner Sandstone Member of the McAlester Formation shortened to Warner Sandstone; subsurface Fanshawe sandstone, Atoka Formation shortened to Fanshawe sandstone). In addition, the petroleum industry's use of the word "sand" for any number of hard, clastic, petroleum reservoirs has been changed to "sandstone".

Guidebook Format and Cautions

This guidebook contains several formats. The road log is perhaps the most important and shows total miles (number on left) and distance between features that are discussed in the text (number on right). Because this is a long road log (231.1 miles) and car odometers vary, total miles are reset to 0 periodically.

In addition to the geologic features described along the field-trip route, more general descriptions of the different geologic provinces that are crossed are included. Also, some of the oil and gas fields that are crossed by the field-trip route are briefly described. The route passes through several historical coal-mining districts; where the ruins of the surface workings of some of these old mines are still visible they are included in the road log. Some of the old coal mines are being reclaimed under the Oklahoma Conservation Commission's Abandoned Mine Land program. The route also passes close to some modern coal mines (now reclaimed) and some active stone quarries. Other historical sidelights ranging from the old (Civil War battlefield sites) to the more recent (Sequoyah Fuels uranium-processing facility) are also included.

Some of the stops in this guidebook are on private property; others are along the public right-of-way. Two stops are private property. The name of one of the landowners (Bond locality) is given in this guidebook; if you would like to visit this site at a future date, please write or call the landowner well beforehand to secure permission. The other landowner asked that his name not be published, but he is willing to allow geologists to visit the site (Canyon Creek) under special circumstances. The roadcuts in this guidebook occur along relatively remote county roads (Arch locality) to very busy highways (Braggs Mountain). Regardless of how much traffic *appears* to be present, please stay to the side of the road (off the road, if possible) and pay attention.

Acknowledgements

Many individuals assisted me in various ways in compiling the information necessary to write this guidebook. Dan Boyd (OGS) allowed me to use preliminary versions of his recently published oil and gas fields map of Oklahoma. Jerlene Bright (OGS) provided me with information on the discovery wells of the different fields the route crosses as well as oil and gas production data, most of which was courtesy IHS Energy Group. Mike Kastl (Oklahoma Conservation Commission) showed me how to use the OCC's Abandoned Mine Land program files and gave me several recent newspaper articles on the program. Darrell Shults (Oklahoma Department of Mines) gave me access to that department's files on recent reclaimed coal mines.

Much of the field-trip area is within Oklahoma's historic coal fields and several individuals shared their knowledge of Oklahoma's coal-mining history with me. I am particularly grateful to Geraldine Vance (Coal County Historical and Mining Museum, Coalgate), Steve Defrange (Krebs Heritage Museum), Joann Potter Tiemann (McAlester Coal Miner's Museum), and Tom Pate (Lutie Coal Miners Museum, Wilburton).

While most of the stops are on public land or right-of-way, Allan Ray graciously allowed us access to his land (Bond locality).

Several individuals at the Oklahoma Geological Survey took my attempts at figures (better called scratchings) and text and turned them into a readable guidebook. These people are Jim Anderson (Manager of the Cartographic Section) and Laurie Lollis (also Cartographic Section). Paul Smith (Manager) and Richard Murray (OGS Print Shop) printed the guidebook. Thank you all, once again, for top-quality work.

Last but certainly not least, I'd like to thank Rick Andrews, OGS petroleum geologist, for suggesting that the Cromwell Sandstone and the Morrowan strata of eastern Oklahoma would make an excellent study (his workshop volume) and field trip (this guidebook). The log interpretations in this guidebook are his, as are many of the photographs. Over the last year-and-a-half we shared ideas, argued, and changed our opinions. At times both of us wanted to give up but didn't, knowing that the other guy would never let us forget it. It is our sincere hope that Rick's workshop volume and this guidebook will provoke continued work on the Cromwell Sandstone, not only as a petroleum reservoir, but as a key unit for understanding the early Pennsylvanian history of Oklahoma.

This guidebook is unreviewed and unedited. The Oklahoma Geological Survey is planning to publish this in its guidebook series in the near future.

ROAD LOG

cum interval
mile

0.0 0.0 Start field trip at intersection of Oklahoma Highway 3 and Union Valley Road (also county road EW160) about 0.8 mi west of Union Valley and about 7 mi southeast of Ada. A large sign pointing to the Union Valley Baptist Church is at the intersection.

Vehicles should park along the shoulder of Highway 3, facing south (toward Coalgate, away from Ada). Pull off the road if the ground is firm.

Introduction – Lawrence Uplift

Lawrence Uplift

The Lawrence Uplift is a roughly triangular-shaped area that extends from near Fitzhugh on the west, to Ahloso on the north, to just north of Stonewall of the east (Fig. 1). It is underlain by gently northeast-dipping Ordovician (on the west) to early Pennsylvanian (Morrowan) rocks (Fig. 2). The uplift is bounded by the generally east-striking Stonewall Fault on its south side and the generally east-striking Ahloso Fault on part of its north side. The east side of the uplift typically is shown on most maps at the unconformity between the Boggy Formation (Desmoinesian) and Mississippian through Morrowan strata. The uplift's northwest margin is an unconformity between Desmoinesian and Missourian strata and Ordovician through Mississippian strata.

The age of the Lawrence Uplift relative to the Franks Graben to the south (see below) and the Ada High subprovince of Northcutt and Campbell (1996) is based on several criteria: the age of the Stonewall and Ahloso Faults, the age of unconformities, and the presence of conglomerates in strata adjacent to the uplift. The Stonewall Fault offsets rocks as young as Missourian (Francis Formation) (Morgan, 1924). The Ahloso Fault offsets rocks as young as Desmoinesian (Wewoka Formation), but "later beds, including those of the Francis, are sharply flexed and, in local areas, slightly faulted along a line representing its probable subsurface trend westward" (Morgan, 1924, p. 151). The presence of rocks as young as the Wapanucka Formation (Morrowan) beneath the unconformity at the base of the Boggy Formation on the east side of the uplift is evidence that uplift and erosion is post-Morrowan. Conglomerates presumably eroded off the uplift occur in the Wewoka Formation immediately north of the Ahloso Fault (Morgan, 1924) are evidence that the uplift was high in the Missourian. These lines of evidence suggest one period of uplift occurred after deposition of the Wapanucka Formation and before deposition of the Boggy Formation during the Atokan to early Desmoinesian and another period of uplift extended from the deposition of the Wewoka Formation to that the Francis Formation during the late Desmoinesian to Missourian.

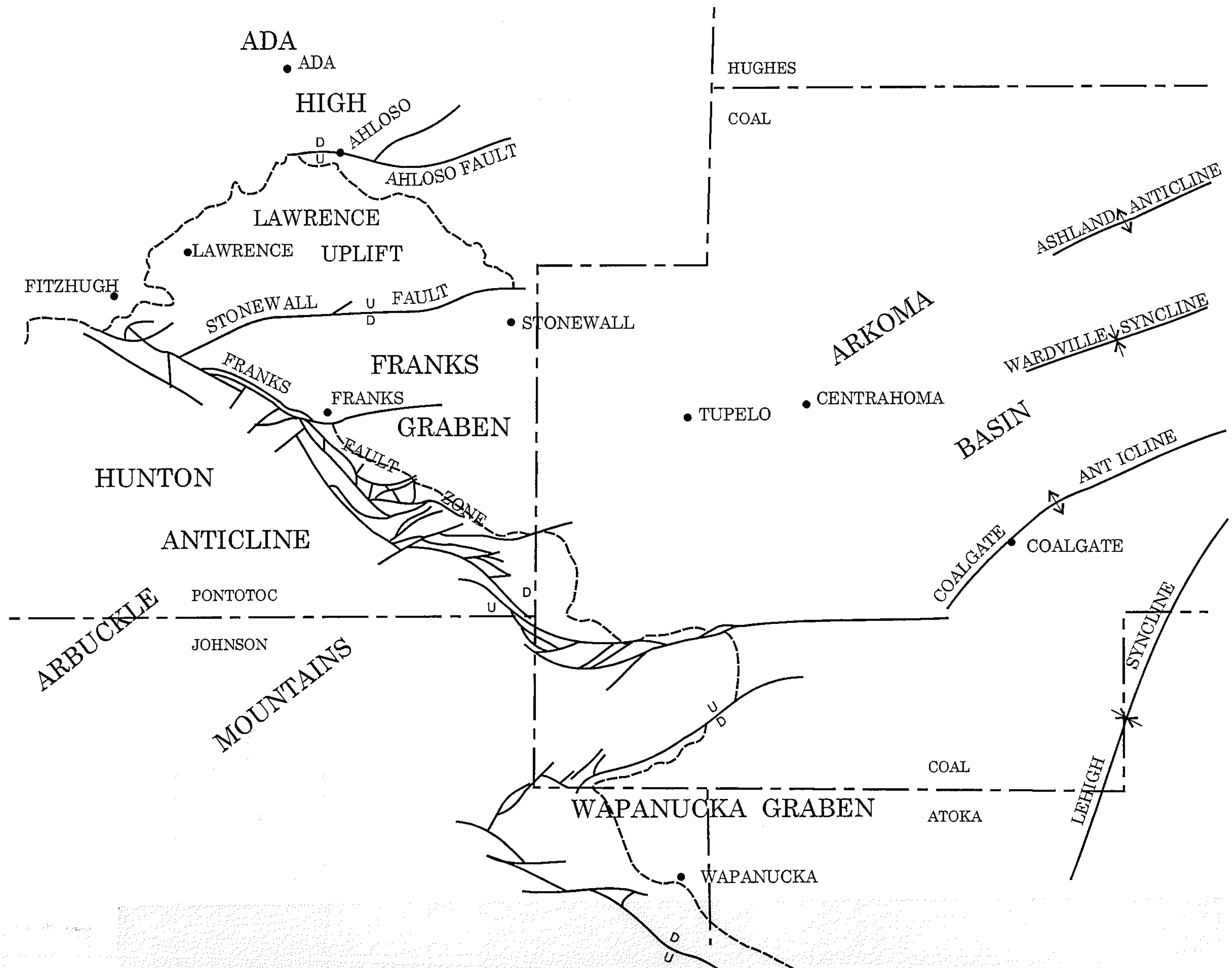


Figure 1. Generalized tectonic and geologic province map showing principal structures referred to in text. Dashed line is unconformity between Middle and Upper Pennsylvanian strata and Lower Pennsylvanian (Morrowan) and older strata. (Modified from Hart, 1974)

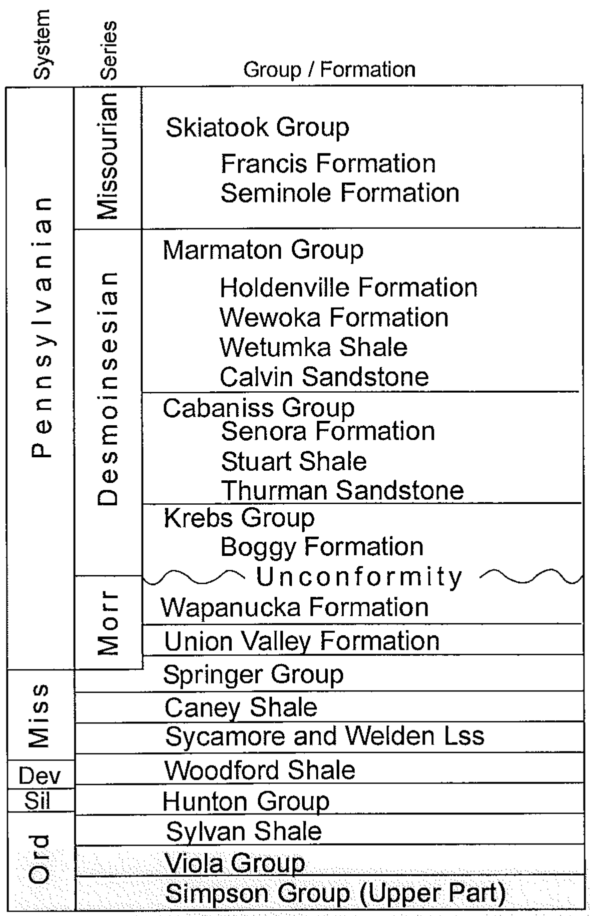


Figure 2. Strata exposed in Lawrence Uplift and adjacent area to northwest, north, and northeast (modified from Ham and McKinley, 1954; Hart, 1974; Lindberg, 1987, Stanley, 2001). Rocks in the uplift are Morrowan to Ordovician. Individual formations within the Hunton, Viola, and Simpson Groups have not been mapped separately. The Seminole, Holdenville, Wewoka, and Boggy Formations unconformably overlie the older strata on the northwest and the Boggy Formation unconformably overlies the older strata on the northeast. The Wetumka Shale to Thurman Sandstone are nowhere juxtaposed against the rocks of the Lawrence Uplift, but are present on the north side of the eastern part of the Ahloso Fault.

The Lawrence Uplift is important because it is one of the few areas where the Cromwell Sandstone Member is exposed (stops 1 and 2).

Stop 1. Union Valley Locality

Location: NW¼NW¼ sec. 32, T. 3 N., R. 7 E., Stonewall 7.5' quadrangle. On south side of Union Valley Road (also county road EW160) immediately east of Oklahoma Highway 3 about 7 mi southeast of Ada and about 0.8 mi west of Union Valley. Pontotoc County.

Introduction

Stops 1 and 2 probably are the best outcrops of the Cromwell Sandstone Member in Oklahoma, although they are hardly spectacular and provide little evidence for determining depositional environment. Both outcrops are in the type area of the Union Valley Formation which consists of a lower sandstone (Cromwell Sandstone Member) and an upper limestone (Union Valley Limestone Member). The Cromwell outcrop belt in this area extends for about 4 mi in a northwest-southeast direction from about 1.5 mi north of Stop 1 to immediately south of Stop 2. The sandstone is unconformably overlain by the Desmoinesian Boggy Formation at its northern extent and truncated by the Stonewall Fault at its southern extent (Hollingsworth, 1933; Barker, 1950) (Fig. 3).

Union Valley Formation

The name Union Valley Formation comes from the name of a schoolhouse located about 1 mi east of stop 1. At one time, this area was noted for its sweet potatoes and the sandy hills of weathered Cromwell sandstone were the site of many fields and barns. Local farmers organized a sweet-potato marketing union and met regularly in the schoolhouse, which was later named Union Valley Schoolhouse (Withrow, 1969, p. 2300).

History of Nomenclature

This Cromwell outcrop belt was originally mapped as Caney Shale by Morgan (1924, p. 53), who noted that "at one zone near the top of the formation sandy strata are often predominant. The upper Caney of the Lawrence uplift is especially sandy". Morgan (1924, p. 56) also noted that the upper part of his Caney is Morrowan. Hollingsworth (1933) mapped the Cromwell as the Union Valley Sandstone Member (including a limestone at the top) of the Wapanucka Formation and stated that this outcrop belt is the only exposure of the sandstone member. Hyatt (1936) separated the Union Valley Sandstone and overlying limestone from the Wapanucka and elevated both rock types to formation status (Union Valley Formation) with a lower sandstone member and an upper limestone member. He also noted that the Union Valley Sandstone is equivalent to the Cromwell Sandstone.

Cromwell Sandstone

The Cromwell Sandstone, field, and town are named after Joe Cromwell (1873-1946), an Oklahoma wildcatter who drilled the first oil well in the Cromwell field in 1923. The discovery well (Cromwell Oil and Gas No. 1 Bruner), located in the NW1/4 NE1/4 SW1/4 sec. 15, T. 10 N., R. 8 E., initially flowed 312 bopd from the Cromwell Sandstone at a depth of 3467 to 3475 ft (Levorsen, 1930). A short distance away, gas had been discovered a year earlier in the sandstone by the Cosden Oil and Gas Company.

The Cromwell Sandstone in the Lawrence uplift is, at present, very poorly exposed, but apparently it was much better exposed 70 years ago when Hollingsworth

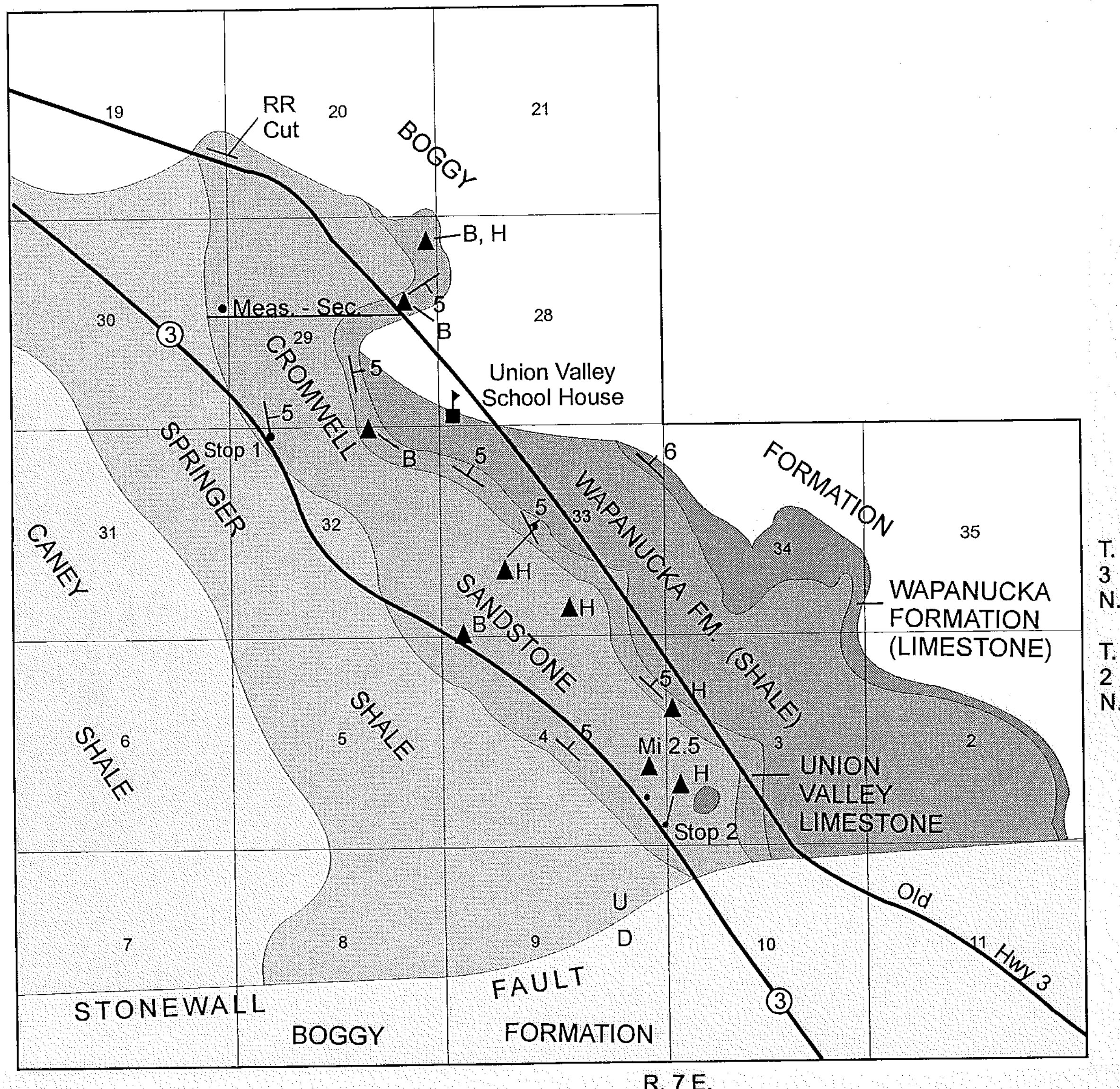


Figure 3. Generalized geologic map of the Cromwell Sandstone Member in the Union Valley area (from Baker, 1950). Location of stops 1 and 2, Union Valley schoolhouse, Hollingsworth's (1933) measured section, Barker's (1950) railroad cut outcrop, key fossil sites (labeled B, from Baker, 1950; labeled H, from Hollingsworth, 1933; miles 2.5 in this report) are also shown.

(1933, pl. 2) measured a complete section across the middle of sections 29 and 30, about 0.5 mi north of Stop 1 (Fig. 3). Hollingsworth's (1933) measured section is reproduced here as figure 4 and is shown by Andrews (2003, pl. 4) on his regional cross section of the Morrowan section of southeastern Oklahoma as locality 2. Of particular interest in the presence of asphaltic sandstone and sandstone containing abundant plant fossils at the base (see stop 2), fossiliferous sandstone from 25 to 75 ft above the base (see mile 2.6), and massive to cross bedded medium- to coarse-grained sandstone above that. The presence of marine invertebrate fossils in a relatively coarse-grained sandstone is evidence for deposition in shallow water subject to strong currents, such as an offshore marine bar.

Hollingsworth (1933) noted that the lower and upper contacts of the Cromwell Sandstone with the Springer Formation (present nomenclature) and Union Valley Limestone, respectively, are gradational.

Barker (1950) added little to Hollingsworth's (1933) description of the Cromwell Sandstone, despite having had the benefit of an excellent exposure along a railroad cut (Barker, 1950, fig. 8, locality 20) (Fig. 3). Barker (1950) noted the sandstone contained trace amounts of glauconite. He also identified poorly preserved casts of pelecypods and gastropods in the sandstone. Based on aerial photographs and measured dips, Barker (1950) calculated the sandstone varied from 150 to 260 ft thick; this is similar to Hollingsworth's (1933) maximum thickness of 235 ft. The presence of glauconite and marine invertebrate fossils confirms that the Cromwell Sandstone is marine.

Outcrop Description

About 18 ft of the lower part of the Cromwell Sandstone is exposed at Stop 1. Based on Barker's (1950) geologic map, this outcrop is very close to the base of the sandstone. The outcrop is moderately well plane-parallel stratified (Fig. 5), although one 3-in.-thick bed is trough cross-stratified. The sandstone is friable, poorly cemented, and porous. It is medium-fine grained, very well sorted, and composed mostly of subangular quartz grains, although trace amounts of very fine to medium grained, rounded, dark-colored minerals or rock fragments are conspicuous in hand specimens. I did not identify any glauconite. Iron-oxide staining is ubiquitous. Trace fossils are present but rare and consist mostly of burrows perpendicular to the bedding planes. The sandstone is fractured and one small fault is present (Fig. 6).

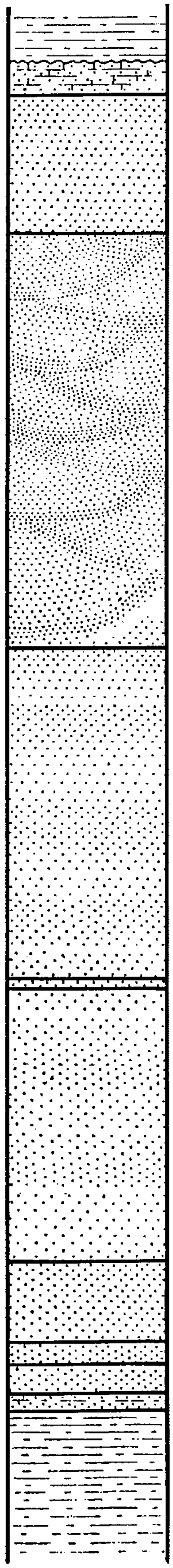
From Stop 1, drive southeast on Oklahoma Highway 3. For the next mile or so, the low hills to the left (northeast) are underlain by the Cromwell Sandstone. The flat area on the right (southwest) is underlain by the shale-dominated Springer Group.

1.8 1.8 Approximately 4-ft-thick outcrop of Cromwell Sandstone on left (northeast) side of highway. Outcrop is a medium gray, mottled (highly bioturbated), silty medium-fine-grained sandstone with rare dark gray sandstone nodules as large as 4 in. in

(following page) **Figure 4.** Reproduction of measured section of Cromwell Sandstone across centers of sections 29 and 30, T. 3 N., R. 7 E. (from Hollingsworth, 1933, pl. II). Hollingsworth (1933) mapped the Cromwell Sandstone as the Union Valley Sandstone Member of the Wapanucka Formation; as a result, shale of the Wapanucka Formation is shown below the sandstone and a sandy limestone is shown at the top. Present nomenclature is Springer Formation below the Cromwell and Union Valley Limestone (Hollingsworth's (1933) "arenaceous, impure limestone") above.

Stratigraphic Section of the Union Valley Sandstone Member of the Wapanucka Formation

At the type locality on the Lawrence Uplift
Sections 29&30-T 3N.-R 7E., Pontotoc County, Oklahoma



Upper shales of the Wapanucka formation. Dark blue shales containing limonite concretions in lower part; fossiliferous in upper part, *Pentremites angustus*, *Hustedia miseri*, etc. 140′ thick.

Thin-bedded, blue-gray, very arenaceous, impure ls.; fossiliferous, containing molluscan, molluscoidean, anthozoan elements and microscopic fauna. 6′

Grayish and tan, fine grained, thin-bedded sandstones. 25′

Light brown and brownish, medium to coarse grained, massive and thin-bedded, cross-bedded sandstones; not fossiliferrous except in one horizon, about the middle, which contains an abundance of *Conularia crustula*. 75′

Brownish, coarse and medium grained sandstones, thin-bedded and not well indurated. 60′

Brownish, coarse-grained, well indurated sandstone. 1′

Tan and light brown, medium and fine grained sandstones, thin-bedded and massive, containing an abundance of molluscan forms in the lowermost portion. 50′

White, yellow and brown sand with streaks of red, fine grained, massive and thin-bedded. 15′

Dark gray to black, argillaceous, fine grained sands; asphaltic ordor. 2′

Dark gray-black, fine grained, asphaltic sand containing iron stained layers. 5′

Dark blue-black, carbonaceous, very argillaceous, thin-bedded, sands, containing many friable plant remains. 3′

Lower shales of the Wapanucka formation. Dark blue shales with intercalated gray shales. 450′ thick in Iowa Refining Company's well in C Sec. 12–T.3N.–R.7E., Pontotoc County, Oklahoma.

Figure 5. Outcrop of Cromwell Sandstone at Stop 1. Plane-parallel stratification is conspicuous. Hammer (center left) for scale.

diameter. Some specimens have a distinct hydrocarbon odor. This outcrop is probably near the base of the Cromwell; Hollingsworth (1933) noted that some of the sandstone near the base of his measured section (Fig. 4) also had a hydrocarbon odor.

2.5 0.7 Approximately 3-ft-thick outcrop of Cromwell Sandstone on right (southwest) side of highway. Outcrop is very similar to that at mile 1.9. Approximately 5-ft-thick outcrop is on left (northeast) side of highway about 25 ft stratigraphically above the right (southwest) outcrop. The higher outcrop consists of wavy-bedded, faintly cross-stratified very fine grained sandstone and siltstone with shale partings. One bed contains weathered-out molds of pyrite(?) (cube-shaped molds) and rare crinoids and a coiled marine invertebrate.

2.7 0.2 Intersection of Oklahoma Highway 3 and Mobil Road (also county road NS362). Stop 2.

Stop 2. Stonewall Locality

Location: Southwest corner sec. 3 and southeast corner sec. 4, T. 2 N., R. 7 E., Stonewall 7.5' quadrangle. On both sides of north-south county road (Mobil Road) immediately north of Highway 3 about 3 mi southeast of Stop 1 and 2.5 mi west-northwest of Stonewall. Pontotoc County.

Figure 6. Small fault (immediately to right of hammer) in Cromwell Sandstone at Stop 1. The sandstone below the hammer is faintly stratified whereas the sandstone at the top of the photograph is conspicuously plane-parallel stratified.

Previous Work

Many previous authors have noted the presence of marine invertebrate fossils in the Cromwell Sandstone. Hollingsworth (1933, table 1) identified four species of pelecypods, six species of gastropods, one species of cephalopods, and plant fragments in this outcrop. In addition to helping determine a depositional environment, the biostratigraphy of the Cromwell Sandstone provides evidence for recognizing the interval when sandstone is absent (e.g., Stop 3 – Canyon Creek locality, and Stop 5 – Arch Locality).

The biostratigraphy of the Cromwell Sandstone and surrounding units, particularly the underlying Springer Group and Caney Shale, has been the focus of many studies because the Mississippian – Pennsylvanian boundary is somewhere within the Springer Group, which includes the mostly Pennsylvanian Springer Formation and the mostly Mississippian Goddard Formation. Hollingsworth (1933) described the megascopic and microscopic fauna of the Cromwell Sandstone and adjacent units near Union Valley and used the fauna as a correlation tool. He did not, however, describe the depositional environment of any of the units. Grayson (1990) used conodonts to refine stratigraphic correlations in the Lawrence Uplift area. He also interpreted the depositional environment of the Caney – Springer – Union Valley (including Cromwell) – Wapanucka interval using lithologic succession and faunal diversity. Grayson (1990) suggested the Caney Shale and Springer Group accumulated under shallow, low-energy, dysaerobic to anaerobic, open marine conditions. The Cromwell probably is an offshore-bar deposit; areas where the sandstone is absent (e.g., Stop 3) represent bar-margin and interbar environments. The unnamed shale below the Wapanucka Limestone Member is lagoonal and the Wapanucka Limestone "records the development and progradation of a carbonate shelf" (Grayson, 1990, p. 89).

Outcrop Description

The outcrop at Stop 2 exposes about 15 ft of the lower part of the Cromwell Sandstone (Fig. 7). The exact thickness is difficult to determine because much of the upper part of the outcrop is poorly exposed or covered. In addition, the measured attitude – N80°E 3°S – does not fit the map pattern, although most of the observed stratification is subhorizontal.

The lower 9 ft of the outcrop consists mostly of well-stratified siltstone and fine-grained sandstone with silty mudstone partings (Fig. 8). Burrows are very abundant on bedding planes; concentric sandstone concretions, plant compressions, and molds of invertebrate fossils (cephalopod) are rare. A small branching fossil or trace fossil, possibly a filamentous algae, is present on some bedding planes. The overall color is gray, although individual beds may be very light-colored or brown. The predominance of siltstone at the bottom of the outcrop may be evidence for a transitional facies between the shale-dominated Springer Formation and Cromwell Sandstone. Hollingsworth (1933, p. 22) noted

"the contact of the (Cromwell) with these subjacent shales is fairly distinct with every evidence of a conformable contact since the shale grades rapidly into the sand, the gradation zone being approximately three feet of dark blue-black, carbonaceous, very argillaceous, thin-bedded sands, containing many friable plant remains. The base of this thin zone is considered the base of the (Cromwell) and the top of the (Springer)."

However, it appears that the "argillaceous zone" of Hollingsworth (1933) is considerably thicker than 3 ft and/or is, in fact, several zones (e.g., mile 2.6).

The upper 3 ft of this lower part is very poorly exposed, but it appears to become more sandstone-rich upwards.

Measured Section, Stop 2
Cromwell Sandstone

***(Location:** SW corner sec. 3, SE corner sec. 4,*
T. 2 N., R. 7 E.; Stonewall 7.5' quadrangle)

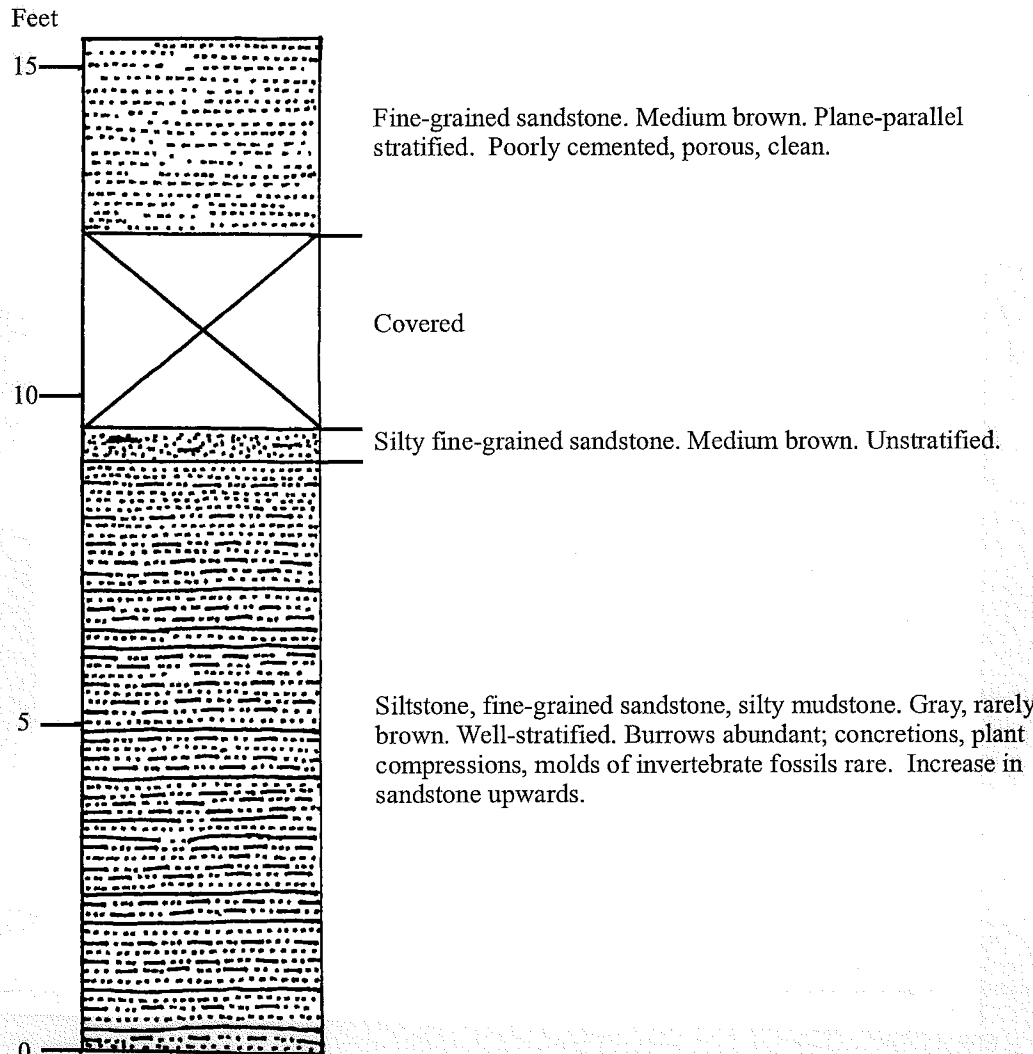


Figure 7. Graphic columnar section of lower part of Cromwell Sandstone at Stop 2.

The gray siltstone/sandstone is overlain by a 6-in.-thick medium brown, poorly stratified, silty fine-grained sandstone. Although the color change is abrupt, there is little difference between the brown and the upper part of the gray rock types. A covered interval about 3 ft thick overlies the brown sandstone. About 3 ft of a plane-parallel stratified, medium brown, fine-grained quartzose sandstone is poorly exposed in cut banks on the right (east) side of Mobil Road above the covered interval (Fig. 9). This sandstone is poorly cemented, porous, and relatively clean except for irregular

Figure 8. Lower part of outcrop of Cromwell Sandstone at Stop 2. The darker layers are siltstone and very thin beds of silty mudstone.

Figure 9. Exposure of weathered Cromwell Sandstone near top of outcrop at Stop 2. Note the faint plane-parallel stratification.

concentrations of iron oxide minerals. The brown sandstone is similar to the sandstone at Stop 1 and represents a cleaner, higher-energy facies of the Cromwell than the gray siltstone/sandstone.

From Stop 2, continue driving east (southeast) on Oklahoma Highway 3.

2.9 0.2 Cross trace of east-striking Stonewall Fault. Boggy Formation exposed in down-thrown block.

Introduction – Franks Graben

Franks Graben

Franks Graben is the westernmost extension of the Arkoma Basin (Fig. 1). It is triangular in shape, with its western apex a few miles southeast of Fitzhugh. It is open to the east, where it merges with the main part of the Arkoma Basin. It is composed of generally gently east-dipping rocks except along its faulted margins where much of the strata assume steep dips. Older rocks (Desmoinesian) are exposed to the east, younger rocks (Missourian) to the west. The boundary between the Franks Graben and the Lawrence Uplift (described above) to the north is the north-side-up Stonewall Fault. The north-side-down Franks Fault Zone separates the Franks Graben and the Hunton Anticline to the south. To the southeast, the fault zone becomes a complexly faulted monoclinal flexure and rocks as old as Ordovician dip steeply into the graben. Stop 3 is an exposure of the Morrowan Union Valley Formation (including Cromwell- equivalent shale) in this faulted monocline.

The age of the Franks Graben probably is similar to that of the Lawrence Uplift (described above), and evidence for that age is based on the age of the Stonewall Fault and Franks Fault Zone and the age of conglomerates eroded off the Hunton Anticline. As described above, the Stonewall Fault is post-Wapanucka (Morrowan) / pre-Boggy (Desmoinesian) to Missourian in age. Hart (1974) shows a strand of the Franks Fault Zone offsetting the Boggy Formation; this is credited to Naff (1962), but Naff doesn't show the fault on his map. If present, at least part of the Franks Fault Zone is as young as Desmoinesian.

Better evidence for the age of uplift of the Hunton Anticline relative to the Franks Graben along the Franks Fault Zone is provide by Morgan (1924), who described several conglomerates that he believed were eroded off the Arbuckle Mountains (Hunton Anticline). "The (conglomerate) beds in the type area were followed eastward and in that direction were found to be traceable ... into the McAlester, Savanna, and Boggy Formations. (Also,) ... several lines of evidence strongly suggest the correlation of the upper part of the conglomeratic strata of the Franks area with the upper Wewoka, Holdenville, Seminole, and Francis Formations" (p. 121). Morgan's (1924) observations are evidence that the Franks Fault Zone was active as early as McAlester time (Desmoinesian) and as late as Francis time (Missourian).

The Franks Graben contains one of the larger oilfields in this part of Oklahoma - the Fitts field (described below).

5.2 2.4 Exit off of Oklahoma Highway 3 to Oklahoma Highway 61 (Stonewall exit).

5.6 0.4 Turn right (south) on Oklahoma Highway 61 (also county road NS364). Two outcrops of sandstones in the Boggy Formation crop out between here and the bridge over Clear Boggy Creek (mile 7.2).

6.7 1.1 Enter Fitts Field.

Fitts Field

The Fitts field was discovered in 1933 by the W.A. Delaney No. 1 Hayden, located in the NE1/4 NE1/4 SW1/4 sec. 30, T. 2 N., R. 7 E. The well was completed as a gas producer on February 16 at a depth 1171 – 1185 ft (open hole) in a sandstone in the Gilcrease zone in the Atoka Formation (Fig. 10). Following this relatively shallow discovery, oil and gas were quickly discovered in deeper formations: the Hunton (Bois d'Arc and Chimneyhill) in July, 1933; the Bromide in June, 1934; the Viola in July 1934, and the McLish in April 1935 (Hyatt, 1936). Oil and gas in the Booch, Cromwell, and Oil Creek were discovered by 1937 and the Wapanucka was a producer by 1969.

The Fitts field is a faulted anticline about 6 mi long and 2 mi wide; production is controlled by cross faults on either end of the anticline, a major south-side-down fault on the south side, and structurally low beds on the north side. In 1937 there were 603 wells in the field; by 1969 only 163 wells were still productive. As of the end of 1967, the Fitts field had produced over 122 million barrels of oil (Withrow, 1969, table 4). As of November 2001, the field had produced about 231 mmb oil, 55 bcf gas, and was still producing about 16 mb oil and 450 mcf gas annually (data courtesy IHS Energy).

7.2 0.5 Cross Clear Boggy Creek.

7.7 0.5 Enter "old" Jesse Field.

Jesse Field

The Jesse field, now part of the Fitts field, was discovered in 1935 by the Anderson and Kerr et al No. 1 Thompson located in the SW1/4 NE1/4 SW1/4 sec. 1, T. 1 N., R. 7 E (Boyd, 1938). The well was completed as an oil producer on February 2 at

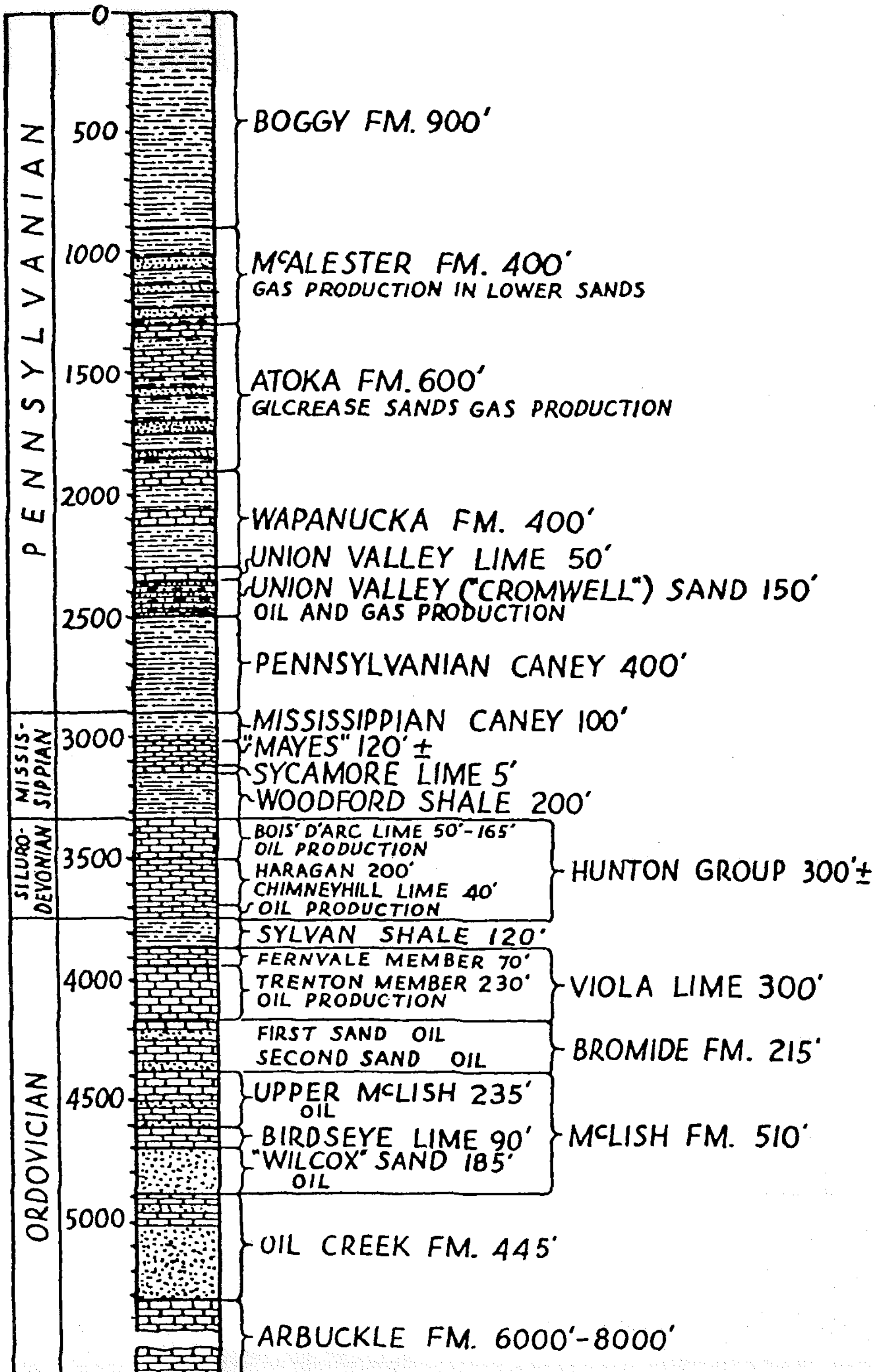


Figure 10. Stratigraphy of the Fitts field (from Teis and Teis, 1937). Gas sands in the lower part of the McAlester Formations are Booch sandstones and the Gilcrease sands in the Atoka Formation typically are in the upper part of the unit. Differences between this figure and figure 2 reflect surface (Fig. 2) vs. subsurface (this figure) nomenclature and currently accepted nomenclature (Fig. 2). The following units are equivalent: Pennsylvanian Caney (this figure) is Springer Group (Fig. 2); Mississippian Caney (this figure) is Caney Shale (Fig. 2); Mayes and Sycamore lime (this figure) are Sycamore and Welden Limestones (Fig. 2). The McAlester and Atoka Formations in the Franks Graben (this figure) were eroded off the Lawrence Uplift and are represented by the unconformity in figure 2.

a depth of 3835 ft in the Hunton limestone. In November that same year, oil was discovered in the basal McLish. By 1938 hydrocarbons had also been discovered in the Gilcrease, Wapanucka, Hunton, Viola, and Bromide; by 1969 the Savanna, McAlester, and Cromwell were also producers.

The Jesse field is about 4 mi long and 1 mi wide and, like the Fitts field, is a faulted anticline.

Most of the old Jesse field is within Withrow's (1969) "transitional lithofacies" of the Cromwell Sandstone. This lithofacies, which varies from about 1 to 6 mi wide, separates an area to the south where the Cromwell is shaly from an area to the north where sandstone predominates. The boundaries between the lithofacies are gradational and somewhat arbitrary. "Sandstone/shale ratios increase gradually from 0/1 in the south to 1/0 in the north" (Withrow, 1969, p. 2303). Figures 11 and 12 are modern logs of the Cromwell in the old Jesse field. They are very similar to those shown by Withrow (1969) as typical of the "transitional lithofacies". The irregular, but coarsening-upward character of the gamma-ray curve is typical of offshore bars (Bouma and others, 1982; Galloway and Hobday, 1983), although the thickness (almost 100 ft) for the "lower" and "upper" Cromwell sandstones suggests that "sand ridge" may be a more appropriate term than offshore bar. Marine shale underlies and overlies the Cromwell.

8.3 0.6 Sandstone outcrop along road. This is the base of the Boggy (Naff, 1962).

9.7 1.4 Small settlement of Jesse. Turn right (west) on county road E1678. For the next 3.2 mi, the road closely follows the contact between the Boggy Formation to the right (north) and the Savanna Formation to the left (south).

10.2 0.5 Turn left (south) following county road.

10.4 0.2 Turn right (west) following county road (now EW168).

13.3 2.9 Park along right (north) side of road near where road crosses shallow creek. This is the departure point for a 0.5-mile hike through the woods to Stop 3. Stop 3 is on private property; if you choose to visit it later on your own, please secure permission from the landowner before you do so.

Stop 3 is best visited during the dry season; Canyon Creek generally flows year-round and the exposed section is best seen when the water is at its lowest. A word of caution – greenbriars are extremely thick along the creek.

Stop 3. Canyon Creek Locality

Location: Along Canyon Creek, E1/2 sec. 8, T. 1 N., R. 7 E., Harden City 7.5' quadrangle. About 2 mi east of U.S. Highway 377 and 3 mi south of Harden. Pontotoc

Owl Creek 1A-36 Ayakatubby
Jesse Field

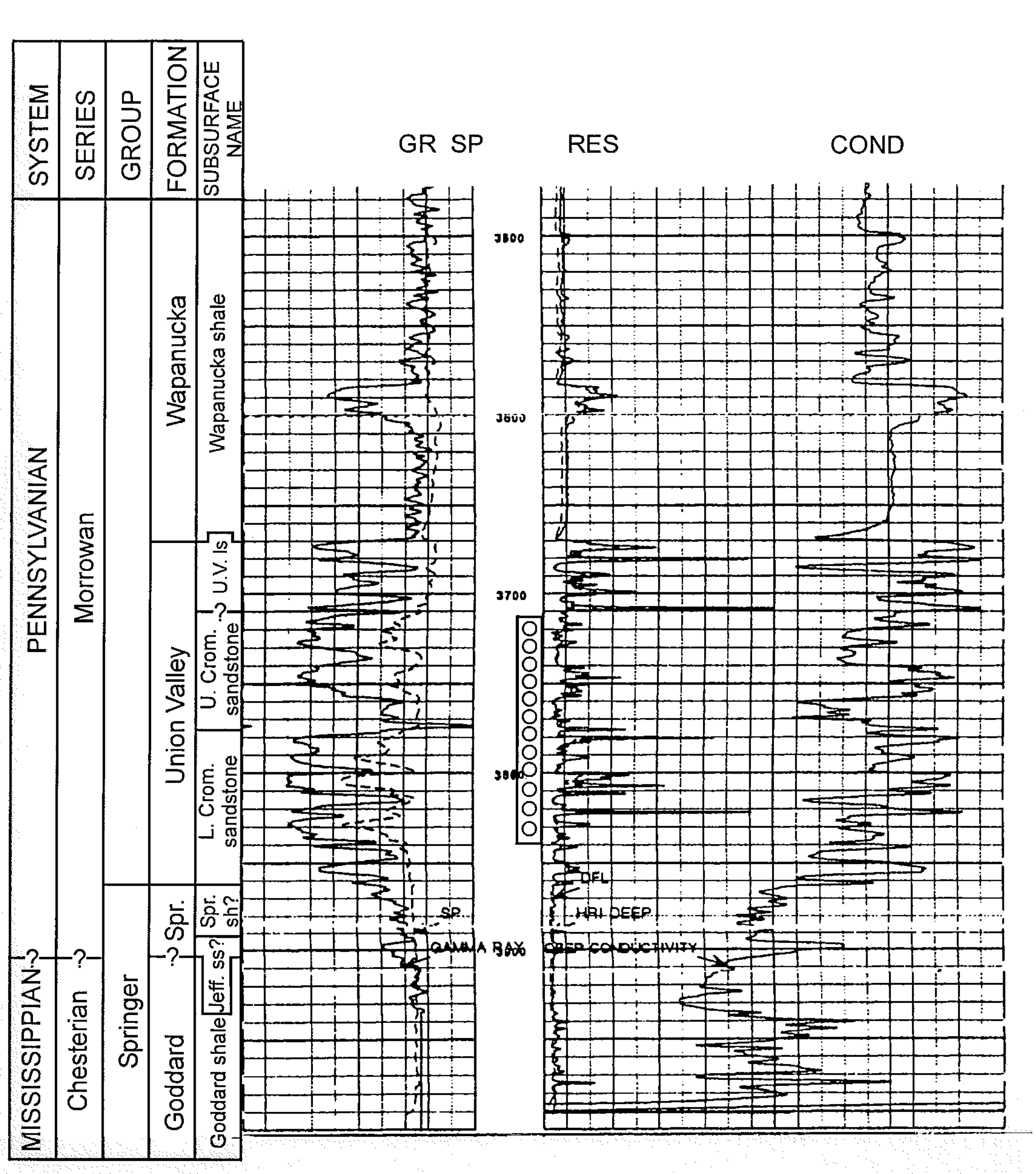


Figure 11. Part of electric log from Owl Creek Production No. 1A-36 Ayakatubby (NW¼SW¼NE¼ sec. 36, T. 2 N., R. 7 E., Jesse field). "Upper" Cromwell sandstone and "lower" Cromwell sandstone are coarsening-upward offshore-bar or sand-ridge deposits. The well produces oil from the Cromwell.

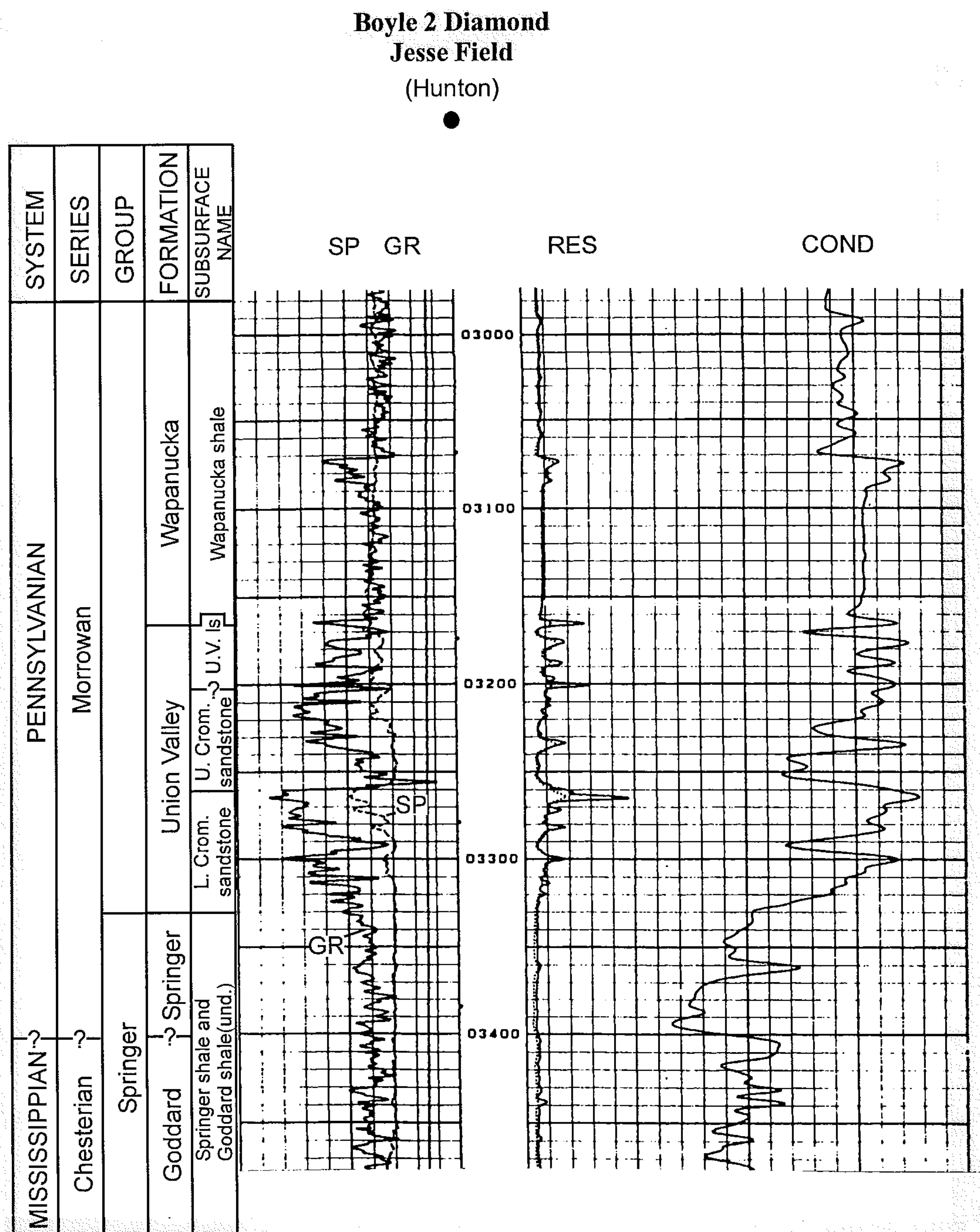


Figure 12. Part of electric log from Philip Boyle No. 2 Diamond (SE¼SW¼SW¼ sec. 35, T. 2 N., R. 7 E., Jesse field). "Upper" and "lower" Cromwell sandstones are coarsening-upward offshore-bar or sand-ridge deposits. The high gamma-ray, low-resistivity, featureless log pattern above and below the Cromwell is typical of marine shale. The well produces oil from the Hunton; the Cromwell was dry.

County. Measured section starts about 0.4 mi south of east-west county road and continues for about 0.6 mi to south edge of section.

Introduction

The Canyon Creek locality (Fig. 13) is the best-exposed section of Morrowan strata along the north side of the Arbuckle Mountains; for this reason, Andrews (2003, pl. 4) included it on his regional cross section A-A' of the Morrowan strata in southeastern Oklahoma as locality 1. In addition to being well-exposed it is almost continuous, containing no significant disconformities (Grayson, 1990). This outcrop is part of a belt that Ham and McKinley (1954) mapped as Springer Formation (including the Union Valley (Cromwell) Sandstone) around most of the east side of the Arbuckle Mountains from about 2 mi northwest of here to about 6 mi southeast of Wapanucka. Outcrops are extremely scarce throughout the outcrop area because most of the formations are easily weathered shale.

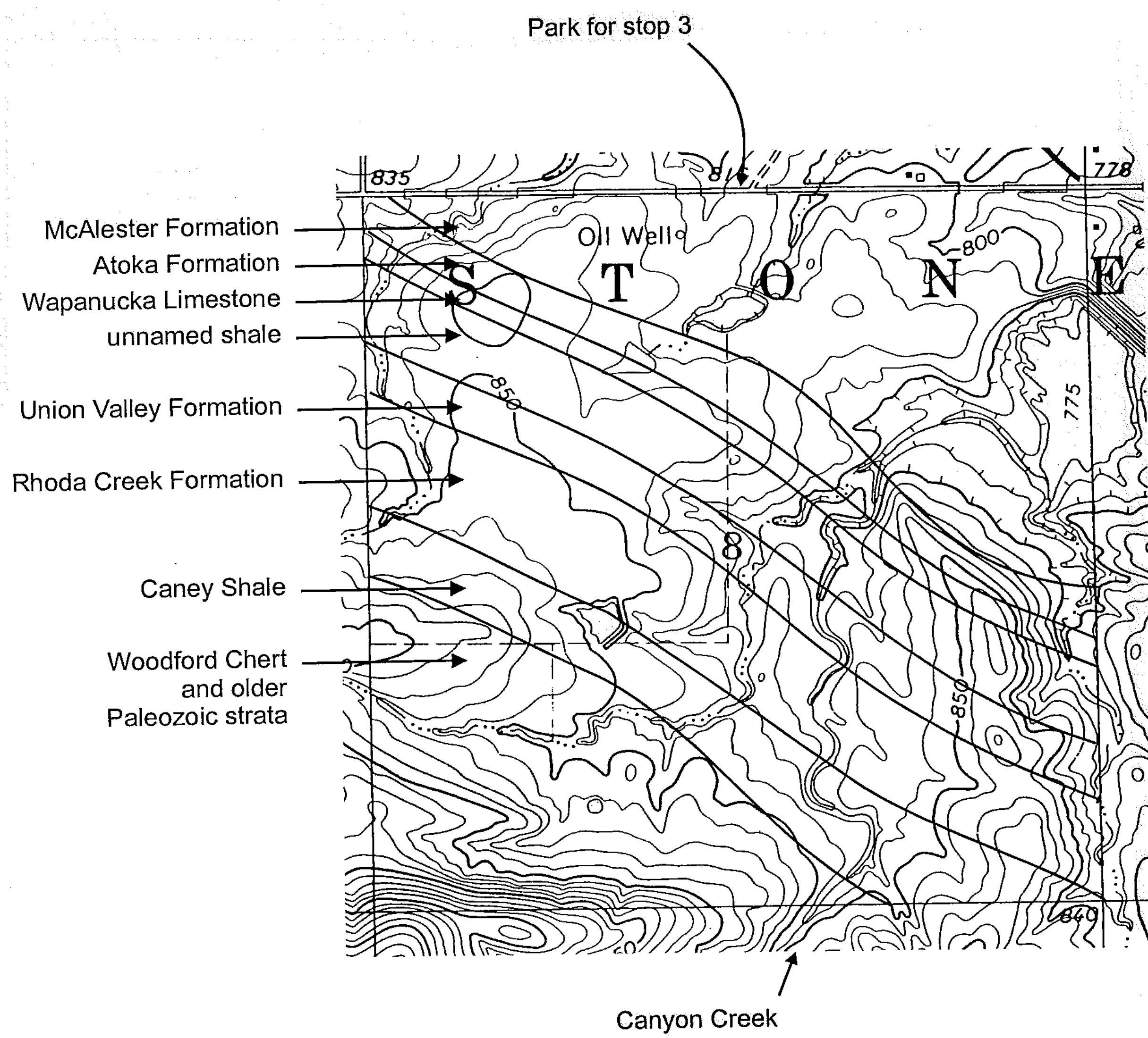


Figure 13. Geologic map of the Canyon Creek locality (Stop 3) (Grayson, 1990). The Rhoda Creek Formation is equivalent to the Springer Group.

Previous Work

The Canyon Creek section is also important because Grayson (1990) documented the conodont biostratigraphy of this part of the Morrowan. His work showed that the Union Valley Formation (including the Cromwell Sandstone) could be identified by the presence of the conodont *Idiognathoides sinuatus* but predated the conodont *I. sinuosus* (Fig. 14). Grayson's (1990) work allows correlation of this section and the Cromwell Sandstone outcrops near Union Valley with Morrowan sections elsewhere in Oklahoma, including those in the frontal belt of the Ouachita Mountains near Arch (Stops 4 and 5) and in the Ozark Uplift (Stops 6, 7, and 8).

The Union Valley Formation along Canyon Creek is composed of black shale, fossiliferous shale, and argillaceous biomicrite (Fig. 14). Sandstone is absent. This contrasts with as much as 235 ft of Cromwell sandstone on the surface near Union Valley (Hollingsworth, 1933) and an average of 125 ft in the Fitts field (Withrow, 1969). Grayson (1990) interpreted the Union Valley Formation in Canyon Creek as having been deposited in a bar-margin or interbar environment.

Return to cars and retrace route to Oklahoma Highway 3.

21.0 7.7 Turn right (east) on Oklahoma Highway 3. Reset odometer to 0.0. For the next approximately 8 mi, the road crosses the Boggy Formation, but there are no outcrops along the highway. The trace of the Stonewall Fault cannot be mapped east of here, and the Franks Graben merges into the Arkoma Basin.

1.0 1.0 Leave Pontotoc County, enter Coal County. Continue east on Oklahoma Highway 3.

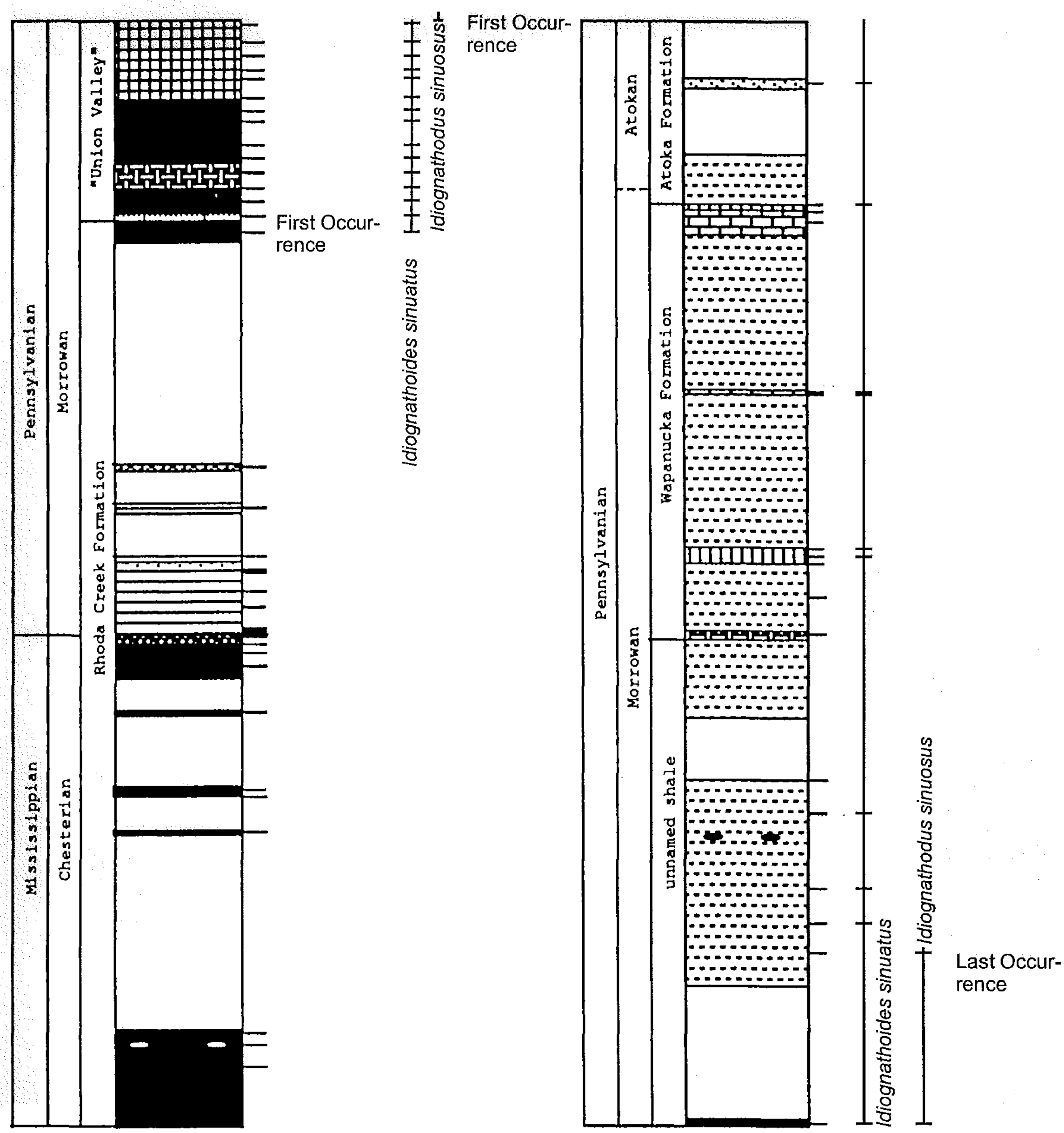
2.0 1.0 Intersection with old Oklahoma Highway 3.

4.0 2.0 The small Tupelo NW field is just to the left (northeast) of the highway. It is a faulted(?) circular domal structure (Mann, 1958; Disney, 1960). The field was discovered in 1952 (oil in the Bromide) by the Beach and Talbot and Sohio No. 1 Guth, located in NW1/4 SE1/4 NW1/4 sec. 22, T. 2 N., R. 8 E.; the Cromwell is also a producer.

6.6 2.6 Intersection with Oklahoma Highway 48 to Tupelo (to right (south)). Continue east on Oklahoma Highway 3.

10.1 4.5 Poorly exposed approx. 4-ft-thick sandstone at base of Boggy Formation just east of top of ridge. Its stratigraphic position suggests it is equivalent to the Bartlesville.

11.3 1.2 Intersection with county road N3745 to Centrahoma (about 0.5 mi to left (north)). Continue east on Oklahoma Highway 3. The town of Centrahoma is near the



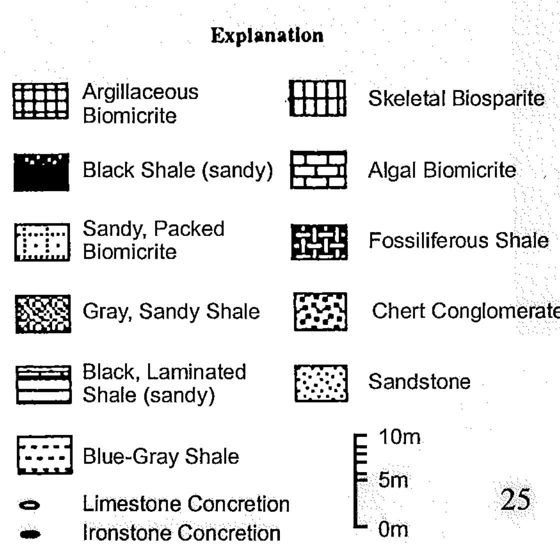


Figure 14. Measured section of middle part of Canyon Creek section showing rock types and conodont distribution. (Modified from Grayson, 1990, fig. 3).

northwest end of the Centrahoma field, which extends from here to just south of Coalgate.

Centrahoma Field

The discovery well for the Centrahoma field is the Carter Oil No. 1 John Thompason, located in the S ½ NE ¼ NW ¼ sec. 34, T. 2 N., R. 9 E. It was spudded on May 12, 1935 and, depending on which author is correct, discovered oil in the Cromwell Sandstone on February 2, 1936 (Dannenburg, 1952) or in the Viola Limestone in May 1937 (Brooks, 1963) or August, 1937 (Anderson, 1974). Following the discovery of oil in the Viola (or Cromwell), gas was discovered in the Atoka in 1941, Cromwell gas in 1949, Oil Creek oil in 1953, McLish oil in 1960, and Booch gas in 1961 (Brooks, 1963). In addition to these units, there is commercial production from the Savanna, Hartshorne, Hunton, Bromide, Wapanucka, and Spiro (Spring, 1994; Herndon, 2002).

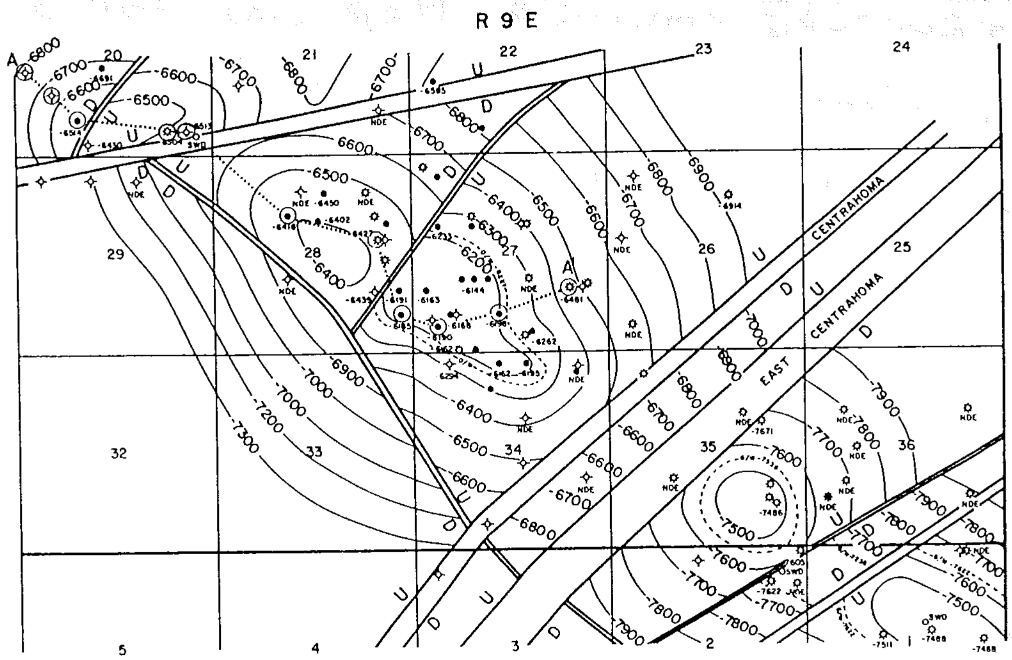
The Centrahoma field is a northwest-trending anticline broken by several northeast-striking faults. Production is controlled mostly by structure, although stratigraphic traps also occur. Dannenburg (1952, p. 13) suggested that the Centrahoma structure "is a typical small dome found in Coal county oil or gas fields"; figure 15 is a structure contour map and cross section of the field.

As of November 2002, the Centrahoma field had produced about 4.2 million barrels of oil and 126 bcf gas. It continues to produce about 45,000 barrels of oil and 800 mmcf of gas annually (data courtesy IHS Energy).

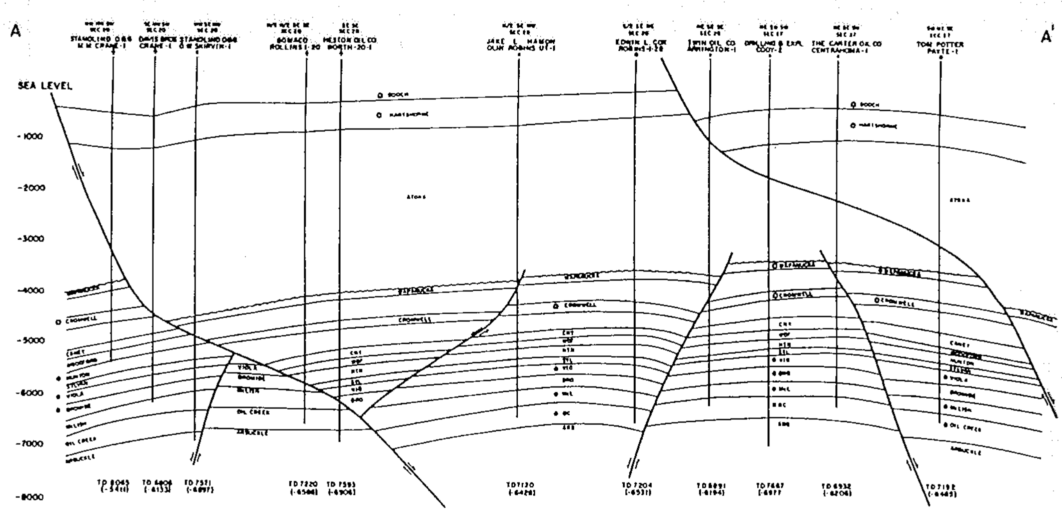
The log character of the Cromwell Sandstone in much of the Centrahoma field is shown by Anderson (1974, fig. 4) and in figures 16 and 17. The Cromwell interval in both wells is an irregular, but generally coarsening-upward sequence that probably represents an increasing proportion of thicker sandstone beds (rather than a grain-size change). Two Cromwell sandstones separated by shale (high gamma-ray "spike" on figure 17) may be present; the upper interval fines upward. The Cromwell Sandstone in both wells is underlain and overlain by a relatively featureless, high gamma-ray, low-resistivity "railroad track" log pattern.

The irregular, coarsening-upward gamma-ray log profile of the Cromwell is characteristic of offshore bars or sand ridges (Bouma and others, 1982; Galloway and Hobday, 1983). Encasement in marine shale ("railroad track" profile) supports a marine origin for the Cromwell. The profile do not support Anderson's (1974, p. 79) interpretation that the Cromwell is "a marine-delta complex".

16.3 5.0 Intersection with U.S. Highway 75 to Calvin (to left (north)). Continue east on Oklahoma Highway 3 / U.S. Highway 75. The surface geology in this area is poorly known. The geologic maps by Naff (1962) and Knechtel (1937) differ greatly. In general, however, the highway is near the Boggy – Savanna contact.



CENTRAHOMA FIELD
COAL CO., OKLAHOMA
STRUCTURE MAP
BASAL OIL CREEK SANDSTONE
C.I. = 100'
0 1MI
ROGER L. SPRING



CENTRAHOMA FIELD
COAL CO., OKLAHOMA
2N – 9E
CROSS SECTION A–A'

Figure 15. Structure contour map on top of the basal Oil Creek sandstone and cross section, Centrahoma field (from Spring, 1994).

Carter 3 Thompson
Centrahoma Field

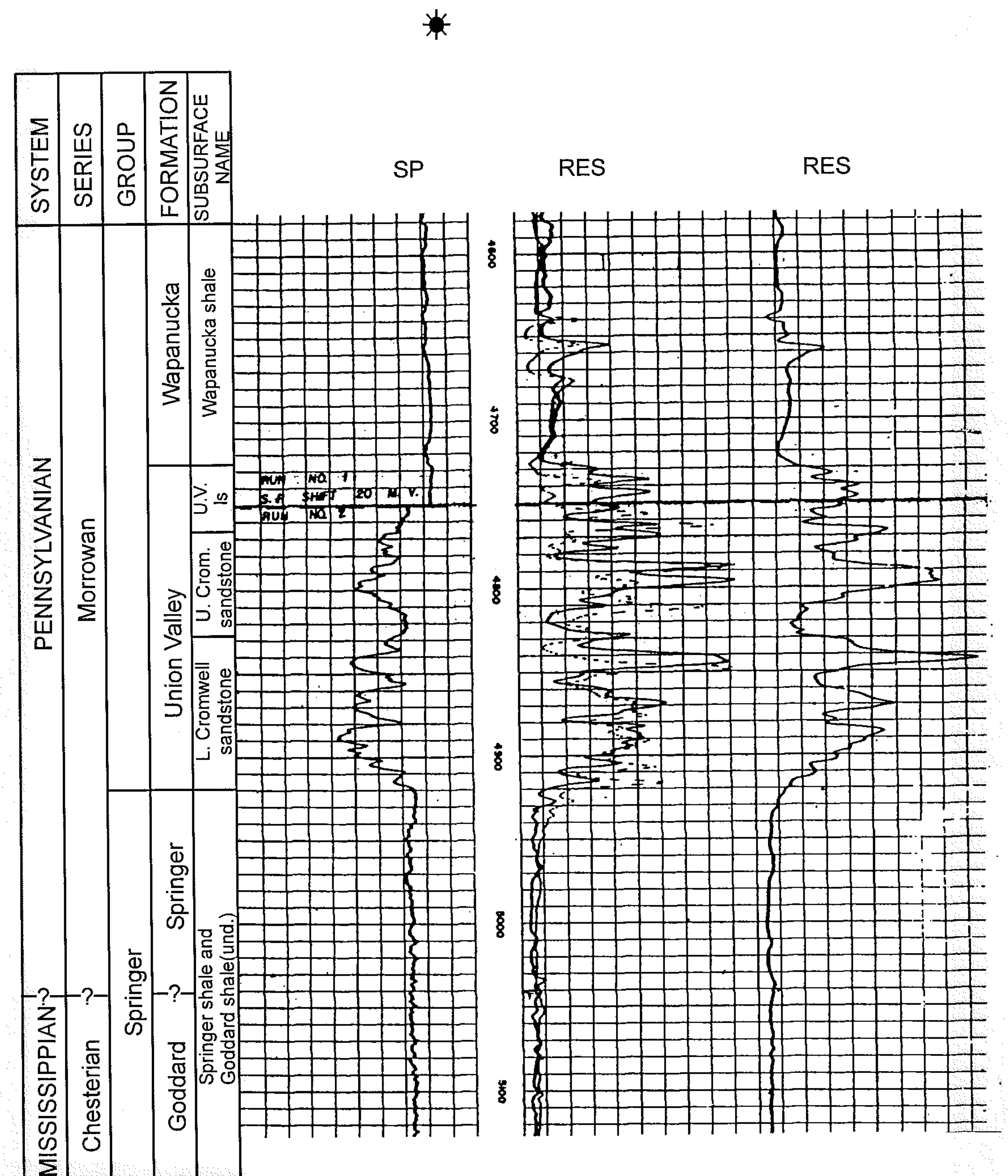


Figure 16. Part of electric log from Carter Oil Co. No. 3 Thompson (NE¼NE¼NW¼ sec. 34, T. 2 N., R. 9 E., Centrahoma field). The well was drilled in 1953 and completed in the Orodvician Oil Creek and Viola Formations. A shaly interval at about 4820 ft may separate the Cromwell into upper and lower parts, both of which coarsen upward. This log pattern is characteristic of offshore bars and sand ridges. The featureless "railroad track" pattern above and below the Cromwell is typical of marine shale. The well has produced oil from the Oil Creek, Viola, and McLish and gas from the Wapanucka and McLish.

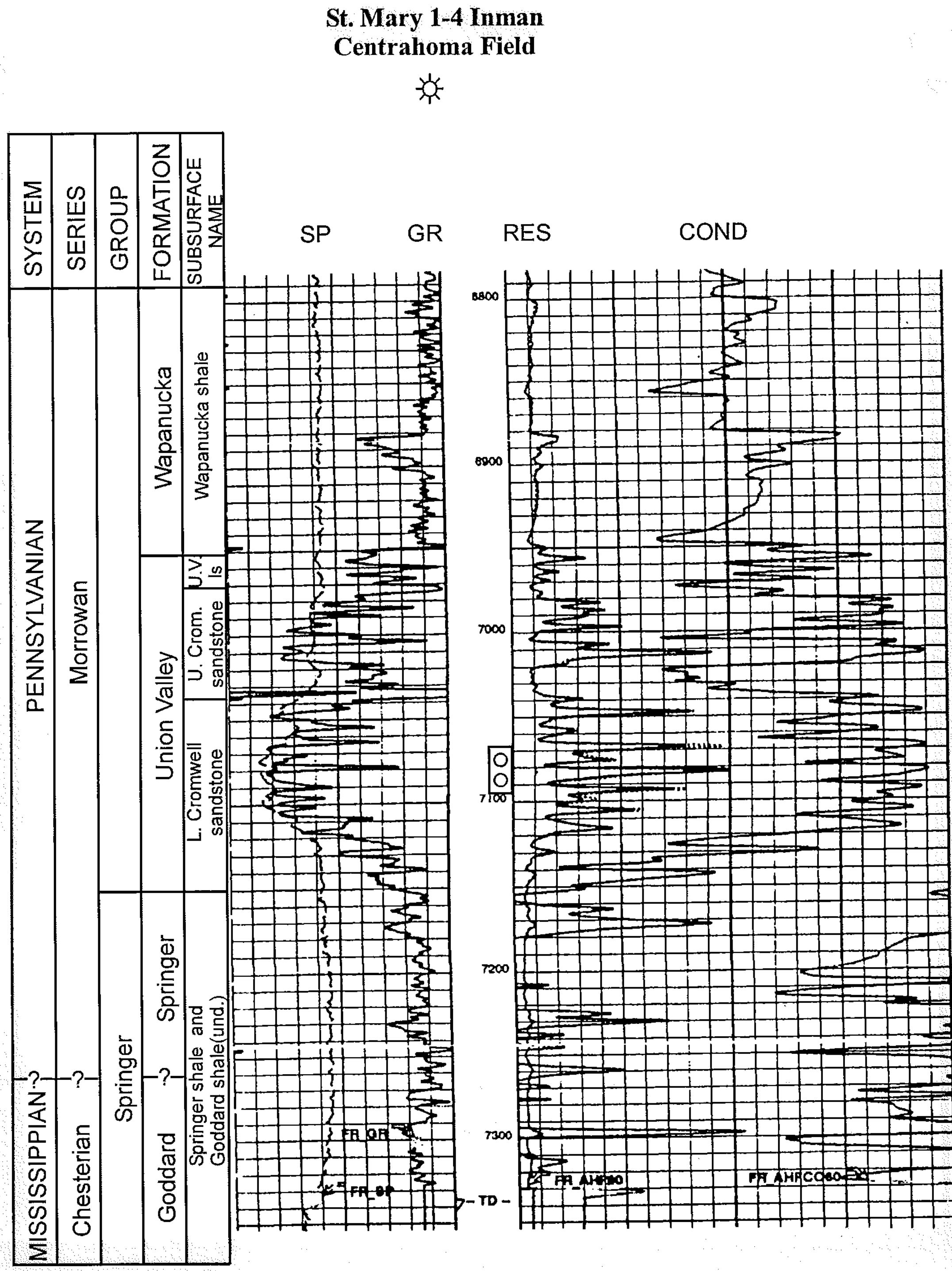


Figure 17. Part of electric log from St. Mary Operating Co. No. 1-4 Inman (N½SW¼NW¼ sec. 4, T. 1 N., R. 10 E., Centrahoma field). The well was drilled in 2001 and completed in the Cromwell Sandstone (725 mcf/day) and Wapanucka Formation. The shale-rich interval from 7020 to 7040 may separate the Cromwell into upper and lower parts. The coarsening-upward profile of the "lower" Cromwell is typical of offshore bars and sand ridges. The well produces gas from the Cromwell and Wapanucka.

18.3 2.0 Outcrop of sparsely fossiliferous sandstone in the Savanna Formation on left (northeast) side of highway. Strata dip northwest, away from the axis of the Coalgate Anticline (see below).

19.5 1.2 About 0.1 mi after crossing Caney Creek, the highway crosses the outcrop of the McAlester (Lehigh) coal (Fig. 18). Although extensively strip-mined in the late 1800's and early 1900's, there is little surface evidence for it here.

20.1 0.6 Intersection with Oklahoma Highway 31 in north end of Coalgate. Turn left (north) on to Oklahoma Highway 31. Reset odometer to 0.0.

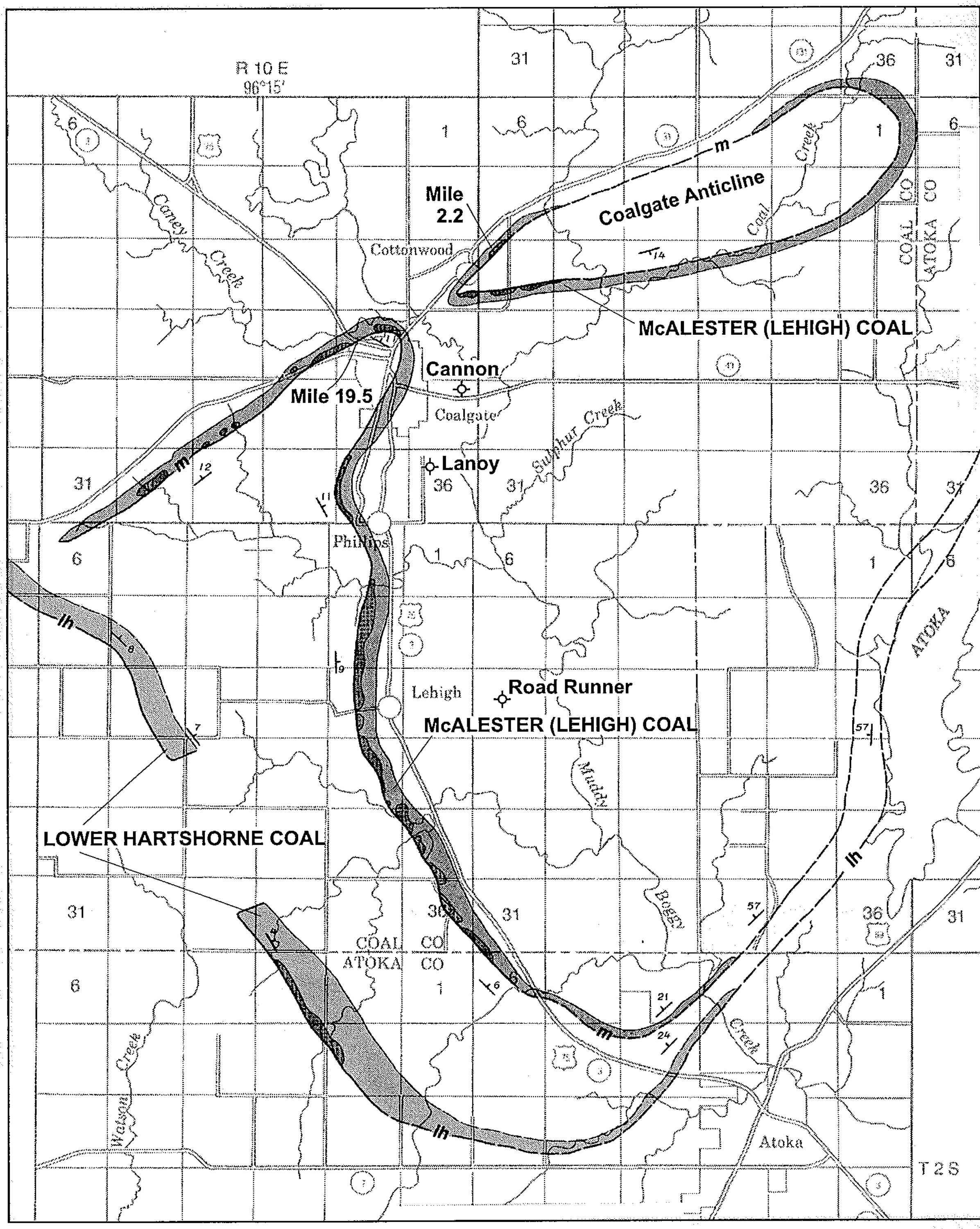
Coalbed Methane near Coalgate, Oklahoma
Brian J. Cardott, Oklahoma Geological Survey

More than 2000 wells in the Oklahoma coalfield have been drilled exclusively for coalbed methane (CBM) since 1988. The Oklahoma coalfield is in the eastern part of the State and is divided into the northeast Oklahoma shelf and Arkoma Basin based on physiographic and structural differences. Most of the CBM wells in the Arkoma Basin are in Haskell (451), Latimer (20), Le Flore (146), and Pittsburg (138) Counties. Three wells southeast of Coalgate in Coal County were completed in 1992 – 2002 to the Hartshorne and McAlester (Lehigh) coals at depths-to-top of coal of 806 to 1610 ft in an area of extensive underground mining. The Indian Nation Illuminating 1 Leon Lanoy wells (sec. 36, T. 1 N., R. 10 E.) was completed to the McAlester (Lehigh) coal (806 to 812 ft) on November 28, 1992 and was plugged and abandoned on July 18, 1994. The Inland Oil 1-25 Mary T. Cannon well (sec. 25, T. 1 N., R. 10 E.) was recompleted to the Hartshorne coal (1610 to 1615 ft) on March 13, 1993 and is currently classified as dry. The Carmac Energy 1-18 Road Runner well (sec. 18, T. 1 S., R. 11 E.) was completed in the McAlester (Lehigh) coal (969 to 976 ft) on August 7, 2002 and is currently shut-in (in July 2003).

Coalgate, Oklahoma

Coalgate was originally founded as the town of Liddle (named for William Liddle, a local coal mine superintendent) when a post office was established on September 18, 1889 (Shirk, 1974). The name of the town was changed to Coalgate on January 23, 1890. Two origins for the name Coalgate have been suggested. One is that the town was named for the then-president of the Missouri Kansas and Texas Railroad, Coalgate Hoyt. The other origin is that the name was derived from a slogan popular in the early coal-mining camps, "a gate to wealth from the coal industry".

(following page) **Figure 18.** Map showing approximate outcrop location and potentially strippable coal beds near Coalgate, Oklahoma (from Friedman, 1982). Also shown are three coalbed-methane wells drilled in this part of the Arkoma Basin and two mileage markers (see text).


R 10 E
96°15'
Mile
2.2
Coalgate Anticline
Cottonwood
McALESTER (LEHIGH) COAL
Cannon
Mile 19.5
Coalgate
Sulphur Creek
Lanoy
Caney Creek
Coal Creek
COAL CO
ATOKA CO
Phillips
Lehigh
Road Runner
McALESTER (LEHIGH) COAL
Muddy Boggy
LOWER HARTSHORNE COAL
ATOKA
Watson Creek
Creek
Atoka
T 2 S

Aldrich (1952, p. 36-37) reported that

"the first coal mine was opened in 1882 within one hundred feet of what is now Main Street. The first vein mined was so close to the surface that the overburden was removed by plows and scrapers and the coal removed with sledges, steel coal pins and shovels. By 1897 there were more than 1500 people in Coalgate. During the next few years the population grew rapidly and by 1900 there were 2614.

"In 1902 the United State Indian Inspector described Coalgate as a mining town that contained a very large number of one-story frame houses. The majority of the houses were occupied by miners and when new cost about $50.00 each. The town was built without regard to any regularity. The population of the town was extremely mixed, being composed of a high per cent of foreign and Negro miners."

Coalgate continued to grow until 1925 when the mines began to close.

Sites of Geological Interest

The Coal County Historical and Mining Museum is located at 212 S. Broadway on the south side of town. The museum contains a large and varied collection of tools and equipment used in the underground coal mines in the area, as well as a number of historic photographs. Call (580) 927-2360 for information.

Introduction – Arkoma Basin

(The following general description of the Arkoma Basin is modified from Hemish and Suneson, 1997)

The Arkoma Basin is an elongate, arcuate, structural and depositional basin lying just north of the Ouachita Mountains fold-and-thrust belt (Fig. 19). It extends from the Arbuckle Mountains and related structures (e.g., the Lawrence Uplift) on the west to just northeast of Little Rock, Arkansas, where it is covered by sediments of the Mississippi embayment. In Oklahoma it is bounded on the south by the Choctaw Fault and on the northeast by the Mulberry Fault. The boundary between the Franks and Wapanucka Grabens to the southwest and the Arkoma Basin is gradational, as are the basin's northwestern and northern boundaries with the Cherokee Shelf (Fig. 19).

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 (Fig. 20). Much of the area, particularly in the southern part, is underlain by north-directed thrust faults, many of which are subhorizontal and parallel to bedding planes. Locally the faults rise to form blind-thrust-cored anticlines. In addition, small south-directed backthrusts and "out-of-the-syncline" faults are present. Structurally, the area forms a classic triangle zone (e.g., Valderrama and others, 1994; Cemen and others, 2001), which is typical of many foreland basins immediately adjacent to fold-and-thrust belts.

The history of the Arkoma Basin can be separated into two phases – basin subsidence and sedimentation followed by compressional deformation. Prior to the

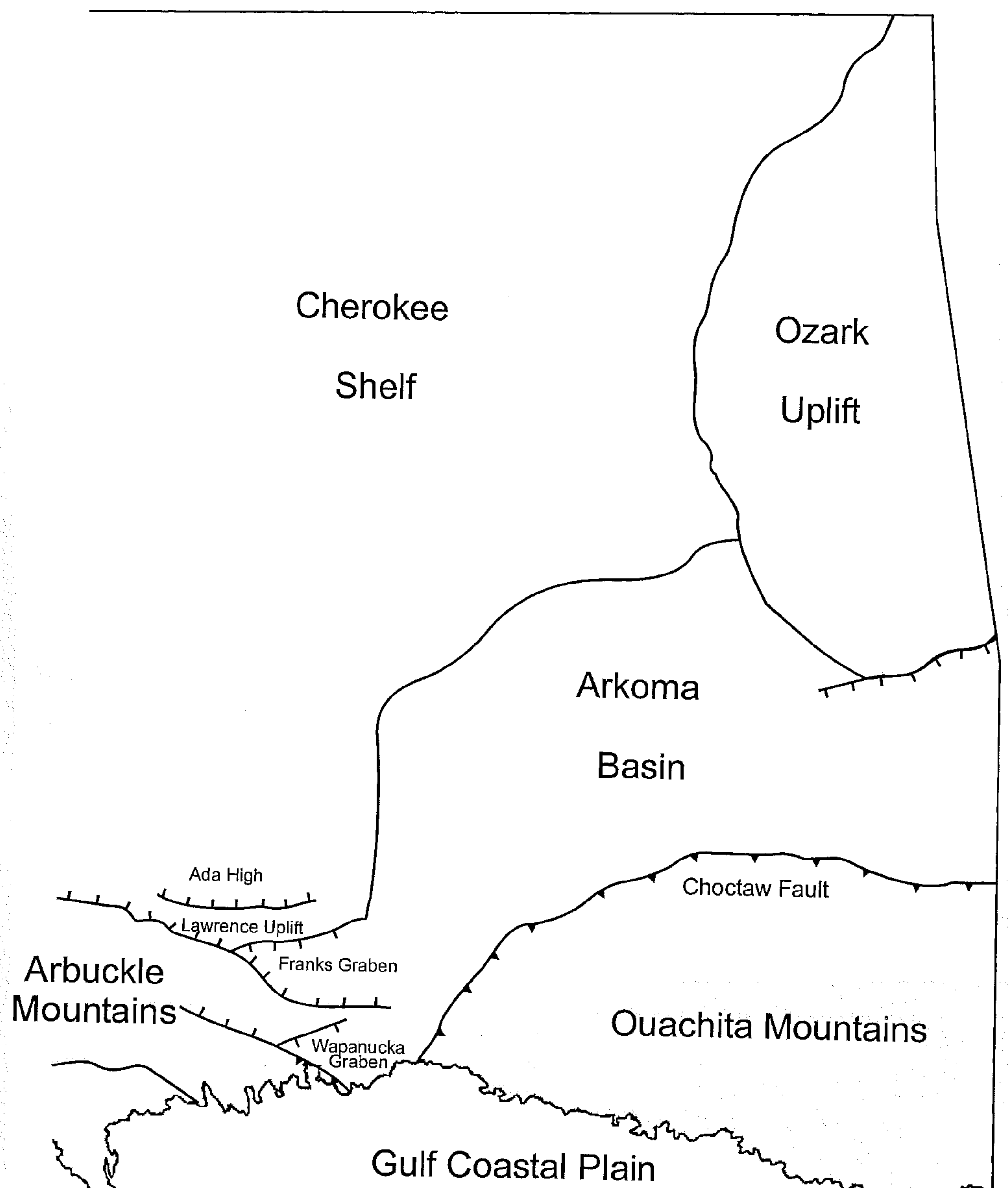


Figure 19. Map showing the location of the Arkoma Basin and adjacent geologic provinces in Oklahoma.

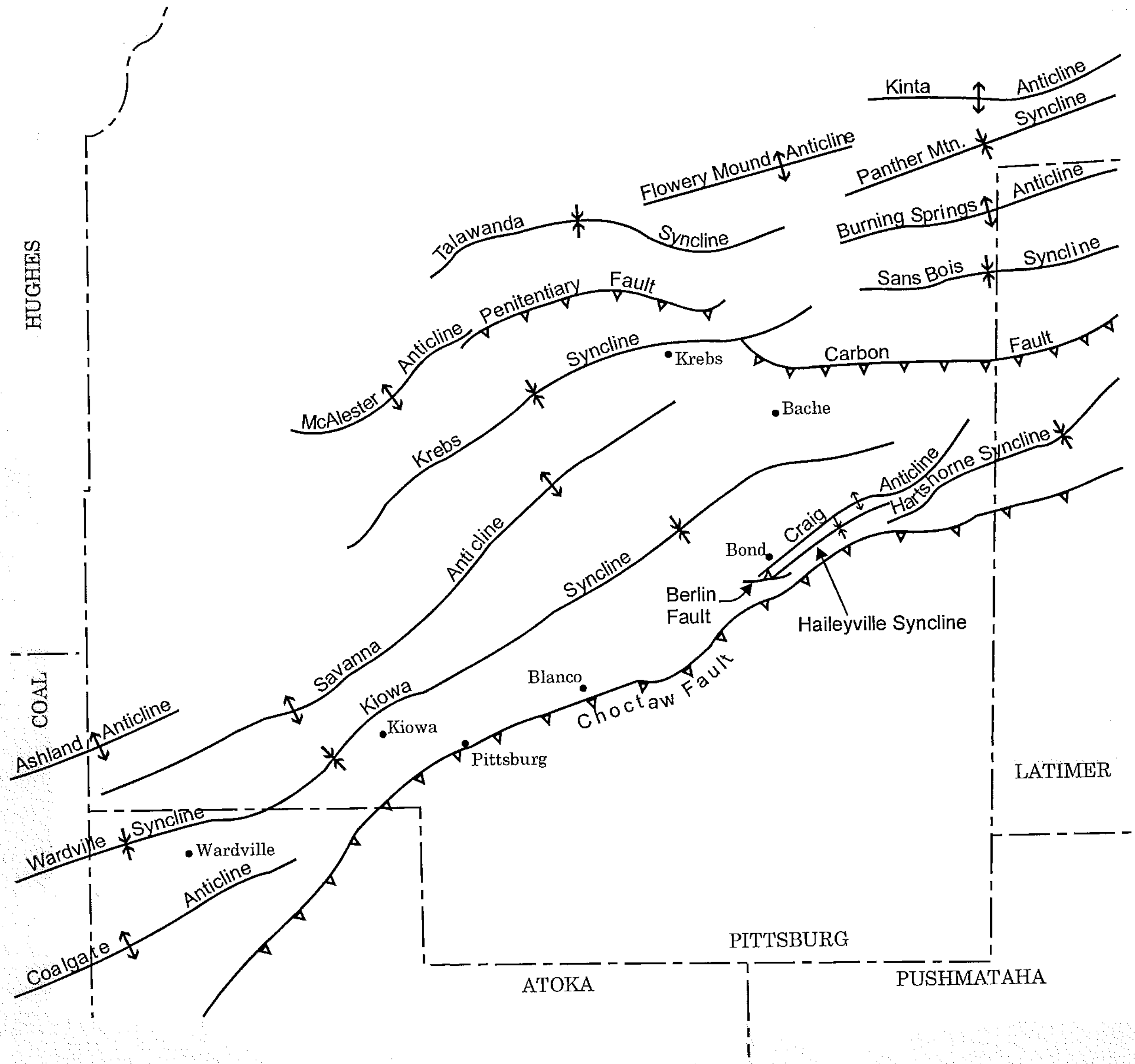


Figure 20. Generalized map of major geologic structures in southern part of the Arkoma Basin near field-trip route. Towns passed through are shown for reference. (Modified from Marcher, 1969; Hart, 1974; Marcher and Bergman, 1983; and Arbenz, 1989.)

Atokan, the Arkoma Basin was part of an epicontinental shelf on which a relatively thin sequence of shallow-water carbonate strata (Wapanucka Formation) and clastic strata (Spiro sandstone) was deposited. Beginning in the middle Atokan, south-side-down normal faults resulted in a rapidly subsiding, major foreland basin that began receiving a thick sequence of deep-water clastic sediments. This thick sequence of dominantly marine beds (Atoka Formation) generally is conformably (but locally disconformably) overlain by deltaic sandstones, siltstones, and coals of the Hartshorne Formation.

Sandstone isopach and facies maps of the Hartshorne Formation (Andrews, 1998), Booch sandstone (McAlester Formation) (Busch, 1959), and Bluejacket Sandstone Member (Boggy Formation) (Visher, 1968) are evidence that the Arkoma Basin continued to subside throughout the Desmoinesian, but at greatly reduced rates compared to that during the Atokan.

In general, the folds and thrust faults in the Arkoma Basin are parallel to those in the Ouachita Mountains to the south (Fig. 20) and most geologists accept a similar tectonic origin for those in the basin and mountains. The inception of compressional folding in the Ouachita Mountains is difficult to date because early-formed deformational structures were overprinted by later mostly coaxial structures. It is likely that the earliest deformation is no older than Meramecian – the age of the lower part of the Stanley Formation. To the north in the Arkoma Basin, earliest folding postdated the middle Atokan normal faults. The age of the cessation of folding cannot be established in the mountains, however, it can be determined in the Arkoma Basin. Sutherland (1988) has shown that the Desmoinesian Krebs Group formations are folded and are overlain unconformably by the unfolded Desmoinesian Cabiniss Group. Thus, folding in the Arkoma Basin was relatively short-lived, extending from the late Atokan to the middle Desmoinesian.

0.3 0.3 Cross outcrop of McAlester (Lehigh) coal near axis of Coalgate Anticline. Several closely spaced slope mines (Coalgate Coal Co. No. 1 mine, also known as "Soup-Bone" Mines) immediately northwest of the highway are now flooded.

1.5 1.2 Turn left in center of Cottonwood. The Coalgate North field is just west of Cottonwood. It was discovered in 1987 by the Santa Fe Minerals 14-1A Witherspoon (SE¼SE¼NW¼ sec. 14, T. 1 N., R. 10 E.) that completed in the Booch at a depth of about 1550 ft. The Hartshorne is also a producer. As of November 2002, the field had produced about 4.4 bcf gas and continues to produce about 40 mmcf gas annually (data courtesy IHS Energy).

Following a period of heavy rain during the week of May 14, 1989, some land immediately south of the center of Cottonwood subsided into an open airshaft associated with a long-abandoned underground coal mine. The Oklahoma Conservation Commission, which administers money from the U.S. Dept. of Interior Abandoned Mine Land trust fund, reclaimed the site. Subsidence is a relatively common occurrence in Cottonwood, Coalgate, and Lehigh (located about five miles south of Coalgate) and other areas in Oklahoma where abandoned underground mines are present.

ABANDONED COAL MINE LANDS RECLAMATION

(modified, in part, from Kastl and others, 2001)

Coal has been mined in Oklahoma since 1872 and since that time, over 70,000 acres of mined land from both underground and surface mining has not been reclaimed.

Abandoned coal mine land occurs in sixteen counties; this field trip will cross reclaimed and unreclaimed land in Coal, Pittsburg, and McIntosh Counties. Most landscape scarring associated with underground mines, the predominant form of mining in Oklahoma prior to 1943, includes scattered gob piles (mine refuse), shaft openings, subsidence features, and abandoned equipment. Features associated with surface mining include elongate ridges of spoils (overburden material), water-filled pits, steep highwalls, and acid-mine drainage. "Unreclaimed areas are unsightly, unproductive, and, in many cases, dangerous." (p. 68). As of June 25, 2002, 25 known deaths had occurred in Oklahoma at abandoned mine sites (Mike Kastl, 2003, pers. commun.).

The first (relatively inadequate) reclamation laws in Oklahoma were passed in 1968 and 1971. In 1977, President Jimmy Carter signed the Surface Mining Control and Reclamation Act of 1977, which (1) required coal mine operators to reclaim the land they were mining and (2) established the Abandoned Mine Land (AML) Trust Fund. The fund, administered by the Office of Surfacing Mining, U.S. Department of the Interior, is generated by a tax on active coal mine operators and is designed to reclaim orphan coal mine lands that endangered the public health and/or safety. Shortly after the federal bill was signed, Governor David Boren designated the Oklahoma Conservation Commission (OCC) as the state agency to oversee the reclamation of Oklahoma's abandoned coal mine lands. Since 1995, Oklahoma has received between $1.5 and $1.6 million for its AML program; however, the OCC believes it would take more the $90 million to reclaim the high-hazard sites identified in Oklahoma.

In 2001, the OCC identified 261 problem AML areas in Oklahoma; nationwide, there may be as many as 12,000 mines that require reclamation (Brinkley, 2002). Since the trust fund was established, it has collected almost $7 billion. "But after 26 years, an estimated 80% of the total area at risk hasn't yet been safeguarded, the trust fund brims with $1.5 billion in unspent funds, and some of the money that is spent goes to projects unrelated to coal" (Fialka, 2003, p. A1). Brinkley (2002) reported that $204 million was spent from the fund in the fiscal year that ended September 30, 2002, but that about $350 million in taxes and interest were paid into the fund. In addition, and despite the clear need for AML reclamation, "the Bush administration is proposing to cut spending to $174 million" (Brinkley, 2002, p. A18).

The principal reason much AML trust fund money continues to accumulate despite the needs of 23 states and three Native American tribes is the federal deficit. Brinkley (2002, p. A18) has described the problem:

"When the abandoned mine trust fund was authorized, it was designated 'on budget,' as are most government trust funds. That means the money is held in the government's general treasury pool, although it cannot be spent on anything else. When the Interior Department asks to spend part of the fund, the request must compete with those from every other program in the department. Any increase in spending must be offset by a decrease somewhere else. A result, federal officials acknowledge, is that the money is held back to help lower the budget deficit."

An additional problem with the fund is that the states that produce the most coal get most of the money in the fund. "The result: about two-thirds of the program's funds are designated for states in the West. Yet 93% of the problems that remain – acid-tainted streams, underground fires, gaping holes and other hazards that would cost an estimated $6.6 billion to fix – are east of the Mississippi" (Fialka, 2003, p. A1).

The failure to adequately fund the AML program is surprising because "the hazards are likely to grow more dangerous and expensive. Nationwide, the US DOI estimates that 3.5 million Americans live less than a mile from hazardous abandoned coal mines, a figure that will rise as housing construction continues to spread into the countryside. And the shafts below get ever more unstable ..." (Fialka, 2003, p. A10). In Oklahoma, surface subsidence over abandoned underground coal mines has recently damaged property in Wilburton and Tulsa.

Continue north (soon to be northeast) on Oklahoma Highway 31.

2.2 0.7 Spoils pile on right (south) side of highway. Here, the strip-mined McAlester (Lehigh) coal dips northwest and is on the northwest flank of the northeast-trending Coalgate Anticline (Fig. 14). Coal, black organic shale, and carbonized plant fossils are abundant on the spoils pile.

2.9 0.7 The low ridge to the left (northwest) is underlain by the basal sandstone of the Savanna Formation. For the next approximately 4 mi, the highway is parallel to the McAlester - Savanna contact.

5.5 2.6 Cairo Corner. Intersection with Oklahoma Highway 131 (straight ahead) and Oklahoma Highway 31 to left (north). Continue straight ahead on Oklahoma Highway 131.

6.4 0.9 "Village" of Cairo. Enter Coalgate Northeast gas field, which was discovered by the Ran Ricks No. 11-A McEntire (CS½NW¼ sec. 11, T. 1 N., R. 11 E.) in 1978. This well was completed in the Wapanucka at about 8400 ft deep. The Atoka and Cromwell also produce gas in the field. As of November 2002, the field had produced about 634 mmcf gas and was still producing about 27 mcf gas annually (data courtesy IHS Energy).

7.0 0.6 Sandstone to right (southeast) is basal sandstone in Savanna Formation.

9.0 2.0 Steeply (65°) dipping sandstone to right (southeast) is either uppermost Savanna sandstone or basal Boggy sandstone (Bluejacket Member).

9.4 0.4 Leave Coal County, enter Atoka County. Continue on Oklahoma Highway 131. The highway is now in the Boggy Formation.

12.5 3.1 Ranch house on ridge on right (southeast). The ridges in this area are long and linear and typically are underlain by sandstone beds in the Boggy Formation. In detail, however, the ridges are discontinuous (Fig. 21); this probably results from strata that are sandstone-rich (prominent ridge) grading laterally into strata that contain significant amounts of siltstone or shale (subdued or no ridge).

About 0.5 mi south of the ranch house is the Wardville South gas field. Gas was discovered by the Enron No. 21-1 Overstreet (NW¼SE¼SE¼ sec. 21 T. 2 N., R. 12 E.) in 1995 in the Hartshorne. The Booch also produces gas in the field.

13.7 1.2 Small community of Wardville on left (north). Continue on Oklahoma Highway 131.

14.7 1.0 The high ridge on the skyline at about 1:00 is underlain by Atoka Formation sandstones in the Ouachita Mountains.

The highway here is near the center of the Wardville gas field which was discovered in 1996. The discovery well for the field is the Enron No. 10-1 Thompson (S½SE¼NE¼ sec. 10, T. 2 N., R. 12 E.) which was completed in the Hartshorne at a depth of about 3700 ft and in the Booch at about 3300 ft. In addition to these units, the Savanna and Atoka also are productive. As of November 2002, the field had produced just over 1 bcf gas and was continuing to produce about 111 mcf gas annually (data courtesy IHS Energy).

18.6 3.9 Cross old railroad grade and begin gentle climb up sandstone-supported ridge. The railroad grade and flat area to the west are underlain by the Boggy Formation; the ridge-forming sandstone is in the Savanna Formation. The railroad is shown as the Chicago, Rock Island, and Pacific by Hendricks (1937a, pl. 1); it served many of the coal mines in this area and is parallel to the outcrop of the McAlester coal and Highway 63 about two miles east of Kiowa (see below).

19.3 0.7 Intersection with U.S. Highway 69. Turn left (north).

The low ridge about 0.4 mi. east of the intersection is the steeply west-dipping Hartshorne Formation (basal Desmoinesian). Suneson (1998, p. 30-33) described the Hartshorne Formation in this area and interpreted most of it to consist of delta-front sediments.

20.5 1.2 Leave Atoka County, enter Pittsburg County.

The one-well Reynolds gas field is just to the east. It was discovered in 1980 by the Hamilton Brothers No. 1-3 Hamilton Vaughan – Duvall (E½E½W½NE ¼ sec. 3, T. 2 N., R. 13 E). The producing formation is the Wapanucka Limestone at a depth of about 11,000 ft.

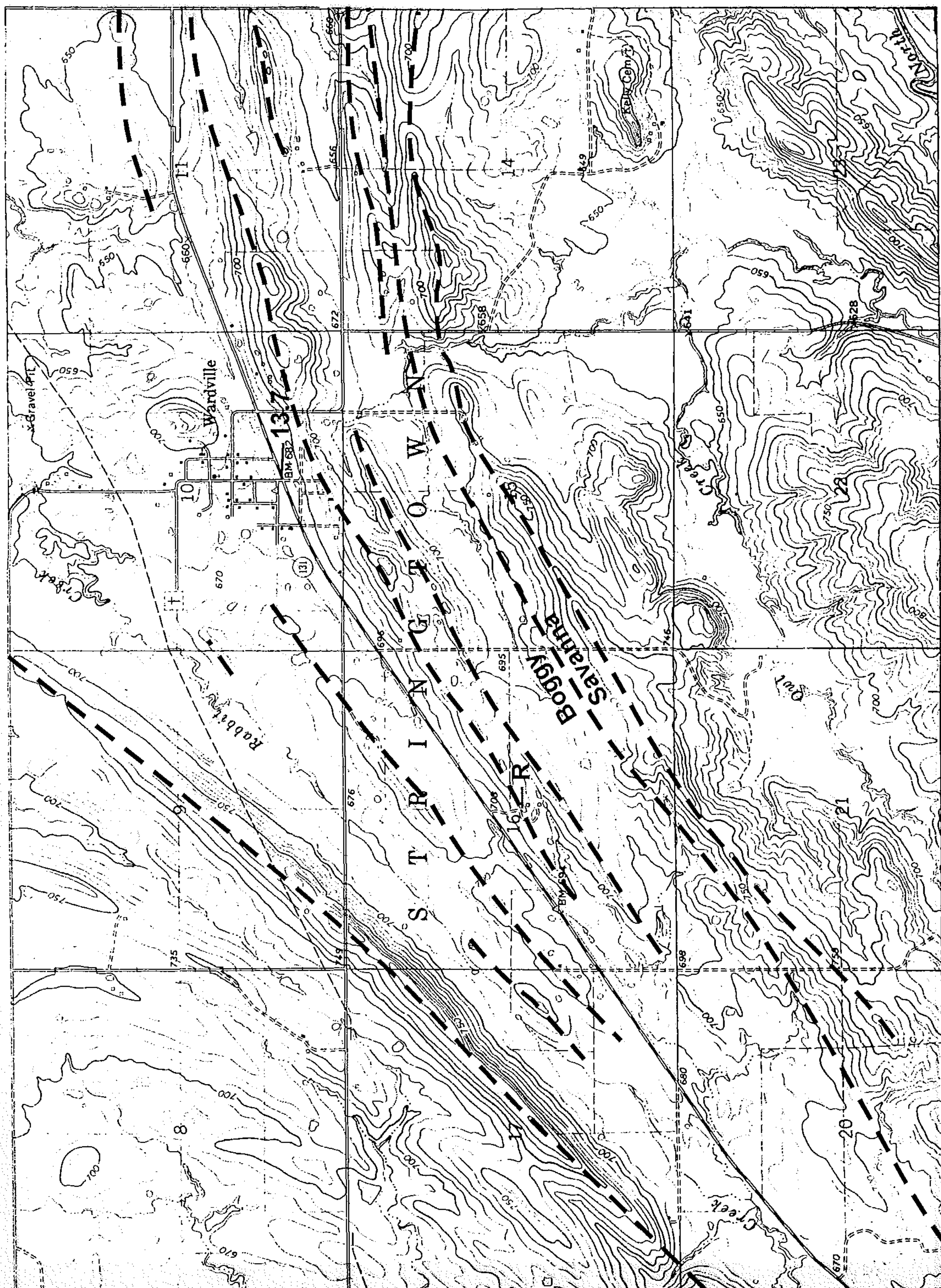


Figure 21. Part of topographic map of Wardville 7.5' quadrangle (T. 2 N., R. 12 E.). "R" is ranch house at mile 12.5. Savanna – Boggy contact is based on Knechtel (1937) who located it at the top of the highest sandstone in the Savanna Formation. Modern geologic maps show the contact at the base of the Bluejacket Sandstone Member of the Boggy. Many of the linear ridges (dashed lines) that parallel the highway are underlain by sandstone beds in the lower part of the Boggy. The discontinuous nature of the ridges is evidence that the sandstone beds also are discontinuous.

Kiamichi Energy Facility

The power plant on the left (west) is the Kiamichi Energy Facility, a 1250-mw natural-gas-fueled power plant. The plant cost $350 million to design and build; construction started in July 2001 and is scheduled to be completed in June 2003. Electricity from the plant will meet the energy needs of more than a million homes.

The natural gas to fire the plant is being supplied by Coral Energy of Houston, Texas. Coral is a subsidiary of Shell.

For the next two miles, the highway crosses moderately northwest-dipping Savanna Formation. The relatively flat area to the east is underlain by the shale-dominated McAlester Formation.

22.3 1.8 Low ridge is underlain by northwest-dipping sandstone in the Savanna Formation. The basal Bluejacket Sandstone Member of the Boggy Formation is thin, poorly exposed, and marked by a very low discontinuous ridge in this area. Hendricks (1937a) included the shale above this sandstone in the Boggy; Marcher and Bergman (1983) (based on Jones, 1957) follow modern terminology and include the shale above this sandstone in the Savanna.

22.9 0.6 Highway crosses unexposed Bluejacket Sandstone.

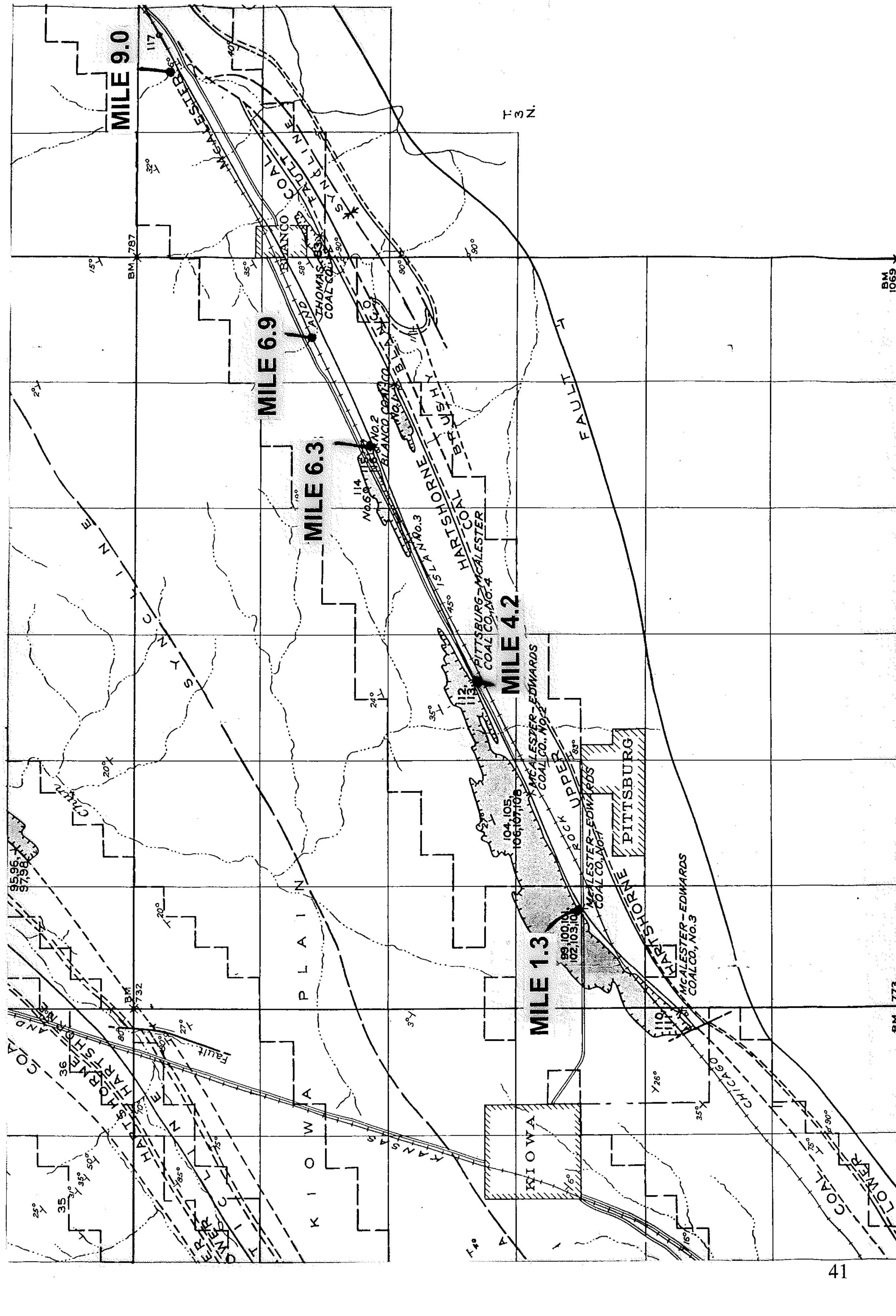
23.8 0.9 Intersection with Oklahoma Highway 63 near center of Kiowa. Turn right (east) on Oklahoma Highway 63. Reset odometer to 0.0.

0.5 0.5 Just past the high school, highway crosses back into Savanna Formation.

0.7 0.2 Outcrop of uppermost(?) sandstone in Savanna Formation dipping 16° to northwest. Weathered chert fragments (probably Ordovician Bigfork Chert or Devonian Arkansas Novaculite) as large as 1/8 in. in diameter are present in coarse-grained sandstone near the base.

1.3 0.6 Highway crosses into the McAlester Formation. It also crosses over a large underground coal mine (McAlester – Edwards Coal Company No. 1 mine) that mined the McAlester coal.

(following page) **Figure 22.** Map showing the location and extent of underground coal mines along field-trip route between Kiowa and Blanco (from Hendricks, 1937a, pl. 7). The road shown on this map is essentially the same as Highway 63 and mileages shown refer to those in text. The Chicago, Rock Island and Pacific Railroad is also shown (mile 18.6, p. 38). The McAlester coal was extensively mined northwest of Pittsburg; only two relatively small mines south and southwest of Blanco produced the Hartshorne coal.



MILE 9.0
MILE 6.9
MILE 6.3
MILE 4.2
MILE 1.3
T3N
T4N
BM 787
BM 1069
BM 732
BM 773
McALESTER
COAL
FAULT
BLANCO
THOMAS
COAL CO.
AND
BLANCO COAL CO. No. 2
No. 6
ISLAND No. 3
HARTSHORNE COAL
BRUSHY
SYNCLINE
PITTSBURG-McALESTER COAL CO. No. 4
McALESTER-EDWARDS
McALESTER-EDWARDS COAL CO. No. 2
McALESTER-EDWARDS COAL CO. No. 1
McALESTER-EDWARDS COAL CO. No. 3
UPPER HARTSHORNE
ROCK
PITTSBURG
KIOWA
KIOWA PLAIN
KANSAS
CHICAGO
LOWER COAL
SYNCLINE
Fault
HARTSHORNE
95,96, 97,98
104,105, 106,107,108
99,100,101, 102,103,104
112
113
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1.8 0.5 Entrance to the McAlester - Edwards No. 1 mine and outcrop belt of the McAlester coal (Fig. 22). This mine was active in 1930 (Hendricks, 1937, p. 57), but there is no longer any trace of the coal mine workings.

The area near the outcrop belt of the McAlester coal between here and mile 8.0 at Blanco is one of the Oklahoma Conservation Commission's Abandoned Mine Land planning units. The area is prone to subsidence over abandoned coal mines, contains open shafts and inclines and gob piles, and is locally littered with old mining equipment and debris.

3.0 1.2 Highway 63 turns left (north) just north of small town of Pittsburg. Continue on Oklahoma Highway 63.

The trace of the Choctaw Fault, which separates the Arkoma Basin and Ouachita Mountains geologic provinces, passes through Pittsburg.

The large Pittsburg gas field surrounds the town of Pittsburg.

Pittsburg Gas Field

The discovery well for the Pittsburg gas field is the Hamilton Brothers No. 1 Chitty - Scott located in the NE¼NE¼SW¼NE¼ sec. 30, T. 3 N., R. 14 E. The well was completed on February 6, 1979; the Wapanucka Limestone and Cromwell Sandstone were found to be productive at depths of about 9400 and 10,300 ft, respectively. As of 1990, the field was about 23 square miles in area and included 28 producing wells (27 Wapanucka completions and 10 Cromwell completions) (Suneson and others, 1990, p. 41). The Woodford, Hunton, and Spiro also are productive (Richardson, 1986). Boyd (2003) shows the Pittsburg field to be about the same size.

Hardie (1988) characterized the subsurface geology of the Pittsburg field as an "incipient triangle zone" dominated by north-vergent thrust faults (e.g., Choctaw Fault), but including a shallow south-vergent thrust fault in the lower part of the McAlester Formation and deeper blind south-vergent thrust faults that form anticlinal traps in the Wapanucka. Gas production is from fractures (Richardson, 1986). To date, the Cromwell Sandstone in the Pittsburg field has not been described.

As of November 2002, the Pittsburg field had produced just over 77 bcf gas and was continuing to produce about 2 bcf gas annually (data courtesy IHS Energy).

The Cromwell Sandstone in the Pittsburg field is thinner than it is in the Fitts (Jesse) and Centrahoma fields (compare Figs. 11, 12, 16, and 17 with 23 and 24; also Andrews, 2003, pl. 1). In addition, the base of the Cromwell in the Pittsburg field is more abrupt and less gradational than it is at Fitts (Jesse) and Centrahoma. This may be the result of scour and rapid filling of channels eroded into the offshore bars (Bouma and others, 1982) or scour and subsequent deposition by storm or tidal currents (Galloway and Hobday, 1983). The log pattern also resembles that which is typical of some parts

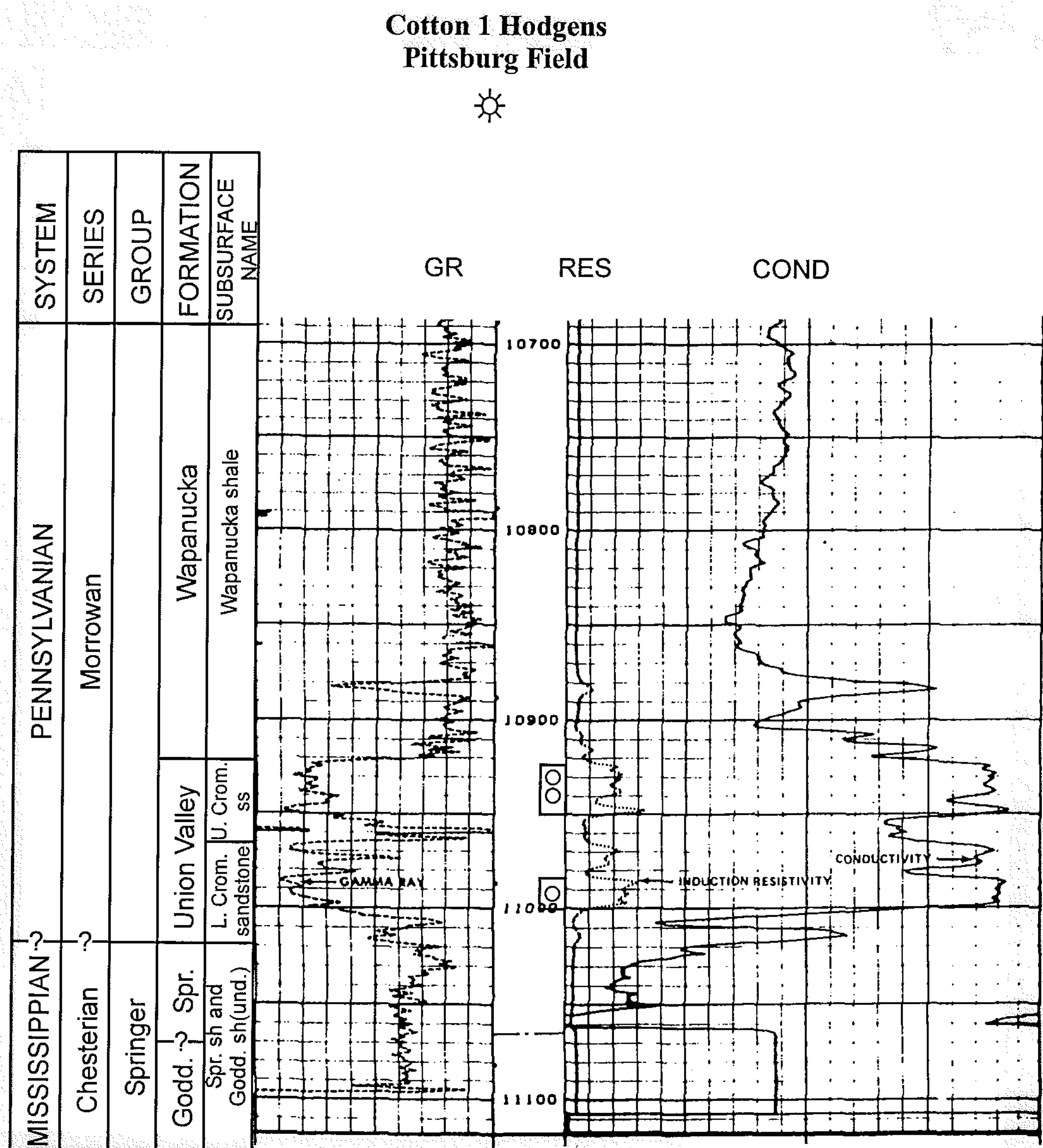


Figure 23. Part of electric log from Cotton Petroleum Corp. No. 1 Hodgens (W½E½SW¼ sec. 16, T. 3 N., R. 14 E., Pittsburg field). Shale at about 10,960 ft separates the Cromwell into upper (40-ft-thick) and lower (50-ft-thick) parts. Both Cromwell intervals coarse upward, as is typical of marine-bar deposits. The Union Valley limestone is absent. The well produces gas from the Cromwell and Wapanucka.

of submarine fans; thus, it is also possible that the Cromwell Sandstone in this part of the Arkoma Basin was deposited by turbidity currents.

3.5 0.5 Turn right. The McAlester – Edwards Coal Co. mine no. 2 (Fig. 25) was located a couple of tenths of a mile to the west.

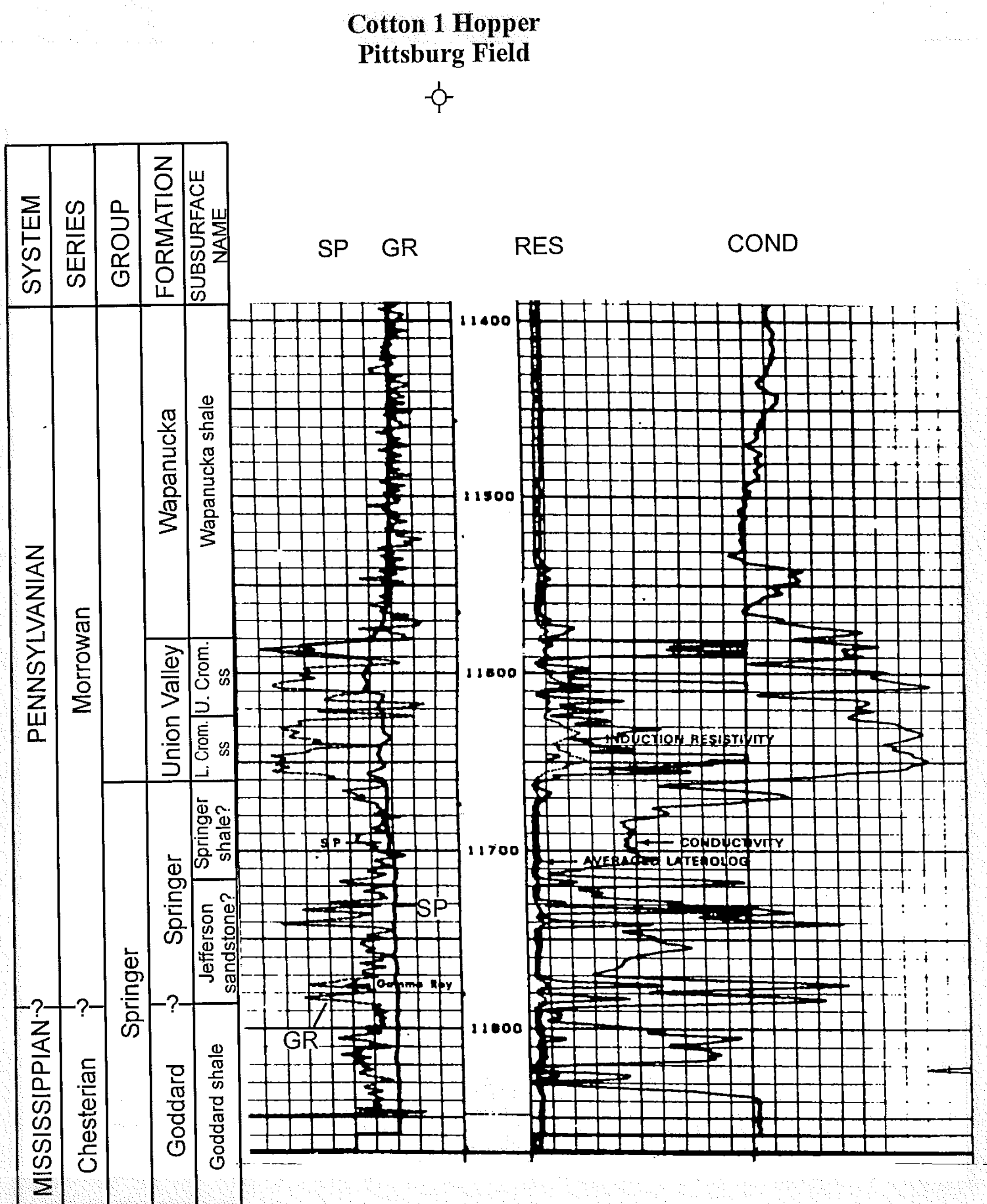


Figure 24. Part of electric log from Cotton Petroleum Corp. No. 1 Hopper (C NW¼ sec. 15, T. 3 N., R. 14 E., Pittsburg field). The Cromwell Sandstone extends from about 11,580 to 11,660 ft and may be divided into upper and lower parts by the shale-rich interval at 11,610 to 11,625 ft. The base of "both" Cromwell sandstones is relatively abrupt. The Union Valley limestone is absent. The well was dry.

For the next several miles, Highway 63 parallels the outcrop of the McAlester coal (Fig. 22). The entrances to several underground mines are located very near the

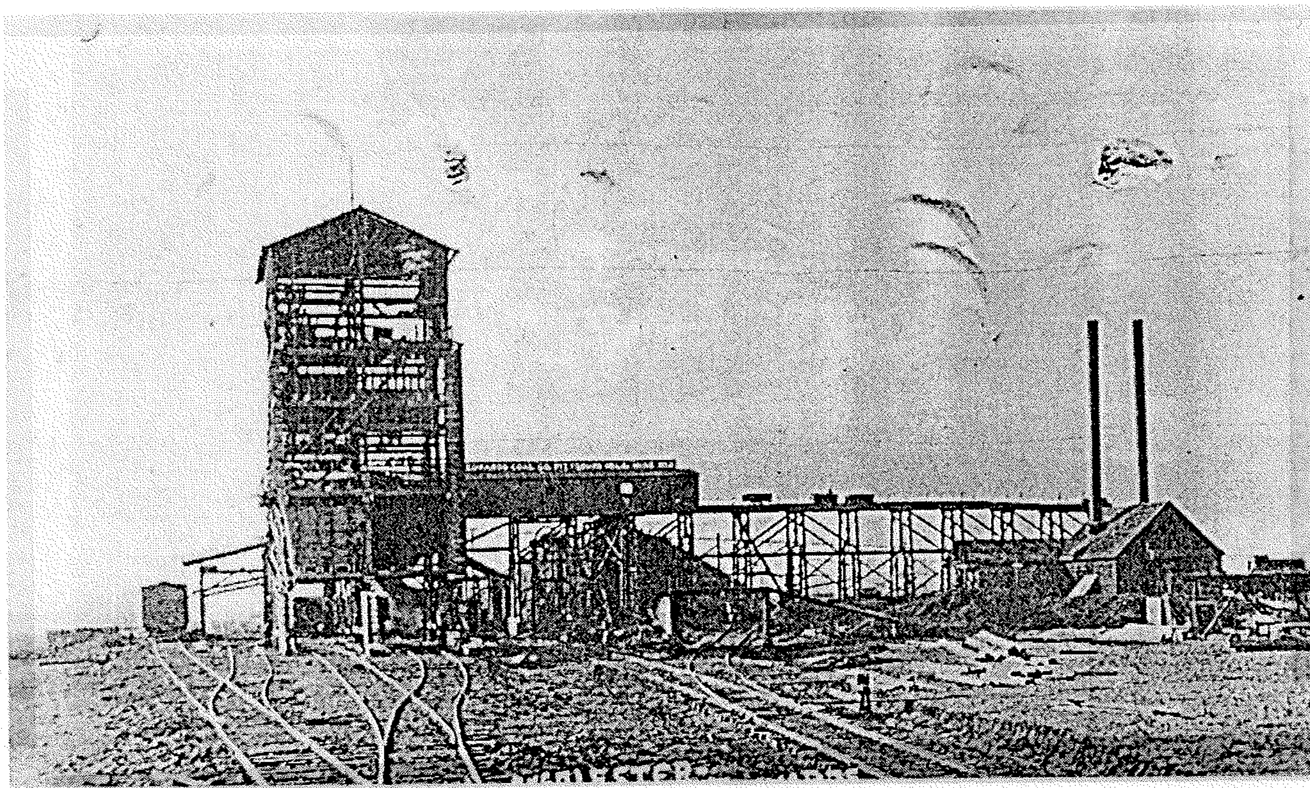


Figure 25. Photograph of McAlester – Edwards Coal Co. mine no. 2 (from Grider, 1998). Date photograph was taken is unknown.

highway, and surface evidence for the workings is still present. In addition, the Chicago, Rock Island and Pacific Railroad grade that served the mines is also still visible at many places along the highway.

4.2 0.7 Ruins of Pittsburg - McAlester Coal Co. No. 4 mine on left (north) (Fig. 26). (This mine is also referred to as the McAlester – Edwards No. 4 mine in Hendricks' (1937a, p. 58) text.)

5.4 1.2 Ruins and spoils piles of Blanco Coal Co. No. 3 mine on right (south) (Fig. 27). This mine, like those just passed, were active in 1930.

6.3 0.9 Spoils pile of Blanco Coal Co. No. 2 mine on right (south). Northeast of the Blanco Coal Company No. 2, the McAlester coal generally is too thin to have been economic to mine.

6.9 0.6 Section line road to right (south). The low ridge immediately north of the highway is underlain by the basal sandstone of the Savanna Formation.

Figure 26. Ruins of Pittsburg – McAlester Coal Co. No. 4 mine.

Figure 27. Entrance to Blanco Coal Co. No. 3 mine and rusted machinery. Hendricks (1937a, pl. 2) shows the McAlester coal varying from 2.9 to 3.9 ft thick and dipping 45° northwest near here; this is about the same angle as the entrance to the mine.

7.2 0.3 Bridge over Wildhorse Creek. Note old but spectacular railroad abutment immediately south (to right) of highway.

This area (sec. 12, T. 3 N., R. 14 E.) is the one-well Blanco gas field, discovered in 1979 by Hamilton Brothers Oil Company in their No. 1-12 Hamilton Sweetin well (E½E½E½NW¼ sec. 12, T. 3 N., R. 14 E.). Production is from the Wapanucka Limestone which was drilled from about 10,886 to 11,114 ft. Hardie (1988, p. 237, cross section C-C', well 15) shows a small south-vergent anticline to be the trapping structure. The Cromwell was drilled from 11,764 ft to 11,834 ft in the well.

7.9 0.7 Highway 63 turns right (south) into small town of Blanco.

8.0 0.1 Highway 63 turns left (east) in Blanco. Continue east on Oklahoma Highway 63.

About 1 mi to the south, Suneson (1998, p. 33-35) interpreted vertical, north-facing Hartshorne Formation as a shallowing-upward prodelta, delta-front, marginal delta-plain sequence.

A small underground coal mine is located near Blanco. The mine produced the upper Hartshorne coal.

8.6 0.6 Highway 63 passes underneath the Indian Nation Turnpike. Continue east on Oklahoma Highway 63.

8.9 0.3 Excellent outcrop of Cameron Sandstone Member of the McAlester Formation to left (north). The sandstone dips 53° north. Several outcrops of McAlester coal occur above the Cameron Sandstone in this area, but the steep dip probably discouraged any attempts to mine the coal.

9.7 0.8 Bridge over Ti Creek. Excellent outcrop of Cameron Sandstone and large railroad abutment to left (north) of highway.

10.7 1.0 Low ridge is Upper Warner Sandstone Member of the McAlester Formation.

11.3 0.6 Highway passes through a ridge underlain by sandstone of the Hartshorne Formation dipping about 45° northwest. For the next couple of miles, the highway parallels the Hartshorne ridge.

Enter Haileyville Southwest gas field, which was discovered by the Oxley No. 1 Whiting (SW¼NE¼SW¼ sec. 25, T., 4 N., R. 15 E) in 1975. The well was completed in middle and lower Atoka sandstones from about 8350 to 8700 ft deep. The field also produces from the Wapanucka as well as the Red Oak, Brazil, and Spiro sandstones (Atoka Formation).

As of November 2002, the Haileyville Southwest field had produced about 134 bcf gas and was continuing to produce about 9 bcf gas annually (data courtesy of IHS Energy).

12.4 1.1 Section line road to right (south). The broad valley to the southeast is underlain by the Atoka Formation; the trace of the Choctaw Fault is in the valley but is difficult to locate precisely because it juxtaposes easily eroded shale of the Atoka Formation and easily eroded shale of the Springer Formation.

Introduction – Ouachita Mountains Frontal Belt area

(The following is **greatly** modified from Suneson and Hemish, 1994)

The Ouachita Mountains in southeastern Oklahoma are part of a long, mostly buried, fold-and-thrust belt that forms the southern margin of the North American craton. This mountain belt extends from Alabama through Mississippi, Arkansas, Oklahoma, and Texas to northern Mexico. In addition to being exposed in west-central Arkansas and southeastern Oklahoma where it is known as the Ouachita Mountains, the mountain belt is exposed in southwest Texas as the Marathon Mountains.

In Oklahoma, the Ouachita Mountains can be separated into three belts based on stratigraphy and structural style. From north to south, these are the frontal belt, central belt, and Broken Bow uplift (Fig. 28). The frontal belt lies between the Choctaw and Windingstair Faults and consists of steeply tilted, imbricately thrust-faulted, and tightly folded strata. Shallow-water Morrowan strata are present in the northern part of the frontal belt and more basinal Morrowan strata (turbidites and olistostromes) occur to the south. The Morrowan units in both parts of the frontal belt are overlain by Atoka Formation turbidites. In the extreme western part of the frontal belt, Ordovician to Mississippian strata crop out near Black Knob Ridge. The central belt is characterized by broad, open synclines, separated by tight, typically thrust-cored anticlines. Except for the tightly folded pre-Mississippian units in the Potato Hills, the only rocks exposed are Mississippian and Early Pennsylvanian. The Broken Bow uplift consists of isoclinally folded and thrust-faulted Early Ordovician to Early Mississippian deep-water strata.

Prior to the Carboniferous, the area of the Ouachita Mountains was part of an epicontinental shelf covered by a relatively thin sequence of shallow-water carbonate and clastic strata. To the south coeval deep-water facies strata, consisting mostly of black shales and cherts, accumulated in the Ouachita trough. Beginning in the Late Mississippian, the Ouachita trough subsided rapidly and large volumes of clastic sediments accumulated in it. This depocenter migrated northward with time; isopach maps of the turbidite-domninated Stanley Group (Mississippian), Jackfork Group (Morrowan), and Atoka Formation (Atokan) are evidence for this migration. Most likely the northward migration of the depocenter was accompanied by a northward migration of a fold-and-thrust front which formed the southern margin of the Ouachita trough, but was not high enough to be a source area of the turbidites.

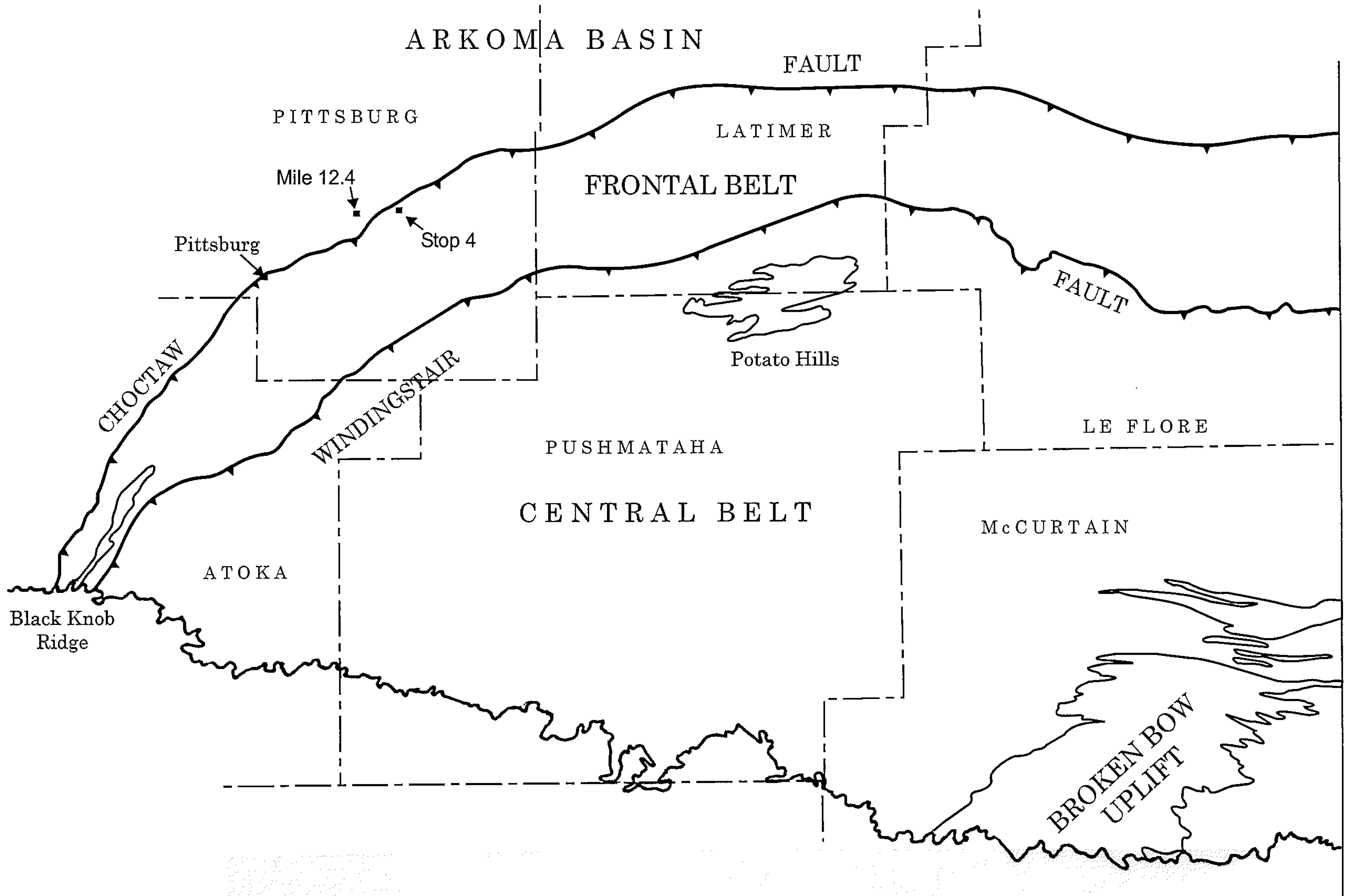


Figure 28. Generalized tectonic map of the Ouachita Mountains in Oklahoma.

The beginning of Ouachita deformation is difficult to establish. As mentioned above, it is possible that the earliest folding and thrust faulting was synchronous with the Late Mississippian subsidence of the Ouachita trough, but located south of it. In contrast, an unconformity at the base of the Thurman Sandstone is evidence that Ouachita-related folding ceased in the Arkoma Basin at the end of the early Desmoinesian. Uplift and erosion of the Ouachita Mountains may have begun as early as the Atokan; evidence for this is the presence of conglomerate beds in the Atoka Formation near Atoka (Hendricks, 1959). Conglomerate containing chert fragments is also present in the Hartshorne Formation near Atoka (Suneson, 1998, p. 28-30), and Knechtel (1937), Hendricks (1937a), and recent OGS mapping have shown that conglomerate beds occur in the McAlester, Savanna, and Boggy Formations south of McAlester (Suneson, 1998). It appears that conglomerates are restricted to lower stratigraphic units (Atoka, Hartshorne) to the south and occur higher in the section to the north. This is evidence that the Ouachita Mountains were progressively uplifted and exposed to erosion from south to north.

13.9 1.5 Highway 63 crosses Gardner Creek and passes through an excellent outcrop of Hartshorne Formation described by Suneson (1998, p. 35-39). Most of the Hartshorne here is interpreted as bar-transition and lower-distributary-mouth bar. Just past the Hartshorne outcrop, the highway crosses back into the McAlester Formation.

15.5 1.6 Entrance to small Berlin Coal mine (McAlester coal) to left (north). This mine had already been abandoned in 1930 (Hendricks, 1937a).

15.9 0.4 Entrance to small Messina Coal Co. No. 1 Craig mine (McAlester coal) to right (south). This mine was still active in 1930 (Hendricks, 1937a). The Oklahoma Conservation Commission reports that the slope entrance is open but partly blocked with concrete debris.

The low ridges just north of the highway are underlain by northwest-dipping sandstone beds in the lower part of the Savanna Formation.

16.6 0.7 Intersection with county road NS414. Turn right (south).

The surface geology for the next mile is complex and largely covered by surficial deposits. From north to south, the road crosses the axis of the Craig Anticline, the Haileyville Syncline, and north-dipping Berlin Fault. These probably are flexural-slip structures on the south flank of the Kiowa Syncline. Along the road, these structures are all within the McAlester Formation.

17.5 0.9 Cross Brushy Creek. The south bank of Brushy Creek is underlain by steeply north-dipping Hartshorne Formation.

17.8 0.3 Turn left (east) on county road EW153. Poorly exposed Atoka Formation is on both sides of road.

18.3 0.5 Park on right (south) side of road. This is the departure point for a 0.3-mile hike across some open fields to Stop 4. Stop 4 is on private property. For permission to visit these outcrops on your own, please contact Mr. Allan W. Ray, HCR 73, Box 29, Hartshorne, OK 74547; telephone (918) 297-2966.

The trace of the northeast-striking Choctaw Fault is about 0.25 mi south of the road. It is not exposed and can only be mapped by examining every small outcrop in each and every stream and gully in the area. Although the Choctaw Fault juxtaposes Morrowan shale against Atokan shale (hence, the poor exposure), they can be distinguished. Shales in the Atoka Formation are never calcareous; Morrowan shales generally are. Also, the rare sandstones in the Atoka do not contain glauconite, as do the Morrowan sandstones, such as the Cromwell.

Stop 4. Bond Locality

Location: Along small tributary to Brushy Creek, SW1/4 NE1/4 sec. 29, T. 4 N., R. 16 E., Hartshorne SW 7.5' quadrangle. About 1.5 mi south-southeast of Bond and about 0.3 mi south of east-west county road. Pittsburg County.

Introduction

The Bond locality is the only site in the frontal belt of the Ouachita Mountains where significant sandstone beds are present in the Morrowan section below the Wapanucka Limestone. Most of the strata below the Wapanucka in the frontal belt are laminated calcareous shale; thin limestone beds are present in places near the top and are similar to the overlying Wapanucka. This locality is very near the base of the hanging wall of the Choctaw Fault, the trace of which is about 500 ft to the northwest. The trace of the Choctaw Fault mapped by Suneson and Hemish (1996) was based on the presence or absence of calcareous shale; noncalcareous shale was mapped as Atoka Formation in the footwall of the fault, and calcareous shale was mapped as "Springer" Formation in the hanging wall. The trace of the fault mapped by Suneson and Hemish (1996) is very close to that mapped by Hendricks and others (1947).

Previous Work

Hendricks and others (1947) mapped this unit as the Springer Formation and described it as follows:

"The Springer consists of shale that is dark gray, gritty, micaceous, and weathers into spheroidal masses that finally disintegrate into small flakes. Concretions and thin beds of siderite that weather to limonite are present at many places. In the upper part of the formation there are beds of tan, calcareous siltstone, 6 in. to 4 ft thick, that weathers (sic) light gray. At places these siltstones contain some fine sand. Microfossils are abundant in the shales and larger fossils are present locally."

Suneson and Hemish (1996) mapped this unit as “Springer” Formation; they used quotation marks because they were unsure that the unit correlated with the type Springer Formation in the Ardmore Basin. Suneson and Hemish (1996) described the “Springer” in this area as follows:

“Predominantly very poorly exposed olive gray to olive black to grayish black, silty, very to slightly calcareous to noncalcareous fissile shale. Unit includes uncommon, but relatively well-exposed calcareous sandstone and limestone beds. Shale generally weathers spheroidally or to small chips or flakes. Locally contains ironstone concretions and layers. Shale interbedded with thin siltstone beds that locally are calcareous, pinch and swell, and locally form concretions. Uncommon sandstone beds are medium gray, quartzose, up to about 1 ft thick, cross-stratified, calcareous, and contain conspicuous grains of glauconite. ... An unsual facies of the “Springer” ... contains shale concretions as large as 3 ft in diameter; this may have been mistaken for the Mississippian Caney Shale by previous workers.”

The shale beneath the Wapanucka Limestone in the Ouachita Mountains frontal belt has been correlated with possible equivalents in the type areas in the Ardmore Basin or western Arkoma Basin. Therefore, the thick shale section exposed may include Springer Group, Union Valley equivalent, and/or the unnamed shale in the lower part of the Wapanucka Formation. The presence of the conodont *Idiognathoides sinuatus* near here (Stop 5) is evidence that little, if any, of the Springer Group is exposed.

Outcrop Description

The Bond locality consists of several relatively small exposures in two streams that are tributaries to Brushy Creek (Fig. 29). Based on the attitudes of the strata at this locality and in the vicinity and the geologic map of the Hartshorne SW quadrangle (Suneson and Hemish, 1996), the exposures are about 1650 ft below the Wapanucka Limestone and 400 ft above the Choctaw Fault. (This thickness (2050 ft) of pre-Wapanucka post-Caney shale is thicker than is present in the adjacent Arkoma Basin. It is possible that 1) unmapped faulting or folding has repeated part of the section or 2) this interval is thicker in the hanging wall of the Choctaw Fault than it is in the footwall.)

Approximately 40 ft of Morrowan shale (either Union Valley equivalent or unnamed shale in lower part of Wapanucka Formation) is exposed here (Fig. 30). Most of the section is shale; two sandstone beds are exposed. The lower sandstone (Fig. 31) is about 8 ft thick and is wavy bedded and mostly plane-parallel stratified, although one or two cross-stratified beds are present. The sandstone weathers to flagstones. The rock is a gray, calcareous, well-cemented fine-grained sandstone that contains trace amounts of glauconite. Weathering has caused the rock to have a brown appearance. The upper sandstone varies from 7 to 16 in. thick and consists of a single to poorly parted unit (Fig. 32), but it is too weathered to show any sedimentary structures. It is calcareous, fine grained, poorly sorted, and contains conspicuous glauconite and shale

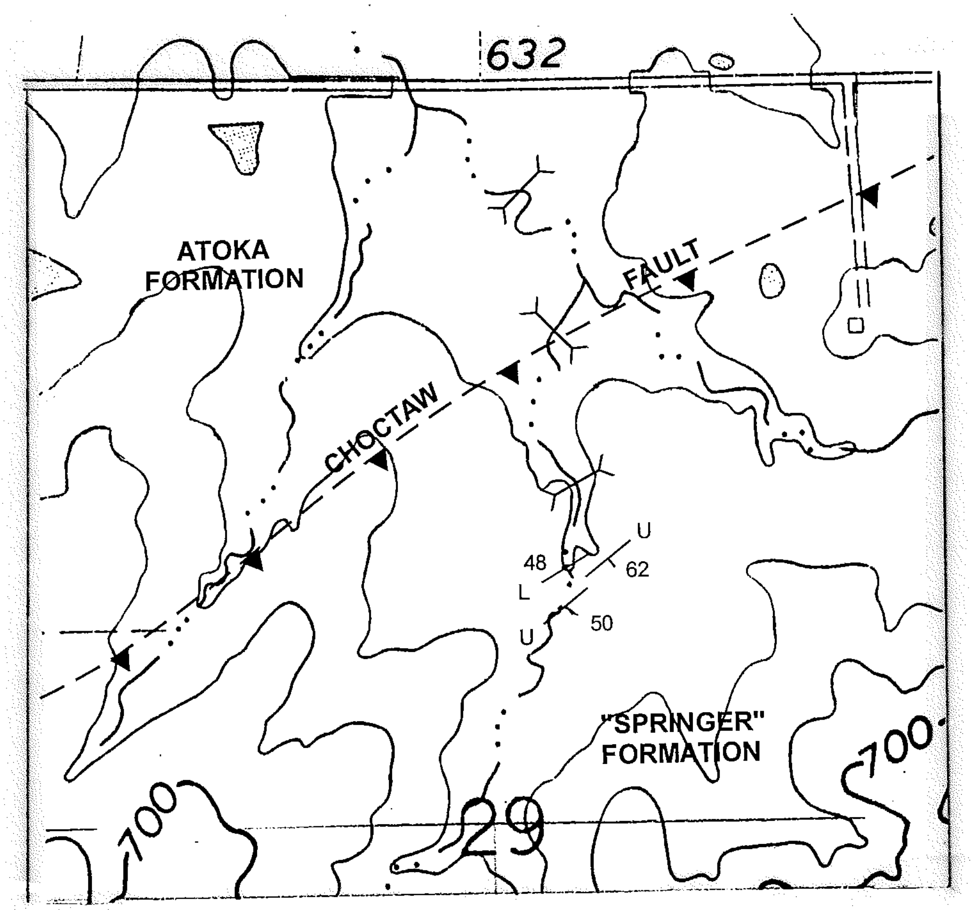


Figure 29. Geologic map of northern part of sec. 29, T. 4 N., R. 16 E., showing location of outcrops (at strike and dip symbols) that make up the Bond locality. The "bridge" symbols are rancher's roads across streams. U and L refer to upper and lower sandstone beds described in text.

rip-up clasts. The upper sandstone was identified in three places over a distance of about 400 ft; thus, it appears to be relatively continuous.

A thin sandy interval about 2 ft thick and consisting of four 1-in.-thick very fine grained sandstone beds is present about 20 ft below the upper sandstone (Fig. 30). Fissile shale separates the beds and the interval from the upper sandstone.

Little can be said about the depositional environment of the sandstone because of the limited outcrops and lack of abundant sedimentary structures. The presence of glauconite and predominance of probable marine shale in the section is strong evidence they are marine. In addition, the absence of any biostratigraphic control makes any correlation of these sandstones with the Cromwell highly suspect. Nevertheless, these are the only Morrowan sandstones I have seen in the Ouachita Mountains frontal belt.

Measured Section, Stop 4
Sandstones in Springer Group

*(**Location:** SW¼ NE¼ sec. 29,*
T. 4 N., R. 16 E., Hartshorne SW 7.5′ quadrangle)

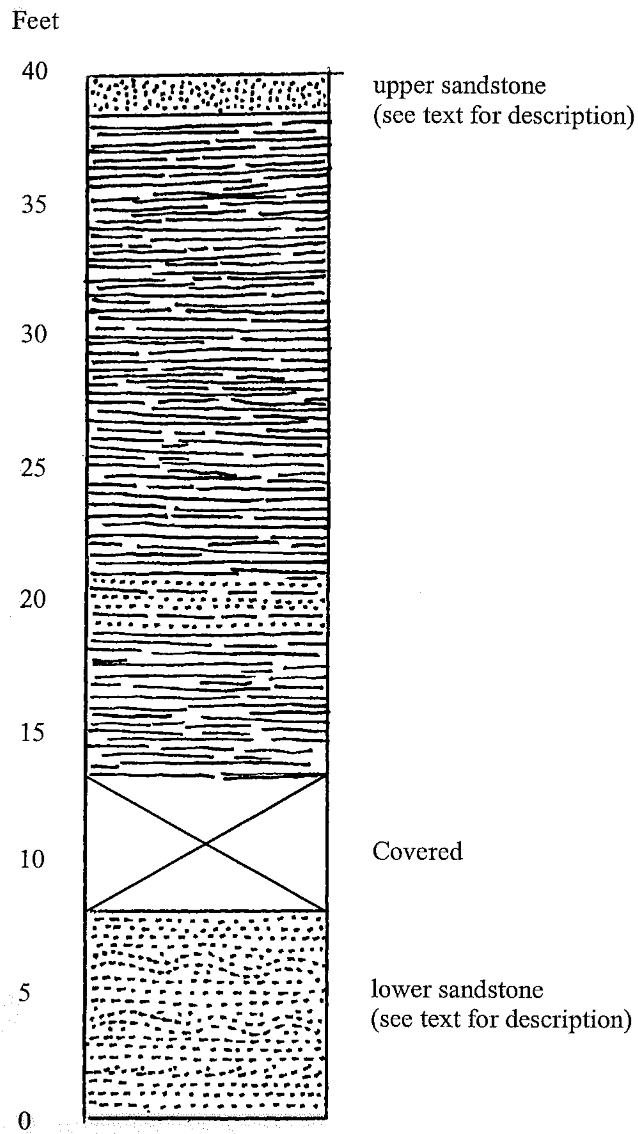


Figure 30. Graphic columnar section of strata at the Bond locality.

Return to cars and retrace route 0.5 miles to county road NS414.

18.8 0.5 Intersection of county roads EW153 and NS414. Turn left (south).

19.4 0.6 Road crosses the trace of the Choctaw Fault.

Figure 31. Lower sandstone at Bond locality. Hammer for scale (against outcrop, lower right).

Figure 32. Upper sandstone at Bond locality. Hammer for scale.

Just south of the trace of the fault and for the next 1.1 mi along the road, there are numerous outcrops of Morrowan shale that vary from poorly exposed and weathered to well-exposed and unweathered (Fig. 33). The outcrops constitute the measured section shown in figure 27. Stop 5 (Arch locality) is the best outcrop of the shale in the measured section and in this part of the Ouachita Mountains.

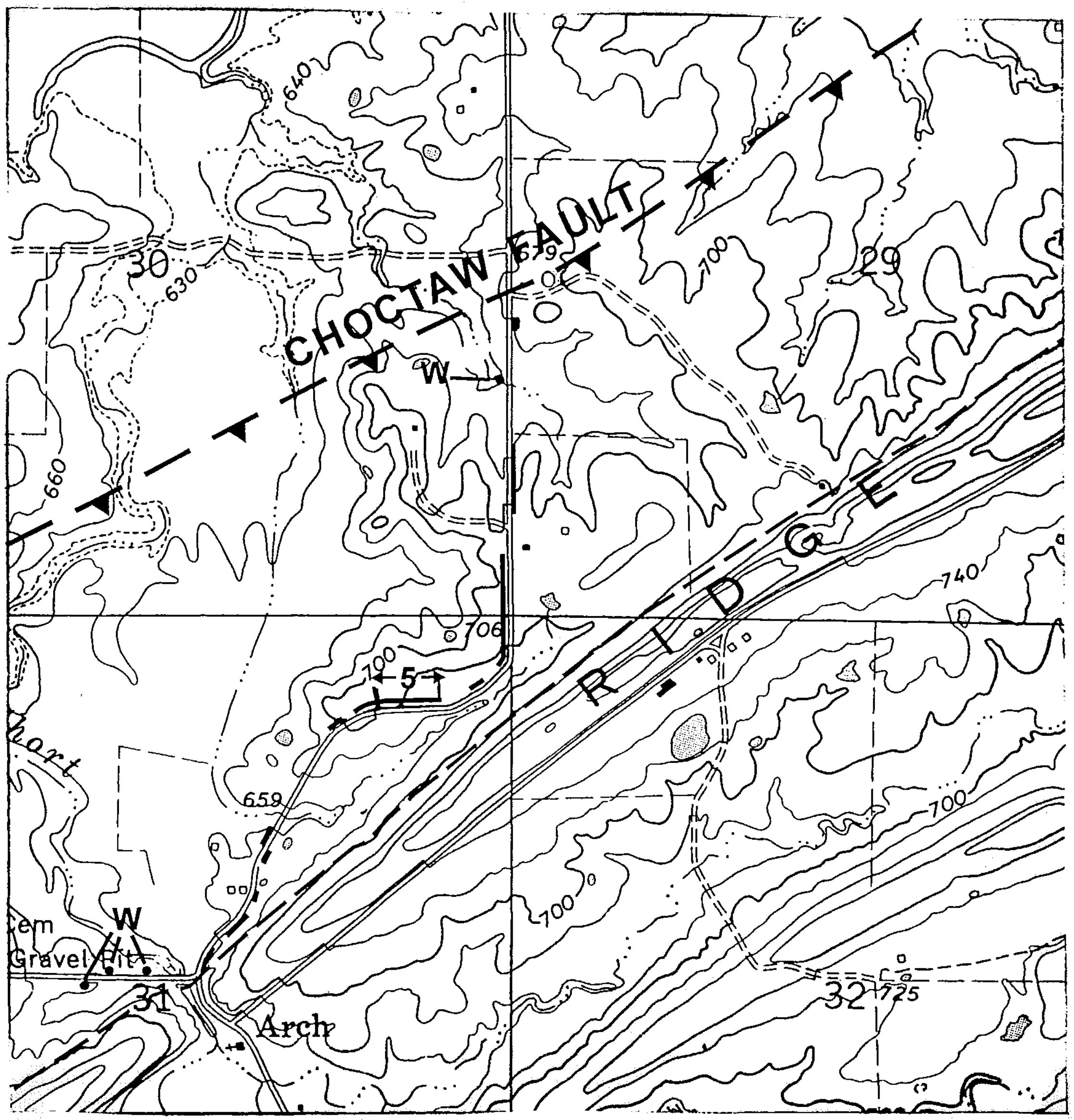


Figure 33. Map of parts of sections 29, 30, 31, and 32 near Arch, Oklahoma. Outcrops, including shaly soil, of Morrowan shale are shown as thick black lines along the side of the county road; these outcrops constitute the measured section shown in figure 27. Stop 5 on east-west segment of road is labeled. "W" indicates location of conodont-bearing samples of Whiteside (1990). Area of Stop 4 is in northeast corner of map. Dashed line on northwest side of Limestone Ridge ("Ridge" on map) is contact between "Springer" Formation of Suneson and Hemish (1996) (Morrowan shale of this report) to northwest and Wapanucka Formation underlying ridge.

20.1 0.7 Outcrop of Morrowan shale on right (north) side of road. This is Stop 5 - Arch locality.

Stop 5. Arch Locality

Location: Along east-west segment of county road about 0.5 mi north-northeast of Arch near center NE1/4 NE1/4 sec. 31, T. 4 N., R. 16 E., Hartshorne SW 7.5' quadrangle. Pittsburg County.

Introduction

The Arch "locality" is part of a long, discontinuous exposure of Morrowan shale that extends for just over a mile along a county road and consists mostly of intermittent bar-ditch exposures (Fig. 33). The Wapanucka Formation (including the overlying Spiro sandstone) is exposed at the south end of the exposure where Short Creek forms a gap in Limestone Ridge. The small "settlement" of Arch is located immediately southeast of the gap. The exposures along this road form the most complete section of Morrowan shale anywhere in the frontal belt of the Ouachita Mountains and Stop 5 is the longest least-weathered outcrop in the section.

Previous Work

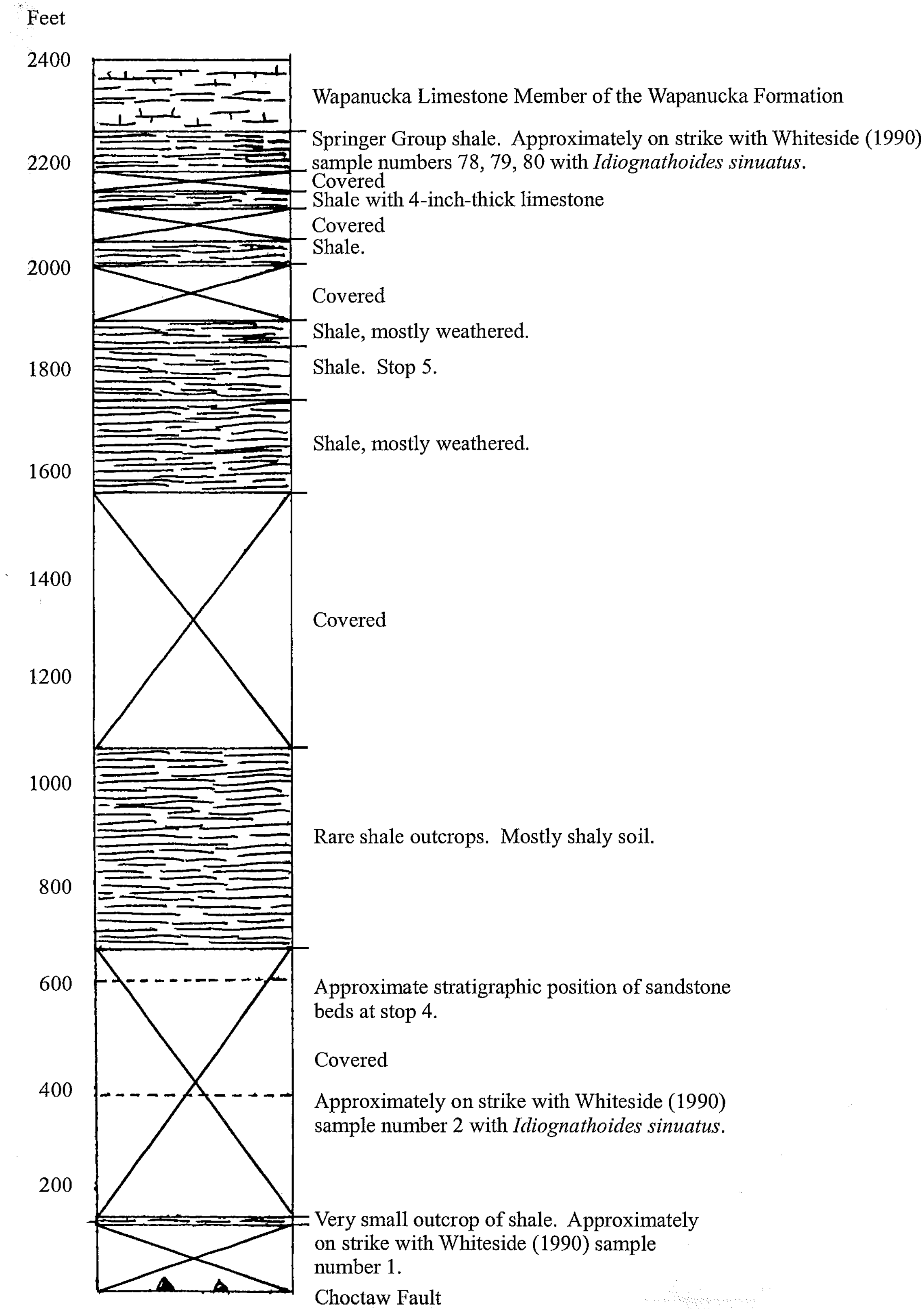
Hendricks and others (1947) and Suneson and Hemish (1996) mapped the "Springer" Formation (Morrowan shale of this report) in this area and located the trace of the Choctaw Fault in about the same place. Most of the strata dip about 65° to the southeast; assuming there are no unmapped structures between the fault trace and Limestone Ridge, the Morrowan shale at this locality is about 2300 ft thick (Fig. 34). As discussed above, however, the section may be structurally thickened or be thicker in the hanging wall of the Choctaw Fault than in the footwall.

Whiteside (1990) studied the conodont biostratigraphy of the Morrowan strata at this locality. The presence of *Idiognathoides sinuatus* in four of the five samples from which conodonts were recovered, including one sample from near the lowest part of the exposed section and three from just below the Wapanucka Limestone, are evidence that these strata are no older than the Union Valley Formation exposed at Canyon Creek (Stop 3, this guidebook). The conodont data are evidence that these strata may be equivalent to the Union Valley and the unnamed shale below the Wapanucka at Canyon Creek studied by Grayson (1990).

(following page) **Figure 34.** Measured section of Morrowan shale along county road. Stop 5 is about 1800 ft above the base of the section.

Measured Section, Stop 5
Springer Group

(***Location:*** *S½ section line between secs. 29 and 30; NE¼ sec. 31, T. 4 N., R. 16 E., Hartshorne SW 7.5′ quadrangle)*



Outcrop Description

The Morrowan shale exposed at Stop 5 is about 470 ft below the base of the Wapanucka Formation. The outcrop extends for about 150 ft on the north wide of the county road. The attitude of the strata is N60°E 65°SE. Thus, about 100 ft of shale is exposed (Fig. 34). The section is a relatively monotonous sequence of dark gray calcareous shales (Fig. 35) that are hard but splinter easily. Locally, the shales are extremely fissile. Sandstone and/or siltstone beds are absent and no fossils were observed. Despite the lack of evidence (or perhaps because of the lack of evidence to the contrary), this probably is a marine shale.

Figure 35. Morrowan shale at Stop 5.

Continue south on county road.

20.5 0.4 County road and new bridge over Short Creek to right (west). Also, this is the approximate contact between shale to the north and the Wapanucka Limestone Member of the Wapanucka Formation.

Continue straight ahead through gap in Limestone Ridge cut by Short Creek.

Grayson (1980) studied the Wapanucka Limestone (including the Spiro sandstone) in detail throughout the frontal belt of the Ouachita Mountains, but did not measure the section exposed along the county road on the east side of Short Creek. At Natural Arch, located about 2.5 mi to the southwest, Grayson (1980, p. 203-209) measured about 64 ft of Spiro sandstone (current nomenclature), 35 ft of his "middle shale member", and 248 ft of his "lower limestone member".

The Wapanucka section exposed at Arch dips 65° southeast and appears to be generally similar to that described by Grayson (1980) at Natural Arch. The following is an approximate measured section (from top to bottom):

	Spiro sandstone (Atoka Formation)
36 ft	sandstone, spiculite, limestone with chert nodules (Spiro sandstone)
	Wapanucka Limestone Member, Wapanucka Formation
32 ft	limestone and cover (possibly shale)
159 ft	limestone
106 ft	cover (probably shale) with single 2-ft-thick limestone bed
23 ft	limestone
	unnamed shale member?, Wapanucka Formation
unmeasured	shale

Compared to the section at Natural Arch, the Spiro appears to be thinner (36 vs. 64 ft); the "sub-Spiro shale" or "middle shale member" of Grayson (1980) is about the same thickness; and the main body of the Wapanucka Limestone Member (Grayson's (1980) "lower limestone member") is thicker. The total thickness of the Wapanucka Limestone plus Spiro sandstone interval is remarkably similar in both sections, however.

20.6 0.1 Road junction is the small (nay, *very* small) settlement of Arch.

Turn around at Arch, reset odometer to 0.0, and retrace route to Oklahoma Highway 63.

3.0 3.0 Intersection of county road NS414 and Oklahoma Highway 63. Continue straight ahead on county road.

Cross into the very southwestern end of the large Wilburton gas field.

Wilburton Gas Field

The Wilburton field is one of the largest natural-gas fields in Oklahoma, extending from here to near the center of T. 6 N., R. 20 E., a distance of about 30 mi. Over this distance the field varies from 2 to 8 mi wide. The Wilburton field includes the former Wilburton North, Wilburton Northwest, and Hartshorne fields. Prior to 1987, this part of the Wilburton field was the Hartshorne gas field (Burchfield, 1985), which was discovered by the Public Service Company No. 1 Craig (NE¼SE¼NE¼ sec. 9, T. 4 N., R. 16 E.) in 1941. This well discovered gasl in the Hartshorne at a depth of about 1200 to 1280 ft. In addition to the Hartshorne, the following also produce gas in the western part of the field: Red Oak, Fanshawe, Spiro, Atoka, Wapanucka, and Cromwell.

The geology of this part of the Wilburton field is relatively well-studied. Wilderson and Wellman (1993) and Valderrama and others (1996) have documented the triangle-zone geometry of this part of the Arkoma Basin and the location of many of the gas reservoirs at the leading edge of blind thrust plates. Gross and others (1995) and Forgotson and others (2000) emphasized the importance of depositional environment, diagenetic history, and thermal maturity for exploring for Spiro sandstone reservoirs. Detailed studies of the other reservoir units, however, are not published.

As of November 2002, the Wilburton field had produced about 1.9 tcf gas and was continuing to produce about 50 bcf gas annually (data courtesy IHS Energy).

3.2 0.2 Road crosses from McAlester Formation to Savanna Formation.

3.4 0.2 Hendricks (1937a) shows a small abandoned slope mine in an unnamed coal in the Savanna Formation approximately ¼ mile west of the road. The Oklahoma Conservation Commission reports that a small area (about 40 ft x 60 ft, 3 to 5 ft deep) of surface subsidence is associated with the mine.

3.9 0.5 This low ridge is a sandstone in the Savanna Formation. The next low ridge about 0.4 mi north of here with the ranch house on top (on right (east) side of road) is underlain by the Bluejacket Sandstone Member of the Boggy Formation.

4.8 0.9 Section-line road intersection (common corners of secs. 5, 6, 7, and 8, T. 4 N., R. 16 E).

The relatively flat topography is underlain by the Gerty Sand, an unconsolidated Pleistocene deposit that probably marks a former course of the Canadian River. This deposit is distinguished from Quaternary alluvial deposits by the abundance of Rocky Mountain-derived pebbles and cobbles, especially quartzite.

5.6 0.8 Road crosses over Peaceable Creek.

Hendricks (1937a, 1937b) studied the Gerty Sand throughout Oklahoma and concluded that "it is probable that the original course of the Canadian River at the time of the deposition of the Gerty Sand was down Peaceable and Brushy Creeks to (near Haileyville)" (Hendricks, 1937a, p. 31).

5.8 0.2 Road turns right (east).

6.2 0.4 Road turns left (north).

6.5 0.3 Road crosses axis of Kiowa Syncline. The low hill just to the north is underlain by southwest-dipping Bluejacket Sandstone.

7.2 0.7 Section-line road intersection. The Wilburton gas field (described above) is to the northeast; the McAlester Southeast gas field is to the northwest.

The McAlester Southeast field was discovered by the Apache No. 1 German Unit well (C SW¼NE¼ sec. 33, T. 5 N., R. 15 E.), which was completed in stray Atoka sandstones on November 15, 1965. Other productive units in the approximately 23-sq-mi field (Boyd, 2002) are the Booch, Hartshorne, Fanshawe, Red Oak, Panola, Atoka, and Wapanucka. Most of the production is from Atoka sandstones (Herndon, 2002). As of November 2002, the field had produced about 69 bcf gas and was continuing to produce about 3.8 bcf gas annually (data courtesy IHS Energy).

8.2 1.0 First of three low ridges underlain by sandstones in the Savanna Formation. Strata dip about 20° south toward the axis of the Kiowa Syncline.

8.9 0.7 Intersection of county road NS414 and Oklahoma Highway 1 / U.S. Highway 270 in small town of Bache. Turn left (west) on Oklahoma Highway 1 / U.S. Highway 270 toward McAlester.

The flat area surrounding Bache is underlain by the Gerty Sand, which overlies shale in the upper part of the McAlester Formation in this area.

On November 22, 1999, the Oklahoma Conservation Commission was notified that an area about 14 ft in diameter had subsided about 12 ft on the southwest side of Bache (Oklahoma Conservation Commission Abandoned Mine Land Reclamation Program 1999 Annual Report). The OCC determined that the collapsed area was over an old air shaft. The air shaft was for the Rock Island Improvement Company's no. 6 mine. At about this time, Unit Petroleum Company was drilling their no. 1 Krause well (surface location N½S½N½SE¼ sec. 19, T. 5 N., R. 16 E., spudded Nov. 12, completed Dec. 13). At 840 ft, Unit drilled into the mine and began to pump water out of it. The OCC believes that the removal of water from the no. 6 mine probably caused subsidence at the air shaft and at another area nearby.

For about the next five miles, Oklahoma Highway 1 / U.S. Highway 270 passes just south of a series of strip mines and over a number of underground mines in the McAlester coal (Fig. 36). The principal companies that developed the larger underground mines are the Rock Island Improvement Company and the Osage Coal and Mining Company (Hendricks, 1937a, pl. 7). The strip mines and the smaller underground mines were developed by a large number of companies (see Aldrich (1952) and Hendricks (1937a) for a partial listing). Figure 37 is a photograph of an (as yet) unreclaimed strip pit immediately north of Highway 270 about 1 mi west of Bache.

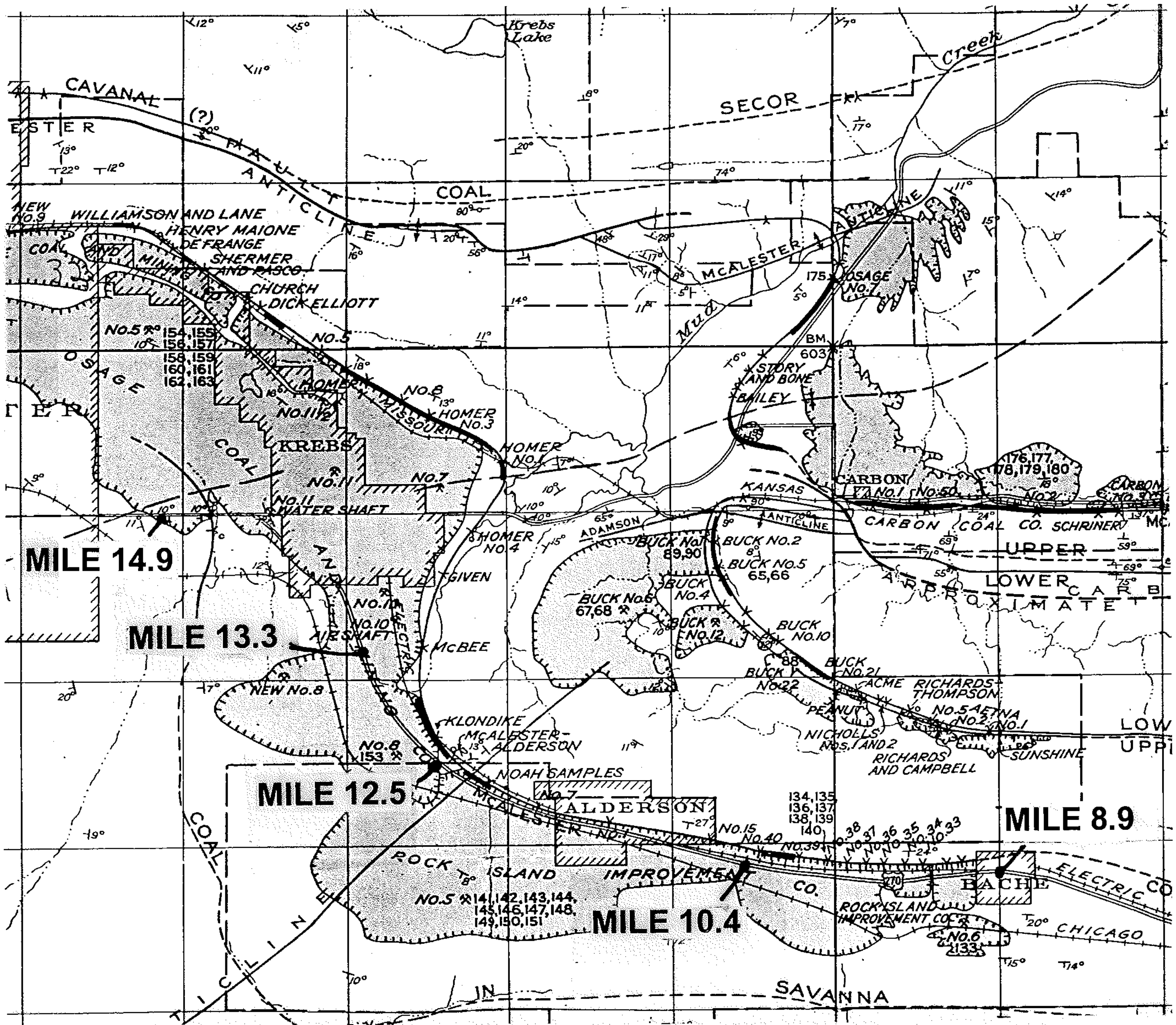


Figure 36. Map showing the location of strip and underground coal mines between Bache and Krebs, Oklahoma (from Hendricks, 1937a, pl. 7). Mileages (this field trip) also are shown.

10.2 1.3 The area immediately north of the highway is the Oklahoma Conservation Commission's Alderson-Bache Mines Problem Area. The Commission has noted that the NE¼ sec. 24, T. 5 N., R. 15 E. is prone to subsidence and that the abandoned underground and surface mines adjacent to the highway have a detrimental effect on residential, business, and industrial development.

10.4 0.2 About ½ mile north of the highway is the one-well Krebs Southeast gas field. It was discovered by the Midwest Energy 1-13 Douglass (SW¼SE¼NW¼ sec. 13,

Figure 37. Strip pit (looking east) in McAlester coal about 1 mi west of Bache, Oklahoma. Spoils piles are on the left (north); McAlester coal dips about 20° to the right (south) (Hemish, 1996).

T. 5 N., R. 15 E.), which was completed on November 25, 1991 in the Cromwell at 10,564 to 19,573 ft. As of November 2002, the field had produced about 73 mmcf gas and was continuing to produce about 4.7 mmcf gas annually (data from Natural Resources Information System).

12.5 1.9 Cross axis of southwest-trending Savanna Anticline (Fig. 20).

13.3 0.8 Intersection of highway with road (on right) to Krebs, famous (deservedly so!) for Italian food.

Krebs, Oklahoma

Early History

The following is a brief description of the early history of Krebs (from Aldrich, 1952, p. 35):

"Krebs was built in the midst of coal mines. William Pulsey (spelling corrected from original) (a Choctaw citizen) opened the first mine there in 1875 and leased it to the Osage Coal and Mining Company. In three years it grew into a thriving town with one hundred and seventy-five miners employed in the mines. Krebs became known for its production of "Choc beer". A drugstore, established there in 1888 was the scene of many emergency treatments, as the drugstore quite often served as a hospital. Vaseline was stocked in five-hundred-pound quantities, raw linseed oil in fifty-barrel lots and iodoform in ten-pound lots. The population of Krebs in 1900 was 2,300."

Krebs is the site of the worst mining disaster in Oklahoma, which occurred when the Osage Coal Mining Company mine no. 11 exploded on January 7, 1892. Ninety-six men and boys (some as young as 12 years old) were killed. They were buried in a mass grave in North McAlester. M. Snodgrass wrote a poem, "Mine No. 11 Explosion, Krebs, Indian Territory, January 7, 1892". A memorial to the victims is located 2½ blocks north of Krebs school, near the original mine entrance.

Site of Geological Interest

The Krebs Heritage Museum, located at 85 S. Main St., contains many displays featuring the many different ethnic groups that settled in the area. Of particular interest is that part of the museum that features old coal-mining equipment.

Mine No. 11 Explosion

Krebs, Indian Territory
January 7, 1892

Mrs. M. Snodgrass

A pleasant winter day had ended,
and five o'clock had blown,
the cage in safety had ascended
five time from that dark mine,
five times – six souls, its precious freight,
two hundred at the bottom wait.

Terrific as the crack of doom,
swift as the lightening's stroke
the ponderous cage shot up aloft,
followed by dust and smoke,
shocked and awed we held our breath,
and felt the air was full of death.

A moment only, then arose,
cries of horror and despair,
as if a sudden grave should close,
over all that we held dear,
for pent below, in fire and gloom,
the men were in a living tomb.

Screaming children, white faced women,
moaning, weeping, everywhere,
works are wrecked, can power of human,
reach the ones imprisoned there?
Do any live? How can we tell?
Hark! Surely some one rang the bell!

A bucket, quickly rigged to go,

swings over the black abyss.
Here comes man from down below,
was ever deed like this?
Five hundred feet! A dreary climb,
that's what I call a nerve sublime.

Yes, men are living, hoist away,
send down good men and true,
the wreckage must be cleared away,
here is work for men to do,
there is danger, yes, let brave men come,
cowards can go and hide at home.

Brave men responded to the call,
the living first we will try to save,
the dead are dead beyond recall,
the wonder, some, perhaps, will live,
burned, mangled, torn, oh, dreadful thing,
in torture slowly up they swing.

And some to the surface come,
dried shivering in the chilling air.
Oh, men, it is a cruel shame,
when life is cheap and blankets dead.
Perhaps our own death beds may be
made harder by this memory.

All night the dreadful work went on
men in mortal agony,
were on the bare, cold floor laid down
to shiver their lives away.
And oh, it seems we might have tried
to ease their suffering as they died.

So all the living were brought up,
some expired immediately,
others have lived through dreadful days
then died in awful agony.
A mercy, sure, to them had been
the sudden death down in the mine.

There were forth-three disfigured dead,
burned, blackened, some dismembered
of arms or feet, one of a head,
a sight to be remembered.
Husbands, brothers, fathers, sons,
God pity all the mourning ones.

Italians, Poles, French, and names
that are hard to spell,
Scotch, English, Irish, Dutch, Americans,
are easy names to tell.
I'll try to mention every one
who died, and who are left to mourn.

George Lindsay left three orphans small,

his wife had gone before,
A Christian man, beloved by all,
a spotless name he bore.
John Lindsay was his brother's son,
his dreadful fate for parents mourn.

Willie Russell's wife, now in despair,
mourns over his orphans three.
Father, mother, sisters, there,
make a mournful family.
And he had meant very soon to go
and leave his dangerous work below.

Tom Kain left wife and children five,
to mourn his fearful death,
they brought him to the top alive,
in agony to yield him breath,
he died, poor man, nor message left
for those beloved ones benefit.

Two weeks a bridge, a widow now,
Ted Kibble's wife may mourn.
God pity her, for youth is strong.
And life must still go on.
In days to come perhaps it will seem
husband and home were but a dream.

Shivering and mourning all that night,
Jack William's wife stayed there.
Indeed it was a piteous sight
her own and children's wild despair,
Seven years ago it was her fate,
at the pit's mouth, her dead to wait.

Poor little Joe and Jimmie Clark
were trappers down below,
a widow's sole support their work,
Jim was burned; but, Oh! Poor Joe
was killed. Indeed 'tis sad,
when children's lives are risked for bread.

Will Mitchell's death left orphans two,
a broken hearted wife,
this grief and woe with her will go,
to darken all her life.
Her children, may forget
the sorrow their young lives met.

Pat Powers left a child and wife,
Bob McConnell, wife and children two,
together had they toiled in life,
together death had laid them low.
Half brothers they, one mother's sons,
many mourn those fated ones.

Young Bennett Moss died down below,

his father burned, but yet alive.
Ed Brandon killed, poor little Joe,
with head crushed in, can scarce survive.
John Hurley's wife and children four,
mourn with his mother and sisters dear.

James, John and Mattock Quin,
a father and two sons.
Michael and Michael J. McShane
were among the fated ones.
Two wives, two mothers, in despair
nine orphans in their grief to share.

Larrie Hunts was killed below;
a wife and child remain.
Pete Collins was his brother-in-klaw,
his wife and two children mourn.
Late had he sent for them to come
from over the sea, their distant home.

Charles, George and Peter Gregory
were three Italian brothers.
Charles had a wife in Italy,
and dear friends mourn the others.
Two wives, three children, in grief and woe,
mourn the brothers Joe and Alex Corante.

James Farmer's wife sad and little ones
bewail his cruel fate,
for him she gave up friends and home,
now she is left desolate.
But not alone, as she must know
this people feel each other's woe.

Mike Kennedy was among the killed,
in distant home his brother heard
the news that over the wires thrilled.
He came, and found the fatal word
was all too true. Oh, grieving brother,
go comfort now your mourning father.

(with thanks to the Krebs Heritage Museum, Krebs, Oklahoma)

The northeast part of Krebs has been identified as the Northeast McAlester and Krebs Mine Problem Area by the Oklahoma Conservation Commission. Abandoned mine land problems include an open vertical shaft, subsidence-prone areas, and polluted water from an underground mine.

14.2 0.9 Highway passes over a low ridge underlain by the basal sandstone of the Savanna Formation.

14.4 0.2 Cross axis of the east-west trending Krebs Syncline.

14.9 0.5 Bear right onto ramp leading to U.S. Highway 69 north to Muskogee. Reset odometer to 0.0 Highway 69 here is on the east side of McAlester.

McAlester, Oklahoma

Early History

McAlester, Oklahoma was "founded" by James J. McAlester, who established a tent store at the intersection of the Texas Road and the California Road in late 1869 or early 1870 (Aldrich, 1952). (The Texas Road was a major early route used by "hunters, trappers, explorers, traders, emigrants to Texas, cattlemen, freighters, and military detachments" (Fugate and Fugate, 1991, p. 1) between Missouri and Texas. The California Road, first used in 1849, was a principal route to the California goldfields.) In 1872 the Missouri, Kansas, and Texas railroad reached the store and a year later a post office at "McAllister" was established. (The spelling was changed to McAlester in 1885.) In 1889, the Choctaw Coal and Railway Company asked J.J. McAlester for $10,000 to build their railroad to intersect the MK&T at his store, but he refused. As a result, the railroads intersected about 1½ miles south of McAlester and a large townsite called South McAlester was laid out. Business boomed and by 1891 300 people lived there (Aldrich, 1952). In 1899, McAlester (North Town) and South McAlester incorporated as cities; in 1906 they consolidated into one city (McAlester) but maintained separate post offices (McAlester and South McAlester). And in 1907 the South McAlester post office became McAlester and the McAlester (North Town) post office became North McAlester.

Sites of Geological Interest

McAlester was the one of the centers of southeastern Oklahoma's coal mining industry and four sites in town recognize the miners. The Pioneer Coal Miner Memorial (400 Block, S. Third at Chadick Park) is a life-sized bronze statue and "Wall of Memories" that pays tribute to the thousands of miners who labored in the mines in the McAlester area, and especially to those who lost their lives in their work. The names of more than 1,700 miners who were killed in the pursuit of their trade over a 100-year period are inscribed on the wall. The McAlester Coal Miner's Museum (in McAlester Foundation Building, 200 E. Adams, Room 209) contains coal mining displays, equipment, and photographs. The Mine Rescue Station Building (507-509 E. Third St.) is listed in the National Register of Historic Places. Originally constructed in 1910 by the Coal Operator's Association, it was bought by the U.S. Bureau of Mines in 1914 to be used as a mine rescue station and to train safety personnel. At one time the building included a wing that was used as a "mock mine" that was filled with dust and gas to simulate a mine accident to train rescuers. Mount Calvary Cemetery contains the mass grave of 24 Mexican miners who were killed in the December 17, 1929 explosion at Old Town Company's Little Bolen Mine in North McAlester. 61 of 66 miners working in the mine at the time of the explosion were killed; and 32 of them were Mexican, including five sets of brothers. 250 surviving family members received $70,000 from around the country after an appeal by Will Rogers and an additional $10,000 from the Mexican government.

0.2 0.2 Merge onto U.S. Highway 69 north.

0.9 0.7 Highway descends a gentle north-facing slope capped by the basal sandstone of the Savanna Formation and underlain by the McAlester Formation.

2.2 1.3 Highway passes through a low ridge of Upper Warner Sandstone Member of the McAlester Formation.

2.4 0.2 Cross trace of Penitentiary Fault (Fig. 20), a south-dipping high-angle reverse fault that in this area juxtaposes gently southwest-dipping McAlester Formation in the hangingwall on the south against almost vertical upper Savanna Formation in the foot wall on the north.

Immediately north of the Penitentiary Fault, enter the McAlester East gas field, which was discovered in 1949 by the Intex No. 1 Welsh Unit located in C NW¼SW¼ sec. 35, T. 6 N., R. 15 E. The discovery unit is a sandstone (Okpen sand reported to Oklahoma Corporation Commission) in the Atoka Formation about 1170 ft deep. The Hartshorne and Red Oak also are productive in the field.

As of November 2002, the field had produced about 1.5 bcf gas and was continuing to produce about 115 mmcf gas annual (Data Courtesy IHS Energy).

2.9 0.5 The long (uphill) slope is underlain by shale in the Boggy Formation. The basal Bluejacket Sandstone Member is thin and poorly exposed near the base of the slope; the top is underlain by a thick sandstone (Pb4 of Hemish (1996)) in the Boggy Formation.

4.2 1.3 Cross axis of Talawanda Syncline (Fig. 20). Highway still underlain by sandstone Pb4 in Boggy Formation. Hemish and Suneson (1997, p. 40-42) described an exposure of this sandstone in a quarry just west of the highway.

4.9 0.7 Highway descends topographically and stratigraphically into poorly exposed shale beneath Pb4.

5.4 0.5 Pass under bridge for Oklahoma Highway 113. For the next several miles, U.S. Highway 69 passes along the west side of Lake Eufala.

The highway here runs through the eastern part of the small (one-well) McAlester Northeast gas field, discovered in 1974 by the Xplor No. 1 Cole. The producing formation is the Booch sandstone at a depth of about 2030 ft.

6.4 1.0 Highway crosses the axis the east-west-trending Flowery Mound Anticline (Fig. 20) with Savanna Formation exposed about 1 mi to the east. Several small old and abandoned slope mines in the Secor coal are present about 500 ft above the base of the Boggy Formation about 0.5 mi east of the highway. As part of its Abandoned Mine Land program, the Oklahoma Conservation Commission identified one hazard in the area – an open (in 1980) and partly subsided entrance (6 ft x 8 ft x 8 ft deep) to one of the slope mines.

Reams Southeast Gas Field

The Reams Southeast gas field is just east of the highway and coincides with the surface expression of the Flowery Mound Anticline. Brooks (1963, p. B171) calls this the Fish Creek field and states that the discovery well is the Choctaw Natural Gas Co. No. 1 Short, located in SW¼SW¼NE¼ sec. 1, T. 6 N., R. 15 E., and completed in July 1915 in the Hartshorne sandstone at 1920 to 2120 ft. Brooks (1963) (possibly based on Dane and others (1938)) also notes that "the discovery well is reported to have furnished gas to the town of McAlester for *several* (my emphasis) years before being abandoned" (p. B171).

The Nomenclature Committee of the Oklahoma Corporation Commission lists the discovery well of the Reams Southeast field as the M.M. Schene No. 1 John C. Schudel, which was completed in the Hartshorne (1958 to 2188 ft) on February 23, 1943. Interestingly, the Schudel well is located in the same 10-acre parcel as the Short well. It appears that the Short well was drilled in 1915, briefly produced gas from the Hartshorne, and was abandoned and perhaps "forgotten" until 1943, when it was twinned by the Schudel well, which "re"discovered gas in the Hartshorne.

In addition to the Hartshorne, the Booch, Spiro, and Cromwell also are productive. As of November 2002, the Reams Southeast field had produced about 38 bcf gas and was continuing to produce about 850 mmcf gas annually (data courtesy IHS Energy).

7.4 1.0 The hills west of the highway are capped by a sandstone in the Boggy Formation (sandstone no. 4 of Dane and others, 1938); the slopes are underlain by shale in the Boggy Formation. (Note that Boggy sandstone Pb4 of Hemish (1996) is not the same as Boggy sandstone no. 4 of Dane and others (1938). Based on a comparison of the edges of the geologic maps, sandstone no. 4 is equivalent to Pb6.)

9.5 2.1 Pass under bridge for Coal Creek Road.

10.2 0.7 Near center of small (one-well) Mekko Northeast gas field, discovered in 1998 by the Sooner Trend Petroleum Co. No. 1-22 Hooser. The well was completed in an Atoka sandstone at a depth of about 1490 ft.

11.9 1.7 Boggy sandstone (no. 5 of Dane and others, 1938) is on top of hill to west overlying excellent outcrop of interbedded Boggy sandstone, siltstone, and shale.

The capping sandstone (no. 5 of Dane and others, 1938) may be equivalent to Boggy sandstone Pb4 of Oakes and Koontz (1967) and thus would be above the Inola Limestone Member of the Boggy Formation. If this correlation is correct, the capping sandstone may be equivalent to the subsurface Red Fork sandstone (e.g., Andrews, 1997).

12.4 0.5 Pass under bridge for Rock Creek Road and Crowder Point Recreation Area.

12.7 0.3 Excellent outcrop of sandstone outcrop in Boggy Formation across water on right (east). Note that the outcrop forms a small anticline.

Reams Northwest Gas Field

Immediately to the left (west) is the eastern end of the large Reams Northwest gas field, which extends from here to the western edge of T. 6 N., R. 13 E., a distance of about 18 mi. At its widest point, the field is about 6 mi wide. The Reams Northwest field was discovered in 1963 by the Steve Gose No. 1 White located in the center NE¼SW¼ sec. 5, T. 7 N., R. 15 E.

Pipes (1980, p. 25) lists the Cromwell as the reservoir rock and states that the field "is on a small Cromwell structure and is cut by several faults (Fig. 38). Most of the production is structurally controlled, but porosity is probably facture controlled, as some of the better wells are close to faulted areas. With 18 producing wells [as of 1980], three have been dually completed, two in the Spiro and one in the Wapanucka Lime." In addition to the units reported by Pipes (1980), the Savanna, Booch, Hartshorne, and Atoka also produce gas in the field. As of November 2002, the Reams Northwest field had produced about 67 bcf gas and was continuing to produce about 2.2 bcf gas annually (data courtesy IHS Energy).

Figure 39 shows the log character of the Cromwell Sandstone in the northeast corner of the Reams Northwest gas field near the field-trip route. The Cromwell (6365 ft to 6644 ft) consists of six sand-rich intervals, all of which exhibit an irregular profile on the gamma-ray log. Some of the intervals coarsen upward (e.g., interval about about 6500 ft); others have a relatively abrupt base (e.g., that at 6640 ft). Most of the sand-rich intervals have abrupt tops – they do not grade into finer-grained rocks. The irregular, coarsening-upward gamma-ray profile is typical of offshore bars. The close association of this profile with profiles that exhibit an abrupt base are evidence that they characterize a similar depositional environment (marine bar or sand ridge) that differs only in detail – whether initial depositon was associated with strong currents (e.g., storm) or more "normal" ("less dramatic") marine processes.

14.9 2.2 Pass under bridge just beyond Crowder exit.

16.7 1.8 Siltstone and shale in Boggy Formation, within Boggy sandstone no. 5 of Dane and others (1938) (equivalent to Red Fork?).

17.8 1.1 Cross section A-A' of Andrews (2003, pl. 4) crosses field trip route. Highway 69 passes between localities 7 (Arkla 1 McKay) and 8 (Andress 2 Searcy) on that cross section.

18.0 0.2 Pass over bridge for Oklahoma Highway 113 to Canadian.

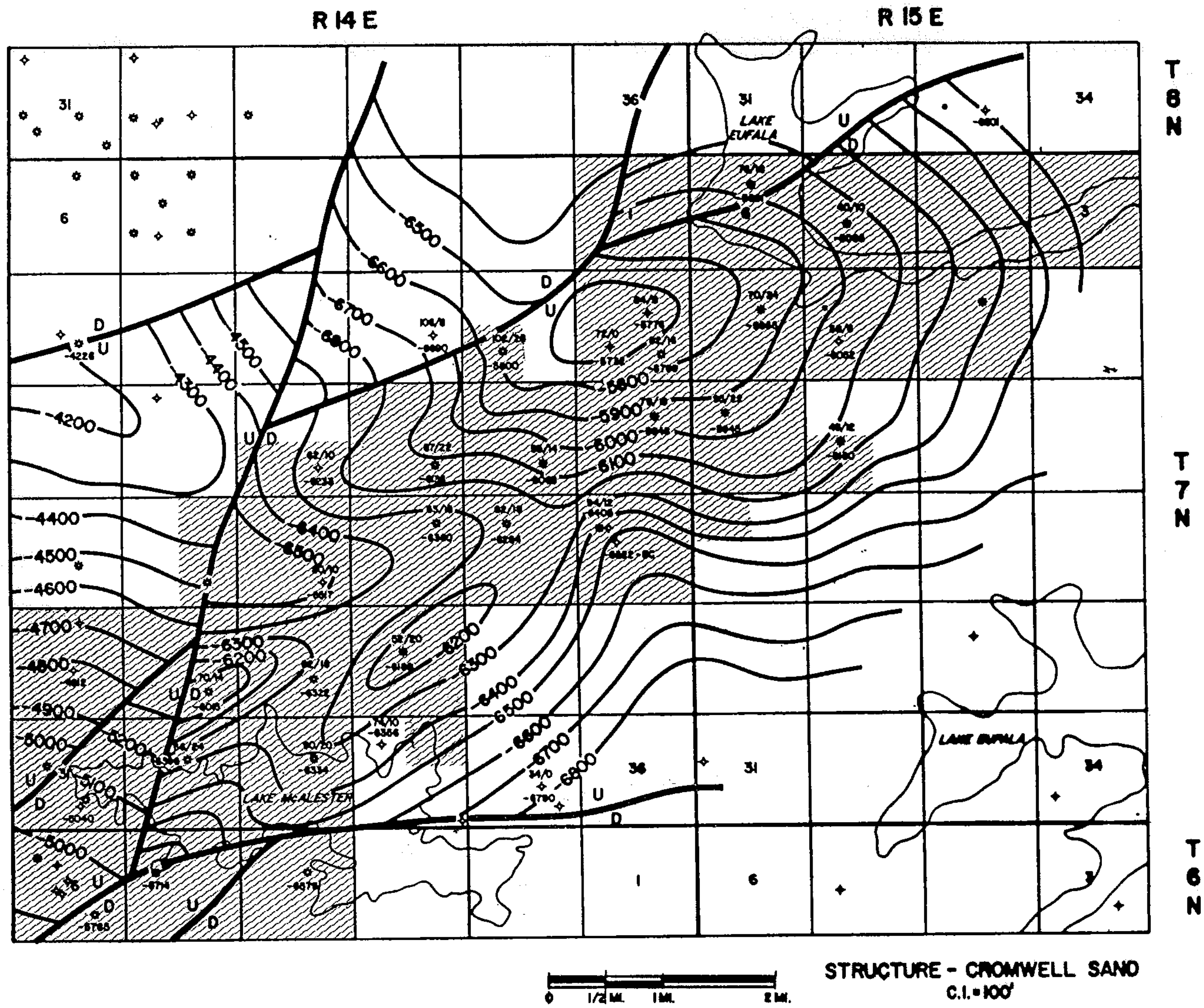


Figure 38. Structure contour map on top of Cromwell sandstone, Reams Northwest gas field (patterned area) (from Pipes, 1980, p. 26). Mile 12.7 is in the SW¼ sec. 2, T. 7 N., R. 15 E., just off the upper right side of the map.

18.2 0.2 Black marine shale with abundant brachiopods in Boggy Formation immediately adjacent to on-ramp on right (east). Shale is overlain by Boggy sandstone no. 6 of Dane and others (1938).

Canadian Gas Field and Canadian Coalbed Methane Field

The town of Canadian is near the center of the Canadian gas field, which is partly coincident with the Canadian coalbed methane field. Both fields extend about 15 mi in a northeast-southwest direction. The Canadian field was discovered in 1978 by the

Ancon 1-3 Collier
Reams Northwest Field

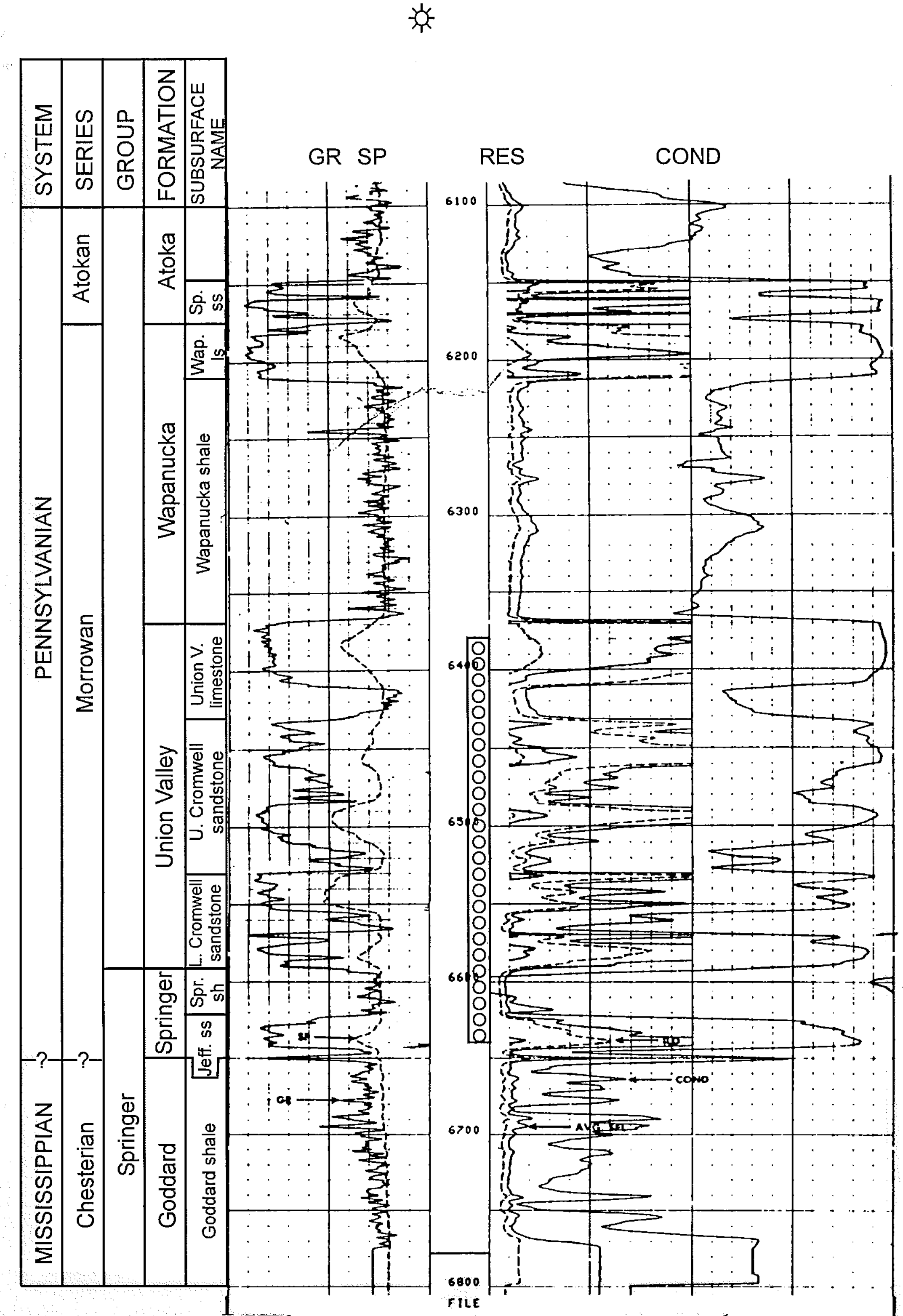


Figure 39. Part of electric log from Ancon Energy Co. No. 1-3 Collier (C N½SW¼ sec. 3., T. 7 N., R. 15 E., Reams Northwest field). Cromwell Sandstone occurs from 6430 to 6592 ft and consists of six sand-rich intervals, most of which coarsen upwards and have abrupt tops. The well produces gas from the Cromwell and Wapanucka.

Glenco Petroleum 12-1 Montcrief which is located in the SW¼NE¼SE¼ sec. 12, T. 8 N., R. 15 E. (Disney (1960), however, lists the field as having been discovered in 1926.) The principal producing formation in the field is the Cromwell Sandstone; other producing formations are the Savanna, Booch, Hartshorne, Gilcrease, Wapanucka, and Jefferson.

Development of the Canadian coalbed methane field began in 1995 and continues to the present. It consists of about 45 wells (Brian J. Cardott, personal communication, 2002) all of which produce gas from the Hartshorne coal at depths ranging from about 1950 ft to 3250 ft. Many of the wells in the field are horizontal. Biddick (2000) has mapped a northeast-trending anticline at the Hartshorne level near the center of the field, located about 1 mi north of here.

As of November 2002, the Canadian field had produced about 122 bcf gas and was continuing to produce about 3.2 bcf gas annually (data courtesy IHS Energy). These figures include coalbed methane.

Electric logs of the Cromwell Sandstone in the Canadian field may exhibit profiles that are dissimilar even for wells that are close to each others and that are atypical of marine bars or sand ridges. Figures 40 and 41 are from wells that are about 4500 ft apart; the only similarities of the Cromwell in each well are that it is about the same thickness (140 ft) and shows a fining-upward profile. The Cromwell Sandstone in the Samson 1 Hearod (Fig. 40) has a sharp base, little interbedded shale, and is divided into two approximately equal sand-rich intervals. The Cromwell in the Agate 1-4 Hightower (Fig. 41) contains much interbedded shale, is divided into a thin lower sandstone (4675 to 4685 ft and a thick upper sandstone-rich interval (4545 to 4660 ft), and has an abruptly coarsening-upward base (upper interval only). The relatively sharp base of the Cromwell in these wells is evidence that strong marine currents (e.g., storm) were active during deposition. The lack of shale in the Hearod well compared to that in the Hightower suggests that the latter may be marginal t the main part of the bar. Alternatively, the blocky sandstone with the sharp base in the Hearod (Fig. 40) may be a filled submarine channel eroded into the bar, which is better characterized by the Hightower profile (Fig. 41).

19.6 1.4 Cross section C-C' of Andrews (2003, pl. 6) crosses field-trip route. The highway passes between localities 7 (KWB 1 Orbison) and 8 (Questar 3 Brown) on that cross section.

21.4 1.8 Exit for Oklahoma Highway 9A. Stay on Highway 69.

22.5 1.1 Pass over bridge over large arm of Lake Eufala. Leave Pittsburg County, enter McIntosh County.

24.2 1.7 The sandstone exposed along the lakeshore at the north end of the causeway over Lake Eufala is Pb-5 (Oakes and Koontz, 1967), the fifth highest of six

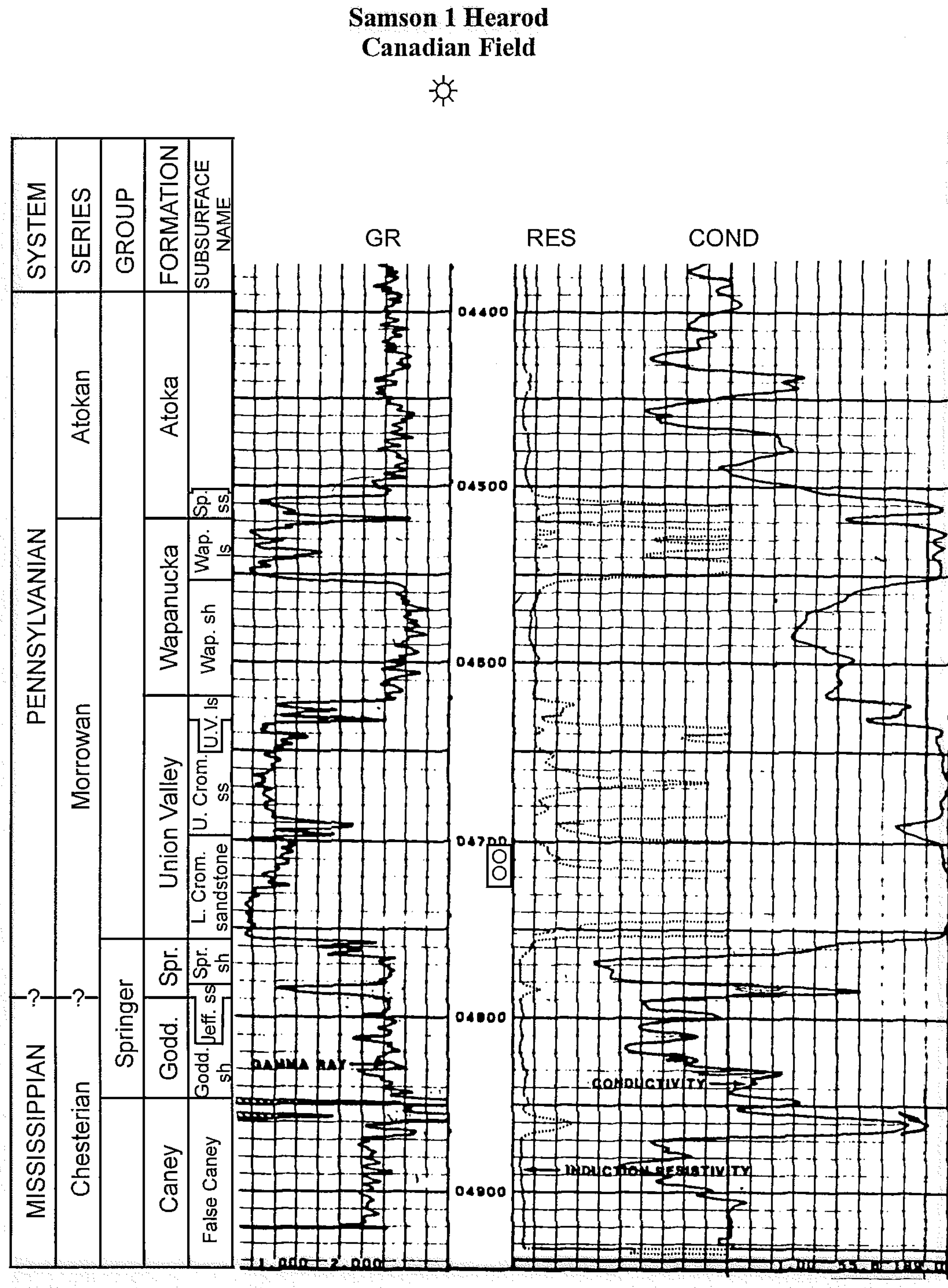


Figure 40. Part of electric log from Samson Resources Co. No. 1 Hearod (SW¼NW¼SE¼ sec. 5, T. 8 N., R. 16 E., Canadian field). The blocky gamma-ray profile of the Cromwell Sandstone is not typical of marine bars or sand ridges. The well produces gas from the Cromwell and Hartshorne.

Agate 1-4 Hightower
Canadian Field

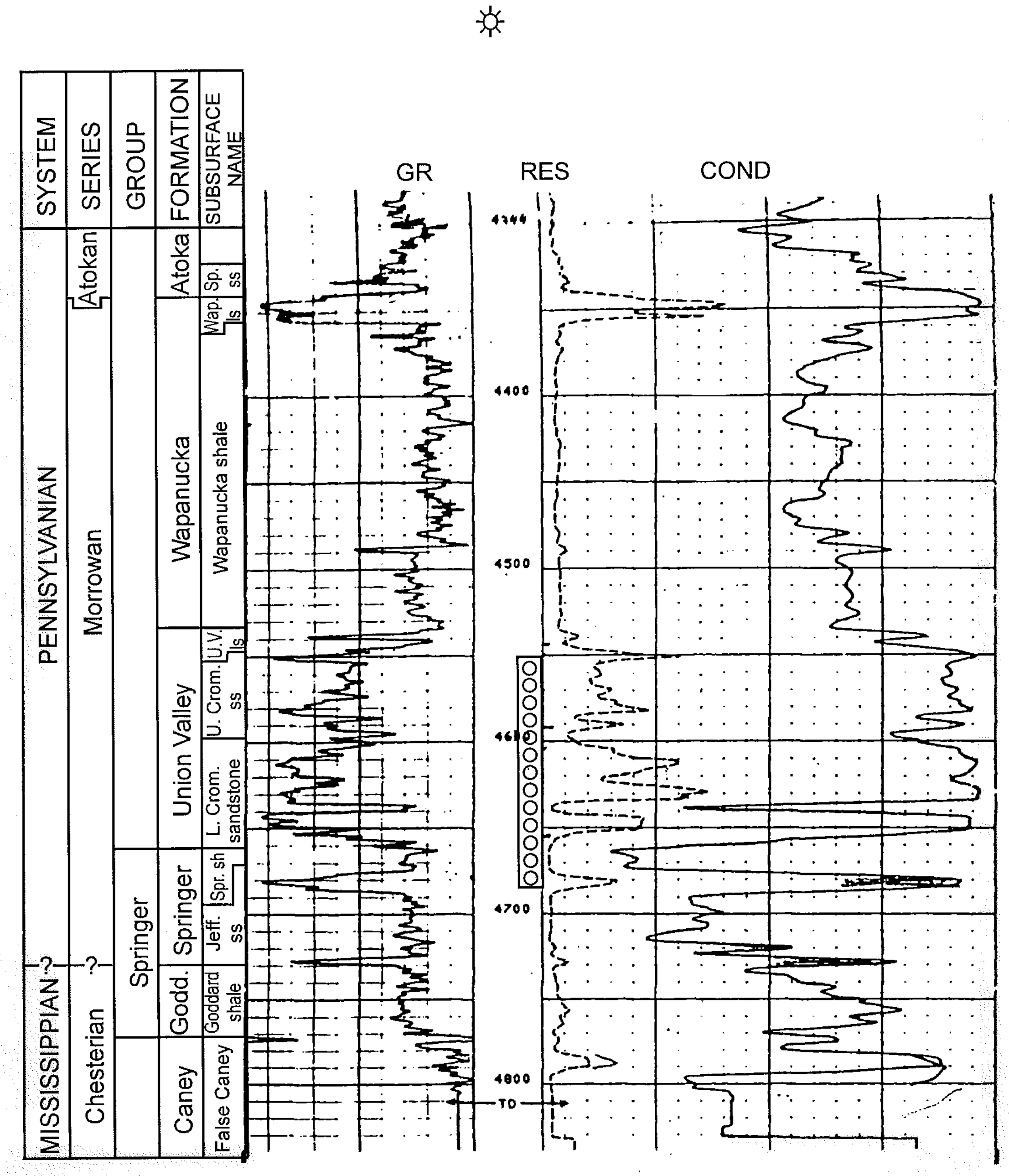


Figure 41. Part of electric log from Agate Petroleum No. 1-4 Hightower (SE¼NW¼NW¼ sec. 4, T. 8 N., R. 16 E., Canadian field). The Cromwell Sandstone has an irregular and fining-upward profile. The well produces gas from the Cromwell and Savanna.

mostly discontinuous sandstones in the Boggy Formation. This sandstone (Pb5) may be equivalent to Boggy sandstone no. 6 of Dane and others (1938) (see mile 11.9). Oakes and Koontz (1967) show the Inola Limestone Member beneath this sandstone; thus, it probably is equivalent to the subsurface Red Fork sandstone.

25.7 1.5 Pass under bridge for Business Route 69 into town of Eufala.

26.4 0.7 At the top of the hill highway passes through Pb-6, the uppermost Boggy sandstone. Pb-6 is preserved in the axis of the Porum Syncline, which trends approximately east-west just south of the town of Eufala.

The Boggy strata here appear to consist of two marine shale sequences separated by several crevasse-splay (delta-plain) sandstones. If this interpretation is correct and there are no delta-front deposits present in the outcrop, the upper and lower boundaries of the delta-plain sequence are unconformities.

27.8 1.4 Bridge over Oklahoma Highway 9. Town of Eufala is to the right (east). The junction of the Canadian and North Canadian Rivers is submerged beneath Lake Eufala about 3 mi east of the town.

Much of the relatively flat terrane for the next 2.5 miles overlies Pleistocene terrace deposits of the North Canadian River.

30.6 2.8 Pass over bridge over large arm of Lake Eufala. This arm drowns the North Canadian River.

32.9 2.3 Pass over bridge over Oklahoma Highway 150.

Highway 69 passes through small (1.25-sq-mi) Onapa Southwest oil and gas field at this point. The field was discovered in 1981 by the Santa Fe Energy No. 1 Chase (C NE¼SW¼ sec. 2, T. 10 N., R. 16 E.); production is from the Gilcrease sandstone.

34.6 1.7 Spoils pile visible to right (east) of highway. Youngman Rock, Inc. is quarrying Boggy sandstone Pb-3b (Oakes and Koontz, 1967) (Fig. 42). The quarry covers most of the W½ sec. 31, T.11 N., R. 17 E.

35.3 0.7 Immediately to right (east) of highway is small strip mine in the Secor Rider coal. The area has been reclaimed and there is little surface evidence for the mine.

The mine is the BBV No. 1 Mine operated by Blevins, Burdett, and Vogt Company. The Oklahoma Department of Mines issued a permit to mine about 15 acres in January 1981 and the company began mining the Secor Rider coal (about 9 in. thick) shortly afterwards. The company estimated about 13,000 tons of coal could be recovered on the property. Mining had ceased by August 1982 and all reclamation activity had ceased by 1986.

35.9 0.6 Pass under bridge for road to town of Onapa, which is located near the axis of the east-west trending Onapa Syncline (Hemish, 1998).

Figure 42. A. Overview of Youngman Rock quarry about 1 mi south of Onapa, Oklahoma.

Figure 42. B. Close-up view of Boggy sandstone Pb3b of Oakes and Koontz (1967) in Youngman Rock quarry.

36.2 0.3 Small mined-out area immediately to left (west) of Oklahoma Highway 69 (Fig. 43).

Figure 43. Reclaimed area in NE¼SE¼SE¼ sec. 24, T. 11 N., R. 16 E. This was the site of an active strip mine in the Secor and Secor Rider coals in 1983.

The mine is the B and V Mine No. 2 operated by the Blevins and Vogt Coal Company. The Oklahoma Department of Mines issued a permit to mine this area and an adjacent area about .75 mi to the north-northwest (total of both areas – 34 acres) in November 1981 and mining of the Secor Rider coal (reported by the company to be about 12 in. thick) began shortly afterwards. The mine was active in 1983 when Hemish (1998) measured two sections in the highwall and determined that the Secor (0.8 ft thick) and Secor Rider (0.5 ft thick) coals were present and separated by about 15 ft of shale and siltstone. In January 1985 the company forfeited some of their reclamation bond money and a different company was contracted in 1987 to finish reclaiming the mined-out area. They failed to complete the work and a third company was contracted. The area was completely reclaimed to the satisfaction of the Oklahoma Department of Mines in March, 1991.

This was an active strip mine operated by Blevins-Vogt Coal Company in 1983 when Hemish (1998) measured two sections in the highwall. The Secor (0.8 ft thick) and Secor Rider (0.5 ft thick) coals are present and separated by about 15 ft of shale and siltstone. The area has been reclaimed (Fig. 43).

37.6 1.4 Cross trace of the North Fault that, to the east, forms the north flank of the Warner Uplift (Fig. 44). (See mile 6.9, below.)

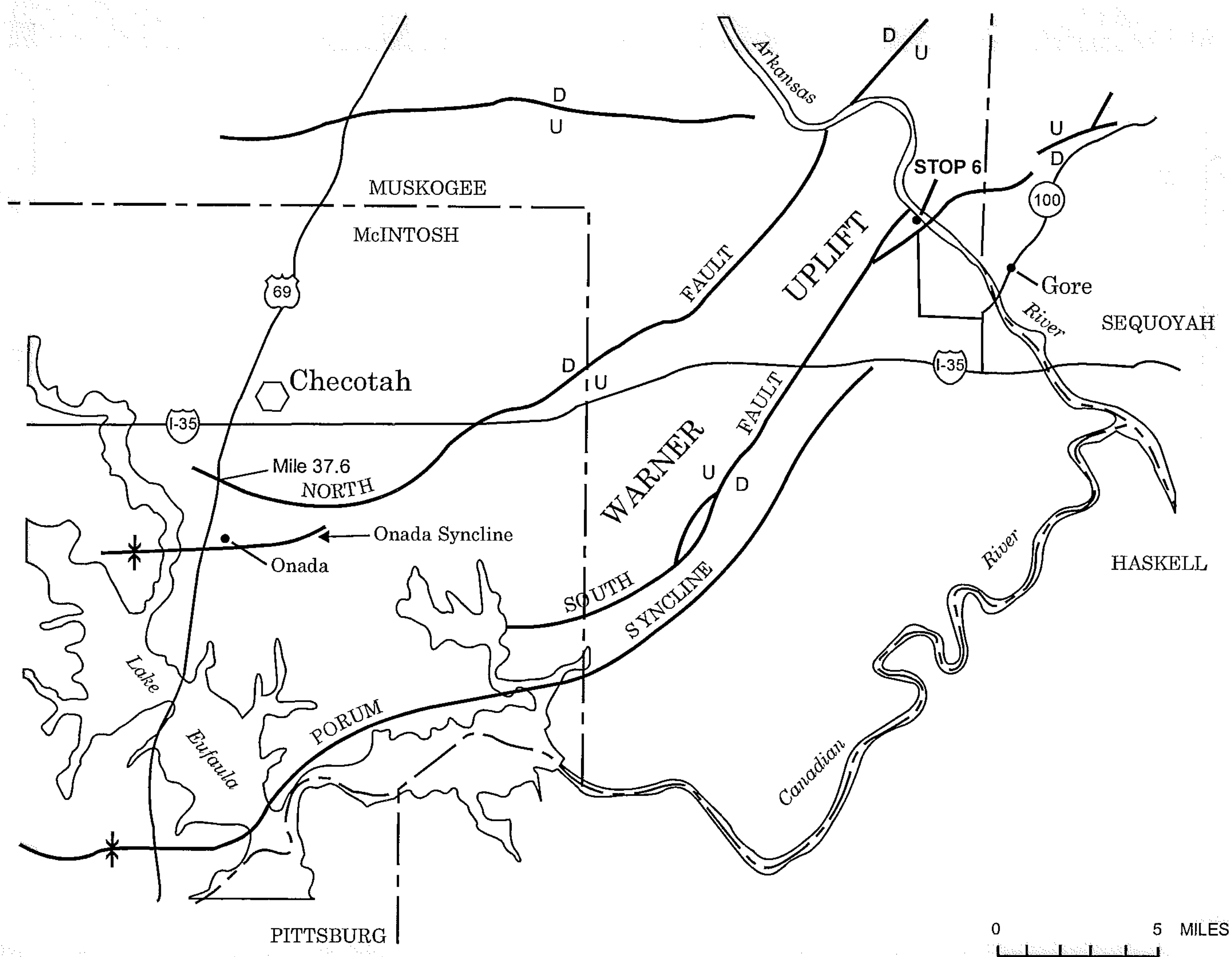


Figure 44. Generalized tectonic map of northern part of Arkoma Basin and southwestern part of Ozark Uplift near field-trip route. Major structures and features referred to in text are shown.

The highway also crosses an arm of the Checotah gas field. The field was discovered in 1919 by the Graham Brothers No. 1 Robinson well located in the NW¼NW¼ sec. 17, T. 11 N., R. 17 E (Oakes and Koontz, 1967, p. 57). This well and five subsequent nearby wells produced gas from the Booch and Atoka sandstones; Oakes and Koontz (1967) reported all the wells as abandoned. The field was "rediscovered" by the Palmer No. 34-6 Storm well in NW1/4 sec. 11 N., R. 17 E., completed on March 11, 1977 in the Booch sandstone. The field also produces gas from the Spiro and Cromwell sandstones.

As of November 2002, the Checotah field had produced about 5.6 bcf gas and was continuing to produce about 140 mmcf gas annually (data courtesy IHS Energy).

39.2 1.6 Bear right off of Oklahoma Highway 69 and onto Interstate 40.

39.6 0.4 Merge with Interstate 40.

40.2 0.6 Interstate passes over old Oklahoma Highway 69 (exit 265) and Missouri – Kansas – Texas railroad. Reset odometer to 0.0.

1.3 1.3 Bridge over Elk Creek.

There is a small pit in the Peters Chapel coal about 1000 ft north of the interstate on the east side of Elk Creek. The Peters Chapel coal is a locally thick (as much as 2.2 ft) coal in the Boggy Formation about 50 ft above the Secor Rider coal. The coal has not been mined recently probably because it has a high ash and sulfur content (Hemish, 1998).

2.4 1.1 Bridge over interstate. Enter small unnamed gas field. Cross outcrop of Inola Limestone Member of Boggy Formation.

4.4 2.0 Bridge under Texanna Road (exit 270).

5.3 0.9 Strip pits.

The northeast end of a 1-mi-long strip mine is immediately south of the interstate. This mine was operated by Inter-Chem Coal Company (Fig. 45) who received a permit to mine 190 acres in sec. 6, T. 11 N., R. 18 E. and secs. 1 and 12, T. 11 N., R. 17 E. from the Oklahoma Department of Mines in July 1987 and began mining shortly afterwards. The company planned to mine coal to a depth of about 60 ft. Mining was reported to the ODM to have been completed in September 1988, although Hemish (1998) reported that the last production from the mine was in 1990 when 46,692 tons of Secor coal was produced. Section 12 was not mined. Hemish (1998) measured 0.5 ft of Secor Rider and 1.0 ft of Secor coal, separated by 18 ft of underclay and shale.

As is typical of most modern strip mines, reclamation was concurrent with and followed mining. Most of the reclamation work consisted of sediment control and reseeding. In January 1996 all of Inter-Chem's reclamation bond money was released.

Just north of the interstate is a large area of strip mines in secs. 29, 31, and 32, T. 12 N., R. 18 E., and sec. 5, T. 11 N., R. 18 E. This area was mined from 1952 to 1961 by the Level Coal Company and later the Magic City Coal Company (Friedman, 1978). The Burdett Company briefly mined a small area near U.S. Highway 266 starting in 1977. The average annual production of Secor coal, which is about 2.5 ft thick in the area (Hemish, 1998), during the period 1952 to 1961 was 178,429 tons. The coal is

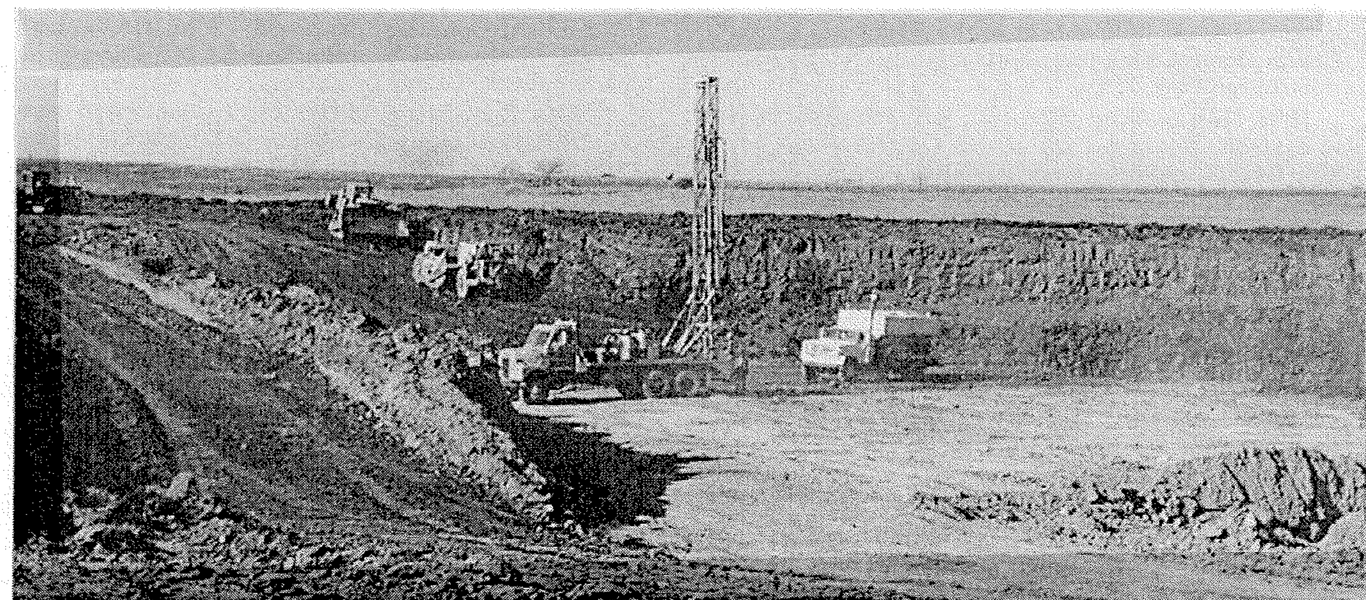


Figure 45. (from Hemish, 1998, fig. 8). The Inter-Chem #2 Mine in the SW¼NE¼NE¼SW¼ sec. 6, T. 11 N., R. 18 E., McIntosh County, in January 1988. Coal was being produced from the 1.0-ft-thick Secor coal bed, although the company reported that it planned to mine the Secor Rider coal.

high-volatile C bituminous and contains 3-4% sulfur. The area is being reclaimed (Fig. 46).

Figure 46. Reclamation of strip pit in Secor coal, SW¼SW¼SW¼ sec. 32, T. 12 N., R. 18 E. Photograph was taken on December 12, 2002.

Because most of the area was mined before the Surface Mining Control and Reclamation Act of 1977 was law, much of the strip pits (now filled with water), spoils piles, and old machinery remains. Sections 29 and 32 "constitute some of the most severely disturbed land in Oklahoma with regard to land form, acid-forming material, and poor vegetative cover" (unpublished Oklahoma Conservation Commission report). Land-use problems associated with the mined lands include dangerous highwalls, trespass for recreation (including ORV use), dumping of solid wastes, and acid drainage into Shady Grove Creek. Part of the site is currently being reclaimed by the OCC using money from the AML trust fund. Cell 1 (56 acres) was completed in 2002 at a cost of $208,817.19; cells 2, 3, and 4 (78 acres) are scheduled for completion in 2003 at a cost of $188,484.05 (OCC Abandoned Mine Land Reclamation Program 2002 annual report). The reclamation program includes eliminating hazardous water bodies and dangerous highwalls, grading disturbed areas to conform to local topography, instituting a storm management plan to control erosion, and establishing a permanent vegetation cover. On-site spoils will be used as fill material and hazardous structures and machinery will be buried on site.

6.0 0.7 Interstate 40 begins relatively abrupt descent.

The top of the escarpment is underlain by the Bluejacket Sandstone Member of the Boggy Formation. The Savanna Formation underlies the Bluejacket and forms much of the lower part of the south-facing slope.

The Bluejacket Sandstone is exceptionally well exposed about 1 mi to the east-northeast at a roadcut along U.S. Highway 266. There, Visher and others (1968) suggest the Bluejacket is a channel deposit within a delta plain and that it overlies a marine shale. An alternative interpretation is a distributary-channel or very proximal crevasse-splay sandstone sequence overlying bay-fill siltstone.

6.9 0.9 Interstate crosses trace of the down-to-the-north North Fault (see mile 37.6, above, north of Onapa), which here forms the north side of the Warner Uplift. The fault trace is difficult to locate precisely because it juxtaposes shale in the Savanna Formation to the north against shale in the McAlester Formation to the south.

Warner Uplift

The Warner Upift is a 4-7-mi-wide horst that extends from the Ozark Uplift northeast of the Arkansas River southwest into the Arkoma Basin (Fig. 44). Its northeast-southwest orientation is similar to other structures on the flanks of the Ozark Uplift and dissimilar to that of the structures in the Arkoma Basin (approximately east-west (Fig. 20)). Here, the North Fault strikes approximately east-west. The primary evidence for the fault and its displacement (north-side-down) is that the Secor coal, which crops out near the highway on the south side of the fault, crops out about 2.5 mi to the east on the north side of the fault (Hemish, 1998, pl. 1).

Interstate passes through small Checotah East gas field, which was discovered by the Service Drilling No. 1-4 Memphis well (E½W½SW¼NE¼ sec. 4, T. 11 N., R. 18 E.) in 1981. The producing unit is the Spiro sandstone at a depth of about 1050 ft.

7.5 0.6 The several relatively flat-topped hills to the right (south) of the interstate are capped by a sandstone in the McAlester Formation. Oakes and Koontz (1967) mapped the sandstone as Cameron/Lequire, but a small mined-out area of Stigler coal identified by Hemish (1998) immediately north of the interstate at the base of the easternmost hill is evidence that the capping sandstone is the Tamaha or Keota.

10.0 2.5 Interstate passes over bridge over U.S. Highway 266. The gently rolling countryside is underlain by the Atoka Formation which is mostly shale and is easily eroded.

10.6 0.6 Leave McIntosh County, enter Muskogee County.

Immediately north of interstate is the Warner gas field. Its discovery well and date are unknown (Brooks, 1963, p. B149), but a review of the Oklahoma Corporation Commission's 1002A forms list the first productive well as the Midwestern No. 2 D.B. Rogers (NW¼SW¼ sec. 31, T. 12 N., R. 19 E) completed on January 4, 1930. The producing unit in the field is the Dutcher sandstone.

12.8 2.2 Bridge over Oklahoma Highway 2/U.S. Highway 266 to Muskogee. Very poorly exposed Atoka Formation on both sides of highway for the next several miles.

14.5 1.7 Cross section A-A' of Andrews (2003, pl. 4) crosses field-trip route. I-40 passes between localities 12 (Service No. 1 Monsanto) and 13 (Webbers Falls Lock and Dam outcrop) on that cross section.

16.7 2.2 Pass under north-south county road near top of low ridge.

16.9 0.2 Cross trace of the northeast-striking South Fault on the southeast side of the Warner Uplift. The fault is southeast-side-down and juxtaposes Atoka Formation to the northwest against very uppermost Atoka Formation to the southeast.

The moderate slope just east of the trace of the fault is underlain by the McCurtain Shale Member of the McAlester Formation. The slope is capped by the Warner Sandstone Member.

A large (500 ac.) strip mine in the Keefton coal is present within the Warner Sandstone immediately south of the interstate. The Eagle Mine was operated by the Inter-Chem Coal Company. The Oklahoma Department of Mines issued a permit to mine in June 1989, mining was completed in April 1991, and the company finished reclamation work in June 1994.

The low hill capped by the Warner Sandstone about 0.5 mi north of the interstate and just south of U.S. Highway 64 is Rabbit Hill. This is one of the sites where raffinate fertilizer was used (see section of Sequoyah Fuels Uranium Conversion Facility, p.103).

18.7 1.8 Interstate passes over Ross Road (exit 284).

19.0 0.3 Low ridge capped by Warner Sandstone is present to right (south) of the interstate.

Another large (457.5 ac.) strip mine in the Keefton coal is present just behind (south of) the ridge. This mine (Eagle No. 2 Mine) was also operated by the Inter-Chem Coal Company from April 1991, when the ODM issued a permit to mine, to January 1994, when mining ceased. Reclamation work was completed during the summer of 1995.

20.7 1.7 Pass beneath bridge to Muskogee Turnpike toll road.

Very flat topography is Quaternary alluvium associated with the Arkansas River.

21.5 0.8 Exit Interstate 40 on exit 287, Oklahoma Highway 100 to Gore.

21.8 0.3 Turn left (north).

21.9 0.1 Pass over Interstate 40.

23.6 1.7 Turn left (west) a few tenths of a mile after road begins gradual right turn.

24.3 0.7 Main road bends left. Continue straight ahead on graded gravel road.

The very gentle rise immediately to the west marks the edge of the Arkansas River alluvium.

24.8 0.5 Turn right (north) on road NS441.

Gently rolling topography is underlain by Atoka Formation.

27.4 2.6 Turn right (east) on road to Webbers Falls Powerhouse.

This small valley is formed by a branch of the South Fault of the Warner Uplift (Oakes, 1977). The main trace of the South Fault is just north of Webbers Falls Dam.

28.0 0.6 Parking lot for access to Arkansas River below Webbers Falls Lock and Dam and Stop 6.

Stop 6. Webbers Falls Lock and Dam Locality

Location: SW¼SW¼SE¼ sec. 34, T. 13 N., R. 20 E. to N½NE¼NE¼ sec. 3, T. 12 N., R. 20 E., Webbers Falls 7.5' quadrangle. Large bluff along west side of Arkansas River just below Webbers Falls Lock and Dam 16. North end of outcrop adjacent to west abutment of dam; outcrop extends for about 0.2 mi to south. Muskogee County.

Introduction

This stop is probably the most studied and visited outcrop by students of Lower Pennsylvanian stratigraphy in Oklahoma. Its primary importance is that it is one of two primary type sections of the Sausbee Formation (including both the Braggs and Brewer Bend Limestone Members) and the McCully Formation (including the Chisum Quarry Member) (Sutherland and Henry,1977). (The other primary type section is about 0.3 mi northeast of here and is shown by Andrews (2003, pl. 4) as locality 13 on his regional cross section A-A' of the Morrowna section in southeastern Oklahoma.) Most of the Morrowan section is exposed. (Only the very basal part is below the level of the road and the very upper part has been truncated by post-Morrowan erosion.) There are no covered intervals and the exposure is long, very accessible, and safe (i.e., no traffic). In addition, the outcrop is the southwesternmost exposure of Morrowan strata in the Ozark uplift; the "next" Morrowan outcrop is in the hanging wall of the Choctaw Fault about 45 to the south near Red Oak. This outcrop, therefore, represents the most outer-shelf facies of Morrowan strata exposed. In the subsurface to the west, the character of the Morrowan strata changes to an outer shelf to more basinal facies (Andrews, 2003).

History of Nomenclature

The Morrowan series in northeastern Oklahoma originally was divided into the Bloyd (upper) and Hale (lower) Formations by Moore (1947), using well-established Arkansas nomenclature (Fig. 47). Moore (1947, p. 73-74) measured the entire Morrowan section in sec. 28, T. 13 N., R. 20 E., about 1.5 mi northwest of this stop; in fact, he measured about 91 ft of Mississippian strata in sec. 28, but these strata are not present here. Huffman (1958) and Oakes (1977) accepted the Arkansas nomenclature.

In 1968, two graduate students under the direction of Dr. Patrick K. Sutherland (University of Oklahoma) questioned the use of the Bloyd and Hale Formations in northeastern Oklahoma. Based on his study of the fauna, Haugh (1969, p. 128) stated that "age correlations with the type sections in Arkansas, are, therefore, very difficult ....". Bowlby (1968, p. 43) was even more direct: "... the lack of any means of consistently subdividing the Morrow rocks into two parts, the Hale and Bloyd Formations as originally defined are meaningless in the thesis area." Later Sutherland students studied several aspects of the Morrowan section (carbonate petrology – Rowland (1970); conodonts – Henry (1970); algae – Kotila (1973); brachiopods – Henry (1973)) in northeastern Oklahoma and subdivided it relatively similarly (see Kotila (1973, p. 18) for correlation chart). Henry (1973) subdivided the Morrowan strata into the McCully

Moore (1947)		Huffman (1958)		Oakes (1977)	
Desmoines	Atoka Fm.	Atokan	Atoka Fm.	Desmoinesian	Atoka Fm.
Morrow	Bloyd Fm. Hale Fm.	Morrowan	Bloyd Fm. Hale Fm.	Morrowan	Bloyd Fm. Hale Fm.
Chester	Pitkin Ls. Fayetteville Sh.	Chesterian	Pitkin Fm. Fayetteville Fm. Hindsville Fm.	Chesterian	Pitkin Fm. Fayetteville Fm. Hindsville Fm.

Figure 47. Correlation of Lower Pennsylvanian and Upper Mississippian strata in northeastern Oklahoma by early workers.

(upper) and Gore (lower) Formations and showed how they correlated with the Bloyd and Hale Formations of Arkansas.

Henry's (1973) work was modified slightly by Sutherland and Henry (1977), who noted a rapid facies change in Morrowan strata from the type area in Arkansas into Oklahoma and showed that the criteria used to recognize the Bloyd and Hale Formations could not be applied outside of eastern Adair County, Oklahoma. Based on this evidence they changed the name of the Gore Formation to Sausbee Formation and formally revised the Morrowan nomenclature in this part of Oklahoma (Fig. 48) and Sutherland and Henry (1977) and Sutherland and Manger (1977, 1979) applied it to this outcrop.

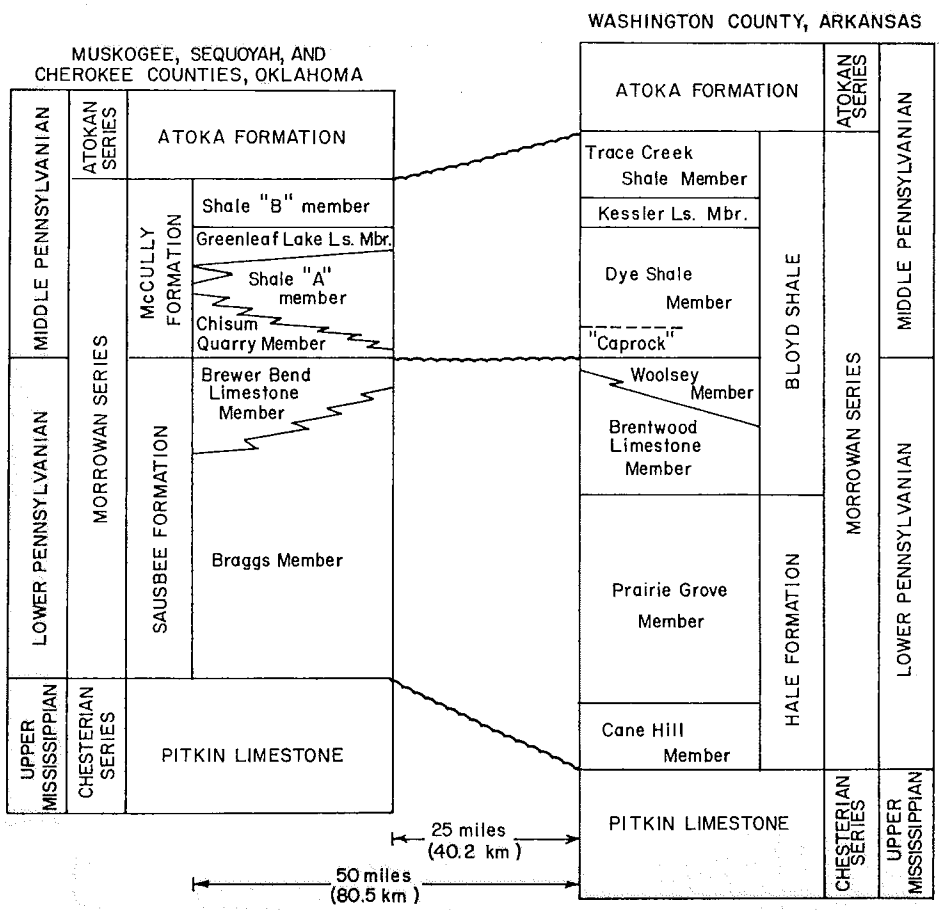


Figure 48. Correlation of Morrowan Formation in northeastern Oklahoma with those in Arkansas. (From Sutherland and Henry, 1977, fig. 2)

Despite the changes in Morrowan nomenclature, the general geology of the area near Stop 6 has been known for some time, probably because the Mississippian Fayetteville Shale and Pitkin Limestone are so distinctive. Wilson (1937), Gregware (1958), and Oakes (1977) mapped the Morrowan strata in this area; the latter two recognized the Bloyd and Hale Formations, but did not differentiate them on their maps. Gregware (1958), possibly anticipating future change in nomenclature, admitted that while "there (Hale and Bloyd) formations are discussed separately (in his thesis), … because of … difficulties of correlation, they are mapped together" (p. 10). All three authors mapped the Atoka Formation overlying the Morrowan. Unfortunately, the nomenclature was revised after this area (Oakes, 1977) and that covering the remainder of the field trip (Huffman, 1958) was mapped.

Outcrop Description

Sutherland and Manger (1977, 1979) described the section exposed here (Fig. 49) and noted that it forms "the most important Morrowan section in northeastern Oklahoma" (p. 30, 34, respectively). Figures 50A and 50B are photomosaics of the section; the Sausbee Formation is particularly well exposed and the Braggs Member (units 1 through 9) is relatively easily accessible. A normal fault (southeast-side-down) with about 16 ft of throw offsets the section at its south end (Fig. 50B). Based on the identification of the conodonts *Indiognathodus sinuatus* and *I. sinuosis* in the Braggs Member of the Sausbee Formation at Cookson (mile 29.2) (Sutherland and Manger,1977, 1979), the Braggs Members is about the same age as the Union Valley Formation at Canyon Creek (Stop 3, this guidebook).

Most of the Morrowan Braggs Member at Stop 6 consists of interbedded coarsely bioclastic grainstone and shale (Fig. 49). Sutherland and Henry (1977) suggested the sediments were deposited on a shallow inner shelf or open-marine carbonate platform. Most of the resistant ledge-forming units (nos. 2, 3 (grainstone channels only), 4, 5 (grainstone channel only), 6 (lower part only), 7, and 9) (Figs. 49, 50A) are grainstone with conspicuous large (to about 1 cm) fossil fragments (Fig. 51). Most of the fragments are crinoids; bryozoans and brachiopods also are present and locally are abundant. Unit 4 locally is sandy. Bedding typically is wavy; individual beds pinch and swell and exhibit planar stratification to low-angle crossbedding (Fig. 52). Unit 6 locally contains some low-amplitude, long-wavelength convex-up beds. On a large scale, channelform deposits (Fig. 53) are common and occur in units 3 and 5; in addition, many beds in unit 6 are truncated and units 7 and 9 are eroded into units 6 and 8, respectively.

The mostly slope-forming shale/siltstone units vary from calcareous to noncalcareous and unfossiliferous to richly fossiliferous.

The sedimentologic evidence in the outcrops at Stop 6 support Sutherland and Henry's (1977) interpretation that much of the Braggs Member was deposited in a relatively high-energy environment. Most of the grainstone units are interpreted to be tidal channels where they clearly erode into older units (e.g., at base of unit 7) or pinch-out into shale (e.g., unit 3). The more continuous grainstone beds may be channels whose edges are not exposed here or are bioclastic sheet sands deposited just offshore in the intertidal zone. Most of these beds were deposited above normal wave base;

STOP 6 LOCK AND DAM

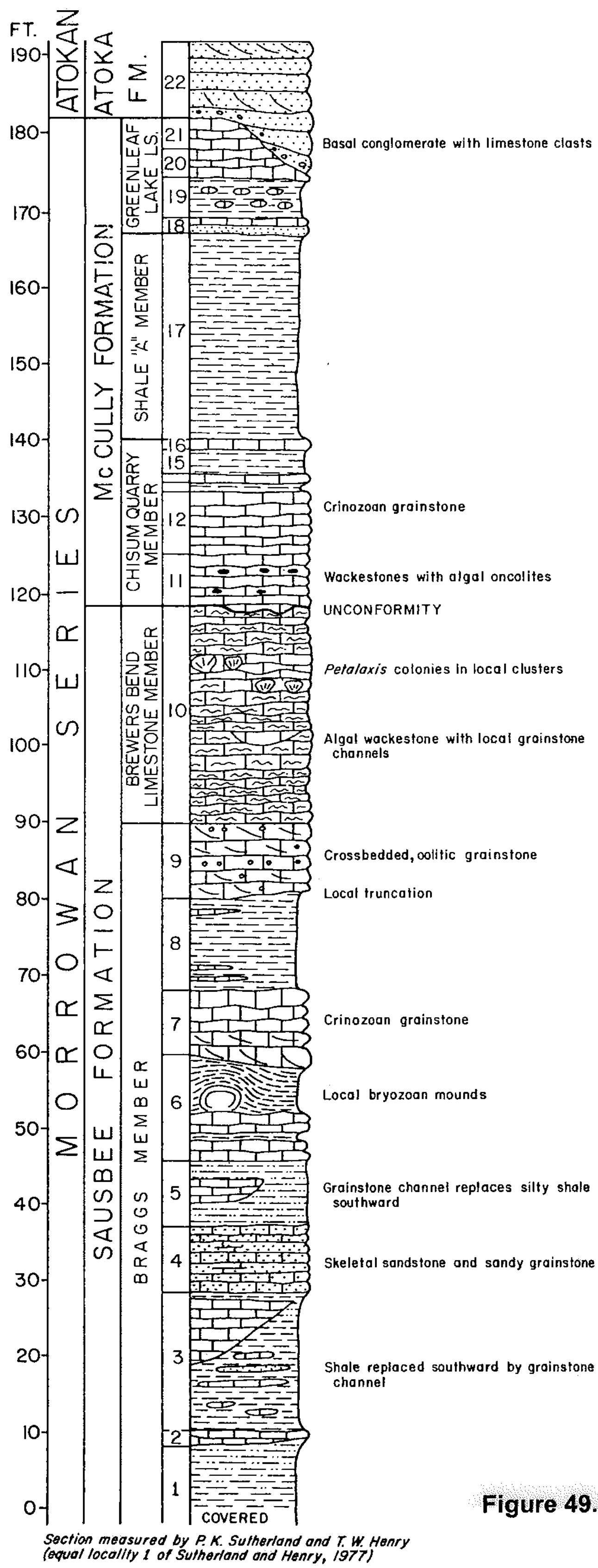


Figure 49. Graphic columnar section for Stop 6.

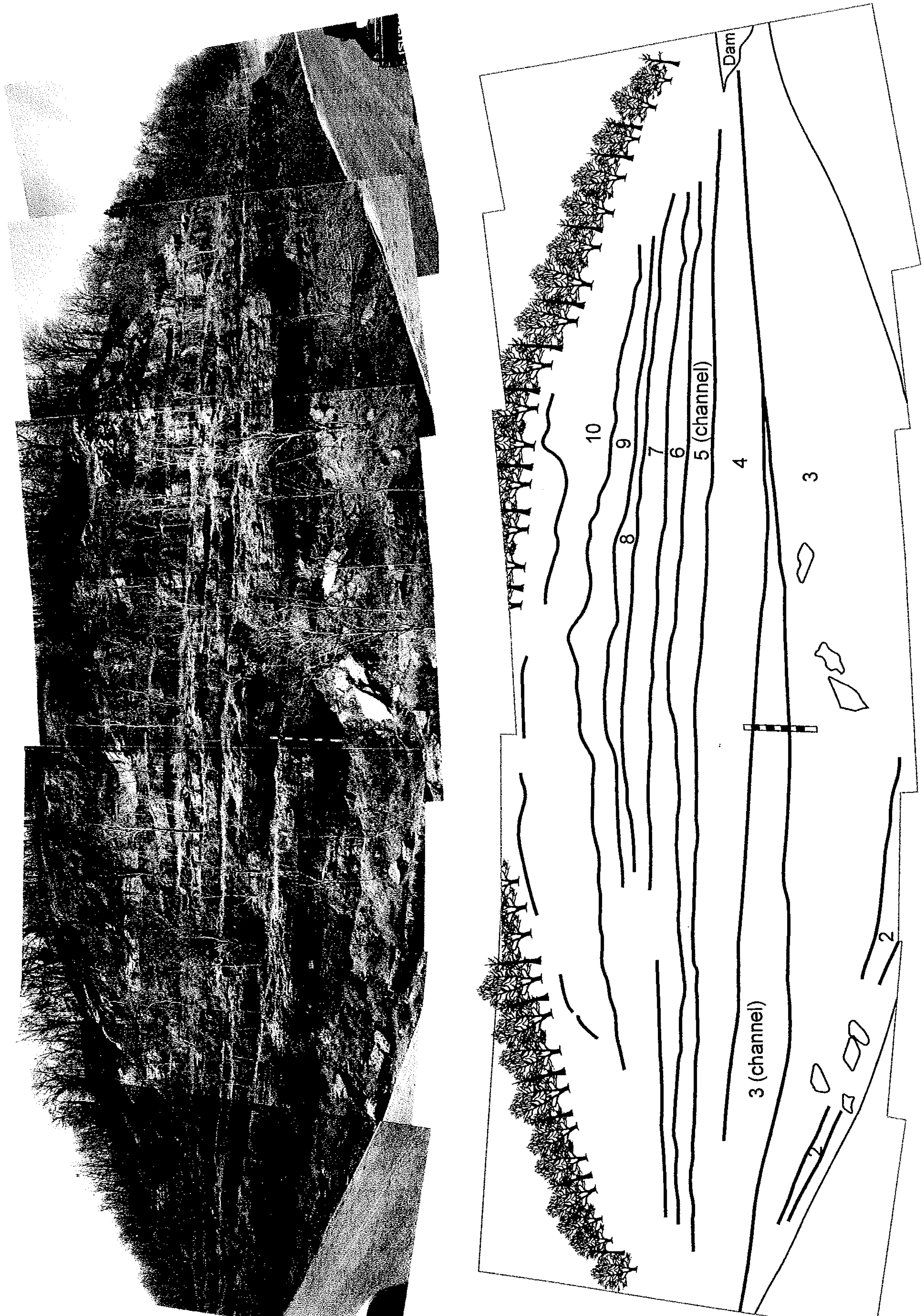


Figure 50. A. Photomosaic of north end of outcrop at Stop 6. Sketch shows units identified in figure 39 and referred to in text.

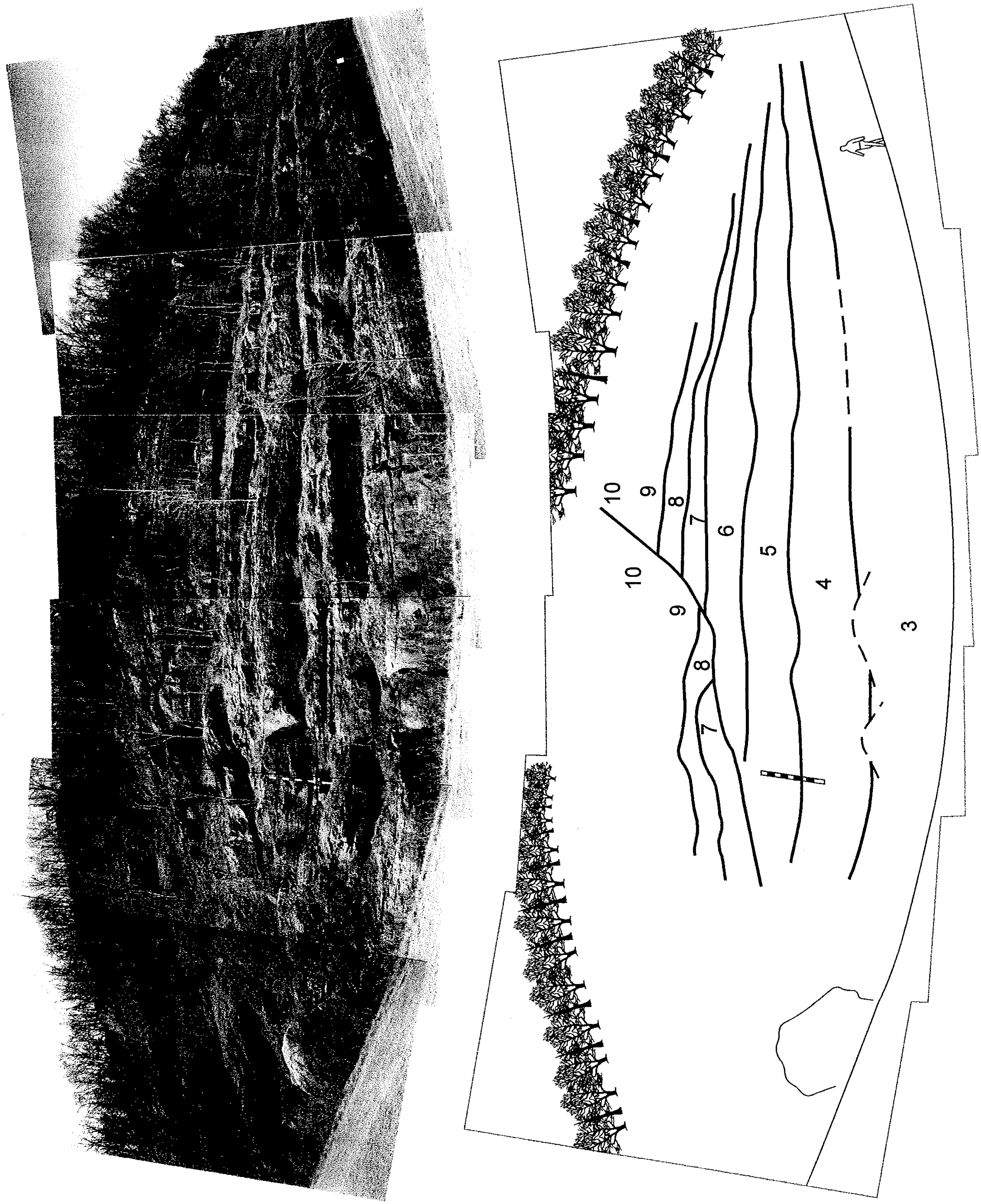


Figure 50. B. Photomosaic of south end of outcrop at Stop 6. Sketch shows units identified in figure 49 and referred to in text. Note fault on left side of photomosaic.

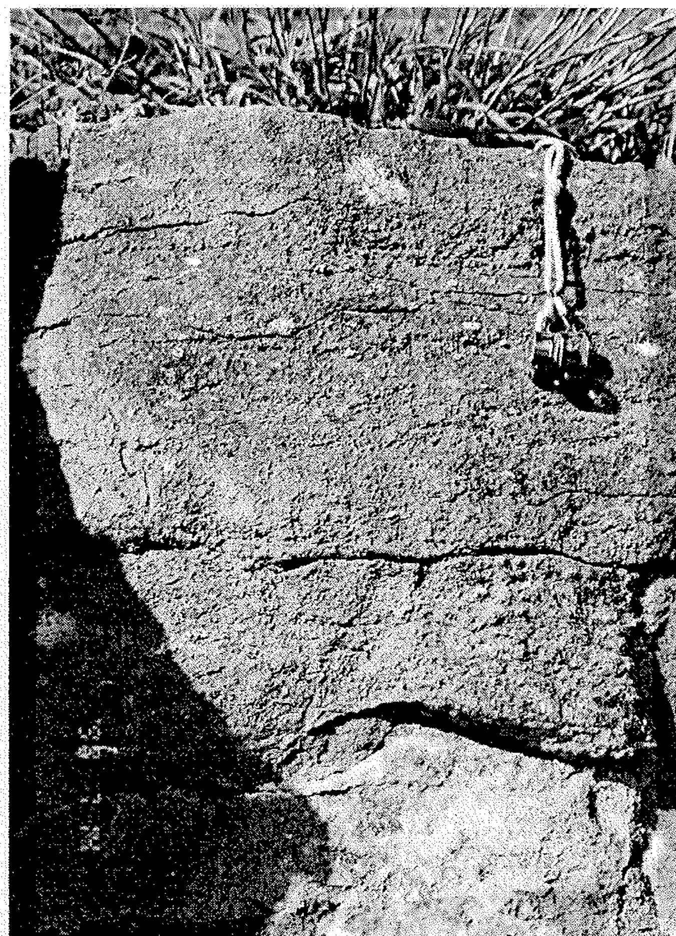


Figure 51. Coarsely bioclastic grainstone (unit no. 5) typical of most grainstone units at Stop 6.

some (e.g., part of unit 6), however, may show hummocky cross-stratification – evidence for reworking by storms.

The shale units, however, represent deposition in a relatively low-energy environment, but most are associated with tidal channels. The presence of bryozoan mounds in the upper part of unit 6, however, may be evidence for a deeper-water environment.

The facies relations exposed here and the regional facies relations to the southwest developed by Andrews (2003) support a carbonate ramp rather than a carbonate platform model (Fig. 54) (e.g., see Stanley (2001); based on Wilson (1975)). Most of the shale units fit into Stanley's (2001, table 2) "facies zones 1: restricted circulation on marine ramp … high intertidal to supratidal". This facies is cut by tidal channels. The sheet-like grainstones are "facies zone 2: washed littoral sands. …

Figure 52. Typical bedding features in grainstone units at Stop 6. Unit 3 (shown here) is wavy-bedded and individual beds pinch and swell. These features occur at smaller and larger scales than shown here.

Figure 53. Grainstone tidal channel in unit 3 at north end of outcrop at Stop 6. Arrows point to base of channel.

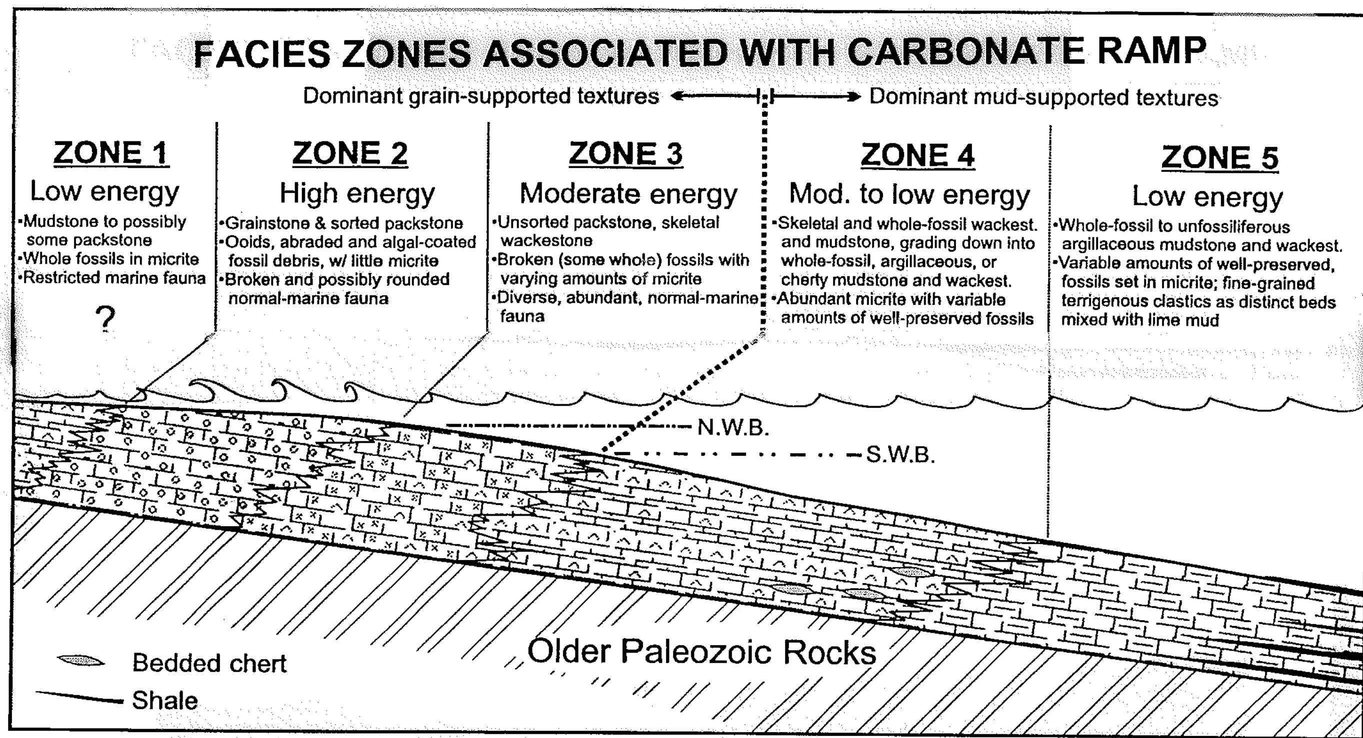


Figure 54. Idealized facies, carbonate-ramp model (modified from Stanley (2001, fig. 6). Most of the shales in the Braggs Member were deposited in zone 1. Most of the grainstones fill tidal channels in zone 1 or are sheet sands deposited in zone 2. N.W.B. and S.W.B. represent normal wave base and storm wave base, respectively. No vertical or horizontal scale is implied.

Intertidal zone, well above normal wave base". The upper part of unit 6 (grainstone with hummocky crosss-stratification, shale with bryozoan mounds) may represent Stanley's (2001, table 2) "facies zone 3: downslope bioclastic sand and mud facies. ... Immediate subtidal zone; below effective wave base but not below storm wave base".

Webbers Falls Lock and Dam
and the McClellan-Kerr Arkansas River Navigation System.
(from brochure distributed by U.S. Army Corps of Engineers)

Location

Webbers Falls Lock and Dam is located at navigation mile 368.9 about 5 miles northwest of the town of Webbers Falls, Oklahoma.

History and Development

The project was authorized by the River and Harbor Act approved 24 July 1946, amended by the Flood Control Acts of 1948 and 1950. Authorized project purposes are navigation, hydroelectric power, fish and wildlife, and recreation. Initial construction began in January 1965, closure was made on 9 November 1970 and the project was placed in useful operation. The Lock and Dam became operational for navigation in December 1970.

Webbers Falls Lock and Dam is a major unit in the multiple-purpose project for improvement of the Arkansas River and its tributaries in Arkansas and Oklahoma.

Watershed

Drainage area above the dam, square miles	97,033

Lake

Elevations, feet above mean sea level	
Top of the upper pool	490.0
Top of the normal tailwater	460.0
Power pondage	487-490
Surface area of the lake, acres	
Top of upper pool	10,900
Storage capacities, acre-feet	
At top of upper pool	165,200
In power pondage	30,000
Shoreline length, miles	157

Dam

Embankment	
Length of dam, feet	4,370
Height of dam above streambed, feet	84

Spillway and Outlet Works

The spillway extends across the left half of the existing river channel, with the powerhouse structure in the right half of the river channel. The spillway is a gated, concrete, ogee-type structure. The crest of the weir is 40.0 and 10.0 feet below the tops of the normal pool and normal tailwaters, respectively. The weir is surmounted by twelve 50 x 41-foot-high tainter gates. The gates are separated by eleven 10-foot intermediate piers which also support a 5-foot-wide service bridge. The capacity of the spillway at maximum discharge is 1,200,000 c.f.s. (The flood of record occurred in May 1943 with an estimated peak discharge at the dam site of 720,000 c.f.s.)

Lock

The lock is a 30-foot normal lift Ohio River type with a culvert and port filling system and side-outlet discharge. The lock is located in the left overbank with excavated approach channels. The chamber is 110-feet-wide by 600 feet long.

Powerhouse

The powerhouse is an integral-type structure with three inclined-axis type units capable of developing a total capacity of 60,000 kw.

Navigation Pool

The lake is operated with a navigation pool level of 490 feet above sea level near the dam, except for anticipated periodic drawdowns for power generation. This forms a lake with a surface of 10,900 acres and a storage capacity of 165,200 acre-feet. The lake extends about 28 miles upstream to the mouth of the Verdigris River, from which point it extends 3.5 miles farther up the Arkansas River, 6.5 miles up the Verdigris River to the site of Chouteau Lock and Dam, and about 8 miles up the Grand (Neosho) River to Fort Gibson Dam. It is location in portions of Muskogee, Wagner, and Cherokee Counties, Oklahoma.

About the Overall Project

The comprehensive project was planned by the U.S. Army Corps of Engineers and built by private contractors under supervision of the Corps. It provides for a navigation route from the Mississippi river through Arkansas and Oklahoma to Catoosa, near Tulsa, Oklahoma, the production of hydroelectric power, additional flood control through upstream lakes, and the related benefits of recreation and fish and wildlife enhancement. The navigation route from the Mississippi River to Fort Smith, Arkansas, was developed by the Little Rock District, and the route from Fort Smith to Catoosa, Oklahoma, was developed by the Tulsa District. Seventeen lock and dam structures were required to establish this stairway of water – 12 in Arkansas and 5 in Oklahoma. The dams form a series of pools. Vessels traveling the entire 440-mile route are raised or lowered a total of 420 feet through the locks, with lifts varying from 14 to 54 feet. The minimum channel depth is 9 feet. Minimum channel width is 300 feet on the Arkansas Post Canal, 250 feet on the Arkansas River, and 150 feet on the Verdigris River. All lock chambers are 110 feet wide and 600 feet long.

Webbers Falls

The present lock and dam are located near a shallow area along the Arkansas River. In 1806, this was the site of a six-foot high waterfall which was later reduced to an area of shallows. Throughout the 1800's these shallows blocked river travel for steamers (Fugate and Fugate, 1991).

Reset odometer to 0.0

Retrace route to Oklahoma Highway 100.

4.4 4.4 Intersection with Oklahoma Highway 100. Turn left toward Gore.

5.4 1.0 Town of Webbers Falls is on right (south). The town is the site of one of Oklahoma's Civil War battles.

Battle of Webbers Falls

The Battle of Webbers Falls was one of the early battles of what has been called the "second federal invasion of Indian Territory". Shortly after the opening of hostilities in the east, the Confederate States of America concluded a number of treaties with most of the tribes in the Indian Territory. Federal forces, who initially policed the Indian Territory, withdrew in April 1861, and Confederate authority was established until October 1862. On June 1, 1862, Federal forces reentered Indian Territory ("first federal invasion") and advanced south to about 15 miles north of Fort Gibson, but an argument among the commanders resulted in a complete retreat on July 19 (Willey, 1966).

In October 1862, federal forces reentered Indian Territory, beginning the "second" invasion. In April 1863, Fort Gibson was occupied. In an attempt to clear this part of the Arkansas River valley of Confederate forces, several skirmishes occurred at Webber's Falls; these were on April 11 and 25, September 9, and October 12 (Wright and Fischer, 1966). The largest of these, the "Battle of Webbers

Falls", occurred on April 25 after a detachment of 600 Union forces under the command of Col. William A. Phillips left Ft. Gibson on the night of April 24 and marched 30 miles to Webber's Falls. On the morning of the next day, the Union forces attacked a Confederate force of about 500 under the command of Colonel Stand Watie (see below). The Confederate force was present "to protect a meeting of the national council of Confederate Cherokees scheduled later that day" (Wright and Fischer, 1966, p. 198). The Union forces surprised and scattered the Confederate forces, who fled towards Ft. Smith, and captured their supplies. Casualties appear to have been relatively light; two Union troops and two Confederate captains were killed. The Union success at Webbers Falls was not so much in winning the battle, rather, "preventing the proposed meeting, basic to Confederate Cherokee organization (Willey, 1966, p. 424).

The Union forces returned to Webbers Falls after the Battle of Honey Springs (July 17, 1863) and burned the village to the ground in retaliation for the killing of Dr. Rufus Gilpatrick, an unarmed Union military surgeon who was on his way to attend to a wounded Confederate soldier at the Battle of Webbers Falls.

Stand Watie (1806 – 1871)

(all quotations from **www.civilwarhome.com/watiebio.htm**, accessed June 2003)

Stand Watie (Cherokee name De-ga-ta-ga; also known as Issac S. Watie) was born in Oothcaloga in the Cherokee Nation (now Georgia). Prior to removal, he served as clerk of the Cherokee Supreme Court and Speaker of the Cherokee National Council. Unlike most Cherokees, he supported removal to Cherokee Nation, West (now Oklahoma) and signed the Treaty of New Echota in 1835, in defiance of Principal Chief John Ross. After removal, he became leader of what was known as the Ridge-Watie-Boudinot faction of the Cherokees and had a "long-running blood feud with the followers of John Ross. He also was a leader of the Knights of the Golden Circle, which bitterly opposed abolitionism.

"At the outbreak of the Civil War, Watie quickly joined the Southern cause. He was commissioned a colonel on July 12, 1861, and raised a regiment of Cherokees for service with the Confederate army. Later, when Chief John Ross signed an alliance with the South, Watie's men were organized as the Cherokee Regiment of Mounted Rifles. After Ross fled Indian Territory, Watie was elected principal chief of the Confederate Cherokees in August, 1862".

Watie or his men participated in 18 battles or major skirmishes with Federal troops during the Civil War, including the Battle of Webber's Falls. "Because of his wide-ranging raids behind Union lines, Watie tied down thousands of Federal troops that were badly needed in the East". In May, 1864 Watie was promoted to brigadier general; he was the only Indian general on either side during the Civil War. On June 23, 1865, Watie surrendered to Federal troops – the last Confederate general to do so.

"After the war, Watie served as a member of the Southern Cherokee delegation during the negotiations of the Cherokee Reconstruction Treaty of 1866". Afterwards, he returned to private life and died at his home along Honey Creek.

5.7 0.4 Bridge over Arkansas River. Leave Muskogee County, enter Sequoyah County. The I-35 bridge over the Arkansas River is visible immediately downstream.

May 26, 2002 Interstate 40 Bridge Collapse

About 3 miles downriver from the Highway 100 bridge, Interstate 40 crosses the Arkansas River. At 7:48 AM EST on May 26, 2002, a towboat owned by Magnolia Marine Transport Company was pushing two empty barges upriver when it collided with the western bridge support, causing a 600-ft span to fall 62 ft into the river. Ten vehicles plunged into the river and 14 people were killed. The towboat was carrying a crew of six and traveling at about 5 mph. The skipper of the towboat apparently blacked out shortly before colliding with the bridge.

The bridge was rebuilt at a cost of about $30 million (nearly twice the original estimate) and reopened on July 29. Most of the additional costs were associated with keeping the detour through Gore, Oklahoma open.

Introduction – Ozark Uplift area

Ozark Uplift

The Ozark Uplift is a broad dome encompassing about 40,000 square miles in southern Missouri, northwestern Arkansas, and northeastern Oklahoma. It is bordered on the south by the Arkoma Basin and on the west by the Cherokee Platform. In Oklahoma, the Ozark Uplift is divided into two physiographic provinces – the Boston Mountains on the south and the Springfield Structural Plain on the north (Huffman, 1958) (Fig. 55). The Boston Mountains are a dissected plateau capped largely by the Atoka Formation. The Springfield Structural Plain is underlain mostly by Mississippian carbonate rocks.

Although most of the Paleozoic periods are represented by the strata in the Ozark Uplift (Fig. 56), the geologic history of the area is one of repeated broad uplift and erosion followed by submergence and deposition. Unconformities within the Paleozoic section occur at the top of the Ordovician Cotter Dolomite, Fite Limestone, and Sylvan Shale; the Devonian Sallisaw Formation; the Devonian - Mississippian Chattanooga Shale; the Mississippian St. Joe Group, Keokuk Formation, Moorefield Formation, and Pitkin Limestone; and the Pennsylvanian McCully Formation (Huffman, 1958; Sutherland and Henry, 1977). Regional tilting that resulted in significant angular unconformities occurred three times (Huffman, 1958). After deposition of the Sallisaw Formation, the area of northeastern Oklahoma was tilted to the south and the basal member of the Chattanooga Shale (Sylamore Sandstone) was deposited on Devonian, Silurian, and Ordovician strata. Northward tilting occurred in the middle Mississippian and most of the Keokuk and Reeds Spring Formations were eroded on the south flank of the Ozarks. Southward tilting at the beginning of the Pennsylvanian resulted in the northward truncation of the Pitkin Limestone.

The age of the most recent uplift of the western part of the Ozarks is based on three lines of evidence: the age of faults associated with uplift; the age of formations that were deposited around but not across the uplift; and the age of formations with a possible sediment source in the Ozarks. There is no evidence that the Ozark Uplift was high during deposition of the Atoka Formation; in fact, Huffman (1958, p. 109) stated that "progressive northward spread of Atoka seas is indicated by overlap of younger

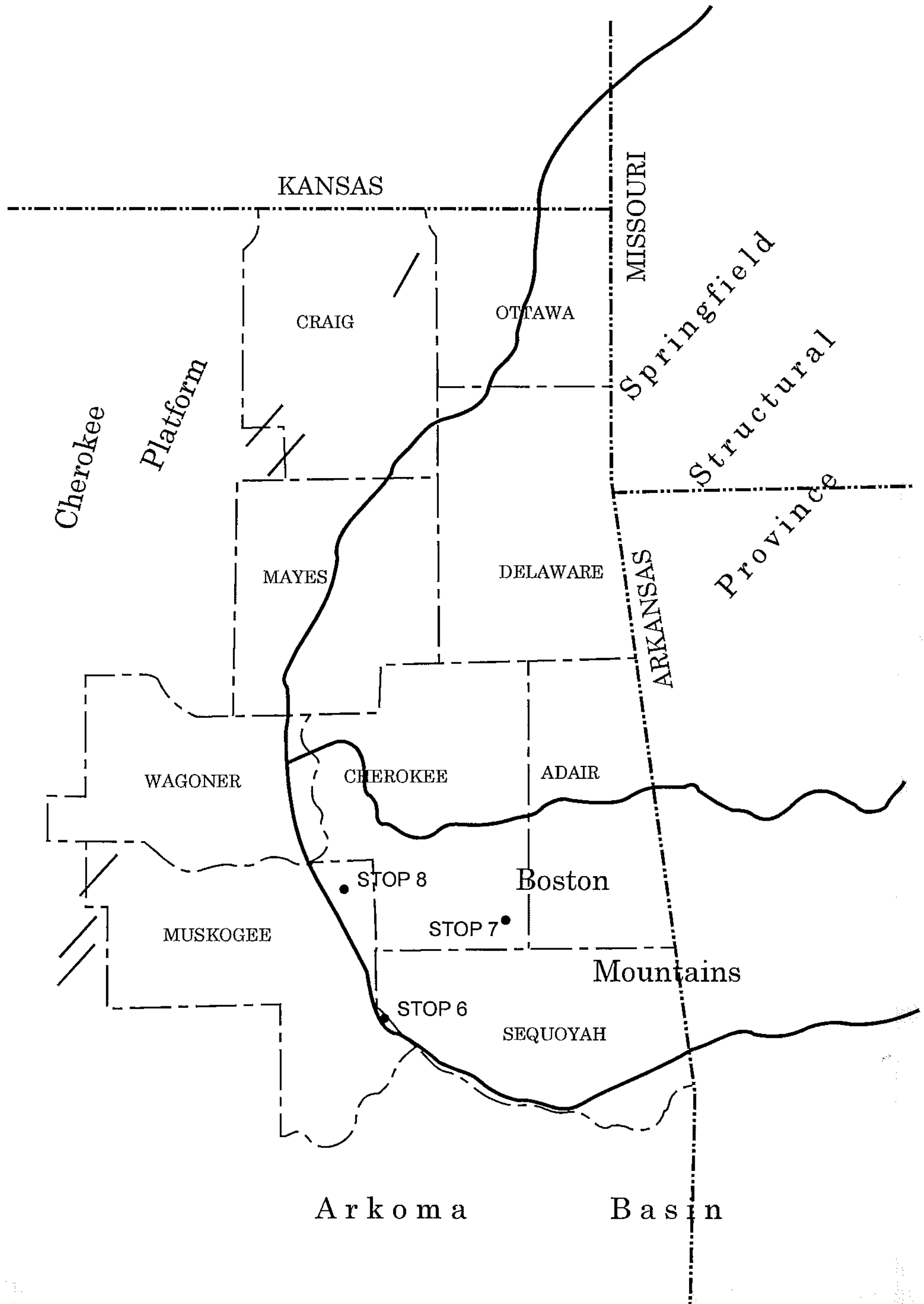


Figure 55. Map of western part of Ozark Uplift showing Boston Mountains and Springfield Structural Plain (from Huffman and others, 1963, fig. 40); modified locally from Northcutt and Campbell (1996). Northeast-striking faults west of Ozark Uplift offset the Senora Formation (from Marcher (1969) and Marcher and Bingham (1971).

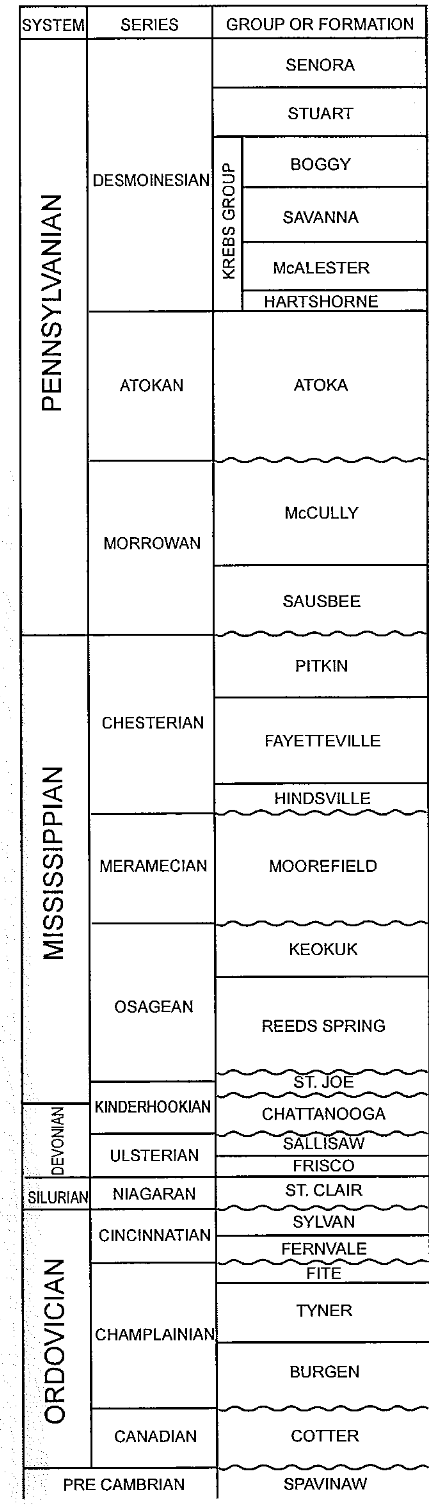


Figure 56. Stratigraphic column for Ozark Uplift and flanks of Ozarks (modified from Huffman, 1958, fig. 2). The Atoka and older formations underlie the uplift; the Atoka and younger formations occur around its flanks.

members of the Atoka from south to north." Evidence that the Ozarks may have been a source of at least part of the Hartshorne Formation (Fig. 56) includes sandstone petrography and sand:shale ratios (Scruton, 1950). Based on ripple-mark and cross-bedding orientations, Agterberg and Briggs (1963) and Briggs and Cline (1967) suggested that a significant sediment source for much of the Krebs Group was the Ozark Uplift. Other evidence that the Ozark Uplift may have been high, but was not necessarily a source of sediment, is the distribution of the Booch sandstone (McAlester Formation) (Busch, 1959) and the Bartleville sandstone (Boggy Formation) (Visher and others, 1971). These fluvial-deltaic systems are west of the Ozark Uplift, which may have been high when the systems were active.

The cessation of uplift of the western Ozarks area is based on the minimum age of northeast-striking normal faults that probably are associated with uplift. Some of these faults offset strata as young as the Senora Formation (Fig. 55). However, there is no stratigraphic evidence in the Senora that it either had an Ozark source or that its distribution was controlled by a topographic high in the Ozarks area.

6.6 0.9 Cross railroad tracks near center of Gore, Oklahoma.

Sequoyah Fuels Uranium Conversion Facility

Immediately south of the Town of Gore is the well-known Sequoyah Fuels uranium conversion facility. To a certain extent the facility, closed since 1993 and the subject of on-going environmental and legal battles, is a microcosm of the problems, both real and perceived, both technical and emotional, that have plagued and continue to plague the nuclear industry in the U.S.

Built by Kerr-McGee for $25 million and dedicated in April 1969, the plant used nitric oxide to convert yellowcake (uranium oxide, U_3O_8) received from a number of uranium mines in New Mexico and throughout the world to uranium hexafluoride (UF_6), which was shipped for further refinement to enrichment facilities operated by the U.S. Atomic Energy Commission. Ultimately, the uranium was used in the manufacture of fuel rods for nuclear reactors. The plant had a design capacity of 5,000 tons/year with a possibility of expanding to 10,000 tons/year (Oklahoma Geology Notes, 1970). This expansion was accomplished in 1975, but annual production ranged between 4,000 and 8,000 tons/year. The plant was one of two privately owned factories in the country that accomplished this conversion. A second process, begun in 1987, converted depleted uranium hexafluoride to uranium tetrafluoride (UF_4), which was used in the manufacture of armor-piercing bullets and shells.

Through 1993 when the plant closed, all radiological material disposed of on-site was in accordance with U.S. Nuclear Regulatory Commission (NRC) regulations, including the building of ponds and the disposal of sludge by burial.

Although controversial and on-going, a number of legal issues cloud plans to decommission the site. A summary timeline of the history of the facility is given below. Sources of information are the Oklahoma Nuclear Risk Management for Native Communities Project (NRMNC) (**http://nrmnc.cas.okstate.edu/Brochures/Timelime-4-clip.pdf**; accessed 5/03), the U.S. Nuclear Regulatory Commission (NRC) (**http://www.nrc.gov**; search Sequoyah Fuels; accessed 5/03); and Kerr-McGee Corporation (KM) (annual reports).

1970. Plant begins production. Wastes stored in on-site ponds.
1973. "Raffinate" fertilizer testing program begins in field next to plant. (Raffinate was produced when the nitric acid used in the uranium extraction process was neutralized with ammonium.) Raffinate contained small amounts of uranium, arsenic, and other impurities. Raffinate stored in ponds, some of which leak. (NRMNC)
1974. Karen Silkwood, a chemical technician at Kerr-McGee's Crescent, Oklahoma plutonium production plant north of Oklahoma City, killed in one-car accident in November. Court cases finally closed in 1986.
1978. Plant capacity doubled from 4.5 million kilograms UF_6 to 9 million kilograms. (KM)
1979. Three Mile Island.
1980. 7.4 million kilograms of UF_6 produced. A record. (KM)
1983. Arsenic, cadmium, chromium, mercury, lead, and selenium levels over EPA's drinking water standards found in groundwater at site. (NRMNC)
Kerr-McGee reorganizes, forms Sequoyah Fuels Corporation (SFC) as subsidiary. SFC produces 5.0 million kilograms of UF_6 . (KM)
1986. In January, an accidental release of uranium hexafluoride kills one worker and 32 others are hospitalized. A large toxic cloud travels off-site. Raffinate fertilizer program expanded to include 9100 acres in the Rabbit Hills and George's Fork areas near Warner, Oklahoma. NRMNC estimates that between 1973 and 1995, about 1.5 million gallons of raffinate was spread on SFC land (about 10,000 acres). (NRMNC)
SFC shuts down for 11 months; results in $25 million loss for Kerr-McGee. (KM)
1987. SFC pays a $310,000 fine for safety violations associated with the 1986 accident. (NRMNC)
1988. Kerr-McGee sells the SFC plant to General Atomics Corporation of San Diego.
1980 – 1989. SFC releases 2,200 lbs of uranium to the air during routine operations over this 10-year period. (NRMNC)
1990. 74,000 lbs of uranium have been released into the Illinois River. (NRMNC)
1989 - 1991. SFC reports an average of 17,760 lbs/year of hydrogen fluoride gas have been released to the atmosphere. (NRMNC)
1991. NRC orders SFC plant shut down. Plant closed for 6 months. (NRMNC)
1992. SFC plant reopens. On November 17, toxic nitrogen dioxide gas is accidentally released. SFC later fined $18,000 by NRC. On November 22, SFC announces plans to close the plant. (NRMNC)
1993. Plant ceased operation and applied to NRC for license to terminate. NRC requires license to remain in effect until radiological contamination clean-up to NRC standards. (NRC)
1998. SFC submits site characterization report (technical analysis and description of site's radiological contamination) and study of mediation alternatives, including on-site disposal cell. (NRC)
1999. SFC submits decommissioning plan to request to terminate license. (NRC)
2002. NRC states that a "significant quantity of materials with long-lived radionuclides (140,000 to 240,000 cubic meters in contaminated soils, sludge, and ground water" is present at the site. (NRC)
Present. NRC is reviewing site reclamation plan and will issue environmental impact statement and technical evaluation report. SFC has requested that some of the waste at the site be considered a byproduct of the milling process; this would allow SFC greater flexibility in the decommissioning process. The Oklahoma State Attorney General has objected to any on-site disposal or storage of wastes. (NRC)

7.0 0..4 Intersection with Oklahoma Highway 10 (to left) to Braggs and Muskogee on north side of Gore. Continue straight on Highway 100.

For about the next five miles, Atoka Formation is exposed in the hills to the left (west), and Quaternary alluvium and terrace deposits associated with the Illinois River are to the right (east). Two northeast-striking, southeast-side-down faults (Webbers Cove Fault, Linder Bend Fault (Huffman, 1958, pl. IV)) are present immediately northwest of the highway.

10.3 3.4 County road to left (north).

An exposure of the Silurian St. Clair Limestone is present about 1 mile to the north on the north side of the Webbers Cove Fault. The dolomitic limestone is currently being quarried by Souter Construction Company of Conway, Arkansas. Most of the material is shipped to the AES Shadypoint Power Plant near Panama, Oklahoma where it is crushed into dust and burned with the coal to reduce the sulfur emissions. The finer material at the quarry is sold as agricultural lime, fertilizer filler, and charcoal filler.

12.3 2.0 Road to Tenkiller Ferry Powerhouse to right (east). For the next mile, Highway 100 passes through several outcrops of Atoka Formation, although a small outcrop of crossbedded coarse-grained bioclastic limestone (Morrowan?) about 500 ft north of the powerlines is evidence that the structure in this area may be more complicated than shown by Huffman (1958).

13.2 1.9 Intersection with Oklahoma Highway 10A (straight). Turn right and continue on Oklahoma Highway 100.

14.4 1.2 West side of spillway dam, Tenkiller Ferry Lake. Powerhouse (Fig. 57) is below dam.

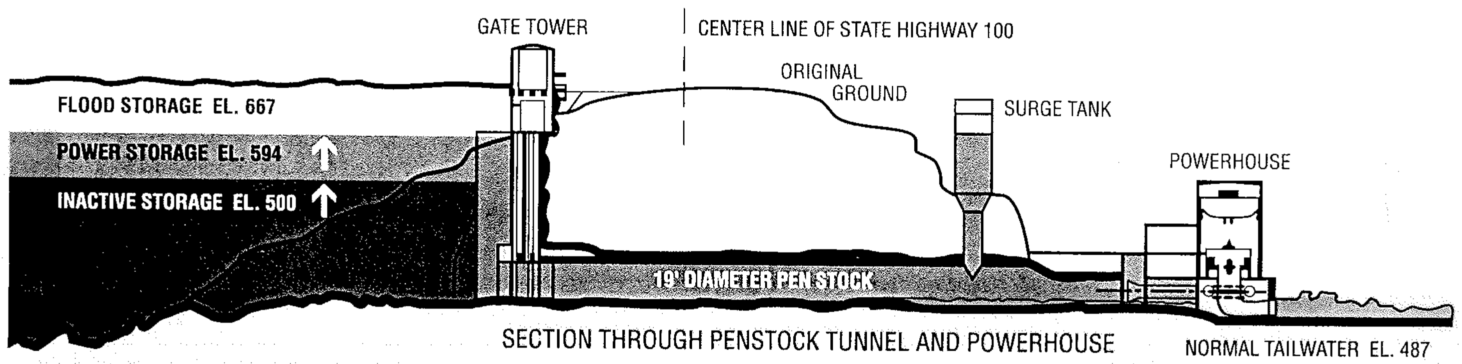


Figure 57. Section through powerhouse (from brochure distributed by Tulsa District, U.S. Army Corps of Engineers) To generate hydroelectric power, water from the lake flows through the gate-controlled penstocks, rotates the turbines in the powerhouse, and discharges through the draft tubes to the river channel below. The turbines are directly connected to generators which produce electric power. The electric current is increased in voltage by large transformers for transmission away from the project.

14.9 0.5 West side of Tenkiller Ferry Dam. Note large outcrops of Atoka Formation above and below east side of dam.

Tenkiller Ferry Lake and Dam

(from brochure distributed by Tulsa District, U.S. Army Corps of Engineers)

Location

Tenkiller Ferry Dam is located on the Illinois River, about 7 miles northeast of Gore and about 22 miles southeast of Muskogee. It impounds a beautiful lake reaching more than 25 miles up the spring-fed Illinois River in Sequoyah and Cherokee Counties. It is 12.8 miles upstream from the confluence of the Illinois and Arkansas Rivers.

Operation

Tenkiller Ferry Lake is a feature of the project for comprehensive development of the Arkansas River and tributaries. In addition to providing flood control, power, water supply, and recreation benefits, the lake aids the McClellan – Kerr Arkansas River Navigation System by assisting in maintaining regulated flows through water releases made for hydroelectric power generation.

To accomplish its function, Tenkiller Ferry Lake has three kinds of storage that are separated by zones from the top to the bottom of the lake; flood control, conservation, and inactive storage (Fig. 47).

The top or "flood control storage" portion of the lake has 576,000 acre-feet that is reserved to catch floodwaters and will remain empty except during times of flood control operation. An acre-foot is enough water to cover one acre to a depth of one foot.

The middle or "conservation storage" provides 371,000 acre-feet of storage for water supply, power generation, and water to support navigation on the McClellan – Kerr Arkansas Navigation System. The water supply portion of the storage will yield 16 million gallons a day.

The bottom or "inactive storage" provides minimum water pressure necessary for power generation and space to contain sediment.

Releases of water are generally made through the generation of power except in the time of flood control operation and will vary from small flows to bank full flows of about 16,000 cubic feet per second. The release rate depends on such factors as power requirements, navigation water requirements, inflow rate, the amount of water in storage, riverflow downstream, and weather conditions. A warning device is sounded at the dam prior to making a change in releases.

History and Development

The Tenkiller Ferry project was authorized by Congress under the Flood Control Act of 1938. Installation of power features was authorized in the River and Harbor Act of 1946. It was designed and built by the Tulsa District, Corps of Engineers, at a cost of $23,687,000. The project was started in 1947, placed in flood control operation in July 1953 and power was placed on the line in December 1953.

Benefits

Tenkiller Ferry Lake has been credited with preventing an estimated $19,310,000 in flood damages through December 31, 1989.

Lake and Dam Facts

Watershed

Drainage area above the dam, square miles	1,610
Lake	
Elevations, feet above mean sea level	
Top of flood control pool	667.0
Top of power pool (normal)	632.0
Top of inactive pool	594.5
Surface area of lake, acres	
At top of flood control pool	20,800
At top of power pool	12,900
Storage capacity, acre feet	
Flood control pool	576,700
Power pool	371,000
Inactive pool	283,000
Lake total	1,230,800
Shoreline length, miles	
At top of power pool	130
Dam	
Embankment	
Length of dam, feet	3,000
Maximum height of dam above streambed, feet	197
Spillway	
Length of spillway, gross feet	590
Spillway crest gates (10), size in feet	50 x 25
Outlet Works	
Outlet conduit (1), diameter in feet	19
Power intake penstock	
Penstock (1), diameter in feet	19
Powerhouse	
Number of power units	3
Rated capacity, each unit, kilowatts	19,550
Total installed capacity, kilowatts	39,100
Average yearly output, kilowatt hours	114,500,000

15.5 0.6 East side of dam. For the next several miles, the highway crosses a gently rolling upland surface underlain by the Atoka Formation.

18.3 2.8 Enter small community of Blackgum.

19.1 0.8 Intersection with Oklahoma Highway 82 to right (south). Continue on Oklahoma Highway 100 (also Oklahoma Highway 82)

19.7 0.6 Oklahoma Highway 100/82 turns left (north).

For the next approximately 5 miles, the highway passes through the lower part of the Atoka Formation; where it crosses creeks, it is underlain by Morrowan or Mississippian strata. In general, older strata are present at lower elevations and younger strata a higher elevations except where faults juxtapose rocks of different ages. This area has not been remapped since Huffman (1958), who divided the Morrowan section into the Hale and Bloyd Formations. The modern stratigraphic nomenclature of

Sutherland and Henry (1977) is recognized only at a select number of widely separated measured sections.

22.0 2.3 Leave Sequoyah County, enter Cherokee County.

24.0 2.0 Excellent view of Tenkiller Ferry Lake to left (northwest).

24.7 0.7 Cross Chicken Creek. Poor (to nonexistant) exposure is typical of the Mississippian Keokuk – Reeds Spring Formations.

25.2 0.5 Cross northeast-striking Blackgum Fault. Here, Morrowan strata on the northwest are juxtaposed against Mississippian strata on the southeast, but there is no evidence for the fault along the road.

25.6 0.4 Cross Terrapin Creek. For the next approximately 1 mile, the highway ascends topographically and stratigraphically from Morrowan strata to the Atoka Formation.

26.5 0.9 Sandstone in Atoka Formation at top of hill on right (east). For the next couple of miles the highway again crosses a gently rolling upland underlain by the Atoka Formation.

28.5 2.0 Enter Cookson.

29.2 0.7 Driveway to East Central Baptist Association Camp on left (north). Cookson measured section of Bowlby (1968), Rowland (1970), Kotila (1973), and Sutherland and Manger (1977, 1979) and MS 26 of Sutherland and Henry (1977) on right side of road. Although this field trip will not stop here, the section deserves mention.

Cookson Measured Section

The Cookson measured section is shown in figure 58; it includes observations on the lithostratigraphy of the limestone beds by Bowlby (1968) and Rowland (1970) and the fauna and algae by Kotila (1973). Of importance to this field trip is Sutherland and Manger's (1977, 1979) identification of the conodont *Idiognathodus sinuatus* at the base of the section and *I. sinuosis* at the base of bed 17 (Fig. 58). These identifications are strong evidence that part of the Braggs Member of the Sausbee Formation is equivalent to the Union Valley Formation.

The section at Cookson is composed of shale, limestone, and sandstone (in decreasing order of abundance). Most of the sandstone, including sandy limestone, occurs in the lower part of the section below bed 7 (Fig. 58). Sandstone is virtually absent above bed 6; thus, the Union Valley equivalent here is a basal sandstone-sandy limestone-limestone interval overlain by a shale- and limestone-dominated interval. The

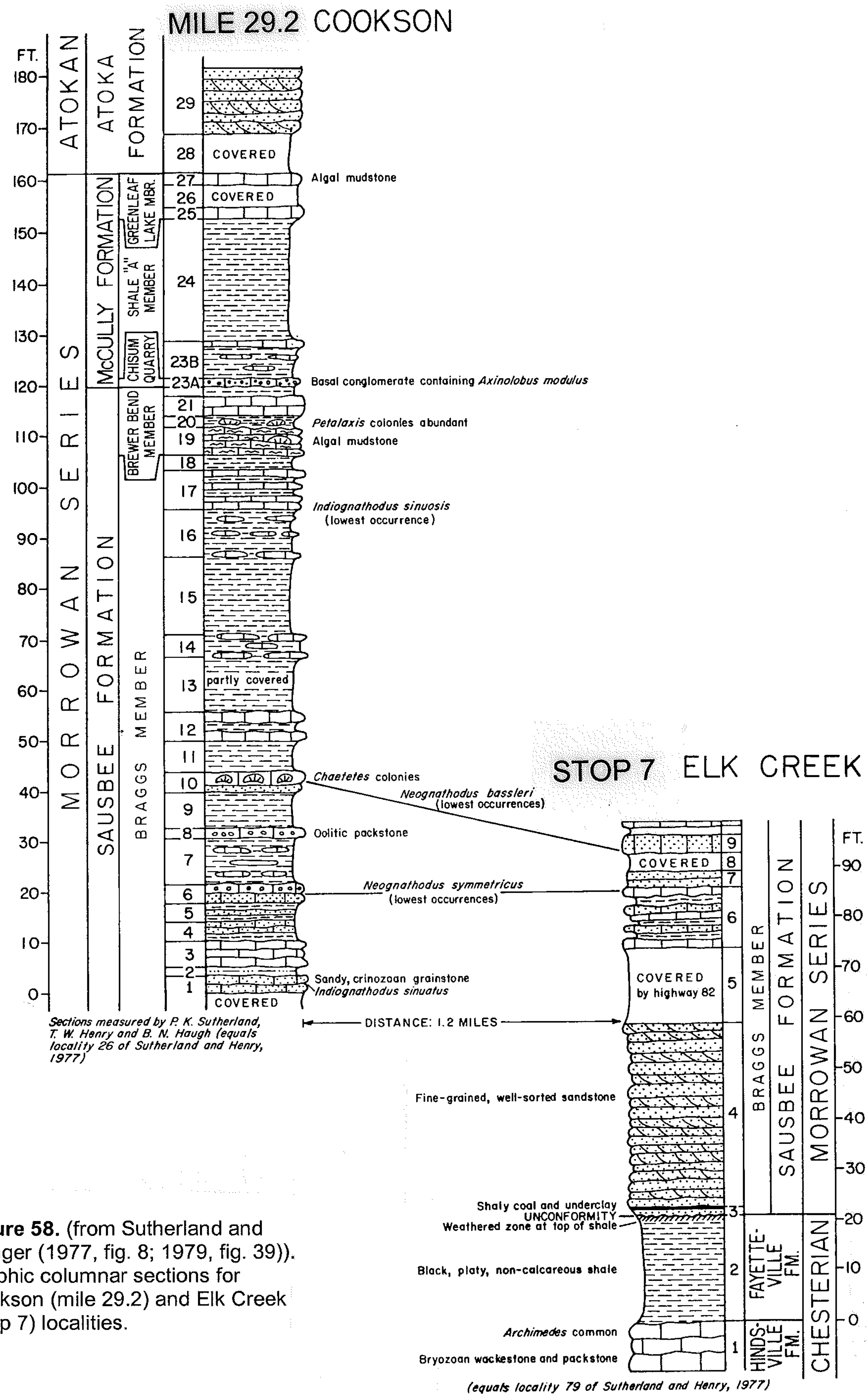


Figure 58. (from Sutherland and Manger (1977, fig. 8; 1979, fig. 39)). Graphic columnar sections for Cookson (mile 29.2) and Elk Creek (Stop 7) localities.

abundance of limestone in the Union Valley interval here makes it significantly different from the same interval throughout most of the Arkoma Basin, where it is dominated by shale.

Several features support a shallow-marine depositional environment for the Braggs Member at this location. A comparison of the strata as described by Bowlby (1968) and Rowland (1970) with the facies zones described by Stanley (2001) suggests most of the Braggs Members at the Cookson section was deposited in lagoons or tidal flats (shale) and in the intertidal to immediate subtidal zone (limestones and sandstones). The abundance of sandstone in the lower part of the section is evidence for a nearby clastic course. In Arkansas most of the equivalent section is sandstone (e.g., Evansville Mountain; Sutherland and Manger, 1979, fig. 28) and the source of the clastic material was to the east and northeast (Sutherland and Henry, 1977).

29.7 0.5 Large outcrop of Hindsville Formation (Mississippian) on left (west) where driveway crosses streambed.

30.3 0.6 Cross Elk Creek. Prepare to stop on right (east) side of highway.

30.4 0.1 Park in flat grassy area on right (east) side of highway. Stop 7 is along Elk Creek next to the bridge.

Stop 7. Elk Creek Locality

Location: Along Elk Creek, NW1/4 SE1/4 sec. 31, T. 15 N., R. 23 E., Cookson 7.5' quadrangle. On southeast side of Oklahoma Hwys. 82 on north side of Elk Creek about 1.8 mi northeast of Cookson and 2.2 mi south of junction with Oklahoma Hwy. 100. Cherokee County.

Introduction

The Elk Creek locality (Stop 7) and the Cookson section (mile 29.2) form an important reference section for the Morrowan series in the Tenkiller Ferry Lake area (Sutherland and Manger,1977, 1979) because they are about half-way between the type section of the Sausbee and McCully Formations of Sutherland and Henry (1977) and the type section of the Hale Formation (Arkansas nomenclature) (partly equivalent to the Union Valley Formation) at Evansville Mountain (Henbest, 1953, 1962). The Mississippian – Pennsylvanian contact here is an unconformity; the Pitkin Limestone and much of the Fayetteville Formation (see Stop 8) were eroded prior to deposition of the Morrowan Braggs Member (Sausbee Formation). The unconformity is extremely irregular; about 31 ft of Pitkin Limestone is present about 2 miles to the east (Moore, 1947, meas. sec. 39, p. 104-105) and about 25 ft. of Pitkin is present about 1.5 miles to the southeast (Huffman, 1958, meas. sec. 33, p. 158-160).

In addition to the unconformity, the outcrop at this locality exposes a well-developed sandstone that is approximately the same age as the Cromwell sandstone. This basal Morrowan sandstone is similar to others that filled depressions on the pre-Morrowan surface (Sutherland and Henry, 1977, p. 430). Based on the abundance of sandstone in the same part of the section in Arkansas (Hale Formation), the source of the sand probably was to the east or northeast.

Previous Work

Manger and Sutherland (in prep.) interpreted this outcrop in terms of sequence stratigraphy. Critical to their argument is the presence of a thin shaly coal and underclay at the base of the Sausbee. The upward progression from shaly coal to high-energy sandstone (this outcrop) to alternating quartz-sand-bearing crinoidal grainstones and dark shales (poorly exposed on west side of highway), ultimately capped by algal wackestones (Brewer Bend Member) is evidence that the Sausbee Formation is a transgressive systems tract. In simpler terms, the Sausbee was deposited under progressively deeper-water conditions, but probably never deeper than storm wave base.

Outcrop Description

The basal Sausbee Formation sandstone here is about 40 ft thick and is fine grained, well sorted, and porous. Most of the sandstone is relatively uniformly stratified (Fig. 59) and weathers to 1- to 3-in.-thick flagstones and slabs. In detail, the sandstone is highly ripple-, cross-, and lenticular-bedded (Fig. 60). Trace fossils on bedding planes are locally abundant. Less common sedimentary structures include soft-sediment deformation features (asymmetric folds) and dune structures. Most of the structures are evidence for sand deposition in a high-energy environment.

After stop, return to vehicles and continue north on Oklahoma Highway 100/82.

31.4 1.0 Cross trace of northeast-striking Barber Fault. Morrowan strata on southeast side (down) are juxtaposed against Mississippian Keokuk – Reeds Spring on northwest side (up). Angular blocks typical of weathered Keokuk – Reeds Spring litter the slope east of the highway just past the trace of the fault.

32.2 0.8 Cross trace of northeast-striking Cookson Fault. Atoka Formation is northwest of the fault; Keokuk – Reeds Spring is on the upthrown block to the southeast.

32.7 0.5 Highway 100 turns right (east). Continue straight on Highway 82. This flooded part of the Illinois River is dammed by the Tenkiller Ferry Dam (mile 14.9).

Figure 59. Sandstone at base of Braggs Member, Sausbee Formation, Elk Creek locality.

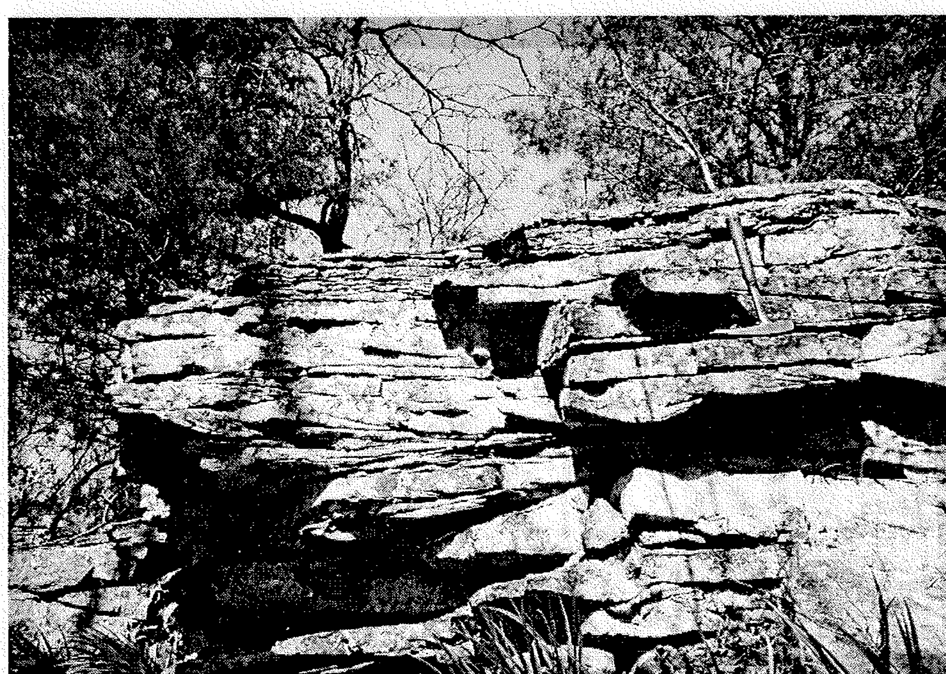


Figure 60. Sandstone at base of Braggs Member, Sausbee Formation, Elk Creek locality. Common sedimentary structures include ripple-bedding (at top of hammer), cross-bedding (immediately below hammer head), and lenticular-bedding (e.g., bed behind middle of hammer).

Note the enormous area of greenhouses on the opposite side of the river. The town of Tahlequah advertises itself as the "Greenhouse Capitol of the World". Small wonder (bad pun).

Greenleaf Nursery Company

This is the corporate headquarters of Greenleaf Nursery Company, a wholesale container nursery. The company was founded in 1945 and this property was purchased in 1957. As a result of the particularly severe winter of 1962-1963 when freezing temperatures killed about 90% of the saleable crop at Greenleaf, the company decided to focus on growing hardier plant types and developing overwintering procedures. "In the fall of 2000, over 10,000,000 square ft (about 2.8 square miles) of steel quonset structures were covered with plastic" (**http://www.glnsy.com/history.htm**, accessed 4/2003). Some of the structures are visible from the field trip route.

Greenleaf's Oklahoma operation currently produces over 10,0000,000 liners and 8,500,000 finishing plants, including 70 varieties of conifers, 570 varieties of broadleaf evergreens and deciduous shrubs, and 45 varieties of shade and flowering trees.

For the next few miles the highway is underlain by the Atoka Formation.

35.2 2.5 Cross trace of northeast-striking fault with relatively minor displacement. The Bloyd Formation to southeast is juxtaposed against the Hale Formation on the northwest, which is underlain by very thin Mississippian Fayetteville, Hindsville, and Moorefield Formations (Huffman, 1958, pl. III), all of which are very poorly exposed.

For the next several miles, the highway overlies poorly exposed to unexposed Keokuk – Reeds Spring Formations. Typically, the only evidence for the Keokuk – Reeds Spring is scattered light-colored blocks in a reddish soil.

37.6 2.4 Road to Pettit Bay to left (south).

38.4 0.8 Cross northeast-striking Qualls – Welling Fault. This is a major normal fault that here juxtaposes Mississippian Keokuk – Reeds Spring on the southeast against Atoka Formation to the northwest. The fault is topographically well-expressed a couple of miles to the northeast along Dripping Spring Hollow (Fig. 61)

40.2 1.8 Highway descends topographically off of Park Hill Mountain and stratigrahically from the Atoka Formation, through Morrowan and Chesterian (Pitkin, Fayetteville, Hindsville Formations) strata to the Osagean Keokuk – Reeds Spring Formations. The section was measured and described by a number of authors (e.g., Henry, 1970; Kotila, 1973) but it is now overgrown.

41.4 1.2 Park Hill Cemetery across field on right. Old town of Park Hill occupied much of the flat area east of the highway.

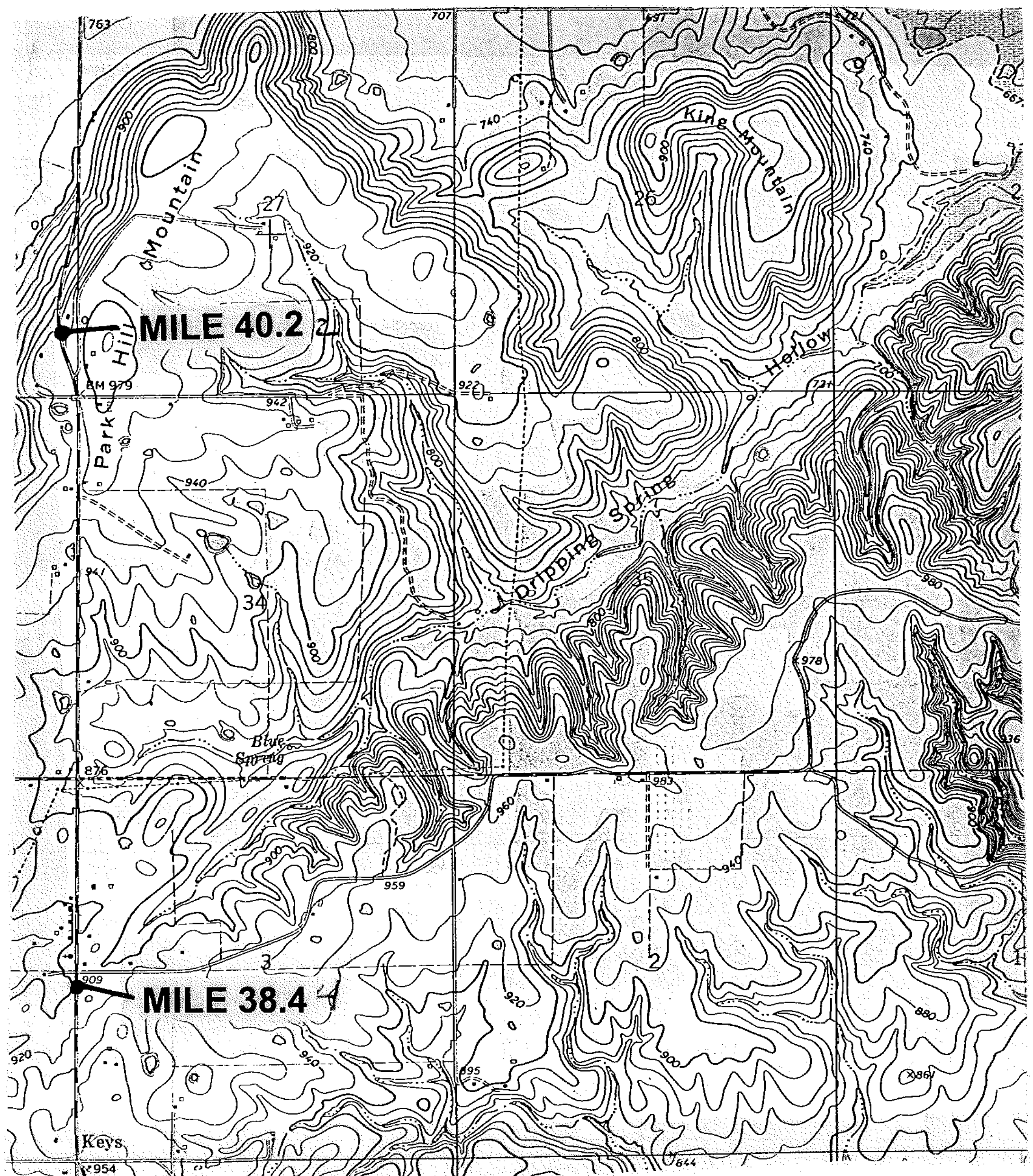


Figure 61. Part of the Park Hill 7.5' quadrangle topographic map. The trace of the Qualls – Welling Fault follows Dripping Spring Hollow. Note the different topography that has resulted from erosion of the chert- and limestone-dominated Keokuk – Reeds Spring Formations on the southeast (up) side of the fault compared to the sandstone- and shale-dominated Atoka Formation on the northwest (down) side of the fault.

Park Hill

"Park Hill is a name that spells romance in the Cherokee annals of Indian Territory. In the history of this small town is incorporated a large measure of the progress of the Cherokee Nation; the enlightenment brought to the region by the New England missionaries in religious and secular affairs; the establishment of the printing presses there and the subsequent production of millions of pages of the New Testament, hymn books, law and text books, and yearly almanacs, not only for the Cherokees, but also for the Choctaw Indians, made the town a center of culture.

"Romance bloomed there, and grim tragedy shows its horrid face in the village; it was swept time and again by war, when women and children were obliged to hide in the woods from the ruthless bushwhackers bent on robbery and destruction." (from Park Hill by Carolyn Thomas Foreman, quoted by Morris, 1977, p. 141).

Some of Park Hill's significant dates are summarized below:

1836. School and mission established.
1837. Rev. Samuel A. Worcester builds printing press.
1839. Cherokee Chief John Ross and brother Lewis establish homes.
1849. Cherokee Female Seminary building completed.
1861. Treaty between Confederate States and Osage, Seneca, Shawnee, and Quapaw Indians concluded at Park Hill Treaty Ground. Cherokees remain neutral.
1862. Union forces remove Chief John Ross and family and Cherokee official records and treasury from Park Hill. Confederate raiding parties and bushwhackers burn most of Park Hill buildings, including church, mission station, and Cherokee printing office and bindery (Wright and Fischer, 1966).
1887. Reconstructed Female Seminary burned.
1888. Tornado destroys part of town.
1942. Ozark and Cherokee Central Railroad, extended through Park Hill in 1902, abandoned.

42.3 0.9 Intersection of Highway 82 with U.S. Highway 62/Oklahoma Highway 10. Tahlequah is about 4 miles to the right (north); Muskogee is to the left (west). Turn left (west). Reset odometer to 0.0.

Tahlequah, Oklahoma

Tahlequah is the county seat of Cherokee County and the home of Northeastern State University. The school's men's basketball team, the Redmen, won the 2003 NCAA's Division II National Championship. Tahlequah was the capital of the Cherokee Nation from 1839 to 1906 after their removal from their eastern homelands.

For the next almost 10 miles, the highway follows a relatively flat valley floor underlain by Mississippian rocks – mostly the Keokuk – Reeds Spring Formations. Outcrops are few and far between and the countryside is relatively flat and featureless, typical of areas underlain by the Keokuk – Reeds Spring.

3.7 3.7 Intersection with north-south county road.

The low hill immediately west of the intersection (straight ahead) is capped by the Atoka Formation, which is underlain by a relatively thin Morrowan section and the upper part of the Mississippian Pitkin Formation. The northeast-striking South Muskogee Fault separates the Keokuk – Reeds Spring Formation here (at the intersection) and in the valley to the south and east from the younger strata in the hills to the north. For most of its length between Tahlequah and mile 9.4 (below), the fault juxtaposes the Atoka Formation (hilly terrain) against the Keokuk – Reeds Spring Formations (flat terrain).

6.9 3.2 View of Red Berry Mountain straight ahead. The mountain is relatively flat-topped and capped by the Atoka Formation.

9.4 2.5 Trace of the South Muskogee Fault crosses the highway.

For the next five miles, the gently rolling terrain on both sides of the highway is underlain by the Atoka Formation. The hills south of the highway are capped by the Atoka Formation and Mississippian and Morrowan strata are exposed in the slopes. The very flat terrain is underlain by alluvium or terrace deposits associated with Bayou Manard.

9.7 0.3 Leave Cherokee County, re-enter Muskogee County.

9.9 0.2 Small outcrop of tilted siltstone in Atoka Formation on left (south) side of highway. Tilt may be caused by nearness to South Muskogee Fault, the trace of which is in the valley just behind the powerlines. The siltstone contains conspicuous sponge spicules.

10.9 1.0 Cross Bayou Menard

Bayou Menard Skirmish

(from Wright and Fischer, 1966, p. 195)

"In the first Federal effort to retake Indian Territory, Major William A. Phillips penetrated to a point about seven miles east of Fort Gibson. Here on the banks of Bayou Menard (erroneously reported by Phillips as Bayou Bernard) he met and routed a force of Colonel Stand Watie's Confederates in a brief skirmish on July 27, 1862, taking twenty-five prisoners and killing and wounding about 100 men. Among the Confederate dead were a lieutenant colonel and three captains. Phillips was pleased with the conduct of his Indian forces in this skirmish. His only difficulty was in restraining their impetuous charge and in keeping back a reserve and guards for the wagons."

13.1 2.2 Cross Four-Mile Creek.

14.4 1.3 Highway begins to turn gently to left (south). Prepare to turn left (south).

14.7 0.3 Turn left (south) on Two-Mile Road at large sign that reads "BRB".

16.7 2.0 Turn left (east) on Oklahoma Highway 10.

17.3 0.6 The hill on the right (south) is capped by the Atoka Formation; Morrowan limestone is exposed in the stream valley on the left (north).

A thin (0.8 ft) coal is present immediately below the cliff-forming sandstone on the right (south) side of the highway. Moore (1947) measured the section at this locality (Fig. 62) and placed the coal at the top of the Bloyd Formation. He also suggested that it might correlate with the Baldwin coal in Arkansas. Huffman (1958) suggested that the coal might be in the lower part of the Atoka Formation. Hemish (1998) included it in the Morrowan section. Regardless of whether this coal is uppermost Morrowan or lowermost Atokan, it is likely one of the oldest coals in Oklahoma (Moore, 1947; Hemish, 1998).

SECTION OF UPPER BLOYD SHALE, ROAD CUT ALONG HIGHWAY 10, NE¼ SEC. 20, T. 15 N., R. 20 E.

	THICKNESS (feet)
DES MOINES SERIES	
ATOKA FORMATION	
9. Pope Chapel sandstone, very fine grained, iron stained, fossiliferous	caps the hill
8. Shale, covered, estimated at	15
On top of Braggs Mountain, southeast of the coal outcrop, about 2 miles along the highway, this shale is silty, green to gray green and locally is carbonaceous; and carries a small coal bed less than 3 feet in areal extent in the road cut.	
7. Coody sandstone, light gray, fine grained with medium grains toward the base; few thin papery carbonaceous streaks; locally calcareous. Lower 2 inches is greenish brown, carbonaceous with included coaly particles, fairly soft, medium grained with a few coarse grains. The lower 12 feet forms the prominent cliff above the coal	18
MORROW SERIES	
BLOYD FORMATION	
6. Coal, carries impurities of pyrite and shale	0.8
5. Shale, thin bedded, highly carbonaceous	0.4
4. Shale, gray, soft sandy. Resembles underclay on weathering	0.5
3. Sandstone, fine to very fine grained, thin bedded, soft; gray and green in color; locally very shaly with the amounts of shale varying along the strike. Carries plant remains	3.0
2. Shale, blue gray, fissile, ironstone concretions; thin sandstone streaks in the upper 2 to 3 feet	25.0
1. Limestone in south road ditch, east of coal outcrop, blue gray, medium crystalline, crinoidal and granular; fossiliferous; *Pentremites*, crinoid stems, arms, plates, and calices, Bryozoa, Brachiopods, at least	6.0
Residue: approximately 1 per cent. Quartz major grades 1/16-1/32 mm, principal subsidary grade 1/8-1/16 mm. Angular. Some glauconite.	

Figure 62. Measured section (from Moore, 1947, p. 41) of coal at base of Atoka Formation or top of Morrowan series.

17.7 0.4 Cross trace of South Muskogee Fault. The highway bends right and ascends through the Chesterian and Morrowan sections, ending in the Atoka Formation at the top of the hill beyond Stop 8.

Because Highway 10 is a busy road and there is no place to stop on the right side of the road, we will drive to the top of the hill, turn around, retrace our route slightly, and park at a safe place (wide spot in the road) heading downhill.

19.6 1.9 Turn left (east) onto gravel road at top of hill. Retrace route down hill.

20.0 0.4 Stop along right side of road where road widens. Stop 8. Please be very careful at this stop. People drive much faster than they should on this road, so be sure to stay well off the road.

Stop 8. Braggs Mountain Locality

Location: Series of road cuts along east side of Oklahoma Hwy. 10, W1/2 SW1/4 sec. 21, T. 15 N., R. 20 E., to NW1/4 NW1/4 sec. 28, T. 15 N., R. 20 E. Measured section extends for about 0.5 mi along highway. Muskogee County.

Introduction

The road cuts along Hwy. 10 on the northwest side of Braggs Mountain (this stop) and the outcrop at the Webbers Falls Lock and Dam (Stop 6) probably are among the best-exposed sections of the Morrowan series on the southwest flank of the Ozark Uplift. The lower Morrowan rocks exposed here and at stop 6 differ greatly from the same age rocks to the west; therefore, they provide key information on the size and nature of the basin that contains the Cromwell sandstone. From a more regional perspective, these rocks also record the details of the Morrowan shelf that extended to the northeast into Arkansas. Andrews (2003, pl. 4) regional cross section A-A' extends from here (locality 15) to the southwest and documents the changes in rock types in the Morrowan section.

Previous Work

The first modern detailed geologic map of the area near Stop 8 is by Beckwith (1950). He divided the Morrowan strata into the Bloyd (upper) and Hale (lower) Formations, using well-established Arkansas nomenclature. Later maps by Huffman (1958) and Oakes (1977) also show the Morrowan as divided into the Bloyd and Hale Formations. These units are no longer recognized in Oklahoma and have been replaced by the McCully and Sausbee Formations (Sutherland and Henry, 1977) (see discussion at Stop 6), but these have not been mapped.

The strata along Hwy. 10 have been described in detail by several authors, including Moore (1947, p. 95), Beckwith (1950, p. 42-43), Huffman (1958, p. 168-169), Kotila (1973, p. 193-197), Oakes (1977), and Sutherland and Manger (1977, p. 35; 1979, p. 36). However, the only original descriptions are those by Moore (1947), who measured 112.2 ft of strata that he divided into the Bloyd and Hale Formations, and Kotila (1973), who measured 141.8 ft of strata that he simply referred to as the Morrow Formation. (The different thickness are due to the fact that Moore (1947) measured the

Morrowan section along the highway and Kotila (1973) measured his section perpendicular to the highway.) Both authors recognized the Morrowan strata along Hwy. 10 consisted mostly of limestone and shale and minor sandstone, with shale predominating in the upper part of the unit, limestone predominating in the lower part, and a calcareous sandstone at the base. (These units are described in more detail below.) Sutherland and Manger (1977, 1979) adopted Kotila's (1973) measured section and numbering system, but divided the it into the McCully and Sausbee Formations and included members (Fig. 63). The contact between the Hale and Bloyd Formations as identified by Moore (1947) is equivalent to the Braggs – Brewer Bend Limestone Member contact identified by Sutherland and Manger (1977, 1979) (Fig. 63).

Outcrop Description

The Braggs Member of the Sausbee Formation is approximately equivalent to the Union Valley Formation, but unlike the Union Valley is composed mostly of limestone and lesser amounts of shale. In general, sand-rich units in the Braggs Member are sandy limestones (although a notable exception is the sandstone at Elk Creek (Stop 7, this guidebook) and unit 4 at this stop). The limestone units in the Braggs Member at Stop 8 range from moderate-energy skeletal wackestones (calcarentie of Kotila, 1973) to high-energy bioclastic grainstones (calcirudite) (Fig. 63). Some units are sandy (e.g., units 4 and 9; Fig. 64) and some are cross-bedded (e.g., units 4 and 6; Fig. 65); these observations support a moderate- to high-energy depositional environment. The shale units in the Braggs Member are poorly exposed at Stop 8, but their close association with relatively coarse fragmental limestones is evidence that they probably are lagoonal and not low-energy deep-water clastics.

Several aspects of the Braggs Member at this stop and regionally favor a carbonate ramp shelf profile over a carbonate platform (Wilson, 1975; Stanley, 2001). Facies distribution within the Braggs Member is irregular but widespread; thus, detailed correlation from measured section to measured section is impossible, but the overall depositional environment is the same. This aspect of the Braggs Member is well-illustrated by Sutherland and Henry (1977, fig. 3). There is no widespread fine-grained lagoonal facies in the Braggs Member east of any recognized carbonate buildup as would be expected in a platform model (see Stanley, 2001, fig. 4). Lastly, the presence of sand in many of the coarse bioclastic limestones is evidence that the high-energy carbonates accumulated relatively close to shore and not near a shelf margin. Interpretation of the sandstone at Elk Creek (Stop 7) as a strand-plain deposit supports this.

STOP 8 BRAGGS MOUNTAIN

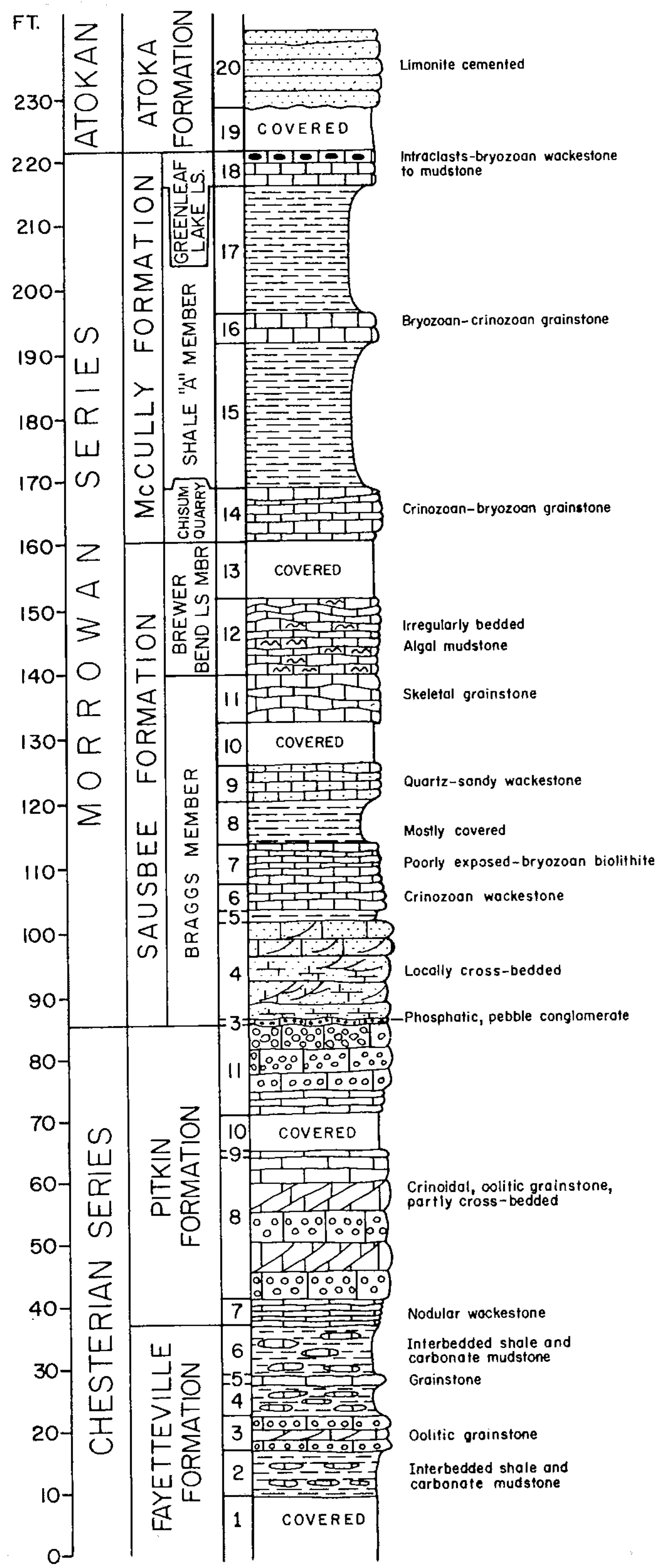


Figure 63. (from Sutherland and Manger, 1977, p. 35; 1979, p. 36). Graphic columnar section for Stop 8.

Figure 64. Contact (at bottom of hammer) between Morrowan Braggs Member, Sausbee Formation and Chesterian Pitkin Formation. The contact is marked by a 0.1- to 1.2-ft-thick conglomerate containing phosphatic pebbles of sandstone, siltstone, shale, and micrite. The basal unit of the Braggs Member is a cross-bedded sandy limestone.

Figure 65. Cross-bedding in coarsely bioclastic unit 6, Braggs Member.

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