THE GEOLOGY OF THE SOUTHWESTERN OZARK UPLIFT

AN INTRODUCTION AND FIELD-TRIP GUIDE

NORTHEASTERN
STATE UNIVERSITY

OKLAHOMA GEOLOGICAL SURVEY
1908

OKLAHOMA ACADEMY OF SCIENCE
RESEARCH · SERVICE · EDUCATION
1909

Oklahoma Geological Survey
Open-File Report 6-95

THE GEOLOGY OF THE SOUTHWESTERN OZARK UPLIFT

AN INTRODUCTION AND FIELD-TRIP GUIDE

John Simms
College of Science, Mathematics, and Nursing
Northeastern State University
Tahlequah, Oklahoma

Fay Simms
John Vaughan Library / Learning Resources Center
Northeastern State University
Tahlequah, Oklahoma

Neil H. Suneson
Oklahoma Geological Survey
Sarkeys Energy Center
100 East Boyd Street, Room N-131
Norman, Oklahoma 73019-0628

Prepared for the Fall Field Meeting of the
Oklahoma Academy of Science

Camp Egan, Tahlequah, Oklahoma
September 29-30, October 1, 1995

OKLAHOMA GEOLOGICAL SURVEY
Open-file Report Disclaimer

INTRODUCTION

The Tahlequah area is located on the southwest end of a regional upwarping of the Earth's crust known to geologists variously as the Ozark Uplift or Ozark Dome. This uplift is regional in scale, encompassing about 40,000 square miles of southern Missouri, northwest Arkansas, and northeast Oklahoma (Fig. 1). In Oklahoma, the Ozark Uplift is divided into two physiographic provinces that are based, at least in part, on geology. The Springfield Structural Plain is underlain mostly by Mississippian-aged rocks (365 to 330 million years old). The Boston Mountains consist of an eroded plateau capped by Early and Middle Pennsylvanian-aged rocks (330 to 310 million years old).

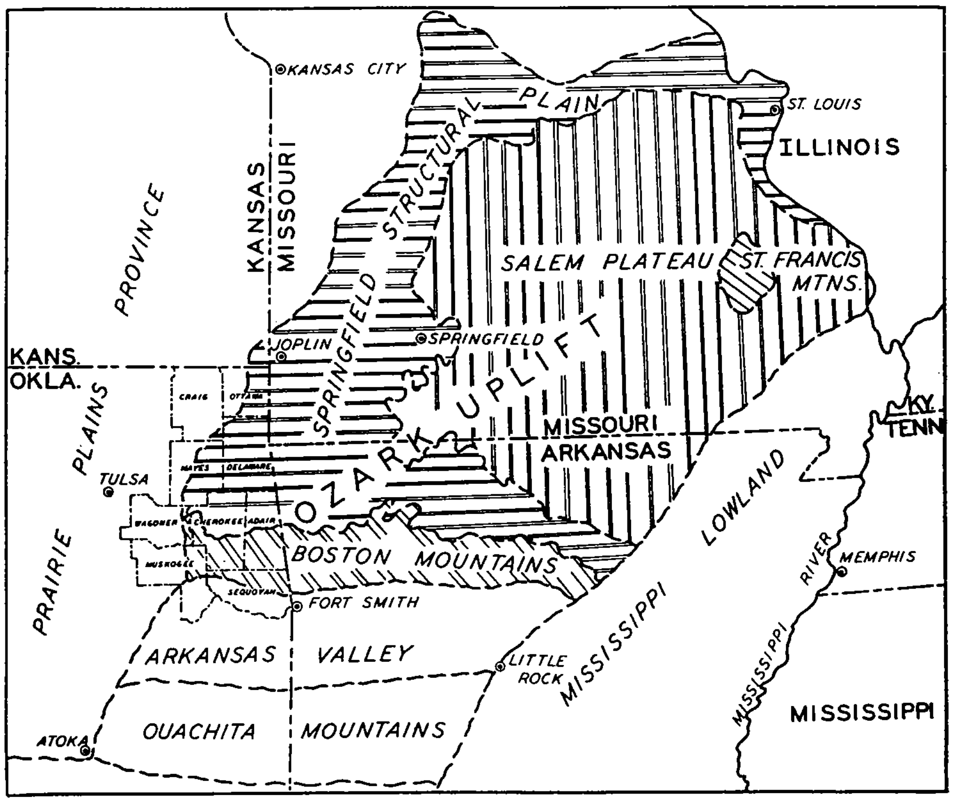

Figure 1. Physiographic provinces of the Ozark Uplift and adjoining areas (from Huffman, 1958).

As we will see, the Ozark Uplift has been uplifted repeatedly over geologic time. To the casual observer, the most obvious effect of this long history of recurrent upwarping is the incisement of much of the drainage in the Ozark area. Many of the streams eroded 200 or more feet below the plateau-like upland surface. This deep stream incisement coupled with the hard, resistant nature of much of the rock strata has resulted in a rugged topography that contrasts greatly with areas to the south and west. Incisement of major Ozark streams is well-evidenced by the Illinois River Valley; the excellent exposures of the Paleozoic rock strata there have provided geologists and paleontologists abundant information to decipher the geologic history of this part of the Earth. The area also affords recreational opportunities for the thousands of people who visit the area each year to float and fish the scenic streams and to observe the abundant wildlife of the area.

GENERAL GEOLOGY

The Ozark Dome is an asymmetrical uplift of the Earth's crust with the apex located in southeastern Missouri. Here Precambrian rocks are exposed at the surface in an area known as the St. Francis Mountains.

The Tahlequah area is located on the southwest flank of the Ozark Uplift in northeastern Oklahoma. This is reflected in the overall gentle southwestward dip (or tilt) of the Paleozoic strata in the area. Interestingly, the structurally highest part of the uplift in northeastern Oklahoma is near the community of Spavinaw, about 40 miles north of Tahlequah. Here, the Spavinaw Granite is exposed in four very small outcrops that are being exhumed along Spavinaw Creek. The Spavinaw Granite is about 1.3 billion years old whereas the surrounding Cotter Dolomite is "only" about 500 million years old. The granite outcrops are believed to be the tops of granite hills that were inundated by the seas that deposited the Cotter; in other words, the Spavinaw outcrops are the tops of hills that existed in northeastern Oklahoma half-a-billion years ago.

In the area of the field trip, the general southwestward regional dip is locally interrupted by folds and faults in the rock strata. The majority of these folds and faults trend northeast-southwest, roughly parallel to the southwestward elongation of the Ozark Uplift (Fig. 2). Where it can be determined, the faults appear to belong to a class of faults known as "normal faults" which suggest tensional stresses in the crust. The faults do not have a consistent sense of offset; in some cases, the southeast side of a fault is up relative to the northwest side. In other cases, the opposite is true. The faults and folds appear to have formed in Middle Pennsylvanian time because younger rocks to the west of the Ozark Uplift are less deformed. Some geologists relate the deformation to recurrent uparching of the Ozark Dome while others attribute it to downwarping of the Arkoma Basin immediately to the south. Other geologists propose a combination of the two processes. None of the faults show any evidence of recent movement.

Regional uplift of the Ozark area in the fairly recent geologic past (Late Tertiary-Early Quaternary) has, however, been proposed by a number of workers. The deeply entrenched stream meanders, abundant bedrock terraces, and Ozark caves have all been cited at various times in support of this idea.

The area around Tahlequah, as typical of much of the Ozark Uplift, is underlain by horizontal to very gently dipping sedimentary rocks of Paleozoic age. Near some faults, however, the strata locally dip as much as 40^{o}. The strata are predominantly what geologists refer to as "shelf" sediments; i.e., they were deposited in a relatively shallow marine environment somewhat analogous to the modern Bahama Banks area. The sedimentary rocks that result from deposition in shelf environments are commonly carbonate rocks (limestones and dolomites), sandstone, and lesser amounts of shale. In general, marine sands are deposited near the shore, in a beach or off-shore bar environment. Mud, which forms shale, accumulates in deeper, relatively quite marine waters. Carbonates may be deposited still farther from shore in deep water (but still shallow enough to support organisms that require sunlight), beyond where mud makes the water cloudy. Therefore, a vertical sequence of, from bottom to top, sandstone, shale, limestone, records the advance and deepening of an ocean.

The Paleozoic strata of the southwestern Ozark Uplift show this sequence to be repeated over and over. This strongly suggests that the sea repeatedly transgressed (advanced) and then regressed (retreated) across the area during the time the strata were

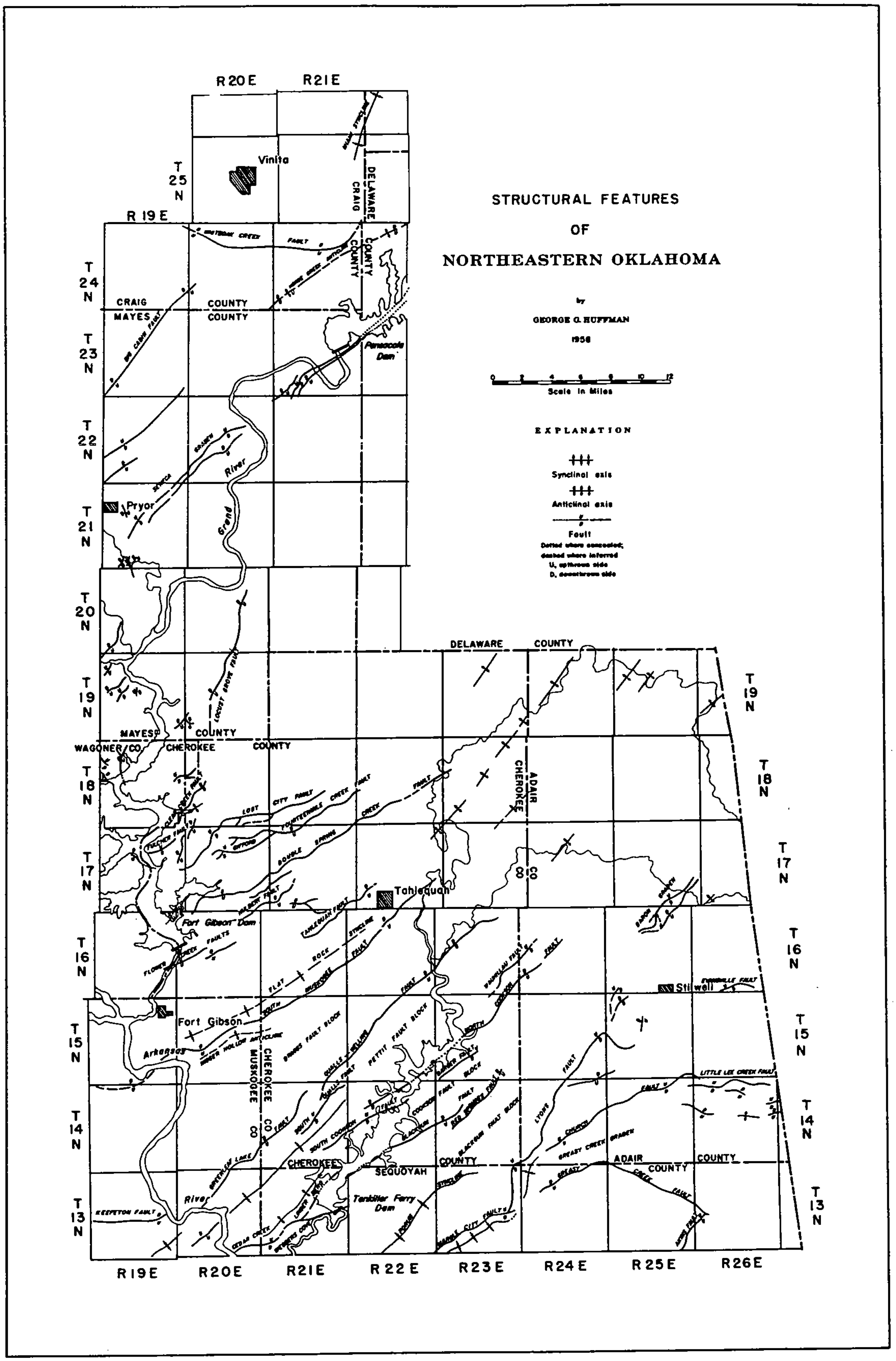

Figure 2. Structural features of the southwestern part of the Ozark Uplift, northeastern Oklahoma (from Huffman, 1958).

deposited. Geologists have found it useful to group the sedimentary layers, each represented by an individual formation, into packages, or sequences, of strata. Each sequence represents a major, possibly worldwide, slow transgression and then regression of the sea. Each sequence is given a name (e.g., Tippecanoe Sequence) that begins with the first sedimentary rock layer or formation (often a sandstone) associated with the advancing sea that was deposited upon an erosional surface formed during the previous retreat of the sea. The top of each sequence is marked by the erosional surface formed when the sea once again retreated from the area. Figure 3 illustrates the named post-Precambrian sequences that geologists have recognized. Several of these sequences are encountered on the field trip. If the land was absolutely stable, the rock layers left by the transgressions and regressions of the sea would be relatively easy to recognize. The Ozark Dome, however, has experienced recurrent uplift during deposition of these sequences; this has somewhat complicated the local recognition of the sequences.

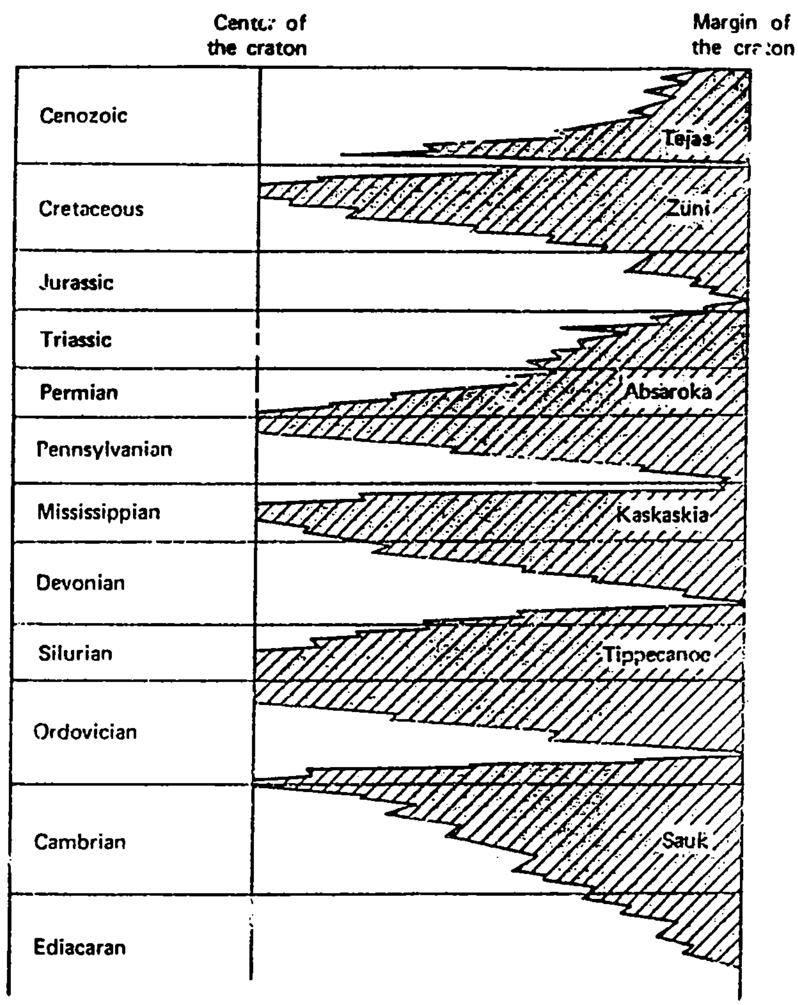

Figure 3. Diagram showing time relationships of major transgressive and regressive sequences. The striped areas are the times that are represented by the sedimentary rock record. The base of the striped areas represent marine transgressions and deposition of sedimentary sequences from the margin of the North American craton to the center of the craton. The top of the striped areas represent marine regressions and periods of nondepositon and/or erosion. (Modified from Sloss, 1963)

The age of the strata that will be encountered on this trip ranges from the 460-million-year-old Middle Ordovician Burgen Sandstone to the 310-million-year-old Middle Pennsylvanian Atoka Formation. The pre-Atoka strata are predominately shelf sediments associated with a number of marine transgressive/regressive cycles. This shelf deposition finally ended in the Pennsylvanian with the influx of fluvial(river)/deltaic sediments represented by the Atoka Formation (Fig. 4).

Most of the fossils encountered in the predominately marine strata of the area are invertebrates. Common examples are horn corals, productid and spiriferid brachiopods, fan-like and branching varieties of bryzoans, crinoid columnals, blastoids, and rare cephalopods and trilobites. Plant fossils are present locally in the Chattanooga, Fayetteville, Sausbee, and Atoka Formations. Figure 5 gives examples of some of the fossils that are found in the area. The only vertebrates reported from the area are very rare sharks' teeth and spines and an early armored fish (Dinichthys).

Age	SYSTEM	GROUP AND FORMATION	ROCK	FEET	CHARACTERISTICS AND FAUNAS
	PENNSYLVANIAN	Mc ALESTER		50-150	Dark gray to black, laminated to fissile shale with layers of clay-ironstone concretions, and with three coals and associated underclay. Marked at base by Warner sandstone.
	PENNSYLVANIAN	HARTSHORNE		0-50	Conglomerate, underclay, coal, shale, and siltstone
	PENNSYLVANIAN	ATOKA		0-600	Sequence of marine and non-marine shales and sandstones with occasional limestone beds. Typically developed in Muskogee-Porum District where it includes in ascending order the Coody sandstone and overlying shale; Pope Chapel sandstone and overlying shale; Georges Fork sandstone and overlying shale; Dirty Creek sandstone and overlying shale; Webbers Falls sandstone and overlying shale; and the Blackjack School sandstone and overlying shale. Units thin northward by convergence and overlap.
	PENNSYLVANIAN	McCULLY		0-200	Blue-gray, unevenly bedded, fossiliferous limestone interbedded with gray, fissile shale. Limestones fossiliferous, with abundant Pentremites. Thins northward to extinction near Union Mission, T. 19 N.
	PENNSYLVANIAN	SAUSBEE		0-150	Massive, blue-gray, sandy limestone with basal beds of brown, calcareous sandstone. Grades laterally into cross-bedded sandstone. Weathers pitted and fluted. Thin conglomerate at base. Abundant Michelinia scopulosa.
330	MISSISSIPPIAN	PITKIN		0-80	Gray-blue, fossiliferous, rubbly-weathering limestone characterized by abundance of Archimedes (Archimedipora), Diaphragmus, Eumetria, Torynifera setigera. Thins northward to extinction in T. 18 N. near Mayes County line.
	MISSISSIPPIAN	FAYETTEVILLE		15-185	Sequence of black, fissile shale with thin interbedded blue-black, lithographic limestone. Fossiliferous with Diaphragmus, Eumetria, Spirifer increbescens, Spirifer leidyi, Torynifera setigera, Linoproductus ovatus.
	MISSISSIPPIAN	HINDSVILLE		0-48	Gray, medium crystalline limestone with Diaphragmus, Spirifer leidyi, Agassizocrinus.
	MISSISSIPPIAN	MOOREFIELD		0-100	Blue-gray to brown calcareous siltstone with Leiorhynchus carboniferum, and overlying black shale Gray, oolitic, cross-bedded limestone with angular chert fragments Blue-gray to brown, argillaceous limestone with Leiorhynchus carboniferum, Moorefieldella eurekensis, Spirifer arkansanum, Griffithides pustulosus. Lies unconformably on Osagean limestones and cherts and on Chattanooga shale near Tenkiller Ferry Dam. Locally contains gray, cherty, crinoidal, glauconitic limestone at base.
	MISSISSIPPIAN	KEOKUK		0-250	Massive, white to tan-flecked, tripolitic weathered chert and blue-gray limestone
	MISSISSIPPIAN	REEDS SPRING		0-175	Blue-white to tan, thin-bedded chert with beds of blue-gray, finely crystalline limestone
	MISSISSIPPIAN	ST. JOE		0-25	Gray, fine-to medium-crystalline, nodular-weathering limestone and green calcareous shale
365	DEV.	CHATTANOOGA		0-70	Black, fissile shale, with basal Sylamore sandstone
	DEV.	SALLISAW		0-25	Brown, calcareous sandstone grading upward into tan and white chert
	DEV.	FRISCO		0-8	Gray, coarsely crystalline limestone, near Marble City only
405	SIL.	ST. CLAIR		0-200	Pinkish-white, coarsely crystalline limestone. Thins northward to extinction near Qualls, T. 15 N.
425	ORDOVICIAN	SYLVAN		0-35	Yellow-brown to green, platy shale
	ORDOVICIAN	FERNVALE		0-25	Gray, coarsely crystalline limestone with Lepidocyclus capax
	ORDOVICIAN	FITE		0-8	Gray, lithographic, calcite-flecked limestone
	ORDOVICIAN	TYNER		0-75	Bright green shales and thin beds of buff sandy dolomite
	ORDOVICIAN	BURGEN		0-90	White to yellow, hard massive sandstone with occasional beds of sandy dolomite and green shale
485	ORDOVICIAN	COTTER		85-125	Gray to buff, finely crystalline, hard, thick-bedded dolomite with occasional thin beds of white sandstone
	PRECAMBRIAN	SPAVINAW		unknown	Red, coarse-grained granite exposed near Spavinaw, Oklahoma

Figure 4. Generalized stratigraphic section for northeastern Oklahoma (modified from Huffman, 1958).

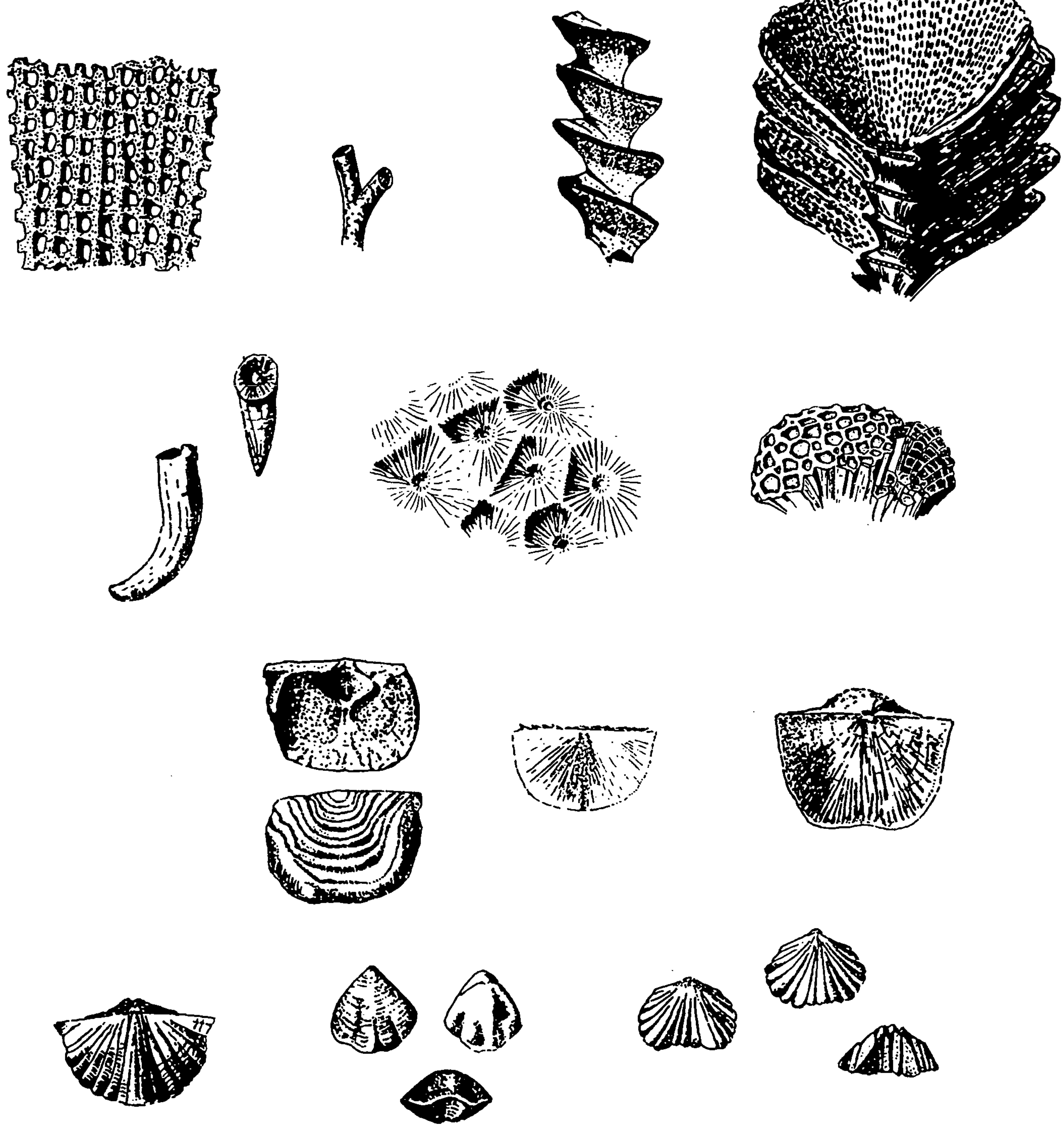

Figure 5. Common fossils found in Paleozoic strata of northeastern Oklahoma. Page 7, Row 1 (left to right): Bryozoans - fan-like, branching, spiral, spiral with fan (Archimedes)(all from Rose, 1967); Row 2: Corals - horn coral, colonial rugose and colonial tabulate corals (from Rose, 1967; LaRocque and Marple, 1965); Row 3: Brachiopods - strophomenid, chonetid, productid (all from Rose, 1967); Row 4: Brachiopods - spiriferid, athyrid i.e., tear-shaped spiriferid, rhynchonellid (all from Rose, 1967).

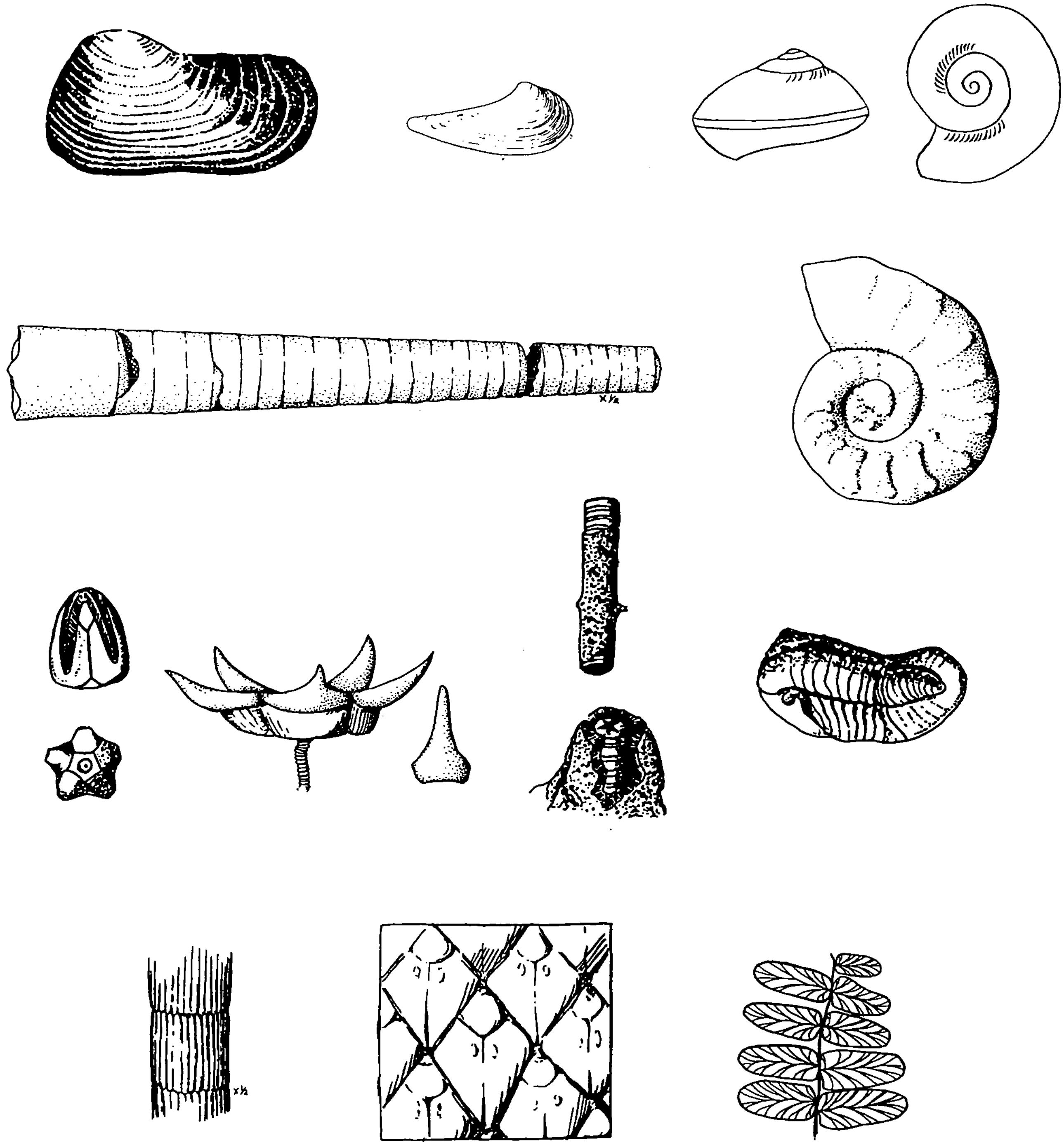

Figure 5 (continued) Page 8, Row 1: Mollusks - pelecypods (bivalves) and gastropods (snails) (from Rose, 1967; LaRocque and Marple, 1965); Row 2: Mollusks (cephalopods) - straight-shelled nautiloid and ammonoid (from LaRocque and Marple, 1965); Row 3: Blastoid - crinoid base and spine, crinoid columnals; Trilobite (from Rose, 1967; LaRocque and Marple, 1965); Row 4: Plant fossils - Calamites, Lepidodendron, fern-like foliage (from LaRocque and Marple, 1965).

Saturday Morning Trip

Leave Camp Egan which is located in the valley of Barron Fork Creek, a major tributary to the Illinois River. Proceed about 3 miles west on Hwy 62, at which point the road merges with Hwy 51. Continue a short distance west on Hwys 51/62 and climb out of the deeply incised Barron Fork Creek Valley by means of a long, steep, switch back known locally as Eldon Hill. Prominent exposures here are in the Mississippian Keokuk Formation. Continue west on Hwys 51/62 about 2.5 miles at which point we will turn right (north) onto a county road marked by a sign labeled "Honda-Acura Car Repair". After going about 1 mile on this blacktop road, we will drop steeply down into the Illinois River Valley. Stay on this road, which follows the east side of the Illinois Valley, for Stops 1, 2 and 3. Then turn south on Hwy 10 near Eagles Bluff for Stops 4 and 5.

About 1.5 miles before Stop 1, the road crosses Tully Hollow. This has also been known as Tooley or Burgen Hollow, and is the place where Joseph A. Taff in 1905 named the Burgen Sandstone.

Stop 1. "Cherokee Baths"

Low-water crossing where Cedar Creek crosses road. Road will become gravel at this point. Exposures here are scenic potholes cut into the Ordovician Burgen Sandstone, the oldest formation to be seen on this trip. The Burgen Sandstone marks the beginning of a major marine transgression that reached this area in the mid-Ordovician. It represents the base of what geologists call the Tippecanoe Sequence. Here the sandstone is a "snow" white, nearly 99+% pure quartz sandstone. It is well-sorted and the sand grains are often frosted. Sandstones such as this that mark the base of the Tippecanoe Sequence are often referred to collectively as the St. Peter Sandstone and are mined in Missouri and other states for making glass.

The depositional environment of the Burgen Sandstone is primarily that of a transgressing beach deposit and includes dune, beach, and longshore-bar components. Because it was deposited on an erosional surface formed during the marine regression that marks the top of the previous sequence, its thickness is variable. Drilling not far from this exposure penetrated nearly 120 feet of Burgen, the base of which was marked by a conglomerate composed of dolomite pebbles from the underlying Cotter Dolomite.

The pot-holes cut into the surface at this stop make this a popular place for local children (and adults) to play. If you look carefully, you will note chert fragments and cobbles in the bottom of each pot-hole. The source of the chert is the Reed Springs Formation exposed higher up on the tree covered valley wall behind you. During high water flow in Cedar Creek, these chert fragments are spun in turbulent eddies in these pools, acting as tools that cut the potholes deeper.

Stop 2. "Goat's Bluff"

About one mile beyond Stop 1 we will park close to a cliff overlooking the Illinois Valley. This spot is locally known as Goat's Bluff and is a well-known locality for rappelling. Exposures here are in the upper part of the Burgen Sandstone. We will walk along a narrow path about 50 yds and then carefully climb down to examine a long alcove in the upper part of the Burgen Sandstone. Here we can discuss the conformable relationship between the Burgen Sandstone and the overlying light greenish-gray Tyner Shale.

As the Tippecanoe Sea continued its transgression, this area became located farther offshore. This is reflected in a gradual decrease in sediments such as sand and a corresponding increase in finer sediments such as clay that could accumulate in quieter waters offshore. Near the upper part of the Burgen Sandstone where we are standing the sandstone is becoming noticeably shaly. A little farther up it becomes a sandy shale and then a greenish-gray shale typical of the overlying Tyner Shale. This is a classic, textbook example of a marine transgression. This gradual change from the Burgen Sandstone into the overlying Tyner Shale results in what geologists call a "conformable contact" and leads to occasional debates as to where the actual contact separating the two formations should be placed.

This gradual transgression of the Tippecanoe Sea was not a uniform advance but was instead punctuated by numerous oscillations. This resulted in several thin "tongues" of shale similar to that of the Tyner occurring in the top part of the Burgen Sandstone. We are seeing the result of one such "tongue" of Tyner-like shale where we stand. The shale is softer and more easily eroded than the sandstone above and below and results in the alcove. It is hoped that the overhang of sandstone above our heads maintains its resistance a little while longer!

Note the width of the Illinois Valley at this location. It is much narrower here than it is at Stop 5. This is because the relatively hard and resistant Burgen Sandstone is at river-level here, forcing the river into a narrow chanel. At Stop 5, the soft and easily eroded Tyner is at river-level and the river was able to carve a wide channel. This is a good example of how differently shaped valleys develop as a result of stream erosion through different kinds of rock.

Stop 3. "Eagles Bluff"

We have now crossed the Illinois River Valley and have turned south on Hwy 10. Above us across the road is Eagles Bluff. This bluff exposes the Tyner Shale and younger formations. (Appendix I is a detailed description of the formations exposed at Eagles Bluff.) Starting at road level and making up the lower half of the slope is the greenish-gray Tyner Shale. Here, the Tyner Shale is about 80 ft thick. Although the formation is named "shale", it contains a variety of other rock types, notably sandstone and dolomite. Sandstone beds tend to be more common toward the base of the cliff (and the Burgen Sandstone below it), whereas dolomite beds are more common toward the top of the Tyner. Some of the shale, dolomite, and sandstone beds near the top of the formation here contain small pyrite crystals and a 1.5-ft-thick dolomite bed about three feet below the top of the formation is characterized by vugs (cavities) containing quartz crystals as long as 1/4 inch.

The Tyner Shale is overlain unconformably by the nearly black Chattanooga Shale that has a thin (six inches) sandstone/conglomerate at its base. The Chattanooga forms the rest of the slope below the vertical cliff. It is about 40 ft thick at this locality and consists mostly of fissile black shale that is locally pyritic. The black color is caused by the shale's high content of organic material.

The contact between the Tyner and Chattanooga Shales, although not very eye-catching, is geologically significant and needs further discussion. After the Tyner Shale was deposited, the Tippecanoe Sea continued to transgress, finally depositing marine carbonates (e.g., Fite Limestone, St. Clair Limestone)(Fig. 4) when this area was far from shore. This general depositional pattern was interrupted by minor regressions across the area that resulted in some shale and sandstone being deposited (e.g., Sylvan Shale). In the Early Devonian, the Ozark Dome was uplifted. This uplift resulted in the Upper Ordovician through Lower Devonian formations being eroded across the crest of the Ozark Dome. Farther south, along the southern edge of the dome, they were not eroded and are still present. This erosional interval was enhanced when the Tippecanoe Sea stopped transgressing and began a slow regression. This contributed to erosion across the area. Thus, in places (like here), the Chattanooga overlies Ordovician-age formations. To the south, however, it overlies formations as young as Early Devonian (Fig. 6).

The next transgressive sequence to be deposited is known as the Kaskaskia Sequence. The Kaskaskia Sea reached this area in the latter part of the Devonian. This resulted in a transgressive basal sandstone/conglomerate called the Sylamore Sandstone Member of the Chattanooga Shale (formation) being deposited directly on the Tyner Shale at this location. This was followed by deposition of black shale, called the Noel Shale Member of the Chattanooga Shale. The deposition of shale continued into the Mississippian as indicated by a sparse Mississippian fossil assemblage in the upper part of the Chattanooga Shale. We will examine the Chattanooga Shale more closely at Stop 5.

As the Kaskaskia Sea continued an overall advance, deposition of shales gave way to marine carbonates as this area became located farther offshore. As a result, the very fossiliferous St. Joe Limestone was deposited on the Chattanooga. The advance, however, must have been marked by minor regressions, because the top of the Chattanooga is marked by a weathered and reworked zone. The St. Joe is 28 ft thick at Eagles Bluff and forms the bottom part of the vertical cliff. The St. Joe locally contains abrupt thickenings that represent what geologists call "bioherms". They must have resembled modern-day "patch-reefs". We will examine crinoidal limestone debris from such a fossil reef at our next stop.

The rest of the bluff above the St. Joe Limestone is a prominent cliff-former along the Illinois Valley and is named the Reeds Spring Formation. It appears as a horizontally "banded" formation with the "bands" being alternating thin layers of limestone and chert. It is about 70 ft thick in this area and it sits unconformably on the underlying St. Joe Limestone. This unconformity is beautifully displayed along the highway about 4 mi north of here at Hanging Rock. At that locality, the St. Joe Limestone can be seen thinning and eventually disappearing altogether to the north. This unconformable contact probably resulted from a minor retreat (oscillation) of the advancing Kaskaskia Sea and/or renewed minor uplift of the Ozark Dome.

Forming the very top of the cliff, but not visible from road level at this stop, is the first formation to be examined on the afternoon trip. It is known as the Keokuk Formation and caps the upland surface over much of the Tahlequah area. The contact of the Keokuk with the underlying Reeds Spring Formation is unconformable, again possibly related to oscillations of the Kaskaskia Sea or renewed uplift in the Ozark Region. The Keokuk Formation is discussed in more detail at Stop 6.

Stop 4. "Reef Facies" of St. Joe Limestone

Stop 4 is along Hwy 10 on the west side of the Illinois River Valley a short distance south of Stop 3. Here debris from a thick bioherm exposed high up on the tree-covered valley wall can be examined across Hwy 10 from the overflow parking lot of Peyton Place. Rocks exposed at road level are dolomite beds in the upper part of the Tyner Shale. Above the Tyner on the tree-covered slope is the Chattanooga Shale. The overlying St. Joe Limestone represents deposits of a clear, warm, relatively shallow sea following an oscillatory regression of the still advancing Kaskaskia Sea. Above the St. Joe are the rhythmically banded limestones and cherts of the Reeds Spring Formation visible through the trees at the cliff.

The "reef facies" occurs in the upper part of the St. Joe. Here masses of crinoidal limestone form lenses in a gray fossiliferous marlstone. The thickest mass of broken up crinoid

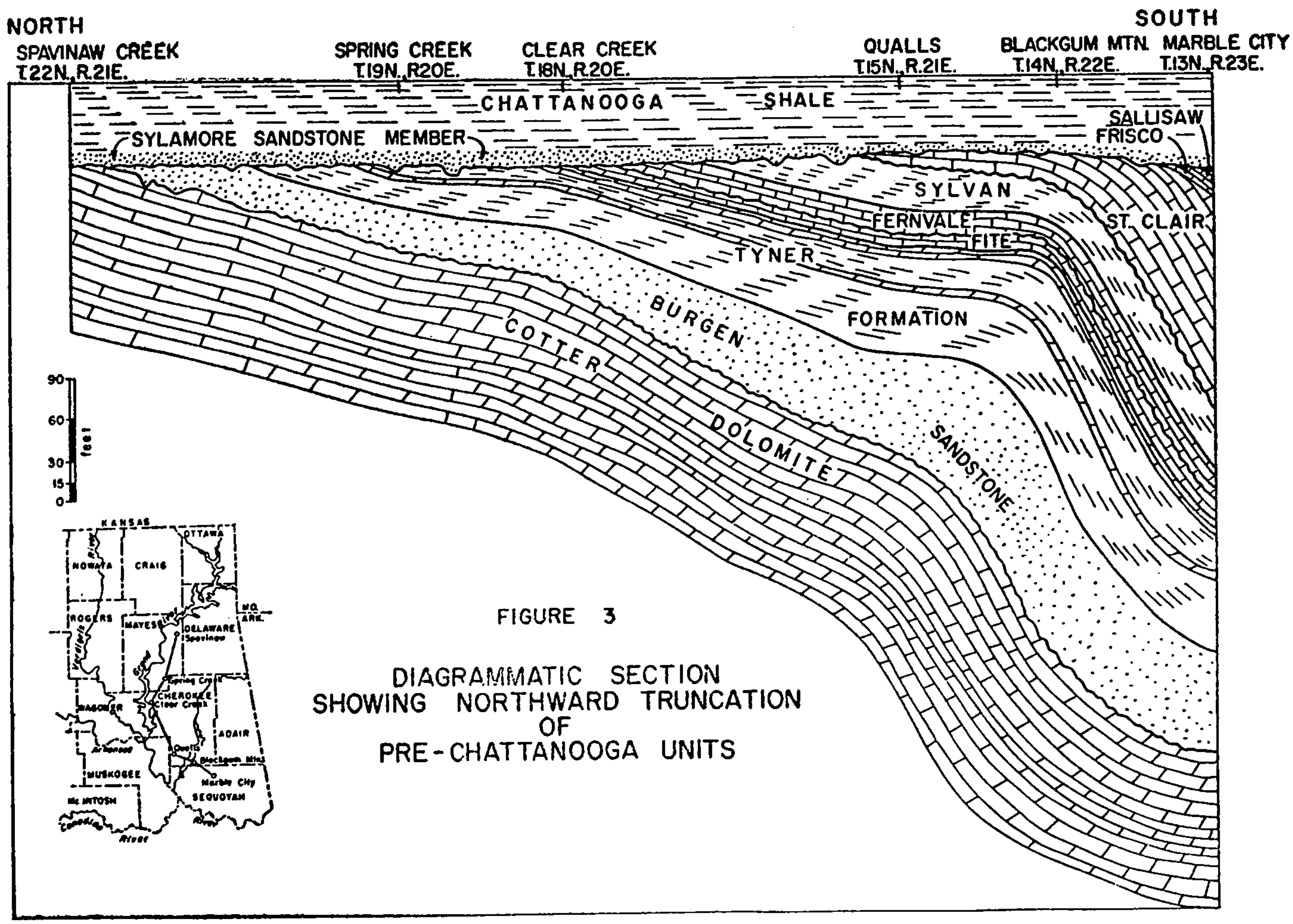

Figure 6. Diagrammatic cross section showing northward truncation of pre-Chattanooga units (from Huffman, 1958).

stems - 70 feet - is high above us near the top of the valley wall across the road. Slide blocks from this bioherm are accessible with a short climb up a gully.

Fossils found in the St. Joe at this stop are predominately crinoid columnals and spiriferid brachiopods. Greenish gray marlstones elsewhere in the St. Joe contain horn corals, fan-like and branching bryozoans, athyrid and chonetid brachiopods, snails and sparse trilobite parts (Fig. 5).

Stop 5. "Chattanooga Shale"

This stop is located at the junction of Hwys 10 and 51/62. **WARNING!!** Do not get too close to the cliff! It is unstable. Examine instead material that has already fallen away from cliff.

Stop 5 is an exposure of the upper 30 feet of the Noel Shale Member of the Chattanooga Shale (Appendix II). The Noel Shale is a black, fissile, carbonaceous shale. It contains abundant small pyrite crystals. Fossils are uncommon. The Chattanooga Shale and its equivalents (e.g., Woodford Shale of the Arbuckle Mountains area) occur over a large part of the central United States. The high organic-carbon content and scattered pyrite crystals along with a scarcity of fossils all suggest deposition in an anaerobic (oxygen-deficient) environment. Why such a large area of the transgressing Kaskaskia Sea became anaerobic is debated among geologists. Some have proposed that the sea was stratified due to vertical changes in salinity or temperature, effectively limiting vertical circulation of oxygenated surface waters. Others have suggested that so much organic matter accumulated that the available oxygen was used up, resulting in anaerobic conditions. The high organic-carbon content of the Chattanooga Shale, like other black Upper Devonian shales, makes it a good source rock for petroleum.

Here the overlying St. Joe Limestone is only 2.5 ft thick, compared to nearly 30 ft at Eagles Bluff. Is this because a lesser amount was deposited here, or because more was eroded away before the overlying Reeds Spring was deposited? What would you look for to determine the answer to this question?

Across the valley to the north are bluffs that expose the Reeds Spring Formation at the same level as the Chattanooga Shale is here. This "juxtapositioning" of strata is a common indication of a fault, and indeed, this is the situation here. The South Muskogee fault trends northeast-southwest, parallel to Hwy 51/62. We are standing on the upthrown side of this fault, resulting in the Chattanooga Shale being brought up to the level of the Reeds Spring Formation north of the highway. The offset of this fault here is about 40 feet, but it increases southward towards Muskogee, where it exceeds 300 feet. This fault will be crossed again this afternoon as we head toward Ft. Gibson.

This is the last formal stop on this mornings trip. From here we will head back east on Hwy 51/62 to Camp Egan. While at the camp this evening try to identify the formations in the camp area - they are some of the same formations you have seen on the trip this morning.

Afternoon Field Trip

Several exposures of strata that are younger than those seen on the morning trip will be visited during the afternoon field trip. Included in these stops will be 330-million-year-old Upper Mississippian to 310-million-year-old Middle Pennsylvanian strata.

From Camp Egan take Hwy 51 west to Hwy 82 (Bertha Parker Bypass). Turn left (south) on Hwy 82. Rocks within Tahlequah are predominantly white to buff Keokuk chert or dark gray limestones and shales of the overlying Moorefield Formation. On the right, just past the bridge over Tahlequah Creek and below the Tahlequah Lumber Company, limestones and shales of the Moorefield Formation drape over a hill of Keokuk chert. This will be Stop 6.

Stop 6. "Unconformity at Top of the Keokuk"

Pull completely off shoulder of the bypass just past the bridge. The prominent exposure here is at the contact between the Keokuk and the overlying Moorefield Formations.

The Keokuk Formation consists of massive, typically brecciated (i.e., highly fractured), white to buff, gray-mottled fossiliferous chert and limestone. In places it is interbedded with irregular stringers and masses of dense, fine-grained, blue-gray limestone. Locally along the western flank of the Ozark Uplift it is is as much as 250 ft thick. Here, it averages about 80 ft thick, and at this outcrop, only the uppermost 30 ft are exposed. The reason for the extreme variability in thickness is discussed below. Geologists are divided as to the origin of the chert. Some geologists have suggested that the Keokuk was originally deposited as a limestone, parts of which were later partially replaced by chert. Other geologists think the chert is primary, i.e., was deposited as chert. Regardless, weathering of this formation results in large quantities of chert rubble in the soil. The abundant chert rubble makes digging difficult and explains why there are not many basements in the Tahlequah area.

The Moorefield Formation is dominantly gray, medium-crystalline limestone with minor amounts of chert, shale, and siltstone. In places, crinoids are abundant in some of the limestone beds. Limestone near the base of the formation contains green specks of the mineral glauconite, which forms only in the marine environment. The Moorefield here is about 22 ft thick.

Note how the gray, sandy limestones of the Moorefield Formation drape over a "fossil" hill composed of the massive chert and limestone containing Keokuk Formation. Note also the the chert rubble, or "fossil" soil zone, at the contact between the Moorefield and underlying Keokuk. The presence of "fossil" hills suggests that the erosional interval that occurred after the Keokuk was deposited must have been quite significant and probably resulted in a rugged, hilly topography. For this erosion to have occurred, the sea must have withdrawn from the area. This regression has been attributed by many geologists to renewed structural uplift of the Ozark Dome. When the still transgressing Kaskaskia Sea finally managed to inundate this area again, it laid down Moorefield transgressive deposits across a rugged, hilly topography.

About 50 yds south of this exposure the sandy limestones of the Moorefield Formation are oil-stained. Freshly broken pieces have a pronounced odor. Considering the morning field trip, what underlying formation would be a likely candidate for the source of the hydrocarbons?

Continue south on the by-pass to the intersection with Muskogee Avenue (Hwy 62). Turn left (south) and take Hwy 62 toward Muskogee and Fort Gibson. Keokuk chert crops out periodically along the roadway. Follow Hwy 62 past the Cherokee Nation offices and Sequoyah High School. Hills along the route are mostly capped with reddish-brown-weathering Pennsylvanian sandstones. We will cross the northeast-trending South Muskogee fault (inactive) close to the Cherokee-Muskogee county line. Along most of the fault in this area, Mississippian-age rocks (Keokuk, Moorefield, etc.) southeast of the fault are juxtaposed against the Pennsylvanian Atoka Formation northwest of the fault. Based on this observation, can you determine which side of the fault went up?

Proceed west on Hwy 62 to the junction with Hwy 80 going north (right) in Fort Gibson. Fort Gibson, established in 1824, served to protect the western frontier. Famous persons such as Jefferson Davis and General Zachary Taylor were stationed here in the 1830's and 1840's. The stockade, barracks and other buildings have been restored as Fort Gibson Military Park. Note the stone buildings made with local sandstone, probably Atoka.

About 2 mi north of town and about one-fourth mile past the Pecan Creek Golf Course, is the old Keough Quarry. Pull off and park on the right. The Neosho River downstream from Ft. Gibson Reservoir is on the left.

Stop 7. "Keough Quarry"

Exposures of Pitkin through Atoka rocks used to be present in the Keough Quarry (Appendix III), but recent roadwork has filled the quarry to the level of the McCully. Now, about 25 ft of the upper part of the McCully is exposed beneath the Atoka Formation.

Fossils found in the McCully include colonial tabulate corals; branching and net-like bryozoans; and productid, rhynconellid, and tear-shaped spiriferid brachiopods. Crinoids, though present, are less abundant than in the Mississippian limestones. A Pentremites (blastoid; Fig. 5, Pt. 2, Row 3) zone occurs near the top of the Sausbee and individuals are present in some of the limestone beds near the base of the exposure. Trilobite parts, ammonoids and straight shelled nautiloids are occasionally found (Fig. 5).

An eight-foot-thick sandstone marks the base of the Atoka Formation and the end of the carbonate-shelf environment. Atoka sandstones are iron-stained, cross bedded, and ripple-marked. The Atoka includes brownish shales (which may be covered with vegetation) and rare, thin, discontinuous limestone beds. Calamites (a large, Pennsylvanian version of the modern-day horsetail reed), fern-like foliage, and carbonized fossil "wood" fragments occur sporadically in the sandstone and indicate that a terrestrial environment was near.

After visiting the Keough Quarry, continue north on Hwy 80 to the 251A intersection. Take Hwy 251A across the Fort Gibson Dam to Stop 8.

Stop 8. "West End of Fort Gibson Dam"

The Fort Gibson Dam blocks the Neosho River about 5 miles north of Fort Gibson to form the Fort Gibson Reservoir. The reservoir is about 39 miles long. The dam, made of concrete and earth, is 110 feet high.

Several important geological relations are exposed at this outcrop. About 20 ft of Upper Mississippian Pitkin Limestone is exposed at the base of the outcrop (Fig. 7; Appendix IV). It is gray, finely crystalline, and contains oolites. Oolites are small, spherical grains of calcium carbonate that form in wave-agitated water. The presence of oolites is evidence that this part of the Pitkin was deposited in shallow marine water.

The contact between the Pitkin and overlying Sausbee marks the boundary between the Mississippian and Pennsylvanian series in this part of Oklahoma. If the contact recorded continuous deposition, we could say the contact is 330 million years old (Fig. 4). But the contact is an unconformity that marks a period of exposure, nondeposition, and erosion; therefore, we can't determine exactly how old the contact is. But 330 million years is probably close. The evidence for the unconformable contact at this locality is (1) the Pitkin is locally eroded to depths as much as 3 ft and (2) these "channels" are partly filled with a conglomerate that contains limestone pebbles eroded from the underlying Pitkin. Elsewhere in this part of Oklahoma, the top of the Pitkin shows as much as 80 ft of relief. Also, the lower part of the Sausbee shows great variability, partly because the underlying Pitkin surface was so irregular, and partly because the open-marine shallow-carbonate shelf was complicated and included lagoons, patch-reefs, coral reefs, and muddy, subtidal environments.

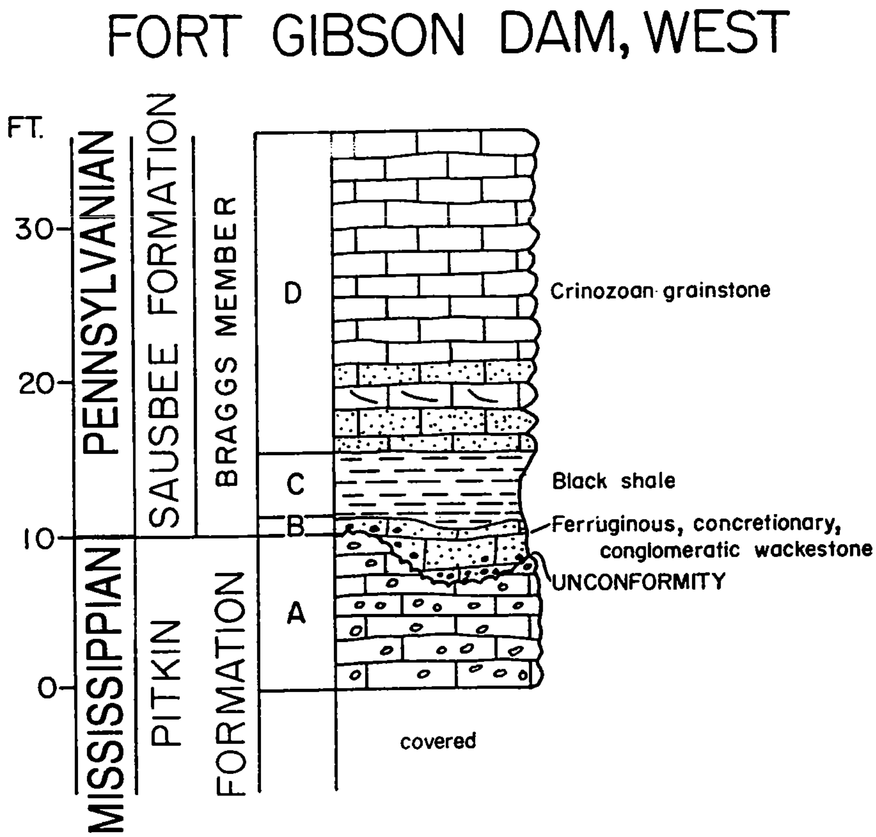

Figure 7. Graphic columnar section for Stop 8 showing unconformity on top of Pitkin Formation (modified from Sutherland and Manger, 1977, p. 37).

The Pitkin Limestone is the youngest formation of the Kaskaskia Sea to be preserved in this area. The overlying Sausbee Formation represents the base of the next major marine transgression, named the Absaroka Sequence by geologists. With the advance of the Absaroka Sea, the beginning of a change from a long history as a carbonate-shelf environment is first noted in the rock record. This change is indicated by the influx of sand into the area, possibly indicating tectonic activity to the east. The change from a dominantly carbonate shelf to a sandstone-dominated environment culminated with the fluvial(river)-deltaic Atoka Formation.

The Lower Pennsylvanian Sausbee Formation, although containing massive limestones, begins to reflect this influx of clastics from the north and east. Sausbee limestones, where weathered, typically feel gritty. This is due to the high sand content of the limestone. While the Sausbee and overlying McCully Formations represent predominantly carbonate-shelf deposits, the equivalent Hale and Bloyd Formations of Adair County, Oklahoma and northwestern

Arkansas contain mostly shale and sandstone. The Hale and Bloyd are the same age as the Sausbee and McCully and were deposited nearby (just to the east), yet consist of different rock types that clearly reflect closeness to land (Fig. 8). In general, the McCully reflects shallower seas than the Sausbee. The McCully contains mostly shale and thinner-bedded, more silty limestones. Fossils present in the McCully are similar to those in the Sausbee. The faunas are distinct from those of the Pitkin, however, perhaps reflecting the increase in silt and sand in the sea bottom.

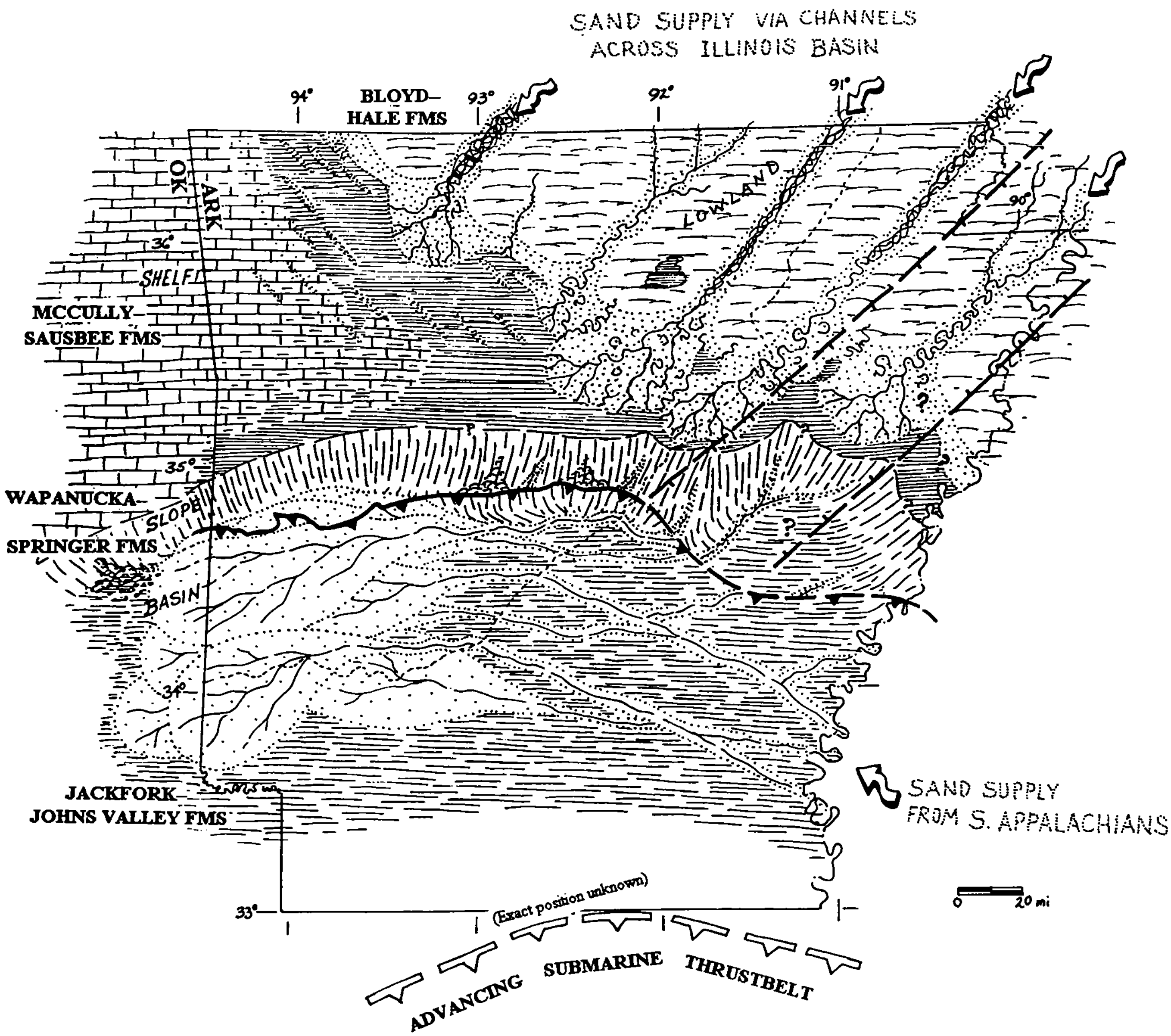

Figure 8. Paleogeographic map of Arkansas and northeastern Oklahoma during deposition of the Sausbee and McCully Formations. Note the carbonate shelf (brick pattern) in northeastern Oklahoma and shale (horizontal lines) and sand (stippled pattern) in north-central Arkansas. The source of the sand and shale is to the northeast. Also shown is the deep Ouachita oceanic basin to the south. (From Roberts, 1994)

The Sausbee Formation here is about 50 ft thick and is overlain by 40 ft of McCully Formation. The Sausbee is mostly limestone whereas the McCully consists of about equal parts limestone and shale. The contact between the two is gradational and is generally placed at the first shale (here, about 4 ft thick) above the massive limestones of the Sausbee Formation.

The contact between the McCully and overlying Atoka Formation is significant because it marks the end of shallow-marine shelf deposition and the arrival of fluvial-deltaic sandstones and shales from the northeast (Fig. 9). The contact is an unconformity and the base of the Atoka is locally marked by a 0.5-ft-thick conglomerate containing limestone pebbles from the underlying McCully and Sausbee Formations. The erosion surface is irregular and cuts further down into the McCully as one goes northward. This suggests that that part of the Ozark Dome north of here was uplifted after deposition of the McCully and during the time the Atoka was deposited. The existence of a topographically high and actively eroding area to the north is also indicated by the presence of chert fragments eroded from outcrops of the St. Joe, Reeds Spring, and Keokuk Formations in conglomerates in the Atoka Formation.

Most of the Atoka Formation here consists of sandstone with abundant burrows and/or feeding trails (called trace fossils by geologists), ripple marks (indicating currents), and rare fossils, fossil molds, and carbonized plant debris (Appendix V). Siltstone, shale, and limestone are less common. All indications are that the sediments accumulated on or near a delta; the limestones probably mark brief transgressions or periods of less mud and sand input. In some places near here the Atoka Formation contains thin coal beds, indicating ancient swamps were present on the delta.

Return to cars and take Hwy 80 east toward Hulbert. At the Intersection of Hwy 80 and Hwy 51 turn right (east) on Hwy 51. Turning left (west) on Hwy 51 leads to Sequoyah State Park, which offers horseback riding, boating, a lodge and a fossil trail.

Drive through Hulbert. **WATCH YOUR SPEED**. Stop 9 is an old quarry on a hill above Pecan Creek where Hwy 51 makes a broad curve just over 2 miles east of Hulbert.

Stop 9. "Abandoned Quarry on Hill East of Hulbert"

Outcrops of the Fayetteville Shale, Pitkin Limestone, and Sausbee, McCully and Atoka Formations can be seen in and around the old quarry beneath the powerlines (Appendix VI). Along the quarry road, the lower pit exposes Pitkin with abundant spiral bryzoans (<u>Archimedes</u>), some with fans still attached. Other fossils include the blastoid <u>Pentremites</u>, productid and spiriferid brachiopods, and horn corals. Globular productid brachiopods occur in a fine lime mud indicating little turbulence and little sand.

Farther up the road, iron staining and increased amounts of sand and clay indicate Pennsylvanian-age rocks. In this quarry, Sausbee limestones tend to be massive and oolitic while the younger McCully is sandier and thinner-bedded with more iron. Blastoids, colonial tabulate coral, branching bryozoans and small brachiopods (Fig. 5) may be found. Atoka Formation caps the hill. As discussed previously, the Atoka marks a major regression of the sea and an end to the dominantly carbonate sedimentation that took place in this part of Oklahoma for 150 million years.

This is the last stop of the afternoon field trip. Continue east of hwy 51 to Tahlequah and then back to Camp Egan.

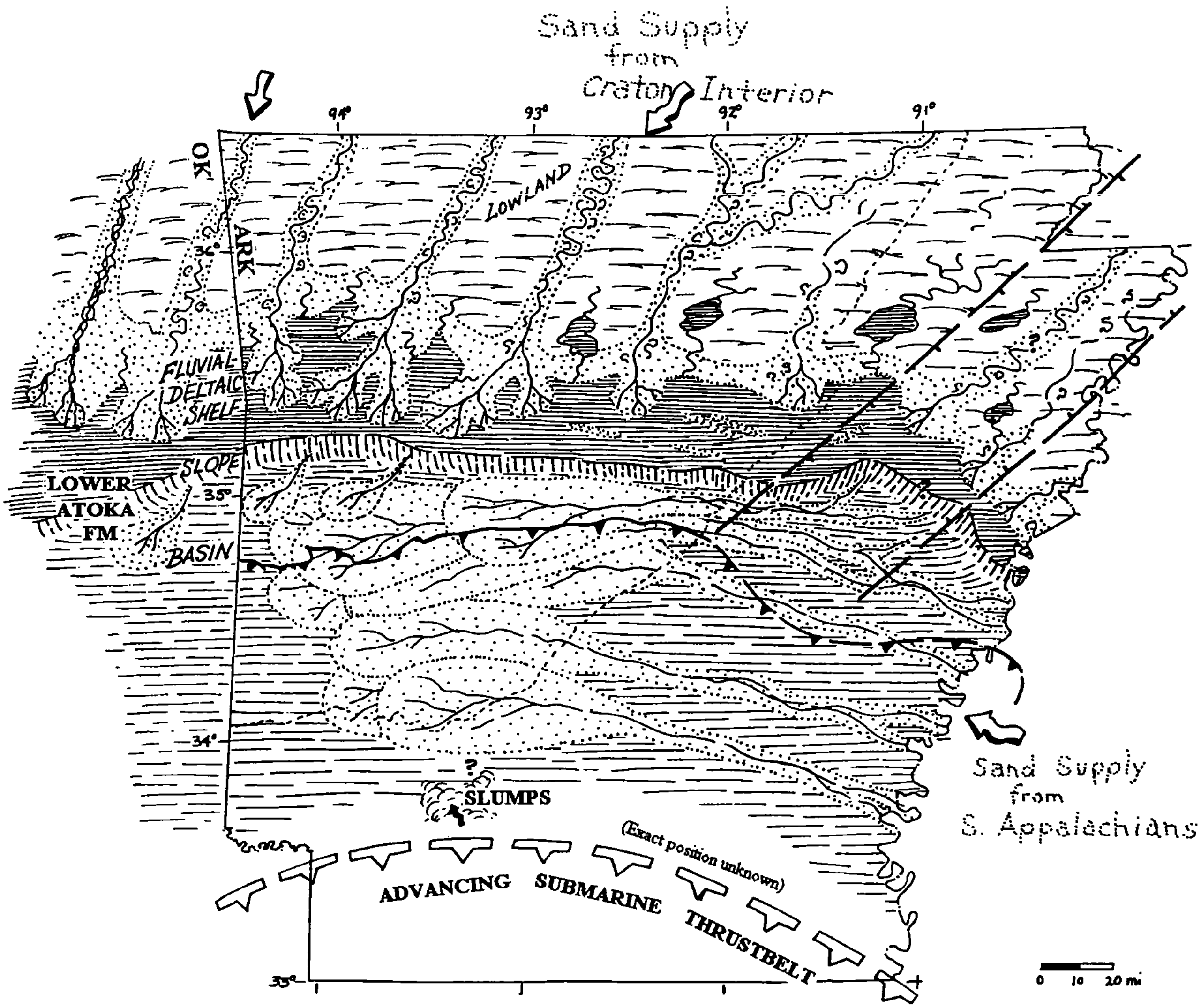

Figure 9. Paleogeographic map during deposition of the Atoka Formation in northeastern Oklahoma. The influx of sand and mud has spread from the east and the shallow-marine carbonate shelf has been replaced by a fluvial-deltaic sedimentary environment. (From Roberts, 1994)

ADDITIONAL READING

Blythe, J.G., 1959, Atoka Formation on the north side of the McAlester Basin: Oklahoma Geological Survey Circular 47, 74p.

Harland, W.B.; Armstrong, R.L.; Cox, A.V.; Craig, L.E.; Smith, A.G.; and Smith, D.G., 1990, A geologic time scale 1989: Cambridge University Press, Cambridge, 263p.

Huffman, G.G., 1958, Geology of the flanks of the Ozark Uplift: Oklahoma Geological Survey Bulletin 77, 281p.

Huffman, G. G.; Cathey, T.A.; and Humphrey, J.E., 1963, Parks and Scenic areas in the Oklahoma Ozarks: Oklahoma Geological Survey Guidebook XII, 95p.

Huffman, G.G., 1964, Stratigraphy and structure of the Oklahoma Ozarks area in northeastern Oklahoma, *in* Kansas Geological Society, 28th Field Conference Guidebook: Kansas Geological Society, Wichita, p. 5-19.

LaRocque, Aurèle, and Marple, M.F., 1965, Ohio Fossils: Ohio Division of Geological Survey Bulletin 54, 152p.

Marcher, M.V., 1969, Reconnaissance of the water resources of the Ft. Smith quadrangle, east-central Oklahoma: Oklahoma Geological Survey Hydrologic Atlas Map HA-1, sheet 1, scale 1:250,000.

Marcher, M.V., and Bingham, R.H., 1971, Reconnaissance of the water resources of the Tulsa quadrangle, northeastern Oklahoma: Oklahoma Geological Survey Hydrologic Atlas Map HA-2, sheet 1, scale 1:250,000.

Montgomery, J.H., 1951, Ordovician formations in the Illinois River Valley of northeastern Oklahoma: Tulsa Geological Society Digest, v. 19, p. 137-168.

Moore, C.A., 1947, The Morrow series of northeastern Oklahoma: Oklahoma Geological Survey Bulletin 66, 151p.

Roberts, M.T., 1994, Geologic relations along a regional cross section from Spavinaw to Broken Bow, eastern Oklahoma, *in* Suneson, N.H., and Hemish, L.A. (eds.), Geology and resources of the eastern Ouachita Mountains frontal belt and southeastern Arkoma Basin, Oklahoma: Oklahoma Geological Survey Guidebook 29, p. 137-160.

Rose, J.N., 1967, The fossils and rocks of eastern Iowa: Iowa Geological Survey Educational Series 1, 147p.

Sloss, L.L., 1963, Sequences in the cratonic interior of North America: Geological Society of America Bulletin, v. 74, p. 93-111.

Starke, J.M., Jr., 1961, Geology of northeastern Cherokee County, Oklahoma: Oklahoma Geological Survey Circular 57, 62p.

Sutherland, P.K., and Henry, T.W., 1977, Carbonate platform facies and new stratigraphic nomenclature of the Morrowan series (Lower and Middle Pennsylvanian), northeastern Oklahoma: Geological Society of America Bulletin, v. 88, p. 425-440.

Sutherland, P.K., and Manger, W.L., eds., Upper Chesterian - Morrowan stratigraphy and the Mississippian - Pennsylvanian boundary in northeastern Oklahoma and northwestern Arkansas: Oklahoma Geological Survey Guidebook 18, 185p.

Sutherland, P.K. and Manger, W.L., eds., 1979, Mississippian - Pennsylvanian shelf-to-basin transition Ozark and Ouachita regions, Oklahoma and Arkansas: Oklahoma Geological Survey Guidebook 19, 81p.

Taff, J.A., 1905, Tahlequah folio, Indian Territory - Arkansas: U.S. Geological Survey Geologic Atlas of the U.S., no. 122.

Zachry, D.L. and Sutherland, P.K., 1984, Stratigraphy and depositional framework of the Atoka Formation (Pennsylvanian), Arkoma Basin of Arkansas and Oklahoma, *in* Sutherland, P.K., and Manger, W.L. (eds.), The Atokan Series (Pennsylvanian) and its boundaries - a symposium: Oklahoma Geological Survey Bulletin 136, p. 9-17.

ADDITIONAL SOURCES OF INFORMATION

American Association of Petroleum Geologists, 1966, Geological highway map, mid-continent region, Kansas, Missouri, Oklahoma, Arkansas: American Association of Petroleum Geologists.

Geological Society of America, 1988, Centennial Field Guide, v. 4, South-Central Section, Decade of North American Geology.

15. Eagle Bluff, SW¼ sec. 13, T. 18 N., R. 22 E.

	Feet	Inches
MISSISSIPPIAN:		
Keokuk:		
Chert, white, massive, fractured; not measured		
Reeds Spring (70 feet):		
Chert and limestone sequence	70	0
St. Joe (28 feet, ½ inch):		
Limestone, light-gray, crystalline, pyritic; many broken crinoid stems; shale partings up to 1 inch thick	15	6½
Limestone, dark-gray, shaly, concentric-weathering	1	4
Limestone, light- to dark-gray, crystalline, shaly to massive, fossiliferous, nodular-weathering; interbedded shale is calcareous, gray to light-green	11	2
Chattanooga (39 feet, 7¾ inches):		
Noel (39 feet, 1 inch):		
Shale, black, fissile, pyritic; cone-in-cone structure common	39	1
Sylamore (6¾ inches):		
Conglomerate, shaly; phosphatic pebbles up to 2 inches in diameter, ferruginous cement	0	2
Sandstone, gray to black, coarse-grained; salt and pepper appearance	0	1½
Conglomerate, coarse-grained matrix of ferruginous cement, phosphatic pebbles	0	¾
Shale, brown, dirty	0	½
Chert nodules and buff dolomite pebbles	0	2
ORDOVICIAN:		
Tyner (78 feet, 6½ inches):		
Dolomite, buff; large pieces of white to gray chert in basal foot	2	2
Dolomite, gray to buff; dense, quartz crystals up to ¼ inch in vugs	1	7
Dolomite, light gray, very fine-grained; color banding of gray and brown	1	1
Dolomite, light-gray to buff	1	2½
Sandstone, gray to green, soft	0	3
Sandstone, green, pyritic; veins of black quartz crystals; outcrop weathers to dark brown	0	10
Shale, light-green, silty, concentric-weathering	1	0
Shale, light-green	0	9
Dolomite, buff to light-gray, pyritic	1	9
Shale, gray to green, pyritic, sandy streaks	1	0
Dolomite, light-gray, pyritic; weathers buff	1	½
Shale, gray-green to olive green, silty; concentric-weathering up to 1 foot in diameter; grades into dolomite above	4	9
Dolomite, buff; pyrite nodules	1	0
Shale, dark-green, concentric-weathering	1	3
Shale, buff to olive-green, pyritic; interbedded with sandy brown dolomite	6	1
Shale, olive-green, dolomitic, concentric-weathering; more massive and buff near top	2	4½
Sandstone, black, coarse-grained; buff dolomite pebbles and green shale interbedded throughout	0	8
Dolomite, buff, shaly, pebbly; forms lower dolomite	0	7
Dolomite, buff, massive, with brown sandy dolomitic streaks; upper 6 inches sandy	3	6
Siltstone, light-green; concentric weathering up to 6 inches in diameter	1	0
Shale, dark-green	0	3½
Shale, olive-green, silty; concentric to blocky weathering	0	6
Shale, dark-green, dolomitic, concentric-weathering	3	10
Dolomite, buff with dark-brown sandy banding	1	7
Dolomite, buff to green, sandy, shaly	0	3
Shale, olive-green, dolomitic, concentric-weathering	0	9

APPENDIX I (CONTINUED)

Shale, olive-green to buff, sandy, dolomitic	0	11
Shale, olive-green to dark-green, dirty; thin sandy beds display mud-crack fillings	4	8
Shale, olive-green to buff, dolomitic; upper 1 inch dark-green; thin buff dolomite beds forming one-foot thick ledges	5	7
Shale, dark-green; weathers into smooth slope	7	1
Dolomite, buff, shaly; brown, crystalline dolomite bands	1	0
Shale, dark-green	0	5
Shale, buff, dolomitic	0	5
Shale, dark-green	0	3
Dolomite, buff, fine-crystalline	0	3
Dolomite, buff, shaly, soft, earthy	0	6
Shale, dark-green	1	0
Dolomite, buff, earthy	0	3
Dolomite, buff with gray banding, fine-crystalline, sandy	0	2½
Shale, gray-green, soft	0	1½
Sandstone, buff with gray-green banding, dolomitic	0	2
Shale, dark gray-green; weathers into small pieces	0	7
Sandstone, mottled buff and dark-gray to green, dolomitic	1	11
Shale, dark-gray, brittle	0	8
Sandstone, fine-grained, dolomitic; thin banding of dark gray, medium-grained sandstone	1	5
Shale, light-green, dolomitic, sandy; weathers shaly and blocky	2	2
Sandstone, light-gray, fine-grained, dolomitic; irregular bedding; weathers gray and buff	0	9
Shale, light gray-green, dolomitic, sandy	0	4
Sandstone, light-gray to white, fine-grained, dolomitic; weathers buff with light-gray banding; some light-gray sandy shale streaks	5	10½
Shale, dolomitic, sandy, light gray-green	0	4
Sandstone, white, fine-grained, dolomitic; weathers rough and buff; base covered	0	7

APPENDIX II

1. Road cut at junction of highways 62, 51, and 10, NE¼ sec. 26, T. 17 N., R. 22 E.

	Feet	*Inches*
MISSISSIPPIAN:		
Reeds Spring (50 feet, estimated):		
Chert and limestone sequence; chert, thin-bedded, light to dark-gray; limestone, thin, even-bedded, light-gray	50	0
St. Joe (2 feet, 6 inches):		
Shale, clayey, greenish-brown	0	4
Limestone, massive-bedded, gray, crystalline	2	1
Limestone, gray, soft	0	1
Chattanooga (35 feet exposed):		
Noel:		
Shale, black, fissile, pyritic, cone-in-cone structure common; base covered	35	0

APPENDIX III

69. KEOUGH QUARRY, SEC. 25 T. 16 N., R. 19 E.

Pennsylvanian	
Des Moines series	
Atoka formation	
29. Sandstone: massive bedded	6.0
28. Covered: sandy and shaly soil and sandstone rubble	26.0
27. Sandstone: fine to medium grained, iron stained; cross-bedded, ripple marked, some thin beds	8.0
Exposed thickness of Atoka	40.0
Morrow series	
Bloyd formation	
26. Covered	12.0
25. Shale: blue gray, fissile, limonite concretions	10.0
24. Limestone: gray to brown gray, medium, some coarse crystals; uneven-bedded; weathers thin-bedded to platy; fossiliferous, crinoidal	8.0
23. Shale: poorly exposed	20.0
22. Limestone: argillaceous, iron stained buff; thin-bedded; fossiliferous, bryozoans abundant	3.0
21. Limestone: Similar to bed 19	1.0
20. Shale: *Pentremites* zone, unfossiliferous along strike	0.5
19. Limestone: brown gray, very fine with coarse crystals; coarsely crinoidal, fossiliferous; few thin shale breaks	8.0
18. Shale: buff to gray, calcareous, limestone concretions; fossiliferous, crinoid remains, corals	1.5
17. Limestone with two shale breaks: light gray, very coarse; fossiliferous, *Dentalium*, crinoidal and with poorly preserved calyces	7.5
16. Shale: similar to bed 14	0.5
15. Limestone: dark blue black, argillaceous with coarse crinoidal material; thin-bedded	2.0
14. Shale: with thin limestone beds; very calcareous, crinoidal; trace phosphatic	6.0
13. Limestone: dark gray, coarse with very coarse crystals, large calcite masses; crinoidal, fossiliferous	1.5
12. Shale: blue black to black, fissile, calcareous; includes a 6-inch hard, iron-stained bed; fossiliferous; trace phosphatic	3.5
Thickness of Bloyd	85.0
Hale formation	
11. Limestone: gray, coarse medium; sandy beds and sandy inclusions that are greenish buff, medium grained, uneven bedded; not so sandy in upper part	10.0
10. Shale: gray with greenish cast, calcareous	0.3
9. Limestone: similar to bed 7	2.0
8. Limestone: uneven bedded, conglomeratic; trace phosphatic	0.5
7. Limestone: pink, very coarse with large calcite crystals; thin greenish sandy beds that show trace of phosphate, few black, small, low grade calcareous phosphatic pebbles in the limestone and especially in sandy lenses; extremely crinoidal, *Pleurodictyum* (*Michelinia*), large corals, crinoidal bases, *Composita*, *Dictyoclostus*, *Hustedia*	14.5
Thickness of Hale	27.3
Mississippian	
Chester series	
Pitkin limestone	
6. Limestone: gray with greenish hue, fine medium with coarse crystals, greenish argillaceous streaks near top; extremely rubbly and uneven bedded; few small black low grade phosphatic calcareous nodules near upper part of bed	2.5
5. Limestone: gray, fine with large calcite masses, jointed; fossiliferous, *Linoproductus*, *Composita*	9.5
4. Limestone and shale: shale, calcareous, fissile; irregularly bedded; limestone in thin beds, gray, sublithographic; light blue on weathering, knobby; *Pleurodictyum* (*Michelinia*.)	2.0
3. Limestone: gray, fine to sublithographic; brittle, conchoidal fracture	8.5
2. Limestone: poorly exposed below top; reddish brown on weathering	6.0
1. Limestone: on floor of quarry, brown with dark calcite crystals, fine with coarse crystals, jointed; weathers by spalling off locally; *Archimedes*, bryozoans, brachiopods	2.0
Covered below	
Exposed thickness of Pitkin	30.5

APPENDIX IV

64. SECTION ALONG WEST SIDE OF FORT GIBSON DAM
Northeast ¼ Section 13, T. 16 N., R. 19 E.

Formational Description	*Thickness in Feet* Of Unit	To Base of Fmtn.
Atoka:		
Siltstone, buff-brown, upper portion thin-bedded and iron-stained, lower part massive and streaked black	16.0	16.0
McCully:		
Shale, bluish-gray, calcareous, weathers iron-stained	3.3	39.5
Limestone, light gray, silty, locally sandy, weathers iron-stained	9.5	36.2
Covered	12.5	26.7
Limestone, blue-gray, fine crystalline with finer crystalline nodules within, weathers fluted and crinoidal, several shale breaks	10.5	14.2
Shale, gray, bryozoans abundant	2.0	3.7
Limestone, blue-gray, fine crystalline, weathers crinoidal, fossiliferous	0.7	1.7
Shale, dark gray to black with greenish cast, fissile, bryozoans	1.0	1.0
Sausbee:		
Limestone, gray to brown, fine crystalline, massive, fluting and crinoidal weathering	19.7	47.1
Limestone, gray, fine crystalline, knobbly, shale partings, pinches out laterally	0.5	27.4
Limestone, reddish-brown to gray brown, medium to coarse crystalline, pink calcite masses, weathers buff and fluted, iron stained, crinoidal	20.2	26.9
Shale, gray to black, fissile, calcareous, thickness varies laterally	4.7	6.7
Limestone, hematitic and concretionary, conglomeratic appearance, shale breaks, great lateral variation in thickness, 6.0 feet in one place	2.0	2.0
Pitkin:		
Limestone, gray, finely crystalline, oolitic	9.5	9.5
Base covered		

APPENDIX V

MEASURED SECTION OF ATOKA FORMATION ALONG ROAD LEADING SOUTHWESTWARD AND WESTWARD FROM FORT GIBSON DAM, THROUGH SECTIONS 13, 14, 23, 22, 15 AND 16, T. 16 N., R. 19 E., WAGONER COUNTY, OKLAHOMA

53.8 ft. Covered to top of hill, SE¼ ec. 16, T. 16 N., R. 19 E. Apparently this interval consists of Webbers Falls siltstones.

5.6 ft. Siltstones, buff. (Northwest corner sec. 22, T. 16 N., R. 19 E. Dip 12½° NW.)

1.3 ft. Limestone, light gray; slightly cavernous.

2.2 ft. Shale, dark gray; calcareous, with large limestone nodules in the upper 0.5 ft.

12.0 ft. Siltstone, buff, porous; light weight; carbonaceous streaks. Horizontal fractures. Dip 8° S 38° E.

26.3 ft. Covered.

4.2 ft. Siltstone, buff; porous; light weight. Well-developed horizontal and vertical fractures. (NW¼ NW¼ sec. 23, T. 16 N., R. 19 E.)

17.8 ft. Covered. Within this interval are slump blocks and occasional thin exposures of Webbers Falls siltstone and ferruginous limestone.

0.3 ft.	Siltstone, buff, with cavities lined with limonitic clay. Carbonaceous streaks.
5.3 ft.	Covered.
2.5 ft.	Limestone, dark gray; shaly; thin-bedded.
2.2 ft.	Covered. Probably shale.
1.0 ft.	Limestone, grayish buff to reddish tan; weathers buff; shaly bedding; contains brachiopods and crinoid columnals.
1.3 ft.	Sandstone, dull olive drab; fine-grained; calcareous; uneven bedded; fucoid-marked.
8.5 ft.	Siltstones and shales, gray to buff, thin-bedded.
7.1 ft.	Limestone, dark gray; argillaceous; thin shaly bedding. NW¼ NE¼ sec. 23, T. 16 N., R. 19 E.
4.0 ft.	Sandstone, light gray; weathers buff; *Taonurus* markings.
24.3 ft.	Covered. Probably A_4 shale interval. Mantled with Webbers Falls slump from hill to the west.
38.1 ft.	Sandstone, pinkish tan to buff to gray; weathers reddish brown; medium grained; friable. Much of this interval is covered. Approximately 15 ft. above base are molds of brachiopods. Massive, friable, buff sandstone appears to be present in the interval from 20 ft. above the base to about 31 ft. above the base. About 7 ft. below the top are buff, slightly conglomeratic sandstones, friable, medium- to coarse-grained, with many brachiopod molds. (SE¼ NW¼ sec. 13, T. 16 N., R. 19 E.)
3.6 ft.	Sandstone, pink to dirty grayish brown; speckled; contains red ocherous clay lenses or pods; some plant stems preserved in black iron- or manganese- oxide impressions; grains subangular.
20.0 ft.	Covered.
11.1 ft.	Siltstone, gray to olive gray; weathers buff; micaceous to argillaceous.
1.3 ft.	Sandstone, olive drab; weathers reddish brown and cinderlike; fine- to medium-grained.
0.6 ft.	Clay, olive drab to reddish brown; silty; rubbly-weathering.
1.9 ft.	Sandstone, olive drab; weathers dark brown; fine- to medium-grained, with limonitic cement and splotches.
1.0 ft.	Clay-ironstone and sandstone, yellow brown; thin; ripple-marked bedding.
52.5 ft.	Covered.
0.8 ft.	Sandstone, light olive buff to light greenish gray; fine-grained; fucoidal; some limonitic cement.
0.5 ft.	Sandstone and clay ironstone, reddish-brown; thin; shaly appearance; ripple-marked bedding.
4.2 ft.	Sandstone, olive drab; weathers buff; interbedded with clay shales, dark gray. Sandstones are ripple-marked, quartzose, with some fucoids.
2.4 ft.	Limestone, reddish-brown, ferruginous, with numerous spiriferoid brachiopods, crinoid columnals, and large chert and chalcedonic sand grains. Upper 0.7 ft. is cross-bedded. Top 0.3 ft. has cinder-like appearance.
23.9 ft.	Sandstone, buff to olive gray to khaki-colored; weathers very light gray; grains appear well-rounded; fairly massive; noncalcareous.
2.7 ft.	Shale, gray to buff; silty; micaceous; thick carbonaceous streaks.

APPENDIX V (CONTINUED)

11.8 ft.	Sandstone, light buff, speckled; fine-grained; calcareous in part.
14.3 ft.	Covered. Interval appears to include sandstone, rusty tan to speckled, fine-grained, fairly massive; and shale, black, with clay-ironstone concretions. One sandstone near top of this interval bears fucoid markings.
0.5 ft.	Conglomerate, reddish-brown, ferruginous; contains limestone pebbles and abraded fossil fragments derived from underlying Morrow group. Contact with Morrow is, in part, gradational. (This unit constitutes the base of the Atoka formation.)

370.9 ft. = Total measured thickness of Atoka formation.

APPENDIX VI

90. CRITTENDEN SECTION. SEC. 30, T. 17 N., R. 21 E.

Pennsylvanian	
Des Moines series	
Atoka formation	
23. Sandstone, poorly exposed	12.0
Exposed thickness of Atoka	12.0
Morrow series	
Bloyd formation	
22. Covered	6.0
21. Shale: poorly exposed	6.0
20. Limestone: gray with greenish streaks, coarse; weathers light blue and light buff; fossiliferous	4.0
19. Shale	4.0
18. Limestone	1.0
17. Shale	3.0
16. Limestone: blue gray to brown gray, coarse; thin-bedded; fossiliferous	4.0
15. Covered	12.0
14. Limestone: thin-bedded, argillaceous, very granular	2.0
13. Limestone, poorly exposed: brown and greenish gray; weathers rubbly and uneven; fossiliferous	10.0
12. Limestone: blue gray, crinoid stems replaced by orange calcite; uneven bedded; weathers brown and rough	2.0
11. Shale: poorly exposed	8.0
Thickness of Bloyd	62.0
Hale formation	
10. Limestone: blue gray; uneven bedded to platy at top, cross bedded, thin-bedded	15.0
9. Limestone: granular	2.0
8. Shale	1.0
7. Limestone	22.0
6. Limestone, argillaceous and sandy: blue gray to brown, medium with very coarse crystals; weathers rough and jointed; fossiliferous, crinoidal	0.5
Thickness of Hale	40.5
Mississippian	
Chester series	
Pitkin limestone	
5. Limestone: light blue and brown gray, fine; weathers rough and jointed	10.0
4. Covered	22.0
Estimated thickness of Pitkin	32.0
Fayetteville shale	
3. Covered	21.0
2. Limestone	1.0
1. Shale and covered to estimated top of Meramec? limestone	4.0
Estimated thickness of Fayetteville	26.0