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# GEOLOGY OF THE BOKTUKOLA SYNCLINE, SOUTHEASTERN OKLAHOMA

by

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# GEOLOGY OF THE BOKTUKOLA SYNCLINE, SOUTHEASTERN OKLAHOMA

ORVILLE B. SHELBURNE, JR.

## ABSTRACT

As mapped for this report the Boktukola syncline area includes 316 square miles in the central Ouachita Mountains in McCurtain, Pushmataha, and Le Flore Counties.

Outcropping rocks are Late Mississippian and Early Pennsylvanian; they are in ascending order, Stanley group, Jackfork group, Johns Valley formation, and Atoka formation. The rocks are a thick flysch facies aggregating 23,000 feet; they were deposited in a rapidly subsiding trough, the Ouachita geosyncline. Flysch characteristics include rhythmic alternation of shale and sandstone, abundance of sole markings and convolute bedding, presence of bedded dark chert and intraformational slump structures, and paucity of fossils, coarse cross-bedding, and ripple marks.

Formations of the Stanley group, described from outcrops in the western Ouachitas, are present in the Boktukola syncline. The formations are, in ascending order, Tenmile Creek, Moyers, and Chickasaw Creek. The oldest rocks exposed in the area are in the lower part of the Tenmile Creek formation. The formation consists of green and gray shale with some graywacke; the name Battiest chert member is proposed for a persistent marker bed which occurs near the middle.

The Moyers formation consists of 1,150 feet of green shale, friable sandstone, and resistant gray sandstone. A thin discontinuous siliceous shale, which is locally intruded by sandstone dikes, marks the base of the formation.

The Chickasaw Creek formation marks the top of the Stanley group; it consists of 140 feet of dark siliceous shale, radiolarian chert, and quartzitic sandstone.

The formations of the Jackfork group are, in ascending order, Wildhorse Mountain, including the Prairie Hollow member, Prairie Mountain, Markham Mill, Wesley, and Game Refuge. Most of the siliceous shales which mark the boundaries of the formations in their type areas in the western Ouachitas are absent in the Boktukola syncline; therefore, the Prairie Mountain and Markham Mill formations can not be adequately separated. The Jackfork group is 55 percent subgraywacke and quartzose sandstone, and 45 percent gray shale. Spicular chert occurs in the Wesley formation. The group thickens eastward, toward the source area; it is 5,400 feet thick in the Harris Creek syncline and 6,500 feet thick in the eastern Boktukola syncline.

The Johns Valley shale is recognized in the area; however, exotic boulders or the Caney fauna have not been found. A Morrowan sandstone mold fauna, Honess' "Morrow fauna," occurs in lenticular sandstones in the middle part of the Johns Valley.

An unknown thickness of the Atoka formation has been removed by erosion but 6,800 feet remain in the Boktukola syncline. The formation is about 75 percent shale and 25 percent quartzose sandstone. The lower part of the Atoka is probably Morrowan; it contains a mold fauna, similar to that of the Johns Valley, and spicular siliceous shales.

The Boktukola fault is a steeply dipping thrust with a maximum displacement of six miles and a trace of thirty miles. It is not a reasonable vehicle for low-angle overthrusting.

Primary sedimentary features typical of a flysch facies are common. Flute and groove casts are similarly alined throughout the sequence. They indicate paleocurrents moving from east to west, parallel to the geosyncline. Sediment transport was longitudinal and the source area lay to the east. The lack of post-depositional torsion of the trends of sedimentary features indicates that the Ouachita orogeny was not so intense as some workers suppose.

# INTRODUCTION

## Purpose of Study and Location of Area

The primary purposes of this investigation in the central Ouachita Mountains of Oklahoma were to study the distribution, character, stratigraphy, and structure of the outcropping Carboniferous rocks of the Boktukola syncline area which lies east of Little River; and to prepare a detailed geologic map of the area. Detailed study of a limited area such as the Boktukola syncline and comparison with similar studies of other areas of the Ouachitas should allow identification of trends in regional stratigraphy and structure and a more complete understanding of the geologic history of the Ouachita Mountains.

The area of this investigation includes Boktukola Mountain and adjacent areas. The mountain is a horseshoe-shaped topographic high which outlines the Boktukola syncline. The area of the geologic map (plate I) is bounded on the south by the center of T. 2 S., on the west and northwest by Little River, on the northeast by a line extending from three miles west of the settlement of Octavia to the town of Smithville, and on the east by the eastern border of R. 25 E. The mapped area includes 316 square miles mostly within northwestern McCurtain County but extending into southern Le Flore and southeastern Pushmataha Counties (fig. 1).

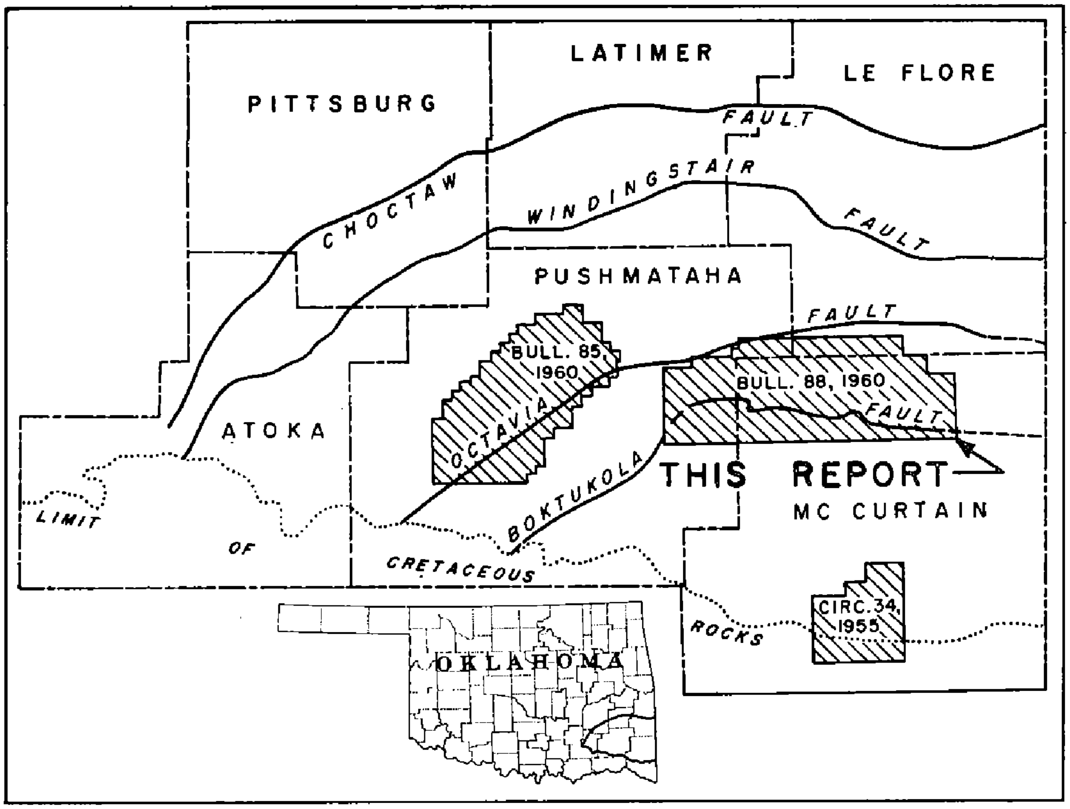

Figure 1. Index map of the Ouachita Mountains, southeastern Oklahoma, showing areas covered by geological maps published by the Oklahoma Geological Survey.

## Previous Work

The geology of the Ouachita Mountains of Oklahoma first became known as a result of mapping by J. A. Taff of the United States Geological Survey. Taff's Atoka Folio (1902) described the structure and stratigraphy of the western edge of the Ouachitas. It was in this report that he named the two dominant formations of the Ouachitas, the Stanley shale and the Jackfork sandstone. Taff also mapped the McAlester, Winding Stair, Tuskahoma, Antlers, and Alikchi quadrangles but these maps were never published; however, they were used by Miser in the preparation of the 1926 Geologic Map of Oklahoma. Parts of the Tuskahoma, Alikchi, and Winding Stair quadrangles lie within the area of the present study.

The geology of the southern Ouachita Mountains of Oklahoma was described by Honess in 1923. His report, which included a geologic map, was based on three seasons of field work from 1917 to 1919. Honess' map included most of the Lukfata quadrangle in northern McCurtain County and adjacent parts of Winding Stair and Alikchi quadrangles in southern Le Flore, eastern Pushmataha, and eastern Choctaw Counties (Honess, 1923). Later Honess extended his studies to the north and west and his results were published in a report on the geology of southern Le Flore and northeastern McCurtain Counties (Honess, 1924); the geologic map in this report included the Boktukola syncline and adjacent areas within the present area of study.

As a result of studies in the western part of the Ouachita Mountains in Oklahoma, Harlton proposed a subdivision of the Stanley-Jackfork-Johns Valley-Atoka sequence. His subdivisions are bounded by siliceous shales within the sequence and he proved the persistence of these shales by mapping the Round Prairie syncline in Atoka County and the southern part of the Tuskahoma syncline in Pushmataha County (Harlton, 1938). Harlton elevated the Stanley formation to group rank and included in the group, from bottom to top, the Tenmile Creek, Moyers, and Chickasaw Creek formations. In a similar manner he elevated the Jackfork formation to group rank and designated the following formations in ascending order: Wildhorse Mountain, Prairie Mountain, Markham Mill, and Wesley. He also proposed the name Prairie Hollow member for a maroon shale which he believed to be in the Prairie Mountain formation. Cline (1956, p. 101) has shown that the type Wildhorse Mountain formation proposed by Harlton includes a part of the Prairie Mountain formation and the Prairie Hollow member occurs in the middle of the Wildhorse Mountain formation in the type section. Harlton applied the name Union Valley to the sandstone lying above the Wesley shale and below the Johns Valley shale. He considered this sandstone equivalent to the Union Valley sandstone member of the Wapanucka formation of east-central Oklahoma. Cline (1956, p. 103) pointed out that Harlton's "Union Valley" underlies the Mississippian Johns Valley shale and can not be equivalent to the Union Valley sandstone, which is of Morrowan age. Because of this discrepancy, Harlton renamed the "Union Valley" of the Ouachitas the Game Refuge sandstone and included it in the Jackfork group.

The frontal belt of the Ouachita Mountains of Oklahoma from the town of Atoka to Oklahoma Highway 2 north of the town of Clayton was mapped in detail by the United States Geological Survey (Hendricks *et al.,* 1947). Hendricks and his co-workers mapped most of the siliceous shales recognized by Harlton but they did not recognize his names or subdivisions.

Recently the Snow area (Willis, 1954), the Findley area (McCollough, 1954) and the Medicine Springs area (Johnson, 1954) in the central Ouachitas were mapped in conjunction with thesis studies at the University of Oklahoma. These reports cover adjacent areas which border the present area of study on the west. Willis and McCollough mapped the formations of the Stanley group on the basis of the siliceous shale markers as proposed by Harlton. Johnson recognized and mapped most of Harlton's siliceous shales in the Jackfork sandstone; however, he considered Harlton's proposal of group rank to be unjustified and classified the siliceous shales as members of the Jackfork formation. These workers have further demonstrated the persistence of the siliceous shales first mapped by Harlton.

Cline mapped the western part of the Lynn Mountain syncline, the first major syncline north of the Boktukola syncline (Cline and Shelburne, 1959; Cline, 1960). He has recognized and mapped most of Harlton's subdivisions. Cline and Moretti (1956) measured and described two complete stratigraphic sections of the Jackfork sandstone in Kiamichi Mountain (Lynn Mountain syncline) and were able to distinguish some of Harlton's subdivisions. As a result, the more persistent units of Harlton's subdivisions of the Jackfork group are known to extend from their type sections in the western Ouachitas almost to the Arkansas state line.

## Field Methods

The field work for this study was carried out during seven months within the summers of 1956 and 1957. Aerial photographs with a scale of 1:20,000 were used as a base map. Locations were determined by stereoscopic observation of the photographs and by pacing. Because the intersection of trails with section lines as well as section corners are marked in the field by land survey tags, the positions of section lines and corners were plotted on the photograph during field work.

Almost all outcrops are in creek beds or in ditches along logging trails. Divides between streams are normally covered by colluvium and blanketed by leaves and pine needles; therefore, key stratigraphic units were traced mainly by locating their position in creek beds and tracing between creeks by stereoscopic observation of the aerial photographs. The positions of distinctive rock types such as the cherts of the Wesley and Chickasaw Creek formations were determined on colluvium-covered divides by noting the highest position of chert fragments in the colluvium.

Direction of paleocurrents, as indicated by primary sedimentary features on the bottom of sandstone beds, was measured in the field. These features are sandstone casts of current flutes cut into a mud bottom prior to the deposition of the sand. The flutes and grooves show a dominant lineation parallel to the direction of bottom currents. Flute casts indicate the direction of current; the blunt end of the flute points up current. Groove casts indicate the trend of current but do not reveal the direction along the trend. The procedure in the field is first to describe the current feature, then record the strike, direction of dip, and stratigraphic horizon of the sandstone bed; and measure the clockwise angle between the lineation of the flute and strike. This angle is measured in the plane of dip with the observer facing the bottom of the bed; it has been called pitch by Crowell (1955, p. 1364). The general direction of current indicated is also recorded if the flute being measured reveals a direction of movement along the trend. From the preceding data the current trend is obtained by mathematically decreasing the dip of the bed to zero, which is assumed to be the dip at the time of deposition. This is done by subtracting the angle of pitch from the azimuth of strike. For example, if the strike is N45°W (315°azimuth) and the pitch is 40°, the current trend would be N85°W. The current may have moved in either direction along the trend. If the direction of current movement along the trend was indicated by the particular flute being measured, its general direction as recorded in the field notes permitted the proper choice of direction along the trend. In mathematically reducing the dip of the beds to zero, it is assumed that simple rotation about the present strike is responsible for the dip. The similar direction of restored current structures (fig. 18, Appendix B) indicates that the assumption is valid.

Described stratigraphic sections (Appendix A) for this report were measured with a Jacob staff with attached Brunton compass.

## Acknowledgments

Dr. L. M. Cline of the University of Wisconsin suggested the problem and introduced the writer to the study area. The late Dr. C. W. Tomlinson of Ardmore, Oklahoma, defrayed the field expenses of the writer and lent aerial photographs necessary to this study. Dr. Cline and Dr. Tomlinson reviewed critical areas in the field with the writer. The Wisconsin Alumni Research Foundation and the Oklahoma Geological Survey gave financial support. The report was submitted as a doctoral dissertation at the University of Wisconsin.

# PHYSIOGRAPHY

## Physiographic Setting

Southeastern Oklahoma is an area of warm, humid, continental climate modified by the adjoining humid subtropical climate of the Gulf Coast. The mean annual temperature at Smithville is 61°, the mean summer temperature is 80° and the mean winter temperature is 42°. Total annual precipitation is 56 inches. The average frost-free period is 195 days.

The Ouachita Mountains constitute a distinct physiographic province characterized by east-west trending mountain ranges separated by broad flat valleys in which the larger streams flow. South of the central axis of the Ouachita Mountains, streams flow southward cutting through the east-west ridges and forming rugged topography. The Boktukola syncline area lies within the area of south-flowing drainage in the central part of the Ouachita Mountains.

## Topography and Drainage

The Boktukola syncline forms an elongate mountain surrounded by a wide valley cut in the soft Stanley shale. Within the mountain long, high, parallel ridges with steep slopes descend to V-shaped valleys filled with debris. The ridges are hogbacks formed by resistant sandstone beds of the Jackfork group and Atoka formation. Boktukola Mountain is a horseshoe-shaped hogback formed of gently dipping sandstone beds which outline the west-plunging axis of the Boktukola syncline.

The pattern of streams in the area is a combination of dendritic and trellis types. The entire area is drained by Little River and its tributaries, Mountain Fork River and Glover Creek. The major streams flow southward and join Little River south of the area of this study. These waters ultimately enter Red River in Arkansas and continue to the Mississippi.

All the minor streams and the headwaters of major streams flow parallel to the ridges. Thus the upper reaches of Little River flow westward; in the lower reaches it turns south and flows across the strike of the formations and ridges near the northwestern border of the study area. Little River forms the western border of the area of investigation where it is fed by subsequent streams as it flows southward through high sandstone ridges.

The Boktukola syncline forms a shallow topographic basin which is drained by southward flowing streams such as the west fork of Glover Creek, Coon Creek, east fork of Glover Creek, Boktukola Creek, and Eagle Creek.

### Relief and Elevations

The highest point in the area of investigation is 1,989 feet on Boktukola Mountain in sec. 31, T. 1 N., R. 24 E. The lowest point is 549 feet on Little River in sec. 13, T. 2 S., R. 20 E; thus, the maximum relief is 1,440 feet. Generally the higher ridges are 700 feet above the adjacent valley floors but the relief decreases to the south where the ridge tops are about 450 feet above the valley floors. This decrease in relief is owing to the south sloping Cretaceous peneplain which is coincident with the tops of the higher ridges. East of Smithville, Boktukola Mountain is 800 feet above the valley of Eagle Creek. At the "Narrows," so called because of a narrow roadway through this water gap, massive sandstone hogbacks rise 700 feet above Mountain Fork River.

# STRATIGRAPHY

## INTRODUCTION

The rocks of the Ouachita Mountains range in age from Cambrian(?) to Pennsylvanian but most of the area of the mountains and all of the area of the present investigation is underlain by the Late Mississippian and Early Pennsylvanian Stanley-Jackfork-Johns Valley-Atoka sequence (fig. 2). The pre-Carboniferous strata occur in anticlines such as the Choctaw anticlinorium of southeastern Oklahoma where thin deposits of each period from Cambrian(?) to Devonian are present. These thin deposits are in marked contrast to the thick accumulations of the overlying Carboniferous strata, which are about four times as thick as the pre-Carboniferous rocks. The thinness of pre-Carboniferous deposits and the occurrence of black graptolitic shales in some of the formations have led some geologists to postulate a starved eugeosynclinal origin for these rocks.

The thick carboniferous rocks aggregate 23,000 feet and are almost entirely clastic and of flysch facies. They are graywackes, subgraywackes, quartzose sandstones, and shales with some thin beds of chert. Limestone is absent and fossils are sparse; therefore, time-rock boundaries within the sequence are uncertain and the ages of the different members are in dispute. The standard rock units of the Late Mississippian and Early Pennsylvanian are, in ascending order, Stanley group, Jackfork group, Johns Valley shale, and Atoka formation.

The age of the Stanley and Jackfork groups has been one of the ubiquitous problems of the Ouachitas. Age assignment is difficult because of the lack of fossils and the lack of lithologic correlation with nearby fossiliferous strata. Lithologic correlation is difficult because of rapid facies and thickness changes as one moves toward the shelf deposits which lie to the north and west. Superimposed on this sedimentary change is the complex structure of the frontal belt of the Ouachitas.

The Stanley-Jackfork sequence was long considered Early Pennsylvanian in age; this assignment was based mainly on the paleobotanical work of David White (1934, p. 1016). White reported that the Stanley-Jackfork plants closely resemble lower Pottsville forms from the Appalachian region.

Recent workers in the Ouachita Mountains consider the Stanley and Jackfork groups to be of Mississippian age. This is a return to the view held by Miser (Miser and Honess, 1927, p. 28) and others prior to White's paleobotanical work. It has recently been demonstrated that the Johns Valley shale is an indigenous formation which overlies the Jackfork formation and contains indigenous fossils of known Late Mississippian age (Cline, 1956, p. 103). Therefore, the Stanley-Jackfork sequence cannot be younger than Mississippian. Hass (1950, p. 1578) collected and examined conodonts from the lower part of the Stanley shale and he is of the opinion that the forms are of Meramecian age.

## Mississippian System

### Stanley Group

The Stanley group is predominantly shale and is composed of the following formations, from bottom to top: Tenmile Creek, Moyers, and Chickasaw Creek. The group is more than 9,000 feet thick; it is probably of Meramecian age.

#### Tenmile Creek Formation

*History of nomenclature.*—The formation was named by Harlton (1938, p. 864) for outcrops along Tenmile Creek at the south end of the Tuskahoma syncline in T. 1 S., R. 15. E.

*Distribution.*—The soft shales and sandstones of the formation erode to broad valleys which surround the Boktukola syncline. The formation is well exposed south of the Boktukola fault on the flank of the Bethel syncline in the northern half of T. 2 S., Rs. 21, 22, 23. and 24 E. The broad valley of Mountain Fork River is underlain by the Tenmile Creek formation (T. 1 S., R. 25 E.) and the Little River Valley north of the Boktukola syncline is cut into this formation.

*Character and thickness.*—In this report the Tenmile Creek formation is mapped as two units, the lower part of the Tenmile Creek formation and the upper part of the Tenmile Creek formation. The units are separated by the Battiest* chert member.

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* Pronounced ba-teest′.

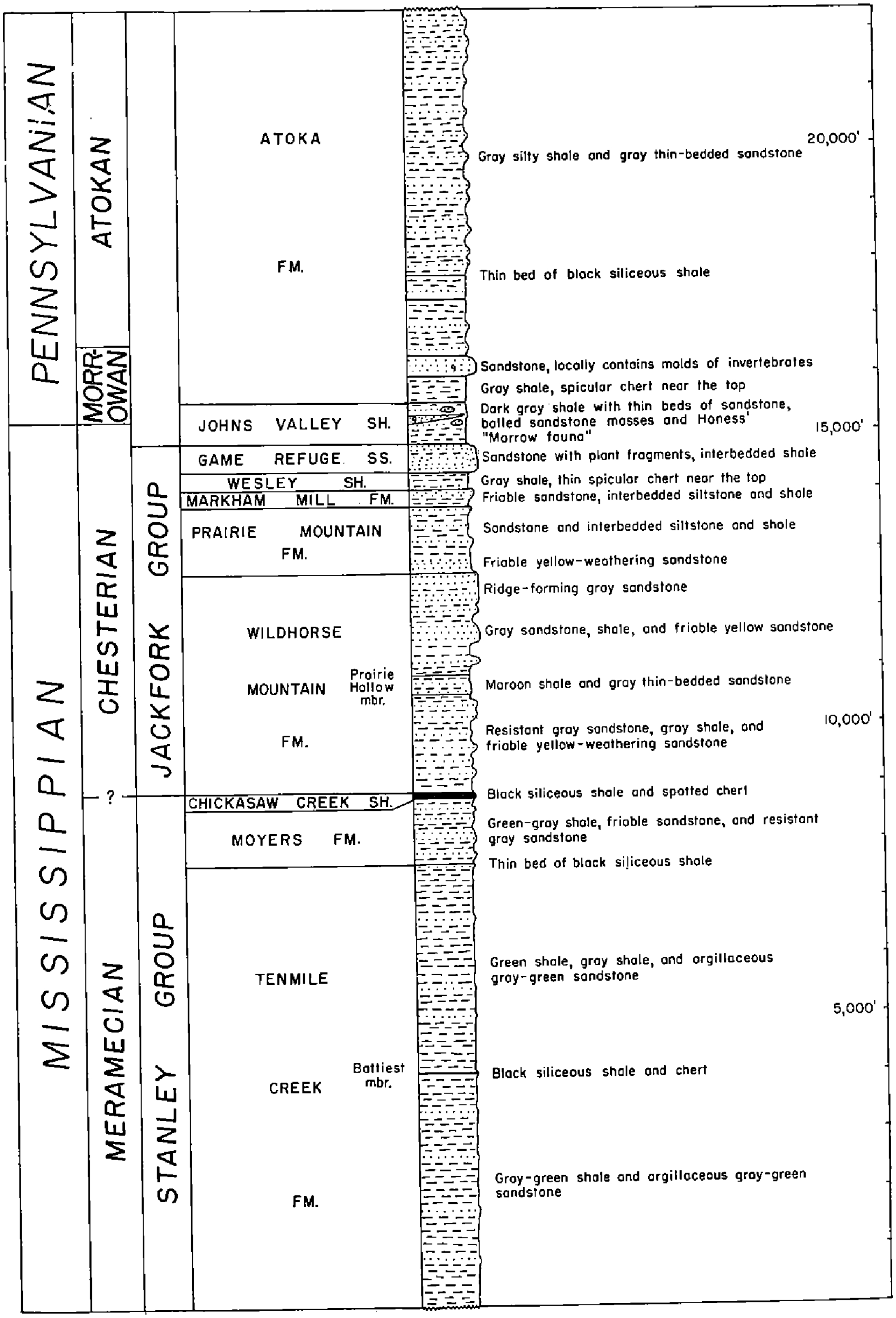

FIGURE 2. Generalized geologic column of the Boktukola syncline.

The lower part of the formation, below the Battiest chert member, is characterized by black shales, dark blue shales, and green argillaceous sandstones. The sandstones are fine-grained, poorly sorted, and have a silty and argillaceous matrix. They contain fragments of argillite, feldspar, and mica; many are graywackes. The sandstones are friable and only slightly more resistant than the enclosing shales. The base of the formation is not exposed in the area. The minimum thickness of the lower part of the Tenmile Creek formation is 4,000 feet on the north flank of the Bethel syncline in and north of sec. 2, T. 2 S., R. 22 E.

The Hatton tuff is about 200 feet above the base of the Tenmile Creek in the southern Ouachitas but does not crop out in this area; however, a short distance south of the area of investigation, ¼ mile south of the NE cor. sec. 19, T. 2 S., R. 25 E., thin tuff beds crop out along old Highway 21. The tuff here is dark gray and resistant but weathers to friable yellow spheroids. This outcrop is a westward extension of tuffs mapped by Honess (1923, plate I).

Honess (1923, p. 150) states that cone-in-cone concretions are characteristic of the lower part of the Tenmile Creek formation but Harlton (1938, p. 868) found them in the upper part and the writer has found none in the Boktukola syncline area.

The name Battiest chert member is proposed for the chert which occurs in the middle of the Tenmile Creek formation. Good outcrops occur along half-section- and section-line roads near the village of Battiest in secs. 7 and 8, T. 2 S., R. 23 E. The Battiest chert member was named "Smithville chert lentil" by Honess (Miser and Honess, 1927, p. 11) for exposures east of the town of Smithville; however, as pointed out by Branson (1957, p. 102), the name has not been used and if allowed to stand, it would preoccupy the name of a well-known Ordovician formation in Arkansas.

The best exposures of the Battiest chert in the Boktukola syncline area are along section line roads on the gently dipping north flank of the Bethel syncline in the northern part of T. 2 S., Rs. 22 and 23 E. West of Battiest, 0.1 mile south of the NE cor. sec. 11, T. 2 S., R. 22 E., the Battiest chert is 15 feet thick and is composed of three-inch beds of dark cherty siliceous shale interbedded with black siliceous shale. One six-inch bed of black chert is cut by veins of milky quartz. Severely weathered chert fragments are white and highly jointed. The upper surface of chert beds is characterized by a hummocky relief. A thin section of the chert revealed a laminated texture of clay and organic matter, tetractinal spicules and some Radiolaria.

The Battiest chert crops out in a series of folds south of Smithville in secs. 25 and 36, T. 1 S., R. 25 E., where it is about twelve feet thick (fig. 3).

In the type area of Honess' "Smithville chert" south of the settlement of Beachton near the center of sec. 11, T. 1 S., R. 26 E., the chert is 15 feet of blue-black chert and siliceous shale which is poorly exposed in a series of tight folds trending east-west. Individual chert beds are five inches thick and are cut by small quartz veins.

On the basis of similar lithology and stratigraphic position, the Battiest chert is equivalent to the middle siliceous shale bed of the Tenmile Creek formation of Harlton (1938, p. 868).

The upper part of the Tenmile Creek formation is composed of dark gray clay shales, green-gray shales, silty shales, argillaceous green-gray sandstone, and dark gray sandstone. The friable green-gray sandstones are graywackes; they are poorly sorted, silty, and contain plagioclase and mica. Thin-bedded sandstones have sharp lower contacts and gradational upper contacts because of increase in argillaceous content near the top (fig. 3). Resistant, dark gray, quartzitic sandstones are not uncommon. The top of the formation is marked by a zone of resistant gray sandstone about 140 feet thick. The upper part of the Tenmile Creek formation is about 3,600 feet thick; thus the total thickness of the formation is greater than 7,600 feet. Post oak with abundant long moss is characteristic of areas underlain by dark massive shales of the upper part of the Tenmile Creek formation and the lower part of the Moyers formation.

### Moyers Formation

*History of nomenclature.*—The name Moyers formation was given by Harlton (1938, p. 870) for exposures at the village of Moyers in T. 2 S., R. 16 E. in the western part of the Ouachita Mountains.

*Distribution.*—The Moyers formation forms the lower slopes of synclinal mountains such as Boktukola Mountain. It crops out on the east side of the Boktukola syncline and on the north flank of the Bethel syncline. A siliceous shale bed marks the base of the formation; it is thin and discontinuous. The siliceous shale was not

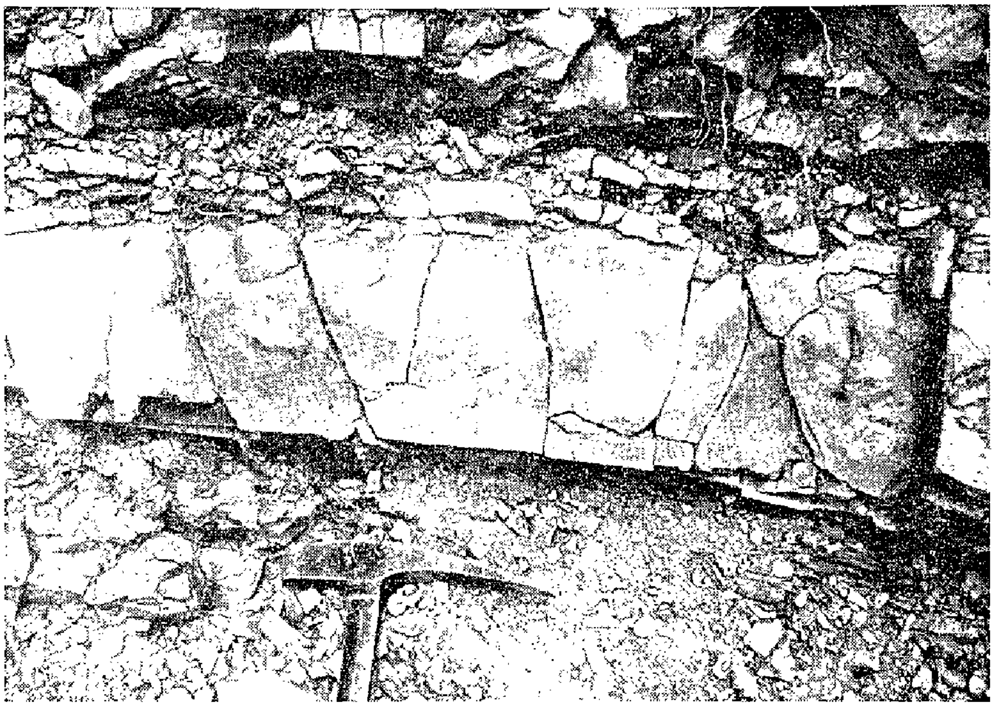

FIGURE 3. Tenmile Creek Formation

*Above:* A typical exposure of the Battiest chert member of the Tenmile Creek formation showing bedded chert and dark siliceous shale near the NW cor. SE¼ sec. 25, T. 1 S., R. 25 E.

*Below:* Argillaceous sandstone beds in the Tenmile Creek formation showing a type of graded bedding evidenced by a sharp lower contact and a gradational upper contact. The exposure is in a quarry in the SE¼ sec. 6, T. 2 S., R. 24 E.

found on the west flank of the Boktukola syncline nor on the south flank of the Harris Creek syncline.

*Character and thickness.*—The Moyers formation is composed of green-gray shale, friable gray-green sandstone and resistant gray sandstone. The shales are clayey and break into smooth subconchoidal or splintery fragments. Most of the sandstones are friable, argillaceous, micaceous and feldspathic; thin resistant sandstones are quartzitic. Resistant sandstone beds in this dominantly shale formation form ridges and benches. Along Mountain Fork River in sec. 9, T. 1 S., R. 25 E., prominent sandstone beds crop out at 190, 370, 440, 530, 800, and 980 feet above the base of the formation. The sandstone which is 800 feet above the base of the formation forms a prominent ridge that can be traced on aerial photographs from the east flank to the west flank of the Boktukola syncline. The upper Moyers formation is described in Stratigraphic Sections II and V*. The formation is about 1,150 feet thick.

The siliceous shale bed at the base of the Moyers formation is well exposed along a section-line road 0.4 mile east of NW cor. sec. 25, T. 1 N., R. 23 E., on the north flank of the Boktukola syncline. The black siliceous shale is about six feet thick here. It contains three-inch-thick chert beds which have white hummocky upper surfaces. Sandstone dikes one to ten inches wide cut the siliceous shale. They were apparently injected into the shale from the underlying massive sandstone, as outcrop patterns in the road show the shale is dragged up at the dike contacts (fig. 4).

In cliffs along Buffalo Creek 0.4 miles south and 0.24 miles east of NW cor. sec. 14, T. 2 S., R. 25 E., the siliceous shale bed is 15 feet of black, massive, siliceous shale which weathers to splintery shards (fig. 4). Lenticular beds of chert one to two inches thick are jointed and form blocks which are scattered about weathered exposures.

On the north flank of the Bethel syncline at a bend in the road near the SE¼ sec. 18, T. 2 S., R. 22 E. the siliceous shale bed is about twelve feet thick. The shale is black and fissile; it contains two thin quartzitic siltstone beds and a three-inch-thick chert bed near the top. The siliceous shale is underlain by siltstone, sandstone, and shale; and is overlain by shales of the Moyers formation.

Other exposures of the siliceous shale bed are along the road near the SW cor. sec. 9, T. 1 S., R. 25 E., and along the old pipe-line

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Measured sections are described in Appendix A.

FIGURE 4. Moyers Formation.

*Above:* The basal siliceous shale of the Moyers formation as exposed on Buffalo Creek in the NW¼ sec. 14, T. 2 S., R. 25 E. Thin beds of dark chert are underlain by black fissile shale.

*Below:* The basal siliceous shale and chert of the Moyers formation dipping toward the bottom of the picture is cut by a vertical sandstone dike. The Moyers siliceous shale is only six feet thick here in road cuts along the north line of sec. 25, T. 1 N., R. 23 E.

right-of-way 0.1 miles west of center of east line sec. 14, T. 2 S., R. 25 E.

Thin sections of the basal siliceous shale bed of the Moyers formation reveal a dense laminated matrix of clay and organic matter with some tetractinal spicules. One thin section contained small circular areas of silica with pyrite in the center; these may be recrystallized and partially replaced Radiolaria.

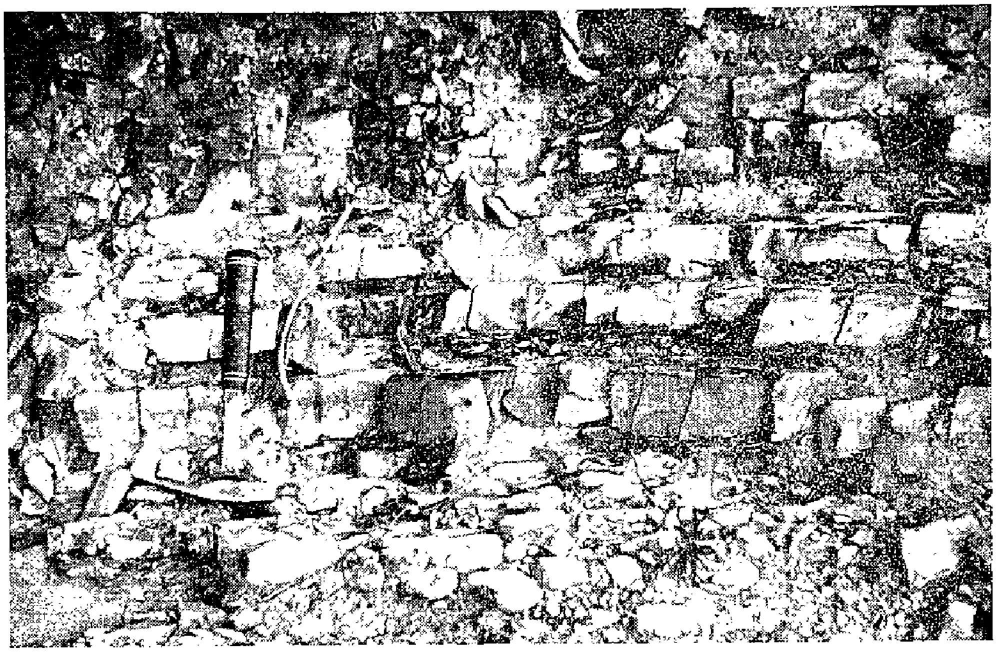
### Chickasaw Creek Formation

*History of nomenclature.*—The formation was named by Harlton (1938, p. 874) for outcrops near Chickasaw Creek in the western Ouachita Mountains (T. 1 S., R. 13 E.). The Chickasaw Creek formation is the uppermost formation of Harlton's Stanley group.

*Distribution.*—The Chickasaw Creek siliceous shale is a persistent and easily recognized formation, both because of its characteristic black cherts with white spots and unique outcrop pattern on aerial photographs. Resistant sandstones associated with the Chickasaw Creek shale form a topographic bench in the steep slopes of hogbacks. Numerous ravines are cut below this bench in the massive Moyers shale. The first resistant sandstones of the overlying Jackfork group are about 150 feet above the Chickasaw Creek siliceous shale. This sequence forms a unique topographic profile in the steep slopes of hogbacks: numerous gullies at the base succeeded by a bench, topped by a smooth receding slope which is capped by resistant sandstones.

The Chickasaw Creek formation crops out around the Boktukola syncline except on the faulted southern flank. It is also present in the Bethel and Harris Creek synclines and in the Big One anticline. Because the formation is thin, it was mapped with the Moyers formation (Mscm) on the geologic map (plate I). The Chickasaw Creek formation is an excellent marker for division of the Stanley and Jackfork groups. It approximates the Stanley-Jackfork boundary mapped in this area by Honess (1923) except on the north flank of the Bethel syncline where it is about 650 feet higher than Honess' boundary.

Two excellent outcrops of the formation are described in Stratigraphic Sections II and V. Other good exposures along logging trails are: NE¼ NE¼ sec. 8, T. 2 S., R. 24 E.; near the center sec. 20, T. 1 S., R. 25 E.; near the center sec. 17, T. 1 S., R. 21 E.; near



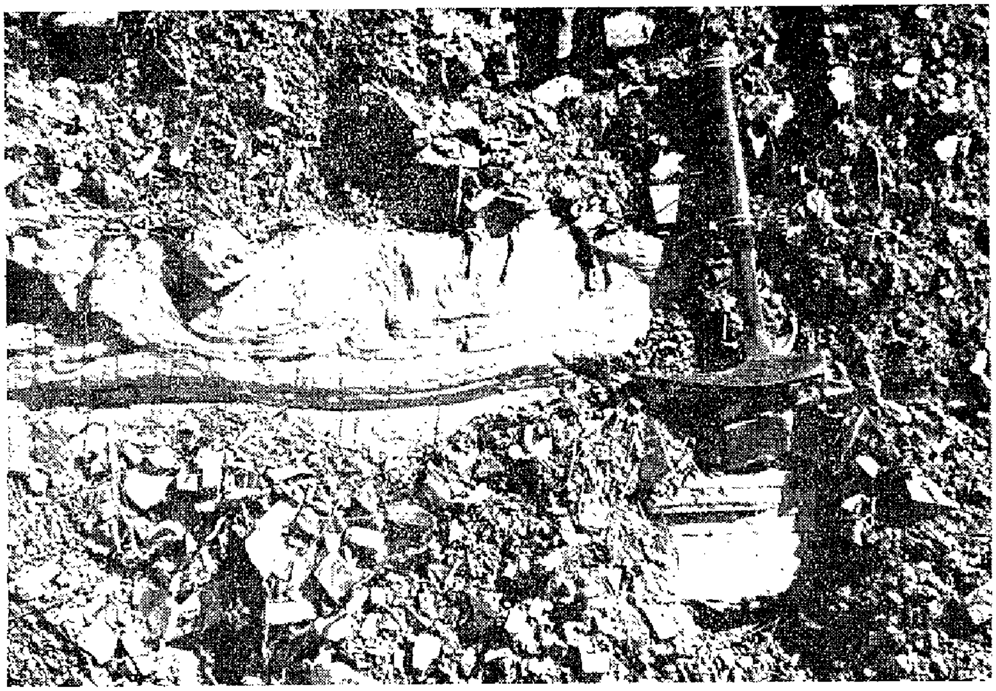


FIGURE 5. Chickasaw Creek Formation

*Above:* Typical bedding of the Chickasaw Creek chert and siliceous shale as exposed along a logging trail in the NE¼ NE¼ sec. 8, T. 2 S., R. 24 E.

*Below:* Convolute bedding within a fine-grained sandstone in the Chickasaw Creek formation in exposures along a logging road in the SE¼ sec. 17, T. 2 S., R. 22 E. The view is toward the south and the central convolution is overturned to the west as one might expect if the convolution were formed by westward moving currents during deposition.

center of the south line sec. 2, T. 2 S., R. 21 E. Outcrops are numerous in steep ravines in the slopes of hogbacks capped by sandstones of the Wildhorse Mountain formation. Fragments of the distinctive cherts of the Chickasaw Creek formation are abundant in float and in stream gravels; the fragments are easily traced up steep ravines to their source.

Vertically dipping beds of the Chickasaw Creek siliceous shale crop out in the east bank of Glover Creek about 0.4 mile east and 0.1 mile north of the SW cor. sec. 5, T. 2 S., R. 24 E. The formation contains a well-exposed 60-foot-thick section of gray shale enclosed by resistant sandstone beds. Thin quartzitic siltstone beds with abundant sole markings are intercalated in the dark gray shale; black cherty beds are common in a zone about ten feet thick in the upper part of the gray shale.

*Character and thickness.*—The formation consists of black siliceous shale, black chert and black to gray fissile shale; interbedded with fine-grained, thin-bedded, convolute-bedded, sole-marked, quartzitic sandstones (fig. 5). The formation in 140 and 131 feet thick in Stratigraphic Sections II and V.

The chert beds of this formation are characterized by small white spots about 1 mm in diameter. The spots are more common in the lower part of a chert bed; indeed, their distribution may be used with discretion as top-and-bottom criteria (fig. 17). In thin section the spots are rounded areas of concentration of cryptocrystalline quartz and ferric oxide; they show no relation to the microfossil content. Most thin sections of siliceous shales and cherts reveal a dense, dark, laminated matrix of clay and organic matter. Radiolaria, partly replaced by pyrite, and tetractinal sponge spicules are common. Weathered samples show patchy recrystallization of the matrix to form dense microcrystalline chert.

At two localities (NW¼ NE¼ sec. 23, T. 1 S., R. 21 E., and NE¼ SE¼ sec. 29, T. 1 S., R. 25 E.) the Chickasaw Creek formation contains thin beds of microconglomerate. The rock is actually a coarse sandstone composed of round quartz grains, angular fragments of dark chert, siliceous shale, and siltstone. Chlorite flakes, muscovite, plagioclase, and pyrite occur sparingly. Ghost rhombs of carbonate form voids in restricted areas of the matrix. These areas may have been limestone fragments. Some samples show minute cross-bedding and graded bedding.

Most sandstones of the Chickasaw Creek formation are gray, fine-grained, and quartzitic, with some muscovite and a matrix of clay. The sandstones are thin-bedded. Convolute bedding and abundant sole markings are characteristic (fig. 5).

## Jackfork Group

The Jackfork group is divided into five formations. From the base upward, they are: Wildhorse Mountain, Prairie Mountain, Markham Mill, Wesley, and Game Refuge. The group ranges from 5,400 to 6,500 feet in thickness with 40 percent gray shale and 60 percent subgraywacke and quartzose sandstone.

### Wildhorse Mountain Formation

*History of nomenclature.*—The formation was named by Harlton (1938, p. 878) for exposures in Wildhorse Mountain north of the town of Moyers in T. 2 S., R. 16 E. Harlton also proposed the name Prairie Hollow member for a belt of maroon shale exposed in Prairie Hollow in sec. 10, T. 2 S., R. 12 E. Harlton considered the Prairie Hollow shale as a member of the overlying Prairie Mountain formation. However, Cline (1956, p. 101) has shown that Harlton's type section of the Wildhorse Mountain formation includes part of the strata of the type section of the Prairie Mountain formation and that the Wildhorse Mountain type section includes the Prairie Hollow shale. Because the name Wildhorse Mountain has page preference, Cline suggested that it remain a legitimate formation and that the Prairie Mountain formation be restricted to those strata between the type Wildhorse Mountain formation and the Markham Mill formation.

In the western Ouachitas, the Prairie Hollow member was mapped by Hendricks and others (1947) as "maroon shale member" of the Jackfork formation.

*Distribution.*—The Wildhorse Mountain formation constitutes the lower half of the Jackfork group. The formation, with its Prairie Hollow shale member, crops out on the flanks of the Boktukola and Harris Creek synclines. The lower part of the Wildhorse Mountain formation is partly exposed near Little River on the north limb of the Big One anticline. The Wildhorse Mountain formation is also present in the Bethel syncline but only the lowermost part is present within the area of this report in T. 2 S., R. 22 E. Sandstones in the lower part of the formation form the outer high ridges of synclinal mountains. The Prairie Hollow member is widespread and commonly forms strike valleys or forms the slopes of hogbacks capped by resistant sandstones of the upper part of the Wildhorse Mountain formation. The best outcrops of the Prairie Hollow member are described in Stratigraphic Section I; they occur along a south-flowing creek in the SW¼ NW¼ sec. 32, T. 1 N., R. 23 E. The Prairie Hollow member crops out around the plunging axis of Nunihchito anticline in T. 2 S., R. 24 E.; however, the typical maroon shales of other outcrops are replaced by green shales. Massive sandstone beds at the top of the formation form the more prominent ridges in the interiors of synclinal mountain ranges.

*Character and thickness.*—On the geologic map (plate I) the Wildhorse Mountain formation is divided into: lower part of the Wildhorse Mountain formation, Prairie Hollow member, and upper part of the Wildhorse Mountain formation. The formation is about 3,880 feet thick in the north limb of the Boktukola syncline.

The lower part of the Wildhorse Mountain formation is composed of 1,700 feet of gray shale, friable yellow-green sandstone, and quartzitic gray sandstone. Thin-bedded quartzitic siltstone and gray shale are common. The first resistant sandstones occur 150 feet above the base of the formation. Sole markings are abundant on thin-bedded quartzitic sandstones and plant fragments occur in friable, argillaceous sandstones near the base of the formation.

The Prairie Hollow member of the formation is distinctive because it contains maroon and chocolate shale. The member is about 310 feet thick and is composed of subequal amounts of gray sandstone and maroon and chocolate shale, with some friable gray-green sandstone. For a more detailed description see Stratigraphic Section I. The maroon shales of the Prairie Hollow member are partially replaced by green shales in outcrops around the east side of the Boktukola syncline and only green shales were found around the nose of the Nunihchito anticline. In the NE¼ sec. 5, T. 1 S., R. 24 E., the Prairie Hollow member contains maroon shale in the upper part with green shale and concretionary masses of brown shale in the lower part. Massive 20- to 30-foot-thick quartzitic sandstone beds with intercalated thin beds of black fissile shale form a bench above the Prairie Hollow shales.

Above the Prairie Hollow member, soft yellow-weathering sandstone is interbedded with gray shales and gray sandstones. Gray shales are typically intercalated with fine-grained, thin-bedded, quartzitic sandstone which locally contains molds of *Lepidodendron.* Harlton (1938, fig. 13) also found *Lepidodendron* in a similar stratigraphic position. Resistant sandstone beds from five to ten feet thick are common in the upper part of the formation. Two resistant sandstone beds, each of which is about 50 feet thick, mark the top of the formation. The upper part of the Wildhorse Mountain formation is 1,771 feet thick in exposures along the Indian Service Road* in Stratigraphic Section I.

### Prairie Mountain Formation

*History of nomenclature.*—The formation was named by Harlton (1938, p. 881) for exposures in Prairie Mountain in sec. 25, T. 1 S., R. 12 E. Cline (1956, p. 101) proposed that the name Prairie Mountain be restricted to those strata above the Wildhorse Mountain type section and below the Markham Mill type section. On plate I the upper part of the Wildhorse Mountain formation, Prairie Mountain formation and Markham Mill formation are mapped together because of difficulty in separating the formations. Siliceous shales which mark the boundaries of these formations in their type areas in the western Ouachitas are not present in the Boktukola syncline area.

*Distribution.*—The formation crops out in the north and south flanks of the Harris Creek syncline, and around the Boktukola syncline, except on the faulted south flank.

*Character and thickness.*—Above the thick resistant sandstone at the top of the Wildhorse Mountain formation, friable yellow-weathering sandstone predominates. The soft sandstone is capped by a thick resistant sandstone near the middle of the formation; and above this, gray shale is interbedded with thin beds of resistant, fine-grained sandstone. Thin-bedded sandstones are light gray and quartzitic and show convolute bedding and flute casts; "worm trails" occur on the upper surfaces of the beds. Carbonized plant fragments occur in thin sandy layers in the interbedded shale.

The formation is well exposed in cuts along the Indian Service Road in the north part of sec. 3, T. 1 S., R. 23 E. These exposures are described in Stratigraphic Section I, where the formation is assigned a thickness of 1,149 feet, and is 47 percent sandstone.

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* Now Oklahoma State Highway 144.

## Markham Mill Formation

*History of nomenclature.*—The formation was named by Harlton (1938, p. 885) for outcrops near a sawmill in sec. 21, T. 2 S., R. 14 E. At the type locality, the formation is predominantly shale with some thin sandstones and is about 400 feet thick.

*Distribution.*—The formation crops out on the flanks of the Harris Creek syncline and around the Boktukola syncline except the faulted south flank. The formation is not distinctive but is easily recognized because it underlies the Wesley shale.

*Character and thickness.*—The base of the formation is marked by a gray fissile shale with abundant three-inch-thick beds of very fine-grained sandstone which weathers to rectangular blocks and squares. "Worm trails" are common on the upper surfaces of the sandstones; some trails with transverse furrows were probably made by gastropods (fig. 6). Some of these thin sandstone beds show vertical burrows, which destroy lamination, and small scale (1 cm) cross-bedding. The basal shale zone may be a facies of the siliceous shale bed which marks the base of the Markham Mill formation in the type area. A massive ridge-forming sandstone occurs above the shale zone. The sandstone is overlain by gray shales and friable sandstones. The formation is 299 feet thick in exposures along Indian Service Road in sec. 3, T. 1 S., R. 23 E.

Fragments of a thin and discontinuous siliceous shale were found along the road about ¼ mile east of the center of the west line of sec. 25, T. 1 S., R. 21 E. This may be the basal siliceous shale of the Markham Mill formation of Harlton but additional outcrops were not found.

## Wesley Formation

*History of nomenclature.*—Harlton (1938, p. 886) named the Wesley formation for outcrops southwest of the village of Wesley in sec. 20, T. 1 N., R. 13 E. The type section is located in a fault slice; the total Jackfork group is less than 1,800 feet thick and the Game Refuge formation is absent, yet Harlton described the Wesley as 500 feet of siliceous shale. Harlton also mentioned outcrops on Campbell Creek* in sec. 2, T. 2 S., R. 12 E. This would probably be a more suitable type section because there are fewer structural complications and there is a more complete development of the en-

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* Shown as "Camel Creek" on U. S. Geological Survey Stringtown, Okla., topographic map (7.5′).

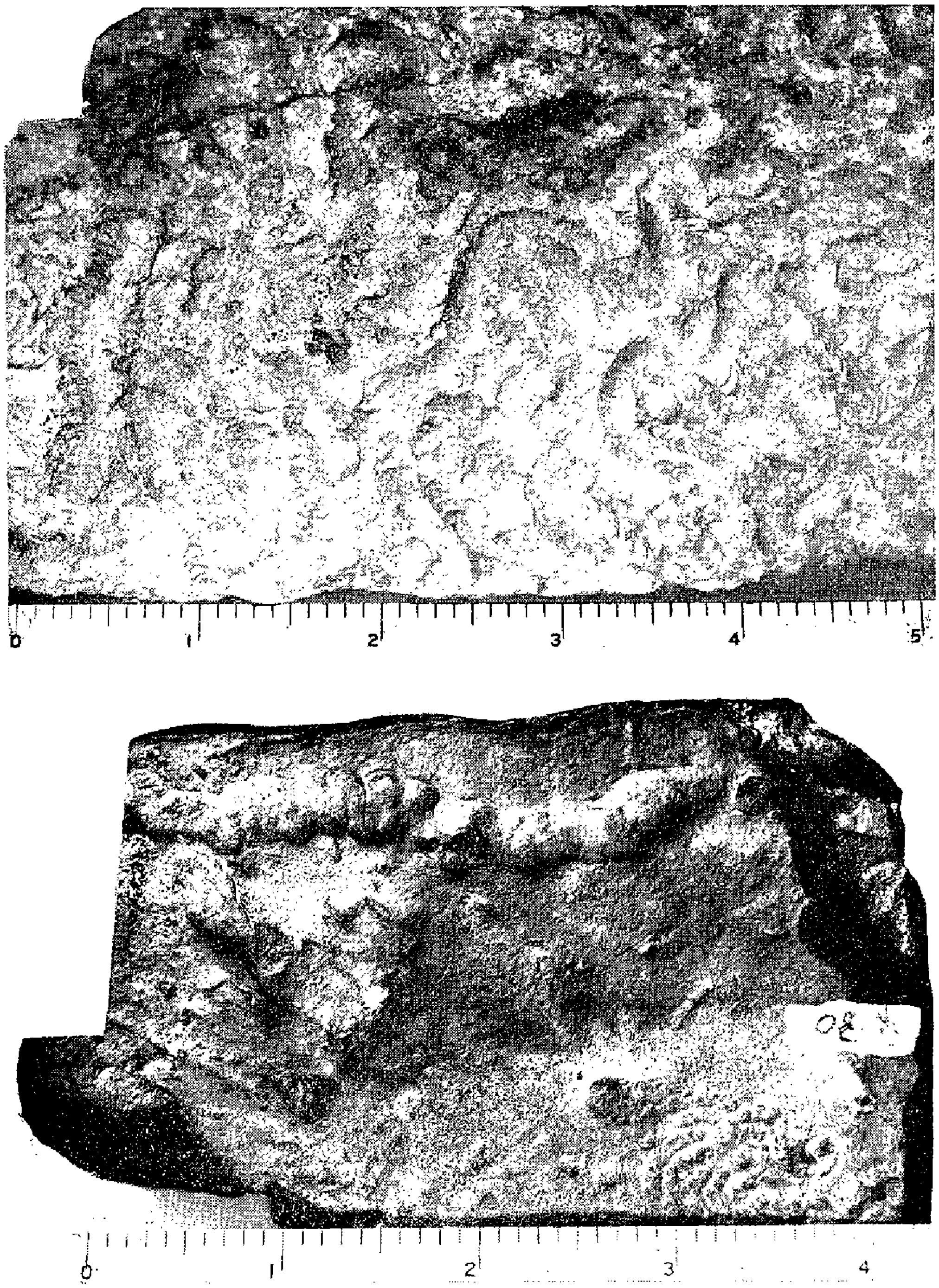

FIGURE 6. Markham Mill and Atoka Formations

*Above:* Gastropod trails on the top of a fine-grained sandstone in the Markham Mill formation in cuts along Indian Service Road in the NE¼ sec. 3, T. 1. S., R. 23 E. Note the transverse ridges characteristic of gastropod trails. Scale is in inches.

*Below:* Burrow casts on the bottom of a sandstone bed in the lower part of the Atoka formation in the NW¼ sec. 11, T. 1 S., R. 23 E. The burrower moved along the contact of the sand and underlying mud shortly after deposition. Note the concentric ropy burrows at the lower right. Scale is in inches.

tire Jackfork group in this area. Hendricks *et al.* (1947) mapped 330 feet of Wesley in the type area although they refer to the shale as "siliceous shale member of the Jackfork formation." The Wesley formation marks the top of Harlton's original Jackfork group (Harlton, 1938, p. 878). Recently, he has included the overlying Game Refuge formation in the Jackfork group (Harlton, 1959, p. 132).

*Distribution.*—The Wesley formation is the most widespread and readily recognized formation of the Jackfork group. It crops out in the Boktukola and Harris Creek synclines extending from Little River east to the drainage of the east fork of Glover Creek.

*Character and thickness.*—The lower portion of the Wesley formation consists of gray shale and friable sandstone; the upper part is a distinctive gray shale with abundant half-inch-thick siltstone beds. A blue-black siliceous shale occurs near the top of the formation. In outcrops on the Indian Service Road (NE¼ SW¼ sec. 2, T. 1 S., R. 23 E.) the upper siliceous shale is 14 feet thick and is cherty in the lower part. The siliceous shale is overlain abruptly by sandstones of the Game Refuge formation. The Wesley formation ranges from 211 to 300 feet in thickness; the upper gray shale is about 150 feet thick.

In the banks of a creek in NW¼ SE¼ sec. 28, T. 1 S., R. 24 E., laminated Game Refuge sandstone is underlain by 45 feet of black Wesley shale with beds of blocky siliceous shale near the bottom; the base of the shale is not exposed. Farther south in section 28, on the east-facing slope of a hogback held up by the Game Refuge sandstone, the Wesley contains thin chert beds with white spots similar to those in the Chickasaw Creek formation. The cherts occur 35 feet below the basal sandstone of the Game Refuge formation.

At the west end of a prominent hogback of Game Refuge sandstone where a south-flowing creek empties into the east fork of Glover Creek (SE¼ SE¼ sec. 32, T. 1 S., R. 24 E.) the Wesley shale is 211 feet of gray shale with intercalated thin beds of siltstone. The Wesley shale is underlain by more than 170 feet of massive sandstone and gray shale and is overlain by more than 60 feet of resistant sandstones with coarse-grained laminae containing molds of fossil fragments. The distinctive cherts of the Wesley are not present here on the south flank of the Boktukola syncline.

Along a creek near the center of sec. 36, T. 1 S., R. 21 E., the Wesley shale is about 300 feet thick and contains blocky beds of black chert in the upper part. Cherts of the Wesley shale crop out along Braggs Trail near the NW cor. sec. 10, T. 2 S., R. 21 E.; they have abundant white spots similar to the spots of the Chickasaw Creek cherts. Thin sections and sections etched with hydrofluoric acid show the chert to be a mass of small spines and spicules with dark laminae of organic matter. The white spots are about 1 mm in diameter. In thin sections they are semi-opaque in transmitted light and seem to be irregular patches of amorphous silica.

In a ditch on the west side of the road in SW¼ sec. 24, T. 1 S., R. 21 E., cherts in the upper Wesley formation weather to a tan color and have abundant white streaks parallel to bedding. A thin section of this chert reveals a profusion of spicules and shows that the white streaks are laminae of abundant spicules within the dark organic matrix. Tan-weathering cherts of the Wesley formation were found in many outcrops in the Boktukola syncline.

*Correlation.*—Harlton considered the Wesley formation to be equivalent to the "Pennsylvanian Caney" or Goddard shale of the Arbuckle Mountains when he proposed the name in 1938. However, the Wesley shale lies below the Johns Valley shale in the southern Ouachitas and must be older than this Mississippian formation. The Wesley shale is probably equivalent to some part of the Caney shale north of the Ti Valley fault in the frontal Ouachitas.

West of Little River in the Medicine Springs area Johnson (1954) mapped as Wesley a thin siliceous shale in the Game Refuge formation. Johnson's Markham Mill siliceous shale is equivalent to the Wesley shale as mapped by the writer in the Boktukola syncline and by Cline in the Lynn Mountain syncline (Cline, 1960).

### Game Refuge Formation

*History of nomenclature.*—The formation was named by Harlton (1959, p. 132) for exposures in the Clayton Game Refuge in secs. 28 and 29, T. 1 N., R. 18 E. Earlier Harlton (1938) had considered this formation equivalent to the Pennsylvanian Union Valley sandstone of the Arbuckle Mountains. Cline (1956, p. 101) pointed out that this correlation was not proper because the "Union Valley" of the southern Ouachitas lies below the Johns Valley shale, which is of Mississippian age. This prompted Harlton to propose the new name, Game Refuge, and to raise the limit of the Jackfork group to include this formation.

*Distribution.*—The formation is widespread and crops out in the Boktukola and Harris Creek synclines. The sandstones of this formation form a ridge which separates the shales of the Wesley and Johns Valley formations. The lower and middle parts of the formation are well exposed in cuts along Indian Service Road in SW¼ sec. 2, T. 1 S., R. 23 E. (Stratigraphic Section I; figs. 8, 9).

The Game Refuge formation is partially exposed along the road in the SE¼ SW¼ sec. 24, T. 1 S., R. 21 E., but the stratigraphic relations are confused by a dip fault and the formation is overturned. Better outcrops occur farther south at a bend in the road near the NE cor. SE¼ SW¼ sec. 25, T. 1 S., R. 21 E.

The lower part of the formation is exposed along the trail to Flashman Tower in the S½ SW¼ sec. 15, T. 1 S., R. 22 E.

*Character and thickness.*—The formation is composed of subequal amounts of gray sandstone and gray shale; it ranges from 450 to 500 feet in thickness but is about 480 feet thick in most places. Most of the sandstones are resistant beds about two feet thick. The sandstones are interbedded with black fissile shale in the lower part of the formation; these black shales are a continuation of Wesley lithology into the lower part of the Game Refuge formation. Sandstones of the Game Refuge formation are medium-grained and quartzose; they commonly contain bands of quartz pebbles, rock fragments, and molds of fragments of marine invertebrates (fig. 8). Reddish-tan friable sandstones containing *Calamites* and abundant plant fragments and molds of fragments are characteristic of the formation (fig. 7). Small-scale cross-bedding is common and sole markings are rare. Silty siliceous shales occur in the lower part and near the top of the formation (fig. 8). A thin section of one of these shales revealed a dark laminated siltstone with abundant clay and organic matter and some spines and spicules.

## MISSISSIPPIAN-PENNSYLVANIAN TRANSITIONAL ROCKS

### Johns Valley Formation

*History of nomenclature.*—The formation was named by Ulrich (1927, p. 21) for exposures near the settlement of Johns Valley in the center of the Tuskahoma syncline in T. 1 S., R. 16 E. The for-

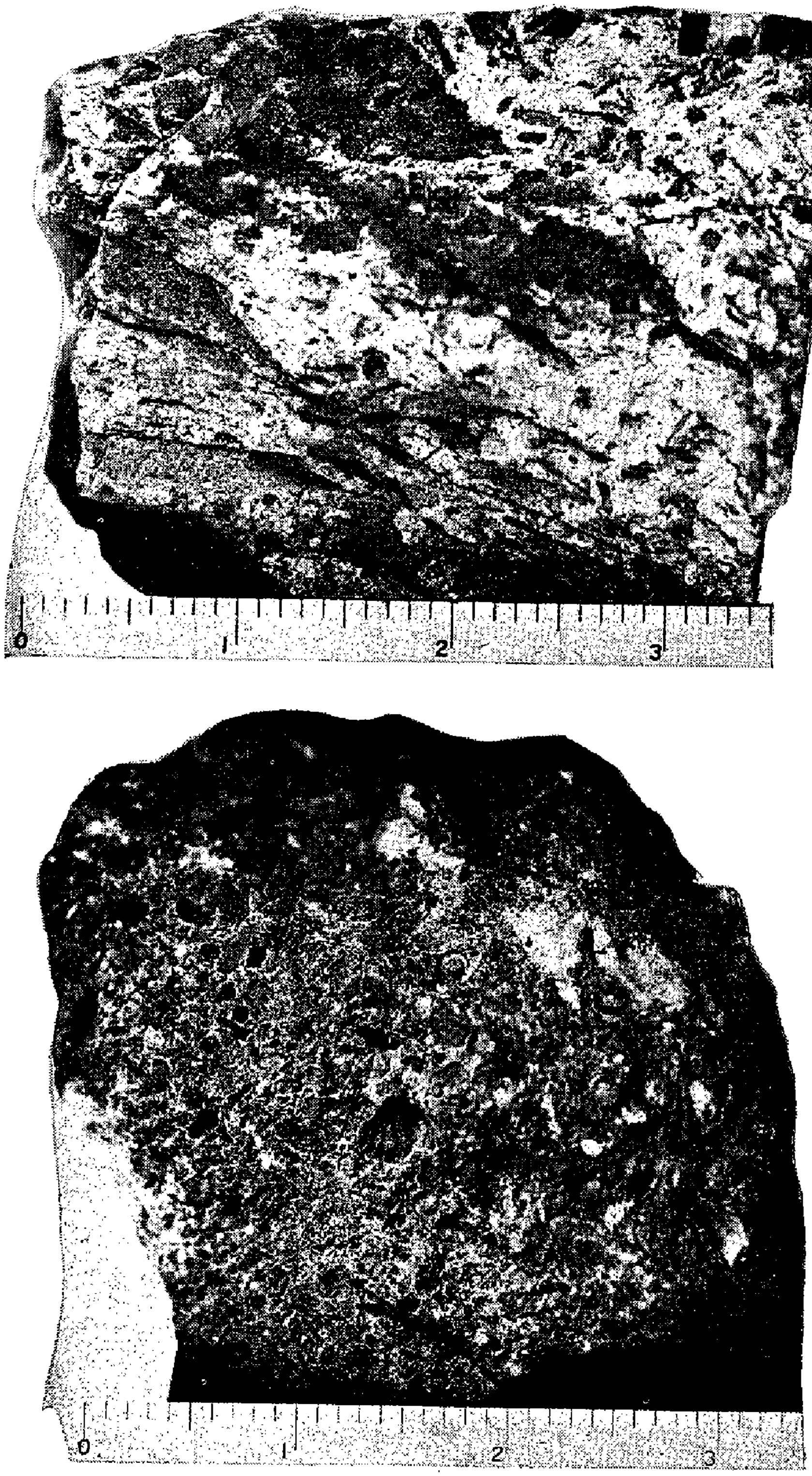

Figure 7. Sandstone Mold Fossils

*Above:* Sandstone of the Game Refuge formation with abundant molds of plant fragments, from the SW¼ sec. 2, T. 1 S., R. 23 E. Scale is in inches.

*Below:* A ferruginous sandstone containing Honess' "Morrow fauna" from the Johns Valley formation at Honess' original collection locality 300 paces north of the SE cor. sec. 6, T. 1 S., R. 23 E. Scale is in inches.

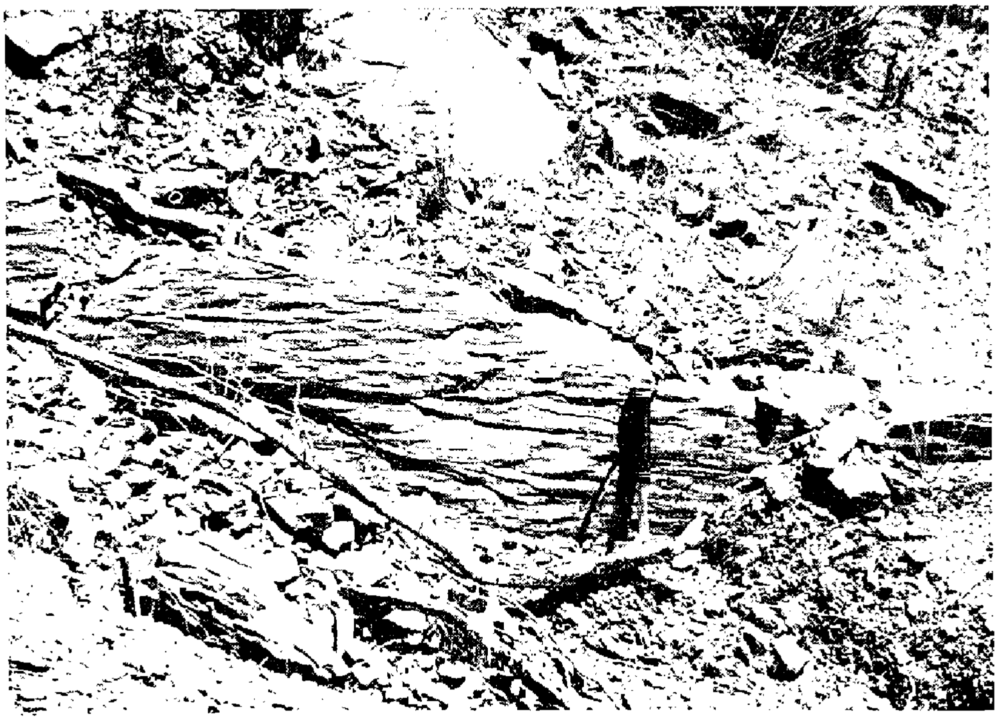

FIGURE 8. Atoka and Game Refuge Formations

*Above:* Flute casts on the bottom of a vertically dipping sandstone bed in the lower part of the Atoka formation at Hairpin Curve on Oklahoma Highway 2, sec. 3, T. 3 N., R. 19 E. The view is toward the NNW and current moved from right to left (toward the WSW).

*Below:* Quartzose sandstone in the Game Refuge formation on Indian Service Road in the SW¼ sec. 2, T. 1 S., R. 23 E. The laminated sandstone below the hammer contains molds of invertebrate-fossil fragments and large round quartz grains.

mation was originally named Caney shale by Taff (1901) for exposures along Cane Creek, now called Johns Creek, in the Tuskahoma syncline. Ulrich proposed the new name Johns Valley because he believed the boulder-bearing Ouachita "Caney" was of Pennsylvanian age and younger than the Caney shale mapped by Taff and others on the flanks of the Arbuckle Mountains. Harlton (1938, p. 896) proposed the name Round Prairie to replace Johns Valley but this has not been accepted by other workers.

*Distribution.*—The Johns Valley formation is widespread. It crops out on the east and north flanks of the Boktukola syncline and extends westward to Little River. On aerial photographs it appears that the formation extends southwestward, as a continuous belt of weak strata, across Little River to the Cretaceous overlap near Antlers, Oklahoma. The formation crops out on the south and north flanks of the Harris Creek syncline and it extends westward across Little River on the south flank.

Exotic boulders, typical of the Johns Valley outcrops north and west of the Boktukola syncline area, have not been found. The nearest outcrop with exotic boulders is near Hardy Creek on U. S. Highway 271, ten miles northwest of the Johns Valley exposures on Little River.

*Character and thickness.*—In the Boktukola and Harris Creek synclines the Johns Valley formation lies conformably above the Game Refuge sandstone and below the Atoka formation. The Johns Valley forms a poorly exposed belt of weak strata lying between resistant sandstones. The formation is predominantly gray silty shale; it contains fossiliferous sandstone including Honess' "Morrow fauna" and resistant light gray sandstone beds which have been "balled" to form rounded sandstone boulders. The Johns Valley formation ranges from 600 to 750 feet in thickness; the upper part of the formation is gradational with the shales of the lower part of the Atoka formation. Exotic boulders, phosphatic concretions, or the Caney fauna which characterize the Johns Valley of exposures farther north have not been found in the Boktukola syncline area.

Rounded sandstone boulders formed by balling of sandstone beds are characteristic of this formation. The boulders are irregular in shape but generally they are oblate-spheroidal (fig. 10). They range in maximum diameter from 3 to 70 inches depending on the thickness of the parent bed. The boulders have smooth or crumpled surfaces and massive-sandstone interiors. They may have been

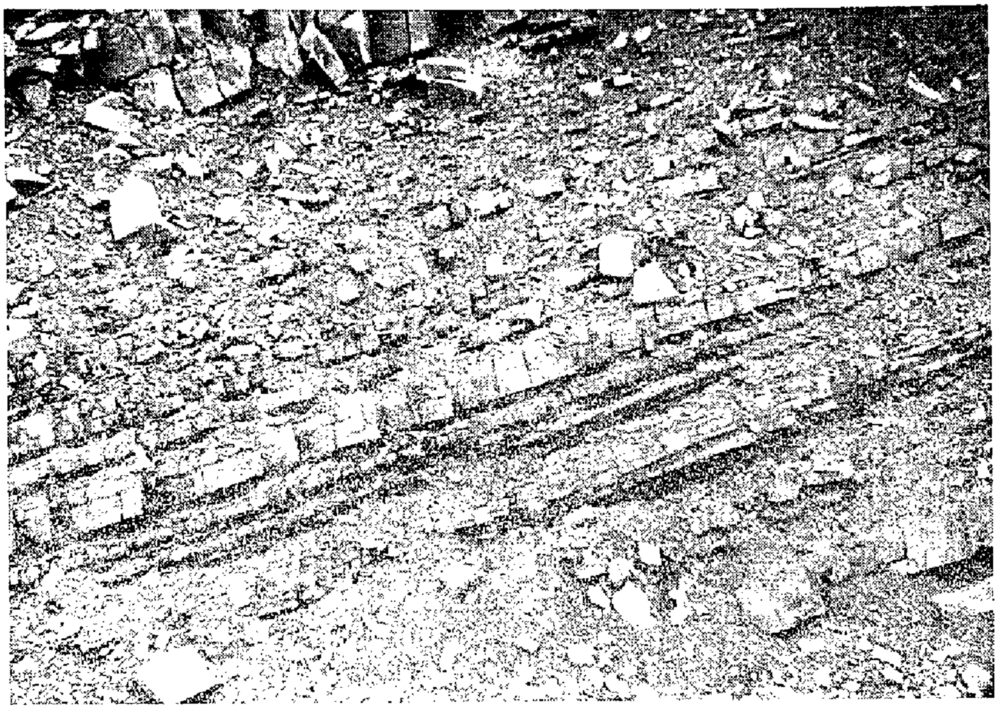

FIGURE 9. Game Refuge and Johns Valley Formations.

*Above:* Thin-bedded siltstone, shale, and silty micaceous shale in the lower part of the Game Refuge formation in SW¼ sec. 2, T. 1 S., R. 23 E. This outcrop is unit 120 of Stratigraphic Section I. The sharp lower contacts of the siltstone beds and rhythmic alternation of psammitic and pelitic layers is characteristic of flysch deposition.

*Below:* Small balled sandstone masses in the Johns Valley formation in NW¼ sec. 11, T. 1 S., R. 23 E. The thin sandstone bed, above the hammer and dipping away from the observer, is probably the parent bed for these cobbles. Note the spindle-shaped cobble to the right of the hammer and the "brain" texture on a cobble below the hammer.

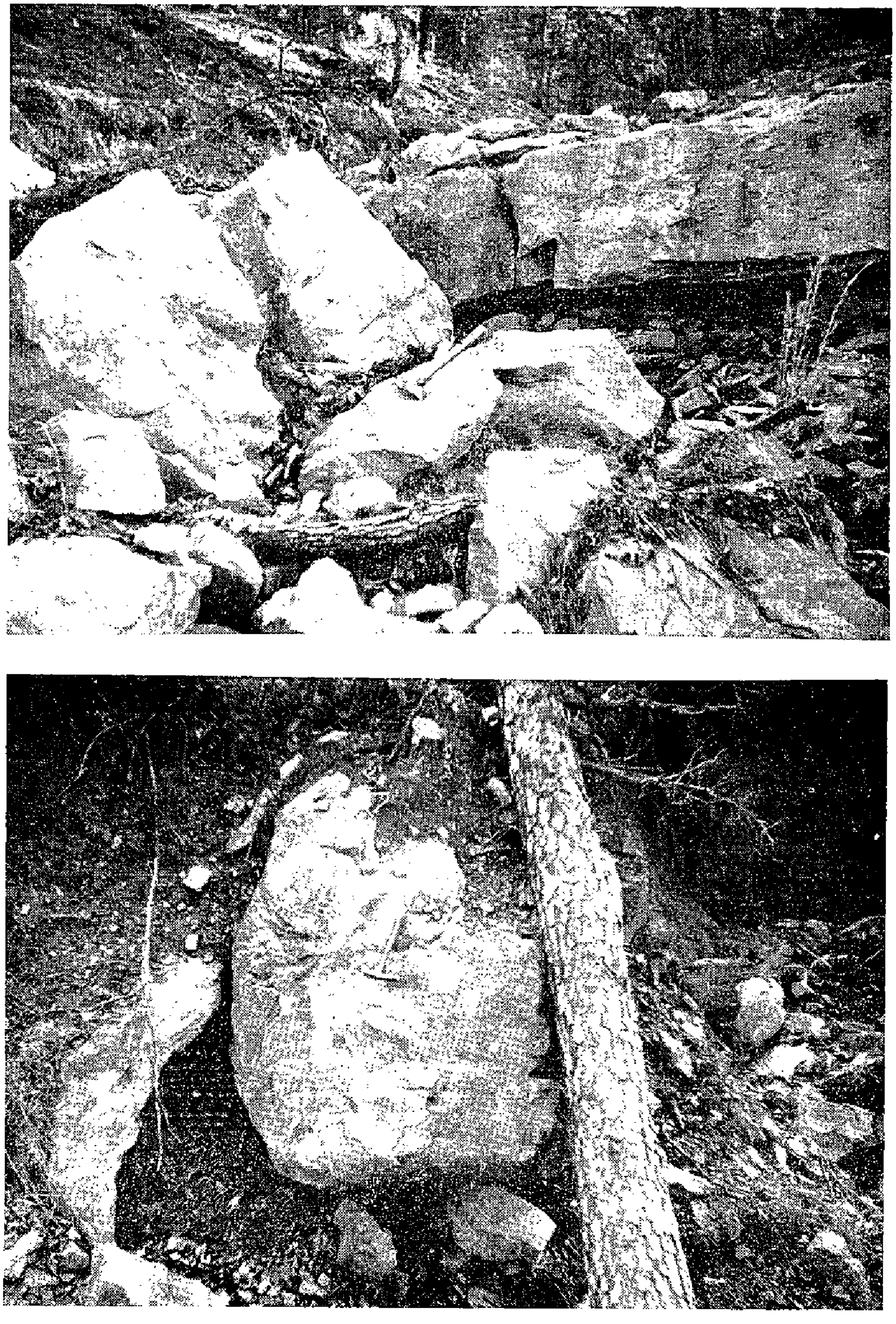

Figure 10. Balled Sandstone Beds

*Above:* Sandstone beds in the upper part of the Johns Valley formation in the NW¼ sec. 11, T. 1 S., R. 23 E. The hammer rests on a discoidal balled sandstone boulder. The thick sandstone bed dipping away from the observer is the parent bed for the large balled sandstone boulder shown in the picture below.

*Below:* Large balled sandstone mass in the upper part of the Johns Valley formation a few yards north of the site pictured above. Massive Johns Valley shale is in the right background with small sandstone boulders in the creek in the right foreground.

formed by penecontemporaneous slumping resulting from deposition on an appreciable slope. The boulders are not more abundant nor better developed in areas of structural complexity; therefore, they are not the result of tectonic activity.

Good outcrops of the sandstone boulders in the upper part of the Johns Valley formation occur along Indian Service Road in NE¼ NW¼ sec. 11, T. 1 S., R. 23 E. A direct relation between size of boulder and thickness of parent bed is well illustrated there. Other outcrops with boulders occur farther east near the SE cor. NE¼ SW¼ sec. 12, T. 1 S., R. 23 E.

The Johns Valley shale with abundant sandstone boulders is exposed in ditches along the road in the E½ SE¼ SW¼ sec. 25, T. 1 S., R. 21 E. Other exposures along creeks in the Harris Creek syncline are near the NW cor. NE¼ SE¼ sec. 35, T. 1 S., R. 21 E.; NE cor. NW¼ SW¼ sec. 17, T. 2 S., R. 21 E.; and SE¼ NE¼ sec. 36, T. 1 S., R. 20 E.

*Honess' "Morrow fauna".*—Honess (1924) identified more than 50 species of depauperate invertebrate fossils from a ferruginous sandstone in the Boktukola syncline in sec. 6, T. 1 S., R. 23 E. (fig. 7). The fauna occurs in the upper part of the Johns Valley formation in a belt of friable sandstone which forms knolls in the soft shale of the Johns Valley formation. Honess listed other fossil localities outside of section 6 and indicated the line of outcrop of the fauna in the Boktukola syncline on an accompanying map. He considered the fauna to be of Morrowan age and equivalent to that of the Wapanucka limestone. The fauna is important because it contains the best-preserved fossils in the 23,000 feet of Carboniferous rocks in the southern Ouachita Mountains.

The fossiliferous sandstone from which Honess collected his Morrow fauna is lenticular and can not be traced outside section 6. Other fossil localities listed by Honess or indicated on his map (1924) range stratigraphically from the Markham Mill formation to the lower part of the Atoka formation. A sandstone mold fauna is present in the upper part of the Johns Valley formation 100 paces south of the NW cor. sec. 11, T. 1 S., R. 23 E.; the sandstone is stratigraphically higher than that of section 6. This sandstone is also lenticular and it is absent in outcrops along Indian Service Road a short distance to the east.

Fossiliferous sandstones in the zone of Honess' fauna form a knoll on the Flashman Tower Trail near the NE cor. NE¼ NW¼ sec. 22, T. 1 S., R. 22 E.

Exposures of fossiliferous sandstone in the Johns Valley formation have not been found in the Harris Creek syncline east of Little River but this does not preclude their presence. West of Little River in the outcrop belt which extends from the Boktukola syncline to the Cretaceous overlap, Johnson (1954) mapped two fossiliferous sandstones in the Johns Valley-lower Atoka sequence. The lower fauna is about 950 feet above the Wesley shale and is probably equivalent to Honess' "Morrow fauna." The upper fauna is about 1,700 feet above the Wesley shale and it is in the lower part of the Atoka formation.

The range of stratigraphic position of the fossiliferous sandstones and the discontinuity of outcrops, suggest that the sandstones are lenses in a thick zone of Morrowan age in the Johns Valley formation and the lower part of the Atoka formation. Honess' type "Morrow fauna" occurs in one of these lenses which has an unusually well-preserved fauna.

The sandstones which contain fossil molds are generally limonitic, and medium- to coarse-grained; they contain quartzite pebbles and fragments of shale and siltstone. Abundant voids represent depauperate fossils and fossil fragments that have been dissolved. Small crinoid columnals are common. The association of coarse clastic material and macerated fossils suggests that the fauna is transported and that it may be a thanatocoenose. The fact that these sandstones are lenses of coarse material in a thick shale sequence supports the view that they are exotic. Perhaps they were washed from a shelf area where the Wapanucka limestone was being deposited.

*Age of the Johns Valley formation.*—The formation is correlated with the Johns Valley formation of the western Ouachitas and is considered to be of similar age. The lower part is probably of Mississippian age although the Mississippian Caney fauna has not been found in the area of investigation. Careful examination of good exposures of the lower beds of the Johns Valley formation might yield the Caney fauna. The upper half of the formation is of Pennsylvanian (Morrowan) age because it contains Honess' "Morrow fauna."

## PENNSYLVANIAN SYSTEM

### Atoka Formation

*History of nomenclature.*—The formation was named by Taff and Adams (1900, p. 273) for Atoka, Oklahoma, which is situated on the outcrop.

*Distribution.*—The Atoka formation forms the interior of the Boktukola and Harris Creek synclines. On the gently dipping north flank of the Boktukola syncline the Atoka forms low hogbacks surrounding a central depression which marks the axis of the syncline. The south flank of the syncline is characterized by steep ridges formed by the vertically dipping Atoka beds.

*Character and thickness.*—The formation consists mainly of flaky silty gray shale. Most sandstones are gray fine-grained thin-bedded subgraywacke or quartzose sandstone. Convolute bedding and sole markings are common (fig. 11). Some sandstone beds are ten feet thick but the total amount of sandstone is probably less than 25 percent. Thin siliceous shales occur in the lower part of the formation. Some fossiliferous sandstone occurs near the base. The entire thickness of the formation is not exposed in the area of investigation; 6,800 feet are exposed in the Boktukola syncline and about 5,800 feet are exposed in the Harris Creek syncline along Little River.

The basal Atoka is composed of gray shale with thin beds of light-gray sandstone and thin layers of spicular chert (Stratigraphic Section IV; fig. 12). The first ridge-forming sandstones at the top of this shale zone are 300 to 500 feet above the base. Thin discontinuous siliceous shales are common in the lower part of the Atoka formation; they have been found at 200, 400, 450, 500, 600, 840, 960, 1,800 and 2,200 feet above the base. Most of the siliceous shales are gray to black and are less than six inches thick; many are laminated with light bands of silt. Cherty siliceous shales contain abundant spicular material and are streaky due to interlaminations of dark organic-rich layers and light spicular layers.

The lower ridge-forming sandstones of the Atoka locally contain molds of invertebrate fossils in the SE¼ NW¼ sec. 22, T. 1 S., R. 22 E. The fossils occur about 300 feet above the base of the formation. Johnson (1954) mapped a fossil-bearing sandstone in a similar stratigraphic position in the Medicine Springs area. He mapped strata above this sandstone as Atoka; thus, his Atoka boundary is

about 500 feet above the boundary as mapped by the writer in the Boktukola syncline area.

*Correlation and age.*—The Atoka formation of the Boktukola syncline is considered to be partly equivalent to the Atoka formation of the frontal Ouachitas. In the frontal Ouachitas the Atoka formation overlies the Wapanucka limestone and in the Boktukola syncline the Atoka formation overlies Honess' "Morrow fauna," which is considered a partial equivalent of the Wapanucka. No age determinations have been made from fossils in the Atoka formation of the Boktukola syncline but it is inferred that the basal part is Morrowan because it contains a sandstone mold fauna similar to Honess' "Morrow fauna." It is inferred that the bulk of the formation is of Atokan age, that is, similar in age to the type Atoka formation of the frontal Ouachitas. However, Laudon (1958, p. 21) has concluded that the lower part of the Atoka formation of the frontal Ouachitas is a time equivalent of the upper part of the Morrowan rocks of the Ozark uplift.

# STRUCTURE

## REGIONAL

The Ouachita Mountains are an east-west belt of folded Paleozoic rocks extending from Little Rock, Arkansas, west to Atoka, Oklahoma, a distance of 220 miles. The Ouachita Mountain outcrops are only a portion of an extensive belt of distinctive structure and stratigraphy which is called collectively the Ouachita facies. Most of the belt lies buried beneath the sediments of the Gulf Coastal Plain to the south and east.

The complex folds and thrust faults of the northern border or "frontal" area of the Ouachitas are bounded on the north and west by the gentle folds of the Arkansas Valley structural province. The central Ouachitas, where the present study area is located, are characterized by synclinal mountain ranges composed of rocks of the Jackfork and Atoka sequence with intervening anticlinal valleys of Stanley shale (plate I; fig. 13). Typically, the northern flanks of synclinal mountains are moderately inclined and the southern flanks are vertical to overturned. Anticlines are narrow and are faulted on the north flank.

In the southern part of the Ouachita Mountains of Oklahoma the Choctaw and Cross Mountain anticlinoria form the core of the Ouachita uplift and expose rocks of Cambrian(?) to Devonian age.

## MAJOR STRUCTURES

### Boktukola Syncline

The Boktukola syncline is the largest fold in the area of investigation and the Jackfork-Atoka sequence on its flanks underlies the major portion of the area. The axis of the syncline is doubly plunging and extends east from sec. 26, T. 1 S., R. 22 E. to the central part of T. 1 S., R. 25 E. On the north flank of the syncline, the rocks dip 10 to 30 degrees and form arcuate belts around the axis. The east end of the syncline plunges about 15 degrees to the west and forms broad arcuate outcrop belts. The south flank of the syncline is vertical to overturned west of the east fork of Glover Creek; it is sharply folded and is cut by the Boktukola fault. East of the east fork of Glover

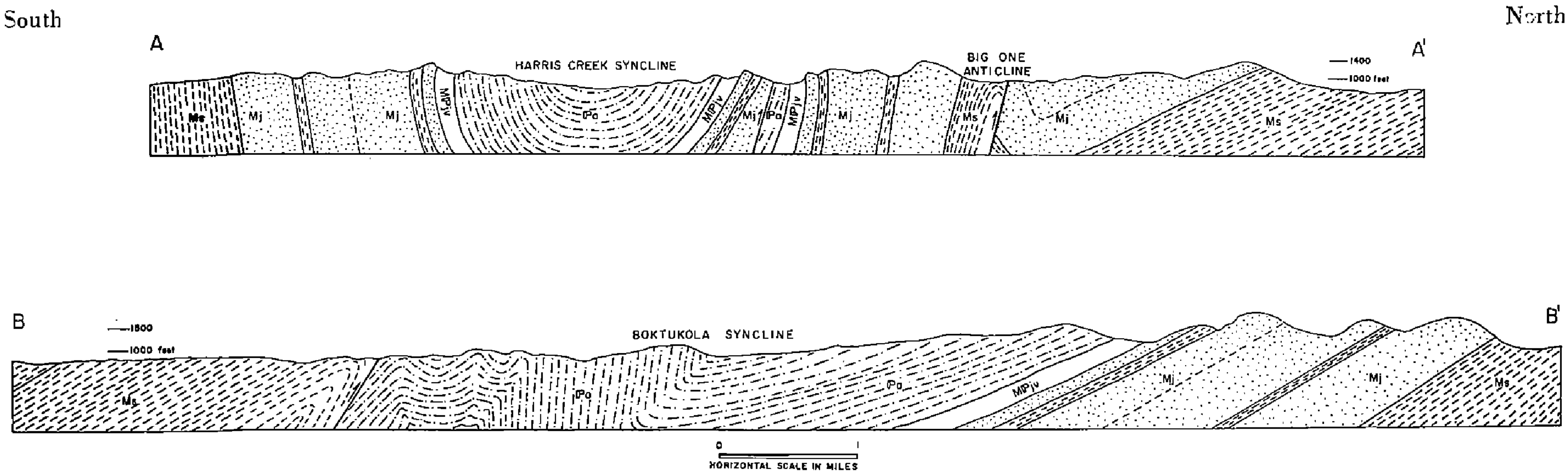

FIGURE 13. South-north structural sections of the Harris Creek and Boktukola synclines. Stanley group (Ms), Jackfork group (Mj), Johns Valley formation (Mℙjv), Atoka formation (ℙa).

Creek the south flank of the syncline dips 20 to 45 degrees to the north and is not overturned.

### Big One Anticline

The Big One anticline was named by Willis (1954, p. 28) for Big One Creek in T. 2 S., R. 19 E. The anticline extends from the Cretaceous overlap near Antlers, Oklahoma, northeast up the One Creek valley, across Little River and can be traced as far as sec. 14, T. 1 S., R. 22 E., where it plunges into the Boktukola syncline.

East of Little River the anticline exposes shales of the Stanley group and forms the valley of Watson Creek. The south limb of the anticline has a uniform dip of 65 degrees but on the north limb the dips range from 45 to 80 degrees and the structure is cut by the Watson Creek fault.

### Harris Creek Syncline

The Harris Creek syncline was named by Johnson (1954, p. 36) for a creek which flows east into Little River in sec. 14, T. 2 S., R. 20 E. Little River cuts across the axis of the syncline.

East of Little River the Harris Creek syncline is a faulted fan fold. The syncline forms a basin carved in the shales of the Atoka formation. The syncline plunges to the east and the axis is cut by the Boktukola fault in sec. 36, T. 1 S., R. 21 E.

The Harris Creek syncline is shown as an anticline of Stanley shale on the Geologic Map of Oklahoma (Miser, 1954). Perhaps the overturned limbs confused earlier workers.

West of Little River the south flank of the syncline is faulted and thrust to the north (Johnson, 1954, p. 36).

### Pickens Anticline

The Pickens anticline was named by Johnson (1954, p. 41) for the settlement of Pickens. Soft shales of the Stanley group crop out along the axis of the structure where erosion has formed an anticlinal valley. The anticline plunges to the southwest; it can be traced from sec. 36, T. 2 S., R. 21 E., northeast to sec. 5, T. 2 S., R. 22 E., where it is intensely folded near the Boktukola fault. A narrow syncline extends along the crest of the anticline and dies out near its plunging southwest termination.

## Bethel Syncline

Only a portion of the north limb of the Bethel syncline lies within the area covered by this report. In the northern half of T. 2 S., Rs. 22 and 23 E., rocks of the Stanley group and lower part of the Jackfork group form an arcuate belt. The beds dip 20 to 45 degrees to the south.

## Nunihchito Anticline

The Nunihchito anticline extends from sec. 9, T. 2 S., R. 24 E., where its west-plunging end is cut by the Boktukola fault, eastward into the northern part of T. 2 S., R. 25 E.

The Wildhorse Mountain formation is folded into a symmetrical anticline in the western part of the structure. However, the eastern part of the anticline, in the Stanley shales, is similar to the Pickens anticline in that it contains a syncline along the crest of the broader anticlinal structure. Here, as in the Pickens anticline, the incompetent Stanley shales show more intense deformation than the sandstones of the Jackfork group.

## Buffalo Creek Syncline (new)

Buffalo Creek syncline extends from sec. 15, T. 2 S., R. 25 E., where it intersects the Boktukola fault, eastward into sec. 17, T. 2 S., R. 26 E. The name was taken from Buffalo Creek which flows along the axis in secs. 17 and 18, T. 2 S., R. 26 E. The syncline is asymmetrical, with a steeper south flank; the axis plunges about 15 degrees to the west.

## Boktukola Fault

While mapping in the southern Ouachita Mountains of Oklahoma, Honess (1923, p. 243) recognized and traced an important east-west fault in northern McCurtain County. He named this fault the Boktukola fault after the creek of that name which flows into Mountain Fork River near the fault line in the SW¼ sec. 9, T. 2 S., R. 25 E. Here sandstones of the lower part of the Wildhorse Mountain formation dip south into contorted shales of the Stanley group and are in straight-line contact. Later Honess (1924) extended the trace of the Boktukola fault from near the Arkansas state line westward across McCurtain County, a distance of 32 miles. With the aid of unpublished quadrangle maps prepared by Taff, Miser extended the Boktukola fault of Honess farther west by connecting it with a large fault in the Alikchi quadrangle. On the recent Geologic Map of Oklahoma (Miser, 1954) the Boktukola fault appears as one of the major thrust faults and is traced from the Arkansas state line westward to the Cretaceous overlap, a distance of 65 miles. Johnson (1954, p. 37) has shown that the connection of Honess' Boktukola fault and the large fault mapped by Taff is incorrect. Johnson renamed Taff's fault the Cloudy fault. He has shown that the Cloudy fault is an important and separate structure.

The entire length of the Boktukola fault is contained in the area of this investigation. The fault extends from the northern part of T. 2 S., R. 25 E., where it dies out in the Buffalo Creek syncline, westward to the southern part of T. 1 S., R. 21 E., a distance of 30 miles. The fault is considered to be a thrust fault which dips steeply to the south.

Along the eastern part of the fault trace, in Rs. 24 and 25, the Wildhorse Mountain formation dips gently southward into the fault. South of the fault the Stanley shales are vertical and dip to the north, away from the Cross Mountains anticlinorium. Other major thrust faults may occur south of the Boktukola fault on the vertical north limb of the Cross Mountain anticlinorium. Honess (1923) has mapped a fault in this area on the basis of a line of vein quartz in secs. 15 to 13, T. 2 S. R. 24 E., and sec. 18, T. 2 S., R. 25 E.

South of the Boktukola fault, in the NW¼ T. 2 S., R. 24 E., a fault slice has been inferred by the presence of a discontinuous outcrop belt of Chickasaw Creek shale and overlying Wildhorse Mountain formation.

The maximum stratigraphic displacement of the Boktukola fault is in the central part of the trace in Rs. 23 and 22 E. The lower part of the Tenmile Creek formation has been thrust in contact with the lower beds of the Atoka formation and about 14,000 feet of strata are faulted out.

The Boktukola fault branches in sec. 32, T. 1 S., R. 22 E., and dies out farther west on the flanks of the Harris Creek syncline.

The straight trace of the Boktukola fault and the high angle of dip of beds near the fault suggest that the fault plane dips steeply. The fault trace is 30 miles long and the maximum displacement along the trace is probably less than 6 miles. The fault is not a reasonable vehicle for the low-angle overthrusting proposed by some workers.

### Watson Creek Fault (new)

The Watson Creek fault originates along the axis of the Big One anticline in sec. 13, T. 1 S., R. 21 E. It extends westward, parallel to Watson Creek, across Little River and may connect with the Big One fault of Willis (1954, p. 28) west of Little River in sec. 36, T. 1 S., R. 19 E.

In the eastern half of R. 23 E., Stanley shales of the north limb of the Big One anticline are thrust northward over the lower part of the Wildhorse Mountain formation. Stratigraphic displacement is small but the Chickasaw Creek shale is absent.

Near Little River the fault trace is farther north on the flank of the Big One anticline and the Chickasaw Creek shale is exposed south of the fault. Here, the north flank of the Big One anticline is thrust over a narrow portion of the Findley syncline so that north-dipping Wildhorse Mountain sandstones are in contact with south-dipping shales of the upper part of the Stanley group. East of Little River the displacement along the fault does not exceed 2,000 feet.

## MINOR FOLDS AND FAULTS

In the northern part of T. 1 S., R. 21 E., north of the Watson Creek fault, the western end of the Boktukola syncline has many small east-west trending folds. Many of these are symmetrical chevron folds; opposed limbs, dipping 45 degrees, are less than five feet apart.

Sharp folds are common in the Atoka formation on the steep south flank of the Boktukola syncline.

Minor folds are common in the shales of the Tenmile Creek formation in the eastern part of T. 1 S., R. 25 E.

Dip faults of small displacement occur in N½ sec. 16, T. 1 S., R. 25 E.; N½ sec. 32, T. 1 S., R. 24 E.; S½ sec. 19, T. 1 S., R. 22 E.; S½ sec. 24, T. 1 S., R. 21 E.; and N½ sec. 23, T. 1 S., R. 21 E.

# SEDIMENTARY STRUCTURES

Primary sedimentary structures typical of a flysch sequence are abundant in the Carboniferous rocks of the Ouachitas. Although many of these structures have been reported from other environments, their variety and profusion is considered unique to flysch sedimentation by turbidity currents.

Sole features, such as flute casts, groove casts, and load casts (figs. 14, 15, 16), are found on the bottoms of sandstone and siltstone beds which overlie shales. Flutes and grooves were cut in the shale by turbidity currents and by solid objects moved by the currents. The same current which produced the flutes and grooves is responsible for deposition of the overlying sandstone. Sole markings are linear and are similarly alined throughout thousands of feet of strata.

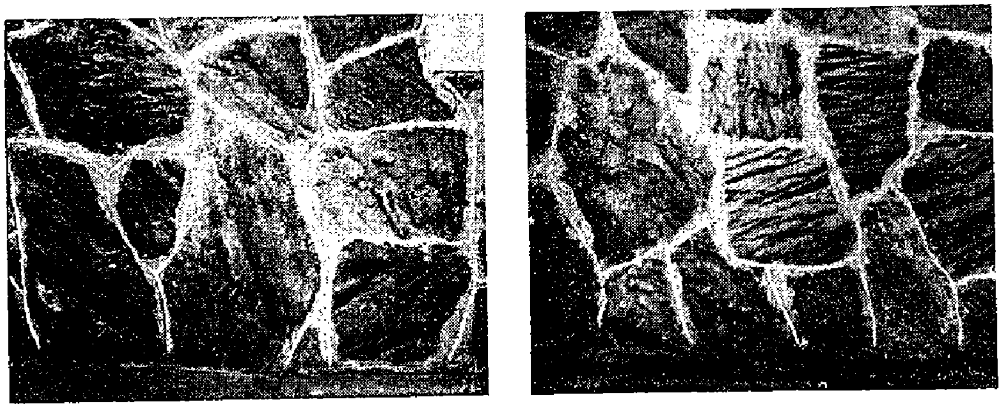

FIGURE 14. Various types of sole markings are displayed on the walls of the bank building in Broken Bow, Oklahoma. Sandstone beds with sole markings are good building stones because they are typically thin-bedded and quartzitic and they are abundant.

Flutes in the mud bottom are cut by vortices of the turbidity current; the flutes are preserved as casts on the bottom of the overlying sandstone (fig. 15).

Groove casts (fig. 16) are formed by filling of long furrows cut by dragging or sliding of solid objects along the mud bottom during current activity. Many grooves show parallel striations within the groove which may be caused by dragging of a rough object such as a fragment of wood. Bounce grooves are about two inches in length and are formed by saltation of pebble-size material.

Load casts (fig. 16) are formed by differential sinking of rapidly deposited sand into the soft mud bottom. The size of load casts is

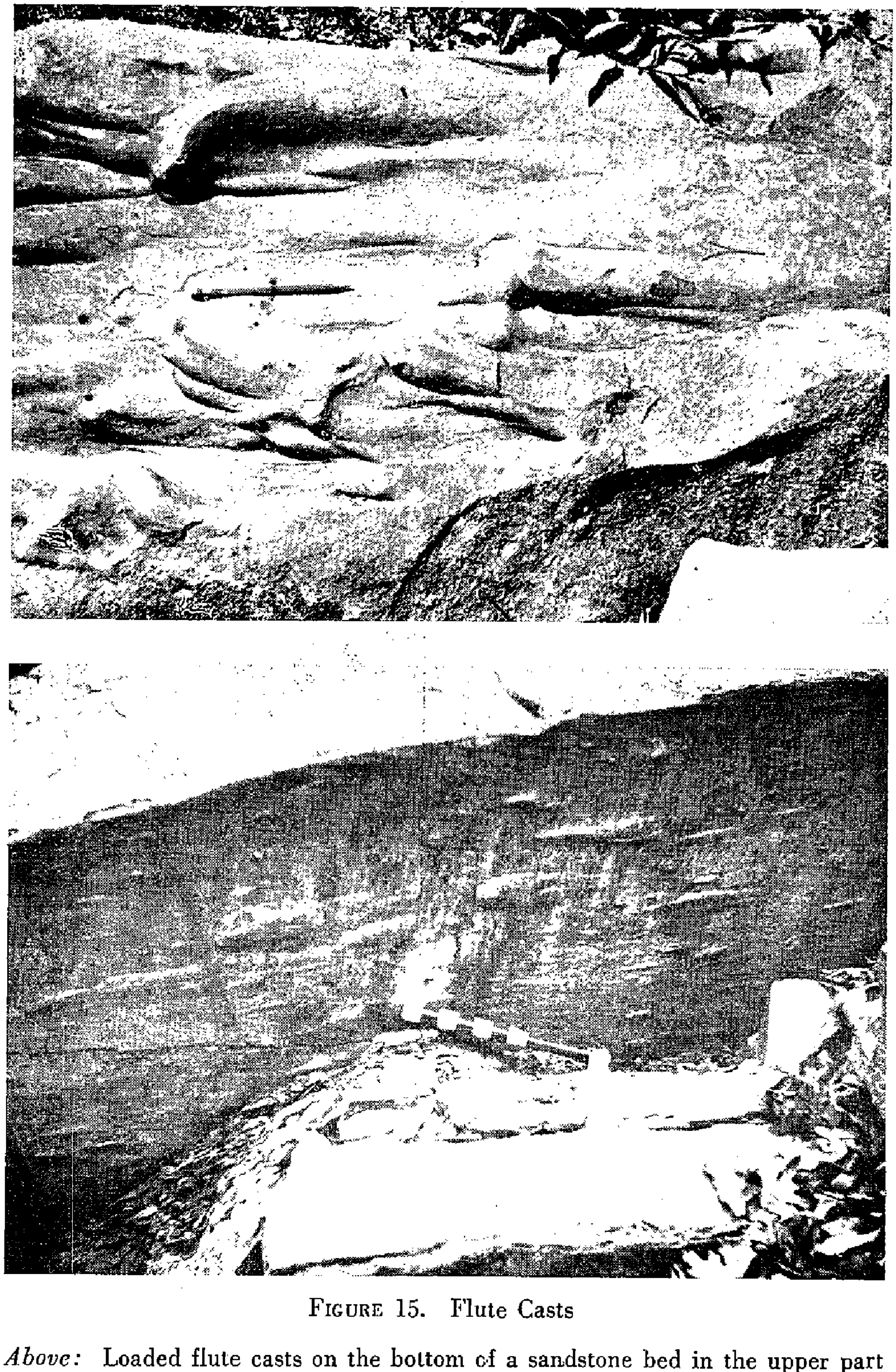

FIGURE 15. Flute Casts

*Above:* Loaded flute casts on the bottom of a sandstone bed in the upper part of the Wildhorse Mountain formation in NW¼ sec. 25, T. 1 S., R. 21 E. Currents which formed the flutes moved from left to right; the flutes in the mud bottom were distorted due to differential loading by the overlying sand. The pencil gives the scale.

*Below:* Flute casts on the sole of a sandstone bed in the upper part of the Wildhorse Mountain formation along Indian Service Road in the NW¼ sec. 31, T. 2 N., R. 22 E. The view is toward the south and the current moved from east to west. The blunt ends of the flutes point up-current.

FIGURE 16. Sole Markings in the Wildhorse Mountain Formation

*Above:* Pit casts, groove casts, and "worm trails" on the underside of a sandstone bed in the lower part of the Wildhorse Mountain formation in the SW¼ sec. 9, T. 2 S., R. 25 E.

*Below:* Looking up at large load casts on the bottom of a thick sandstone bed in the lower part of the Wildhorse Mountain formation in road cuts at "The Narrows" in the SW¼ sec. 9, T. 2 S., R. 25 E. The hammer in the lower part of the picture gives the scale.

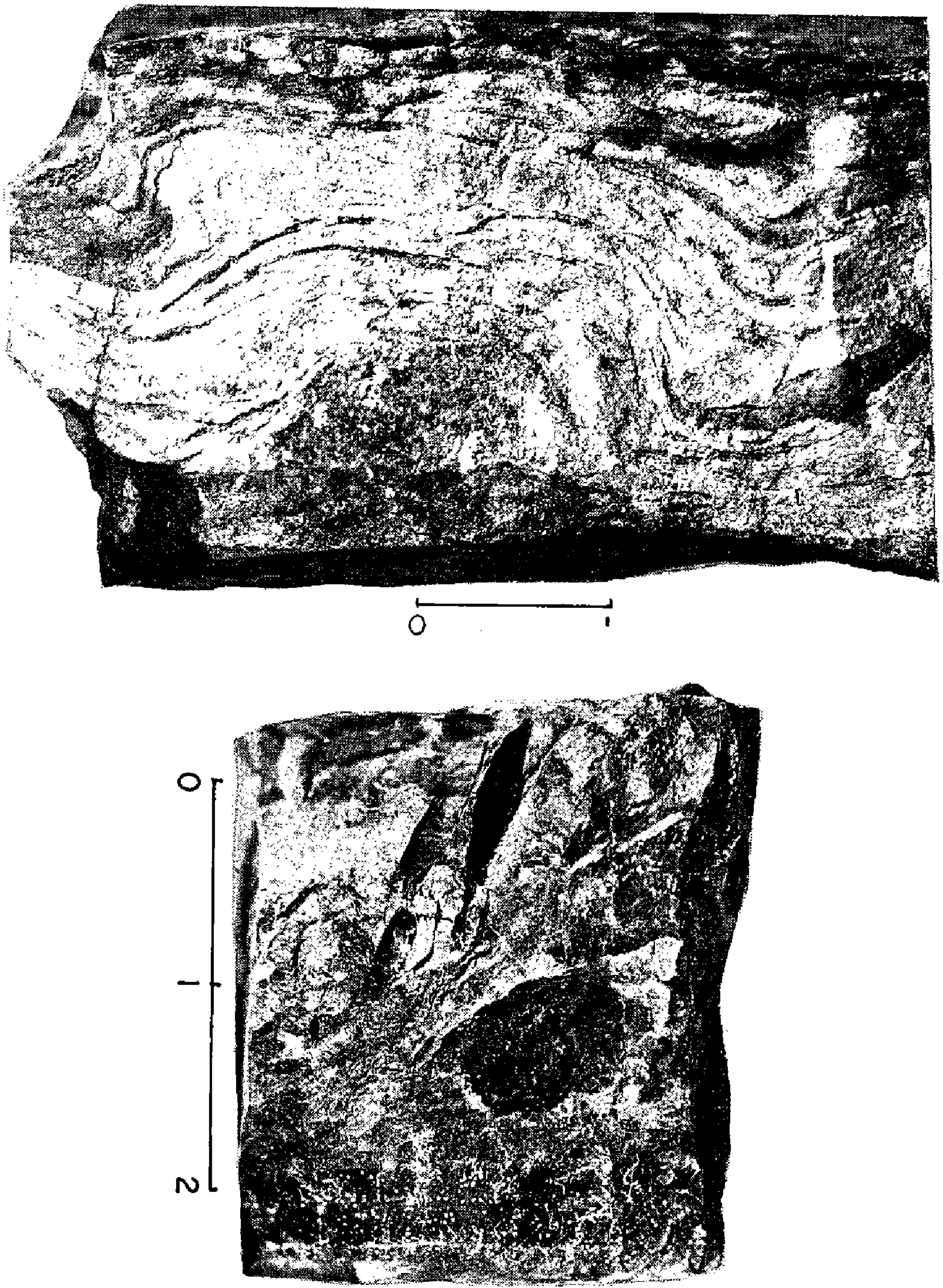

FIGURE 17. Convolute Bedding and Chickasaw Creek Chert.

*Above:* Convolute bedding in a thin bed of Atoka sandstone. The view is normal to bedding. Scale is one inch.

*Below:* A chert bed of the Chickasaw Creek formation showing the characteristic position, near the bottom, of the dark layer containing white spots. Scale is in inches.

proportional to the thickness of the sandstone bed. Large flute casts are loaded to varying degrees, producing gradations from simple flute casts to distorted load casts (fig. 15).

Non-directional sole features include pit casts and various burrows, trails, and plant impressions. Pit casts (fig. 16) are probably the result of filling of caved-in tops of siphon holes and other vertical burrows.

The upper surfaces of some thin-bedded sandstones are marked with delicate "worm trails" and gastropod trails. The gastropod trails (fig. 6) are similar to those described from the alpine flysch by Götzinger and Becker (1934, p. 80).

Convolute bedding (figs. 5, 17) is common within thin-bedded sandstones of the Chickasaw Creek formation, Jackfork group, and Atoka formation. Convolute bedding is formed during deposition of the sand by hydraulic pressures acting upon the rapidly deposited and water-saturated "quick sand" (Kuenen, 1953).

Ripple marks and coarse cross-bedding are characteristically rare in a flysch facies. Some ripple marks and small-scale cross-bedding are present in the Jackfork group and in the Atoka formation. All large ripple marks observed by the writer showed ripple crests trending north-south in conformity with the dominant east-west paleocurrents. Balled sandstone masses in the Johns Valley formation (fig. 10) are structures formed by penecontemporaneous slumping of thin beds of sandstone within a thick shale sequence. Similar slumping phenomena have been reported in the Silurian flysch sediments of Wales (Jones, 1937; Wood and Smith, 1959; Earp, 1938). "Exotic-boulder" shales of the Johns Valley formation of other areas are similar to the alpine "wildflysch."

# GEOLOGIC HISTORY

## Deposition of the Carboniferous Rocks

The Carboniferous rocks of the Boktukola syncline were deposited in a rapidly subsiding trough, the Ouachita geosyncline. Deposition of the thick flysch sequence began in Late Mississippian (Meramecian) time with the shales and graywackes of the Stanley group and continued through Early Pennsylvanian (Atokan) time although the Atokan rocks show some aspects of a shelf facies due to filling of the geosyncline. The flysch clastics which filled the geosyncline are 23,000 feet thick and are composed of rhythmic alternations of dark shale and fine-grained sandstones with some black siliceous shales, radiolarian cherts, and spicular cherts. The sediments are characteristic of the typical alpine flysch. Flysch characteristics include rhythmic alternation of shales and sandstones; paucity of fossils, ripple marks, and coarse cross-bedding; abundance of sole features on sandstones, including flute casts and groove casts; presence of convolute bedding; and presence of shales with exotic boulders (wildflysch). Graded bedding, common in many flysch sequences, is inconspicuous and generally absent in the Ouachitas. Some sandstones, especially those of the Stanley group, have a sharp lower contact and a transitional upper contact with the enclosing shale. The difference in the lower and upper contact is due to increase in argillaceous content near the upper contact; this is a type of graded bedding (fig. 3). The general absence of graded bedding may be due to deposition of uniform fine-grained sand. Kuenen (1958, p. 330) states that some unquestionable European flysch formations are very poorly graded. Flysch sedimentation is probably normal pelitic or pelagic deposition interrupted by periodic deposition of sand brought in by turbidity currents (Sujkowski, 1957). This hypothesis, which is in accord with observations in the Ouachitas, implies that the sediments were deposited in relatively deep water, below wave base.

It has been suggested that the Stanley and Jackfork groups are flysch facies and the Atoka formation is a molasse facies (van der Gracht, 1931, p. 1005). In marginal cratonic areas the Atoka formation may be a molasse facies but in the central Ouachitas it is a flysch facies.

During Meramecian and Chesterian time the thick Stanley-Jackfork flysch was deposited in the Ouachita geosyncline. Radiolarian cherts of the Stanley group probably represent periods of quiescence during which little external sediment was being transported along the trough. The wide distribution of these cherts indicates that uniform conditions prevailed over large areas in the geosyncline. It has been suggested that the cherts were formed by halmyrolysis of volcanic ash (Goldstein and Hendricks, 1953, p. 440) but there is a lack of temporal and spatial association with volcanic ash.

The cherts of the Jackfork group and Atoka formation differ from those of the Stanley group in that they contain abundant small spicules. In many of these cherts the bulk of the rock is spicular material. There may be a fundamental difference in the origins of radiolarian and spicular cherts. Perhaps the spicular cherts are formed of fine spicular debris washed from the slope area in the vicinity of the frontal Ouachitas where spiculites, such as the Chickachoc chert, were being deposited.

The distribution of siliceous shales suggests that the formation of these deposits is effected by proximity to the slope or marginal shelf environment. The number of siliceous shales and thickness of individual siliceous shales decreases from the frontal Ouachitas to the central Ouachitas. Several siliceous shales and cherts have been found in the Tenmile Creek formation around the Potato Hills; only one, the Battiest chert, occurs in the Boktukola syncline. The Moyers chert is thin and discontinuous in the Boktukola syncline. The Chickasaw Creek siliceous shale is thinner in the Boktukola syncline than it is in the Lynn Mountain syncline to the north. Most of the siliceous shales of the Jackfork group which Harlton used to subdivide the group in the western Ouachitas are absent in the southern Ouachitas.

In late Chesterian and early Morrowan time the massive shales of the Johns Valley formation were deposited in the rapidly sinking trough. Thin beds of exotic sandstone were deposited by turbidity currents during deposition of the shale. The thin sandstone beds within the massive clay shale were unstable on the slope of the trough. Penecontemporaneous intraformational slumping resulted in the formation of balled sandstone masses. Some of the sandstone masses show flute casts of the original sandstone bed.

Sandstone-mold faunas of Morrowan age in the upper part of the Johns Valley and lower part of the Atoka formations are depauperate and fragmental. They probably represent exotic debris brought in by currents from shelf areas where life was abundant. Fossil fragments are generally associated with coarse sandstone and rock fragments. This seems to be a natural result of the effect of competence of currents on particle size and shape. The Morrowan-Atokan boundary probably lies in the lower part of the 6,800 feet of shales and sands of the Atoka formation. A shallowing of the geosyncline during Atokan time is indicated by the abundance of subgraywacke and quartzose sandstone and by the presence of ripple marks and small-scale cross-bedding. The axis of maximum deposition during Atokan time was probably northeast of the Boktukola syncline in the frontal Ouachitas of Arkansas where 19,000 feet have been measured (Reinemund and Danilchik, 1957).

## Source Area and Paleocurrents

For some time it has been commonly accepted that the source area for the Carboniferous rocks of the Ouachitas was "Llanoria," the hypothetical landmass which lay to the south of the present site of the Ouachita Mountains. Honess (1924, p. 22) believed Llanoria lay in southern McCurtain County, Oklahoma, a short distance south of the present Cretaceous overlap. He noted thickening of the Stanley shale to the south and passing of Atoka shales into brown sandstones in a southerly direction. Miser (1934, p. 980) stated that most of the Carboniferous rocks of the Ouachitas had a southern source and that the ancient landmass (Llanoria) which supplied the sediments lies concealed underneath the coastal plain sediments in Louisiana and East Texas. Miser observed northwestward thinning of sandstone beds in the Stanley and Jackfork groups and northward disappearance of grit in the Jackfork group. He also noted that the presence of thick beds of tuff in the southern Ouachitas and their absence farther north indicated a southern source area.

Sole markings are abundant in the Carboniferous rocks of the Ouachita Mountains. Flute casts and groove casts are important indicators of the directions of paleocurrents. Knowledge of the directions of paleocurrents allows a better understanding of paleogeography, including the location of the source area. Directional current structures are similarly alined throughout the upper Stanley, Jackfork, and Atoka rocks. This must have sedimentary significance. Studies of the sole markings in the Boktukola syncline and limited observations by the writer in other parts of the Ouachitas show that most currents during the Late Mississippian and Early Pennsylvanian moved in a westerly direction, parallel to the axis of the geosyncline. Ninety percent of the 35 directional current structures measured by the writer indicate a direction within 35 degrees of west (fig. 18; Appendix B). This limited study indicates that sediment was transported from east to west and it is inferred that the source area lay to the east.

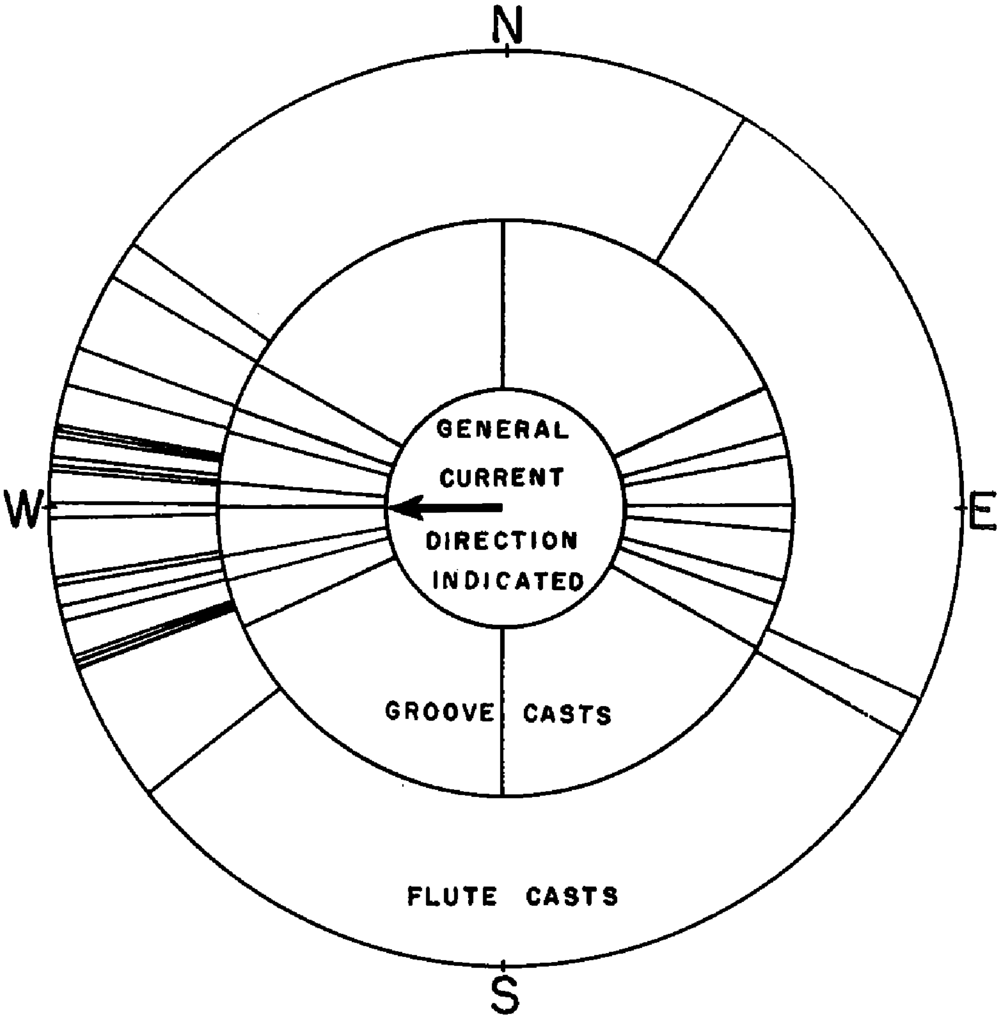

FIGURE 18. Current-rose diagram of the Carboniferous rocks of the Boktukola syncline and adjacent areas as indicated by sole features of sandstone beds. See Appendix B for complete data.

Other recent workers in the Ouachitas have reported evidence of westward moving currents. In a report on the Waldron quadrangle in Arkansas, fifty miles northeast of the Boktukola syncline, Reinemund and Danilchik (1957) state that sediments of the Atoka formation were mostly in transport southwestward. This conclusion was based on the orientation of flow markings, channels, cross-lamination, convolute bedding, intraformational breccias, and ripple marks. Scull, Glover, and Planalp (1959, p. 172) state that paleocurrent indicators and sand distribution in the Atoka formation of the frontal Ouachitas and southern part of the Arkansas Valley show that most of the sediments were derived from the east. Preliminary observations by Cline (Cline and Shelburne, 1959, p. 206) in the Lynn Mountain syncline indicate westward-moving currents in the Jackfork and Atoka rocks.

Limited observations of directional current structures by the writer extend from T. 2 S., R. 16 E., in the Lynn Mountain syncline eastward to State Highway 103, north to Hairpin Curve on State Highway 2 in T. 3 N., R. 19 E., and as far south as the Bethel syncline in T. 2 S., R. 23 E. Most flute and groove casts from the Moyers formation through the Atoka formation indicate currents coming from the east. Sole markings are not numerous enough in the Tenmile Creek formation to allow determination of current direction.

Published data on the directional current features are meager and scattered; no regional studies have been made. However, it is this writer's belief that the concordance of observations in parts of Oklahoma and Arkansas represent a regional paleocurrent direction in the Ouachita geosyncline during Late Mississippian and Early Pennsylvanian time.

Currents from the east, parallel to the trough, were at first surprising because one might expect the dominant source areas to be on the steep sides of the trough; however, longitudinal filling of flysch troughs is common. Recent directional current studies of flysch troughs in Europe reveal longitudinal filling (Kopstein, 1954; Kuenen, 1957, 1958; Dzulynski, Ksiazkiewicz, and Kuenen, 1959; ten Haaf, in press; Kuenen and Sanders, 1956; Wood and Smith, 1959). A large master river is the major sediment source of some modern elongate basins such as the Gulf of California and the Adriatic Sea; sediment transport is longitudinal. Kuenen (1958, p. 359) suggests that flysch troughs derived their great quantities of relatively fine-grain rocks from distant source areas. The classic concept of an adjacent rising cordillera is incongruous; a sharp cordillera shedding a great quantity of clastics should yield some coarse clastics. The sediments of the Ouachitas were probably derived from a distant source area to the east, but perhaps the sediments were brought by large rivers from the cratonic area to the northeast and then were distributed westward along the geosyncline.

Some of the longitudinal currents in the Ouachitas may be the result of turbidity currents which began flowing in north-south trends down the flanks of the trough but turned to follow a westward plunge down the axis of the trough.

The concept of an eastern source area is supported by the regional eastward thickening of the Jackfork group in the central Ouachitas. In the Medicine Springs area, in T. 3 S., R. 18 E., the Jackfork group is about 5,400 feet thick (Johnson, 1954); eastward it is 5,400 feet thick on the south limb of the Harris Creek syncline in T. 2 S., R. 21 E. Twelve miles northeastward the group is 6,000 feet thick on the north flank of the Boktukola syncline in Tps. 1 S., and 1 N., R. 23 E. Farther east on the shallow east flank of the Boktukola syncline the Jackfork group appears to be 6,500 feet thick. Sections of the Jackfork group measured by Cline and Moretti (1956) show eastward thickening in the Lynn Mountain syncline. They found the Jackfork group to be 6,000 feet thick in T. 2 N., R. 22 E. Twenty-two miles to the east in exposures along State Highway 103 they found the group to be 6,600 feet thick. Thus, the Jackfork group has gained 1,200 feet in thickness between the Harris Creek syncline and the eastern part of the Lynn Mountain syncline, a distance of thirty miles.

## Deformation of the Carboniferous Rocks

Rocks of the Boktukola syncline were folded and thrust faulted by Late Paleozoic orogeny. The only information revealed in the Boktukola syncline concerning the time of deformation of the Ouachitas is that beds as young as Atokan are affected by the deformation; younger beds have been removed by erosion. Opinions concerning the time of deformation of the Ouachitas range from mid-Pennsylvanian to Permian time; most evidence is meager and indirect. In the Marathon uplift of West Texas, deformation of the Ouachita system has been dated as Late Pennsylvanian (King, 1938). As a result of studies of joints and faults in central Oklahoma, Melton (1930, p. 71) suggested that the Ouachita deformation was of Permian age. Tanner (1956, p. 130) believes that the present attitude of unconformities in Seminole County indicates a Permian age for the Ouachita orogeny. Miser (1934, p. 1009), Powers (1928, p. 1031), and Honess (1923, p. 259) believe that the major deformation of the Ouachitas was during Pennsylvanian time.

Deformation of the Carboniferous rocks was probably not so intense as some workers suppose. All flute casts and groove casts on steeply dipping beds have similar trends after reduction of the dip of the beds to the horizontal by simple rotation about the present strike. This indicates that deformation was free from torsion; that is, folding has been simple pivoting about lines along the old sea floor. Surely, directional current structures would show discordance in different fault slices if these slices are overthrust sheets which have glided across considerable distances.

## PHYSIOGRAPHIC HISTORY

Following the Late Paleozoic orogeny, Permian and Early Mesozoic erosion reduced the Ouachitas to a lowland of moderate relief. The Comanchean (Cretaceous) sea transgressed this lowland and further reduced the area to a peneplain. Remnants of this Comanchean peneplain are seen today as the flat tops of the higher elevations in the mountains. Water-worn gravels have been found on the summits. The present southward slope of the Comanchean surface is manifest by a southward decrease in the elevation of the higher ridges.

Widespread seas of Upper Cretaceous time may have covered the Ouachitas but no deposits have been found in the mountains.

Cenozoic epirogeny and erosion have effected removal of most of the gravels of the Comanchean peneplain and have cut deep into the underlying Paleozoic rocks to form the present topography of the mountains.

# SUMMARY

1. The Late Mississippian and Early Pennsylvanian Stanley-Jackfork-Johns Valley-Atoka sequence of the Boktukola syncline area is a thick flysch facies aggregating 23,000 feet. Typical flysch characteristics include rhythmic alternation of shale and sandstone, abundance of sole markings and convolute bedding, presence of bedded dark chert and intraformational slump structures, and paucity of fossils, coarse cross-bedding, and ripple marks.

2. Sole markings on sandstone beds include flute casts, groove casts, load casts, bounce casts, pit casts, and various trails and burrows. Flute and groove casts are sedimentary structures formed by currents and by material moved by currents; they are similarly alined throughout the upper Stanley, Jackfork, and Atoka rocks. These directional current structures indicate paleocurrents moving from east to west, parallel to the axis of the geosyncline. Sediment transport was longitudinal and it is inferred that the source area lay to the east.

3. Seventeen units have been mapped in the Boktukola syncline area and their distribution is shown on the Geologic Map (plate I). The formations of the Stanley and Jackfork groups, the Johns Valley formation, and the Atoka formation have been mapped in the Boktukola syncline area; thus, their persistence from type areas in the western Ouachitas to the central Ouachitas is demonstrated.

4. The formations of the Stanley group are, in ascending order, Tenmile Creek, Moyers, and Chickasaw Creek. The Tenmile Creek formation is more than 7,600 feet thick; the Moyers formation is 1,150 feet thick and the Chickasaw Creek formation is 140 feet thick.

5. The name Battiest chert member is proposed for a persistent zone of chert and siliceous shale near the middle of the Tenmile Creek formation. This member is equivalent to the "middle Tenmile Creek siliceous shale" of the western Ouachitas.

6. The formations of the Jackfork group are, in ascending order, Wildhorse Mountain, Prairie Mountain, Markham Mill, Wesley, and Game Refuge. In the Boktukola syncline the Wildhorse Mountain formation, including the Prairie Hollow member, the Wesley formation, and the Game Refuge formation are dis-

tinctive and can be easily recognized. Most of the siliceous shales which mark the boundaries of the formations in their type areas in the western Ouachitas are absent in the Boktukola syncline; as a result, the Prairie Mountain and Markham Mill formations can not be adequately separated.

7. The Jackfork group increases in thickness in an easterly direction, toward the inferred source area. The thickness of the group ranges from 5,400 feet on the south flank of the Harris Creek syncline to 6,500 feet on the east flank of the Boktukola syncline.

8. The Johns Valley formation is present in the Boktukola syncline; however, neither exotic boulders nor the Caney fauna have been found. Balled sandstone beds formed by penecontemporaneous slumping are characteristic of the formation; they indicate an appreciable slope during or shortly after deposition.

9. A sandstone mold fauna of Morrowan age, Honess' "Morrow fauna," is present in the middle part of the Johns Valley formation. Sandstone beds which contain this fauna are discontinuous. The fauna is depauperate and fragmental and is probably a thanatocoenose.

10. The Atoka formation is 6,800 feet thick in the Boktukola syncline; an unknown thickness had been removed by erosion.

11. The basal part of the Atoka formation is Morrowan. It contains sandstone mold faunas similar to Honess' "Morrow fauna" and spiculitic cherts which may be partially equivalent to the Chickachoc chert.

12. The middle and upper parts of the Atoka formation of the Boktukola syncline are equivalent to the Atoka formation of the frontal Ouachitas.

13. The Harris Creek syncline is a fan fold which exposes the Atoka formation, rather than an anticline of Stanley shale as shown on the Geologic Map of Oklahoma.

14. The Boktukola fault is a steeply dipping thrust fault with maximum stratigraphic throw of 14,000 feet, maximum displacement of about six miles, and a trace of thirty miles; it is not a reasonable vehicle for low-angle overthrusting.

15. Orientation of primary sedimentary features in the Carboniferous rocks indicates that the present dip and strike of beds is the result of simple pivoting about lines along the floor of the depositional trough. The orientation of the sedimentary features has not been disturbed by torsion during the Ouachita orogeny.

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# APPENDIX A

## MEASURED STRATIGRAPHIC SECTIONS

**I. Section measured along United States Indian Service Road south of Honobia, Oklahoma. The top is near the center of sec. 11, T. 1 S., R. 23 E. The base is at a south bend in a creek near the SE cor. NW¼ NW¼ sec. 32, T. 1 N., R. 23 E.**

| | | Feet |
|---|---|---|
| *Atoka formation:* | | |
| 133. | Shale; gray, interbedded with thin siltstone, thin black siliceous shale near the top weathers to one-inch-thick tabular blocks which are streaky gray on fractures normal to bedding | 475 |
| *Johns Valley formation:* | | |
| 132. | Shale; gray, abundant balled sandstone masses of fine-grained dark-gray sandstone; most masses are irregular oblate spheroids with a diameter of two feet, one sandstone mass is six feet in diameter | 300 |
| 131. | Covered; forms valley of Glover Creek | 480 |
| *JACKFORK GROUP* | | |
| *Game Refuge formation:* | | |
| 130. | Covered; probably sandstone and shale as below | 222 |
| 129. | Sandstone; gray, resistant; two-foot beds are separated by thin gray shales; fracture surfaces normal to bedding show saccharoidal pink sides; a two-foot gray shale near the base weathers red to pink and contains a thin fucoidal sandstone | 25 |
| 128. | Shale; gray, with thin gray sandstone beds in the lower portion, poorly exposed | 45 |
| 127. | Shale; gray, with thin beds of gray sandstone in the lower part | 15 |
| 126. | Sandstone; soft, abundant plant fragments and molds of fragments | 3 |
| 125. | Covered; probably soft sandstone and shale; sandstone with plant fragments is common in the float | 35 |
| 124. | Shale; dark-gray, some soft sandstone, a zone of coarse-grained sandstone with some fossil molds is present 15 feet up from the base | 35 |
| 123. | Covered | 10 |
| 122. | Shale; gray, soft | 7 |
| 121. | Sandstone; light-gray, resistant, quartzitic | 7 |
| 120. | Shale; dark-gray to black, fissile, with thin well-bedded siltstones and silty siliceous shale, siltstones weather to one-inch squares. This shale was mapped as Wesley by Johnson west of Little River | 10 |
| 119. | Sandstone; gray, resistant, weathers to rust color | 3 |
| 118. | Shale and sandstone; gray fissile shale, fine-grained gray sandstone | 4 |
| 117. | Sandstone; gray, quartzitic, beds are two feet thick, some thin black shales | 9 |
| 116. | Sandstone; quartzose, common quartz pebbles and fossil fragment molds, thin beds of soft sandstone occur at the base with a massive bed above | 2 |
| 115. | Shale; dark-gray | 2.5 |
| 114. | Sandstone; gray, quartzose, medium-grained, quartz pebbles and fossil fragment molds at the base of sandstone, gray shale at base of unit | 1.5 |
| 113. | Sandstone; gray, quartzitic, resistant one- and two-foot bedding units, intercalated thin black shale | 44 |
| | *Total Game Refuge* | 480 |

| | | |
|---|---|---|
| | *Wesley formation:* | |
| 112. | Shale; black, slightly siliceous, fissile, weathers to rust color | 12 |
| 111. | Shale; siliceous to cherty, blue-black, weathers to 1 x 2 x 3 inch rhombs | 1.5 |
| 110. | Shale; gray, weathers to rust-brown color, common half-inch-thick siltstones become abundant in lower portion | 140 |
| 109. | Shale; poorly exposed, forms red-brown subsoil, may contain some soft yellow sandstone | 70 |
| | *Total Wesley* | 223.5 |
| | *Markham Mill formation:* | |
| 108. | Covered; probably shale and soft sandstone | 120 |
| 107. | Sandstone; friable, massive, weathers to pink and yellow, iron oxide-stained fractures common | 50 |
| 106. | Shale; gray, weathers to reddish-brown | 32 |
| 105. | Covered; contains contorted sandstone; may be a fault of small displacement | 10 |
| 104. | Sandstone; massive, gray, some soft gray sandstone, forms ridge which is cut by road | 55 |
| 103. | Sandstone; gray, quartzitic, with gray shale, sandstone develops irregular bedding planes upon weathering, two-foot-thick massive sandstone bed at bottom and two-foot shale at the top | 8 |
| 102. | Shale; gray, fissile, abundant three-inch-thick beds of fine-grained sandstone which weather into resistant rectangular blocks and squares; "worm trails" and gastropod trails are common on the upper surfaces of the sandstones; small-scale cross bedding is present but not apparent except in thin sections or polished section. | 34 |
| | *Total Markham Mill* | 299 |
| | *Prairie Mountain Formation:* | |
| 101. | Sandstone; light-gray, resistant, quartzitic, sugary texture on fracture surfaces due to deposition of silica, two-foot-thick bedding units, some soft gray sandstone and gray fissile shale | 23 |
| 100. | Shale; sandy, gray, weathering reddish, some soft yellow-weathering sandstone which has limonite-stained joints | 110 |
| 99. | Covered; forms strike valley, probably similar to the unit above | 105 |
| 98. | Shale; poorly exposed, some soft yellow sandstone, forms red subsoil | 50 |
| 97. | Sandstone; gray, resistant, quartzitic, convolute bedding common, two-foot-thick bedding units, intercalated gray shale | 40 |
| 96. | Shale; gray, fissile, common thin beds of fine-grained gray sandstone | 19 |
| 95. | Sandstone; light gray, resistant, two-foot quartzitic beds with sugary textured fracture surfaces normal to bedding, convolute bedding and flute casts common, "worm trails" on top of beds, carbonized plant fragments common | 15 |
| 94. | Shale; gray, abundant three-inch-thick sandstone beds which are quartzitic and fine-grained, some soft shaly sandstone, basal portion poorly exposed | 185 |
| 93. | Sandstone; gray two- to three-foot-thick beds in the lower part and thin-bedded in the upper part | 60 |
| 92. | Shale; gray, thin beds of sandstone common | 55 |
| 91. | Covered; the top of this unit is near the intersection with Boktukola Trail | 100 |
| 90. | Shale; sandy, poorly exposed, weathers to rust-red color | 20 |
| 89. | Covered | 10 |
| 88. | Shale; reddish-brown color developed due to weathering, sandy | 15 |
| 87. | Sandstone; friable, yellow-weathering, some gray resistant beds in the upper part | 26 |
| 86. | Shale; gray, weathers to rust color, sandy | 34 |

| | | |
|---|---|---|
| 85. | Sandstone; friable, gray, some zones of soft yellow sandstone | 45 |
| 84. | Shale; gray, weathers to rust color | 12 |
| 83. | Sandstone; friable, weathers to yellow sand, poorly exposed | 190 |
| 82. | Sandstone; friable, weathers to yellow color | 35 |
| | *Total Prairie Mountain* | 1,149 |

*Wildhorse Mountain formation:*

| | | |
|---|---|---|
| 81. | Sandstone; light-gray, resistant, massive, develops bedding after exposure to weathering, a ridge former | 50 |
| 80. | Shale; gray, some yellow soft sandstone | 55 |
| 79. | Sandstone; massive, gray, resistant, develops bedding after weathering | 48 |
| 78. | Covered | 7 |
| 77. | Sandstone; gray, massive, some shaly and soft sandstone zones | 107 |
| 76. | Sandstone; gray, shaly | 5 |
| 75. | Sandstone; gray, resistant, shaly partings | 40 |
| 74. | Shale; sandy, weathers to a rusty pink color | 10 |
| 73. | Sandstone; gray, massive, resistant beds up to ten feet thick | 40 |
| 72. | Shale; gray, weathers to reddish color, some thin-bedded sandstone | 19 |
| 71. | Sandstone; resistant, gray, massive beds up to five feet thick | 30 |
| 70. | Shale; gray, some sandy shale, thin-bedded fine-grained sandstone beds break into squares which are abundant in float; a two-foot-thick quartzitic bed is 20 feet above the base | 65 |
| 69. | Sandstone; gray, friable | 20 |
| 68. | Shale; gray, sandy | 10 |
| 67. | Sandstone; weathers yellow, some shale present intercalated with soft sandstone | 12 |
| 66. | Covered | 30 |
| 65. | Shale; gray, clayey, with thin beds of gray quartzitic fine-grained sandstone | 60 |
| 64. | Sandstone; gray, quartzitic, resistant, sugary pink fracture surfaces normal to bedding | 14 |
| 63. | Shale; clayey, brown, weathers to red-brown, molds of the bark of *Lepidodendron* sp. are rare | 40 |
| 62. | Sandstone; weathers to yellow color, friable, shaly near the base | 50 |
| 61. | Sandstone; gray, thin shale beds near the base, some soft yellow-weathering sandstone, three-foot massive sandstone bed at the top | 96 |
| 60. | Shale; gray, sandy near top, some thin beds of quartzitic fine-grained gray sandstone | 80 |
| 59. | Sandstone; gray, some soft yellow zones | 34 |
| 58. | Sandstone; friable, weathers to yellow color | 25 |
| 57. | Shale; gray, blocky, one-foot-thick sandstone bed in the middle | 15 |
| 56. | Sandstone; light-gray, resistant, quartzitic, massive beds up to five feet thick | 45 |
| 55. | Sandstone; soft, weathers to yellow color | 7 |
| 54. | Sandstone; light-gray, weathering gray | 20 |
| 53. | Sandstone; yellow-weathering, friable, silty shale at the top | 23 |
| 52. | Sandstone; white, weathering to gray, quartzitic, fine-grained | 13 |
| 51. | Covered; probably soft sandstone or shale | 80 |
| 50. | Shale; gray, blocky, resistant one-foot-thick sandstone near the base | 35 |
| 49. | Sandstone; yellow-weathering, iron oxide-stained joints common | 22 |
| 48. | Shale; gray and rusty colored, some soft yellow sandstone zones | 35 |
| 47. | Shale; gray and rusty colored, silty | 3 |
| 46. | Sandstone; friable, weathering to yellow color, iron oxide-stained joints common | 20 |
| 45. | Sandstone; gray, resistant, projecting | 3 |

| | | |
|---|---|---|
| 44. | Sandstone; friable, yellow-weathering, some sandy shale | 54 |
| 43. | Sandstone; gray | 3 |
| 42. | Sandstone; yellow-weathering, friable, iron oxide-stained joints, some reddish sandy shale and gray shale, lower portion poorly exposed | 160 |
| 41. | Sandstone; gray, friable | 3 |
| 40 | Sandstone; weathers to yellow color, friable, small amount of red sandy shale | 5 |
| 39. | Sandstone; gray, 1.5-foot sandstone beds separated by gray sandy shale | 9 |
| 38. | Sandstone; gray, medium-grained, massive, blocky weathering | 19 |
| 37. | Sandstone; light-gray, micaceous, massive beds up to three feet thick separated by subequal thickness of reddish-weathering gray sandy shale | 40 |
| 36. | Sandstone; gray, medium-grained, massive but develops thin bedding after weathering | 10 |
| 35. | Covered | 200 |
| | *Total Upper Wildhorse Mountain* | 1,771 |
| | *Prairie Hollow member:* | |
| 34. | Sandstone; green-gray, weathers tan, quartzitic, fine-grained, massive beds four feet thick are separated by maroon shale partings | 50 |
| 33. | Sandstone; massive, gray, fine-grained, resistant, forms steep dip slope above the creek | 6 |
| 32. | Shale; chocolate-brown, weathers maroon, blocky, some soft green sandstone is interbedded | 4 |
| 31. | Sandstone; tan, resistant, massive | 4 |
| 30. | Sandstone; green, soft | 3 |
| 29. | Sandstone; gray, fine-grained, resistant, massive | 10 |
| 28. | Shale; chocolate-brown, weathers to pink-tan flakes, firm brown-gray sandstone in one-foot beds is common | 37 |
| 27. | Sandstone; green-gray, fine-grained, quartzitic, massive, a ridge former | 30 |
| 26. | Sandstone; green-gray, thin-bedded, quartzitic, some chocolate-brown shale weathers to gray-brown | 25 |
| 25. | Sandstone; gray, fine-grained, thin green shale at the base | 15 |
| 24. | Sandstone; green-gray, massive, quartzitic, fine-grained, two-foot-thick beds, forms a rapid in the creek | 24 |
| 23. | Shale; green and red-chocolate, interbedded thin beds of gray-green sandstone, poorly exposed | 15 |
| 22. | Sandstone; gray, quartzitic, one-foot bedding units, abundant chocolate-colored blocky shale weathers to beige color in float | 18 |
| 21. | Sandstone; gray, quartzitic, fine-grained, green shale partings | 7 |
| 20. | Shale; red-chocolate and gray-green, thin-bedded quartzitic sandstone is common | 6 |
| 19. | Shale; red-chocolate, blocky, clayey, sandy zone near the middle of this unit | 5 |
| 18. | Sandstone; gray-green, firm, spheroidal weathering is well developed, fine-grained, some red-chocolate shale in the lower portion | 5 |
| 17. | Shale; chocolate-colored, massive to blocky, poorly exposed | 6 |
| 16. | Sandstone; gray, quartzitic, massive, fine-grained, base not exposed, forms waterfall in creek | 3 |
| 15. | Covered | 47 |
| | *Total Prairie Hollow* | 320 |
| 14. | Sandstone; tan-gray, resistant, massive, quartzitic, fine-grained | 22 |
| 13. | Covered; forms plunge pool in creek and is probably shale or soft sandstone | 20 |
| 12. | Sandstone; gray, quartzitic, fine-grained, massive | 5 |
| 11. | Covered | 16 |

| | | |
|---|---|---|
| 10. | Sandstone; gray, quartzitic, fine-grained | 2 |
| 9. | Sandstone; weathering to yellow, friable, some thin-bedded gray quartzitic sandstone with flute casts | 28 |
| 8. | Sandstone; gray, fine-grained, massive, quartzitic | 6 |
| 7. | Sandstone; blue-gray, fine-grained, quartzitic, six-inch-thick beds are interbedded with gray shale, flute casts indicate current to N60°W | 21 |
| 6. | Shale; gray-green to olive, weathering red, rounded discoidal to fissile, clayey | 30 |
| 5. | Sandstone; gray, massive, resistant | 9 |
| 4. | Sandstone; gray, thin-bedded, some soft sandstone and shale poorly exposed | 21 |
| 3. | Sandstone; light salmon-gray, massive, quartzitic, a ridge former | 68 |
| 2. | Sandstone; gray, quartzitic, thin-bedded, interbedded gray shale poorly exposed | 60 |
| 1. | Sandstone; light-gray, quartzitic, fine-grained, massive, weathers to beds two to four feet thick | 145 |
| | *Total Lower Wildhorse Mountain exposed* | 453 |

**II. Section measured in cuts along Dierks Lumber Company road; the top of the section is near the SE cor. sec. 17, T. 2 S., R. 22 E.**

*JACKFORK GROUP*

| | *Wildhorse Mountain formation:* | *Feet* |
|---|---|---|
| 43. | Sandstone; gray, thin-bedded, quartzitic, interbedded with thin blue-gray shale | 10 |
| 42. | Sandstone; weathers to yellow color, friable. | 10 |
| 41. | Shale; gray, fissile | 12 |
| 40. | Sandstone; gray, interbedded thin gray shale | 8 |
| 39. | Covered | 20 |
| 38. | Sandstone; weathers to light-yellow color, friable | 20 |
| 37. | Shale; gray, severely weathered | 8 |
| 36. | Sandstone; friable, argillaceous, contains one resistant ledge | 5 |
| 35. | Shale; gray | 8 |
| 34. | Sandstone; gray, weathers yellow | 3 |
| 33. | Shale; blue-gray, fissile, some gray sandstone layers | 10 |
| 32. | Shale; gray-green weathers blue-gray | 13 |
| 31. | Sandstone; gray, weathers yellowish, medium coarse-grained, argillaceous | 5 |
| 30. | Shale; green, clayey, some orange-weathering zones, intercalated one-inch-thick gray siltstones common | 50 |
| 29. | Sandstone; yellow-green, weathers to orange, argillaceous | 20 |
| 28. | Shale; gray in the lower portion and green in the upper portion, thin gray siltstones common | 13 |
| 27. | Sandstone; gray, resistant, quartzitic | 2 |
| 26. | Shale; green, and yellow-green argillaceous sandstone | 20 |
| 25. | Sandstone; yellow-green, weathering tan, friable, argillaceous | 20 |
| 24. | Shale; gray, intercalated thin quartzitic sandstones | 63 |
| 23. | Sandstone; yellow-green, argillaceous, some gray resistant zones, forms topographic bench | 23 |
| 22. | Shale; gray, with subequal amounts of yellow-green argillaceous coarse-grained sandstone in one-foot bedding units | 55 |
| 21. | Sandstone; yellow-green, massive, argillaceous, some light-gray zones, slightly resistant, contains a one-inch-thick violet shale with abundant plant fragments | 30 |
| 20. | Shale; gray, intercalated one-foot-thick sandstone beds common | 25 |
| 19. | Sandstone; gray-green, argillaceous | 29 |
| 18. | Shale; dark-gray | 10 |
| 17. | Sandstone; gray, weathering white on fracture surfaces normal to bedding | 10 |
| 16. | Shale; gray, some intercalated thin siltstone beds | 35 |

| | | |
|---|---|---|
| 15. | Shale; gray, intercalated four-inch-thick siltstones common | 35 |
| | *Total Wildhorse Mountain exposed* | 572 |

*STANLEY GROUP*
*Chickasaw Creek formation:*

| | | |
|---|---|---|
| 14. | Shale; bright blue-gray | 8 |
| 13. | Shale; siliceous, blue-gray, earthy texture, rust-colored on fracture surfaces, poorly exposed | 10 |
| 12. | Shale; gray, with thin-bedded siltstone beds | 25 |
| 11. | Shale; siliceous, blue-gray, thin-bedded, some cherty layers contain small white spots 0.05 inches in diameter | 18 |
| 10. | Siltstone; two-inch-thick bedding units, interbedded dark blue-gray shale | 15 |
| 9. | Covered; float indicates some siliceous shale | 10 |
| 8. | Shale; dark blue-gray, with some thin gray siltstone beds | 15 |
| 7. | Sandstone; gray | 19 |
| 6. | Sandstone; gray, thin- to medium-bedded, convolute bedding common, some interbedded dark blue-gray shale | 20 |
| | *Total Chickasaw Creek* | 140 |

*Moyers formation:*

| | | |
|---|---|---|
| 5. | Shale; green, some freshly exposed flakes are blue, orange-colored in weathered near-surface zones, no sandstone | 60 |
| 4. | Sandstone; soft, argillaceous | 35 |
| 3. | Sandstone; and soft green shale, poorly exposed | 120 |
| 2. | Covered | 200 |
| 1. | Shale; green, interbedded soft argillaceous sandstone | 310 |
| | *Total Moyers exposed* | 725 |

**III. Section measured along a small creek about 0.3 miles north of the center of the S line of sec. 7, T. 1 S., R. 24 E.**

*JACKFORK GROUP*
*Wesley formation:*

| | | *Feet* |
|---|---|---|
| 12. | Siltstone; gray, eight-inch beds separated by black shale partings | 2 |
| 11. | Shale; black, common thin-bedded siltstones, some soft siliceous shale near the middle of this unit | 22 |
| 10. | Sandstone; fine-grained, light-gray, massive, quartzitic | 1.5 |
| 9. | Siltstone; light-gray, three-inch-thick bedding units, intercalated black fissile shale | 12 |
| 8. | Shale; black, common half-inch siltstone beds, some thin siliceous shale near the base | 17 |
| 7. | Sandstone; fine-grained, dark gray, poorly developed convolute bedding | 1 |
| 6. | Shale; black, with common one-inch-thick beds of siliceous shale and siltstone | 3 |
| 5. | Shale; siliceous, cherty, black, white streaks elongate parallel to bedding, two- to four-inch bedding units with one massive six-inch chert near the base | 1.5 |
| 4. | Siltstone; medium-gray, quartzitic, resistant, the lower two inches of this unit is a siliceous shale with an undulatory upper surface | 0.5 |
| 3. | Shale; black, common four-inch-thick siltstones which are gray and quartzitic | 5 |
| 2. | Shale; dark gray, abundant gray siltstone beds one inch in thickness | 3 |
| 1. | Shale; dark gray, common gray siltstone beds one to four inches in thickness, poorly exposed, base not exposed | 70 |
| | *Total Wesley formation exposed* | 138.5 |

**IV. Section measured along a ditch on west side of old logging road, 0.1 mile north of center of S line sec. 29, T. 1 S., R. 24 E.**

| | *Atoka formation:* | *Feet* |
|---|---|---|
| 21. | Sandstone; yellow-gray, friable, argillaceous, micaceous, massive | 10 |
| 20. | Sandstone; gray, quartzitic, resistant, some friable argillaceous sandstone in the middle portion of this unit | 19 |
| 19. | Shale; green-gray to black, one-inch-thick tan-colored siltstone beds common | 20 |
| 18. | Sandstone; gray, weathering rust-brown, fine-grained, quartzitic, resistant, sugary texture on weathered fractures, convolute bedding common, one- to two-foot units interbedded with dark-gray shale | 13 |
| 17. | Sandstone; tan, argillaceous, friable | 2 |
| 16. | Shale; green to black, thin siltstone beds common | 17 |
| 15. | Shale; black, two-inch-thick siltstone beds common at top and base | 3 |
| 14. | Shale; siliceous, black, weathers streaky gray on fractures normal to bedding, weathers into blocks | 0.3 |
| 13. | Shale; black to greenish-gray, thin siltstone beds rare, contains rectangles of concentric iron-oxide bands formed by weathering | 65 |
| 12. | Shale; siliceous, soft, black, hard one-inch siliceous shale at the base weathers into rectangular blocks and is streaky gray on fractures normal to the bedding | 1 |
| 11. | Shale; black, weathers to reddish color, one-inch-thick siltstone beds rare | 5 |
| 10. | Shale; black, soft one-inch siliceous shale common, one-inch-thick gray chert at the top varies in thickness and is locally absent | 3 |
| 9. | Shale; siliceous, cherty, black, abundant spicular material, streaky gray in color on fracture surface normal to bedding due to concentrations of spicular material, appears to be one massive bed which breaks into two-inch bedding units upon weathering | 2 |
| 8. | Shale; black | 35 |
| 7. | Shale: siliceous, black, fissile, weathers into thin slabs ⅛ x 10 x 4 inches | 1 |
| 6. | Shale: black to green-gray, vertical iron oxide-stained joints common | 22 |
| 5. | Shale: black, gray siltstone beds one-half to one inch thick common | 47 |
| 4. | Covered: probably shale as above | 15 |
| 3. | Shale; black, weathers to reddish color and has reddish fracture surfaces, one-half- to two-inch-thick siltstone beds weather into small blocks | 25 |
| 2. | Sandstone; very fine-grained, laminated and small-scale cross-laminated, gray, weathers to mottled rust and green-gray, six- to ten-inch beds of sandstone are separated by thin dark-gray shale, massive two-foot bed of sandstone occurs at top of unit | 16 |
| 1. | Shale: black, fissile, hard, some one-half-inch-thick siltstone beds some of which break into small blocks upon weathering: this unit is approximately 300 feet above the top of the Johns Valley formation | 44 |
| | *Total Atoka exposed* | 365.3 |

**V. Section measured in ditches and roadcuts along road up Boktukola Mountain. The base is 0.23 miles west of the SE cor. sec. 35, T. 1. N., R. 24 E. The top is at an intersection of trails near 0.5 miles east and 0.25 miles north of the SE cor. sec. 34, T. 1 N., R. 24 E.**

| | | Feet |
|---|---|---|
| | *JACKFORK GROUP* | |
| | *Wildhorse Mountain formation:* | |
| 42. | Shale; light-gray, with some gray quartzitic fine-grained sandstone with flute casts | 10 |
| 41. | Sandstone; light salmon-gray, quartzitic, massive | 7 |
| 40. | Shale; gray, with six-inch-thick gray quartzitic fine-grained sandstone beds with flute casts | 10 |
| 39. | Sandstone; firm, yellow to purple | 6 |
| 38. | Shale; light-gray | 6 |
| 37. | Sandstone; firm, yellow-gray, fine-grained | 6 |
| 36. | Sandstone; yellow, friable | 12 |
| 35. | Sandstone; gray, case-hardened near surface but soft where grader has cut deeper in ditch | 9 |
| 34. | Sandstone; soft, yellow, poorly exposed | 70 |
| 33. | Sandstone; weathering to yellow color, friable | 7 |
| 32. | Shale; dark-gray and pink-gray | 6 |
| 31. | Sandstone; gray, friable, some light-gray shale | 19 |
| 30. | Sandstone; gray, quartzitic, fine-grained, massive | 4 |
| 29. | Sandstone; gray, friable, dirty, light-gray and rust shale at the top | 5 |
| 28. | Sandstone; weathering to yellow, friable, poorly exposed | 7 |
| 27. | Covered | 36 |
| | *Total Wildhorse Mountain exposed* | 220 |
| | *STANLEY GROUP* | |
| | *Chickasaw Creek formation:* | |
| 26. | Shale; dark-gray, some thin siltstone beds in the upper part are similar to chert beds in the unit below, poorly exposed | 36 |
| 25. | Shale; blue-black, siliceous to cherty, some two-inch-thick chert layers, poorly exposed | 12 |
| 24. | Shale; dark-gray to black, slightly cherty | 6 |
| 23. | Sandstone; light-gray, quartzitic, massive | 2.5 |
| 22. | Shale; dark-gray, thin-bedded gray siltstones show convolute bedding | 5 |
| 21. | Sandstone; gray, fine-grained, quartzitic, six-inch-thick convolute beds, subequal amounts of dark-gray to black slightly siliceous shale | 13 |
| 20. | Shale; black, siliceous, weathers to streaky gray on fractures normal to bedding, one two-inch-thick chert is present | 2 |
| 19. | Sandstone; gray-green, fine-grained, four-inch-thick convolute beds are intercalated with black fissile shale | 17 |
| 18. | Sandstone; gray-green, resistant, three-foot-thick beds intercalated with thin black shale | 16 |
| 17. | Shale; gun-metal gray, weathers to rust color, massive | 22 |
| | *Total Chickasaw Creek* | 131.5 |
| | *Moyers formation:* | |
| 16. | Shale; green-gray, with friable yellow-weathering sandstone | 120 |
| 15. | Sandstone; olive-green, friable | 12 |
| 14. | Sandstone; green-gray, resistant | 2 |
| 13. | Sandstone; green-gray, friable, interbedded with green-gray clay shale | 37 |
| 12. | Sandstone; gray, resistant | 3 |
| 11. | Shale; green-gray, weathers to rust color, poorly exposed | 160 |
| 10. | Sandstone; green-gray, resistant, thin-bedded, micaceous, interbedded with green-gray shale | 8 |

| | | |
|---|---|---|
| 9. | Shale; gray, with friable green-gray argillaceous sandstone | 28 |
| 8. | Sandstone; gray, friable, poorly exposed | 5 |
| 7. | Sandstone; gray, resistant, argillaceous, micaceous, a ridge former | 9 |
| 6. | Sandstone; green-gray, weathers to yellow color, friable | 15 |
| 5. | Sandstone; green-gray, resistant | 3 |
| 4. | Sandstone; gray-green, friable, argillaceous, some gray shale is interbedded | 10 |
| 3. | Shale; gray-green, clayey, some two-inch-thick intercalated siltstone beds | 27 |
| 2. | Sandstone; gray-green, fine-grained, dense, micaceous | 2 |
| 1. | Shale; gray-green, clayey, weathers to rust-red color, base not exposed | 10 |
| | *Total Moyers exposed* | 451 |

# APPENDIX B

## DIRECTIONS OF PALEOCURRENT STRUCTURES

| | Type and Horizon | Location | Strike[1] | Dip | Pitch[2] | Trend[3] | Direction |
|---|---|---|---|---|---|---|---|
| 1. | Groove cast, lower Moyers fm. | T. 2 S., R. 16 E. | 345 | 10W | 90 | 255 | |
| 2. | Groove cast, upper Moyers fm. | T. 2 S., R. 16 E. | 355 | 55W | 85 | 270 | |
| 3. | Flute cast, upper Moyers fm. | 0.5 mi. S NE cor. sec. 30, T. 1 N., R. 23 E. | 85 | 50S | 150E | | 115 |
| 4. | Groove and flutes, Chickasaw Creek fm. | SW¼ sec. 17, T. 2 S., R. 22 E. | 240 | 40S | 150W | | 270 |
| 5. | Small flute casts, Chickasaw Creek fm. | SW¼ sec. 34, T. 1 N., R. 24 E. | 125 | 25W | 25W | | 280 |
| 6. | Flute casts, Chickasaw Creek fm. | State Hwy. 103, T. 2 N., R. 25 E. | 240 | 40S | 170W | | 250 |
| 7. | Groove casts, Chickasaw Creek fm. | NW¼ sec. 14, T. 2 S., R. 25 E. | 220 | 90S | 115W | 285 | |
| 8. | Bulbous flute; 250′ above Chickasaw Creek shale | SE¼ sec. 33, T. 1 N., R. 24 E. | 125 | 25W | 25W | | 280 |
| 9. | Bulbous flute; 200′ above Chickasaw Creek shale | SE¼ sec. 33, T. 1 N., R. 24 E. | 125 | 25W | 55W | | 250 |

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[1] Azimuth in degrees.

[2] Pitch is the angle between the strike of the bed and the lineation of the current structure; it is measured clockwise in the plane of dip.

[3] Currents moved in the direction of trend or in the opposite direction.

APPENDIX B (cont.)

| | Type and Horizon | Location | Strike[1] | Dip | Pitch[2] | Trend[3] | Direction |
|---|---|---|---|---|---|---|---|
| 10. | Groove cast, lower Wildhorse Mtn. fm. | State Hwy. 103, T. 2 N., R. 25 E. | 260 | 40S | 140 | | 300 |
| 11. | Groove casts, lower Wildhorse Mtn. fm. | SW¼ sec 9, T. 2 S., R. 25 E. | 290 | 39S | 15W | 275 | |
| 12. | Groove cast, middle Wildhorse Mtn. fm. | center N line sec. 9, T. 2 S., R. 24 E. | | | | 260 | |
| 13. | Thin groove, small flute; lower Jackfork | NW¼ sec. 2, T. 1 N., R. 24 E. | 125 | 24 | 5E | | 120 |
| 14. | Flute casts, upper Wildhorse Mtn. fm. | 0.1 mi. E of SW cor. sec. 36, T. 1 S., R. 24 E. | 55 | 20N | 155W | | 260 |
| 15. | Thin flute cast, Prairie Hollow mbr. | center W line sec. 10, T. 2 S., R. 21 E. | 40 | 85W | 115W | | 285 |
| 16. | Bulbous flute cast, Prairie Hollow mbr. | 0.36 S and 0.15 W of NE cor. sec. 32, T. 1 N., R. 23 E. | 85 | 36S | 170W | | 275 |
| 17. | Groove casts, Prairie Hollow mbr. | sec. 17, T. 1 S., R. 22 E. | 305 | 50N | 15 | 290 | |
| 18. | Small flute casts, upper Wildhorse Mtn. fm. | NW cor. sec. 31, T. 2 N., R. 22 E. | 77 | 51S | 0W | | 257 |
| 19. | Bulbous flute casts, upper Wildhorse Mtn. fm. | NW cor. sec. 31, T. 2 N., R. 22 E. | 77 | 51S | 45N | | 32 |
| 20. | Large load casts, upper Wildhorse Mtn. fm. | NW cor. sec. 31, T. 2 N., R. 22 E. | 81 | 51S | 165W | | 276 |
| 21. | Groove casts, middle Jackfork group | NE cor. sec. 28, T. 2 S., R. 22 E. | 270 | 20S | 10W | | 260 |
| 22. | Groove casts, middle Prairie Mtn. fm. | SE¼ sec. 31, T. 1 S., R. 17 E. | 210 | 45E | 135 | 255 | |

APPENDIX B (cont.)

| | Type and Horizon | Location | Strike[1] | Dip | Pitch[2] | Trend[3] | Direction |
|---|---|---|---|---|---|---|---|
| 23. | Flute cast,<br>Markham Mill fm. | center sec. 36,<br>T. 1 S., R. 21 E. | 295 | 65S | 20W | | 275 |
| 24. | Flute cast, upper<br>Markham Mill fm. | 0.1 mile E of NW cor. sec. 27,<br>T. 1 S., R. 21 E. | 268 | 90S | 0W | | 268 |
| 25. | Flute cast, upper<br>Jackfork group | 0.1 mile E of SW cor. sec. 30,<br>T. 1 S., R. 21 E. | 270 | 45N | 170W | | 280 |
| 26. | Groove cast, middle<br>Johns Valley fm. | 0.1 mile W of center of E line<br>of sec. 32, T. 1 S., R. 17 E. | 40 | 90S | 150 | 250 | |
| 27. | Groove cast, lower<br>Johns Valley fm. | center of SE¼ sec. 32,<br>T. 1 S., R. 17 E. | 40 | 90S | 40 | 180 | |
| 28. | Bulbous flute,<br>lower Atoka fm. | NW¼ sec. 36,<br>T. 1 S., R. 21 E. | 260 | 90N | 150W | | 290 |
| 29. | Groove cast,<br>lower Atoka fm. | ½ mile S of NE cor. sec. 31,<br>T. 1 S., R. 24 E. | 100 | 90N | 160 | 300 | |
| 30. | Groove cast,<br>lower Atoka fm. | NW¼ sec. 35,<br>T. 1 S., R. 19 E. | 30 | 10W | 115W | | 275 |
| 31. | Groove cast,<br>lower Atoka fm. | Hairpin Curve. center sec. 3,<br>T. 3 N., R. 19 E. | 255 | 90N | 10 | 245 | |
| 32. | Flute cast,<br>lower Atoka fm. | center sec. 3,<br>T. 3 N., R. 19 E. | 255 | 90N | 0W | | 255 |
| 33. | Flute cast,<br>lower Atoka fm. | center sec. 3,<br>T. 3 N., R. 19 E. | 255 | 90N | 24W | | 231 |
| 34. | Flute cast,<br>lower Atoka fm. | sec. 18,<br>T. 1 S., R. 19 E. | 90 | 15N | 20W | | 250 |
| 35. | Bulbous flute cast,<br>middle Atoka fm. | ¼ mile S of NE cor. sec. 33,<br>T. 1 S., R. 22 E. | 310 | 20S | 5W | | 305 |

# INDEX

**(Main references are in boldface)**