TULANE STUDIES IN GEOLOGY

Volume 4, Number 4 August 24, 1966

# GEOLOGY OF THE MENA-BOARD CAMP QUADRANGLES, POLK COUNTY, ARKANSAS

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*NEW ORLEANS, LOUISIANA*

CONTENTS



## Abstract

The Mena and Board Camp quadrangles are in the Ouachita folded belt in west-central Arkansas. Rocks ranging in age from Middle Ordovician to Middle Mississippian crop out in these two quadrangles and include representatives of two distinct depositional environments. The Bigfork Chert, Polk Creek Shale, Missouri Mountain Slate, and Arkansas Novaculite were deposited during a period of tectonic inactivity and are deficient in arenaceous clastic material. The bedded siliceous sediments of this sequence are primary deposits, at least partly biochemical in origin, which probably were deposited in relatively shallow water. The northward thinning of the Arkansas Novaculite is due largely to nondeposition rather than to erosion. These Middle Ordovician to Lower Mississippian sediments have a total thickness of about 3,000 feet. They crop out in the southeast and south portions of these quadrangles and are referred to as the core of the Ouachitas. The Stanley shales and Jackfork sandstones were deposited in a subsiding basin during a period of uplift of adjacent land areas. The three formations of the Stanley Group described in Oklahoma can be recognized in this portion of Arkansas. These two groups are Middle Mississippian and are approximately 12,000 feet thick.

The general strike of the fold axes and the bedding is east-west and northwest-

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southeast. The plunge of the folds is to the west. In the Board Camp quadrangle the axial planes of these folds dip to the north; to the south and west and axial planes dip south.

High-angle reverse faulting is the dominant type of structure in the Arkansas Novaculite and older rocks in the core area, whereas low-angle thrusting is characteristic in the Stanley and younger formations. The Windingstair fault, a low-angle thrust which has been traced from the Ouachitas in Oklahoma eastward into the Mena quadrangle, is the most prominent fault in the area studied. The displacement along this fault decreases in an eastward direction and the fault apparently dies out in the shales of the Stanley Group.

## I. Introduction

The Mena and Board Camp quadrangles, seven and one-half minute quadrangles located in extreme west central Arkansas (see Location Map, Fig. 1), include an area of approximately 122 square miles within the belt of folded Paleozoic sediments that form the Ouachita Mountains.

A broad valley (five miles wide) in the northern and central portions of the mapped area is formed by the erosion of the Stanley shales. This topographic low is bounded on the north by the resistant sandstones of the frontal Ouachita Mountains. To the south are sharp linear ridges of chert and novaculite, and valleys formed by the erosion of softer formations of pre-Mississippian age. The shale valley controls the agriculture and population of the region. Within this area the land is generally suitable for farming or cattle raising. The mountainous terrain is used primarily as a source of timber.

The Ouachita River, a tributary to the Red River, rises a few miles north of Mena and flows eastward through both quadrangles. The remaining drainage is tributary to the Ouachita River.

The town of Mena lies at the western extremity of the Mena quadrangle approximately halfway between Ft. Smith and Texarkana. Other small towns in these quadrangles include Board Camp, Ink, Nunley, and Old Dallas. Access to the area from the north and south is provided by U.S. Highways 71 and 59. Arkansas State Highways 8 and 88 traverse the area from east to west. Polk County maintains gravel-topped roads which interconnect and serve the rural areas.

The Mena and Board Camp quadrangles previously have not been mapped geologically and, except for gross geologic features which appear on the geologic map of Arkansas, published in 1929 by the Arkansas Geological Survey, the geology has not been known. The quadrangles are bounded on the south by the DeQueen quadrangle, which was mapped by H. D. Miser and A. H. Purdue (1929).

The data obtained from mapping the Mena and Board Camp quadrangles were interpreted to determine the depositional history of the rocks and their structural evolution. Special attention was focused on several points: comparison of the two distinct sedimentary sequences in the area; recognition of the continuation of the formations of the Stanley Group as defined in Oklahoma; determination of the cause of the northeast thinning of the Devonian-Mississippian Arkansas Novaculite; and recognition of the extension of a major regional thrust fault into this area.


## Acknowledgments

The Arkansas Geological and Conservation Commission provided a stipend to defray field expenses, and provided the topographic base maps and aerial photographs used in this study. Appreciation is expressed to this commission, and to its director, Norman F. Williams, and his staff. Further appreciation is expressed to the Geological Society of America for providing a grant from the Penrose Fund to cover the cost of preparing thin sections and a portion of the travel expenses to the field.

Thanks are extended to Mr. B. W. Miller of the Gulf Oil Corporation, who initially stimulated the writer's interest in the geology of the Ouachita Mountains, and aided in getting the project started.

The writer is indebted to Professors Harold E. Vokes, John P. McDowell, Hubert C. Skinner, Raymond O. Steinhoff, and Garrett Briggs of Tulane University, and the late Roy A. MacDiarmid of Fredonia College, Fredonia, New York, for their advice and criticisms throughout the study and preparation of the manuscript.

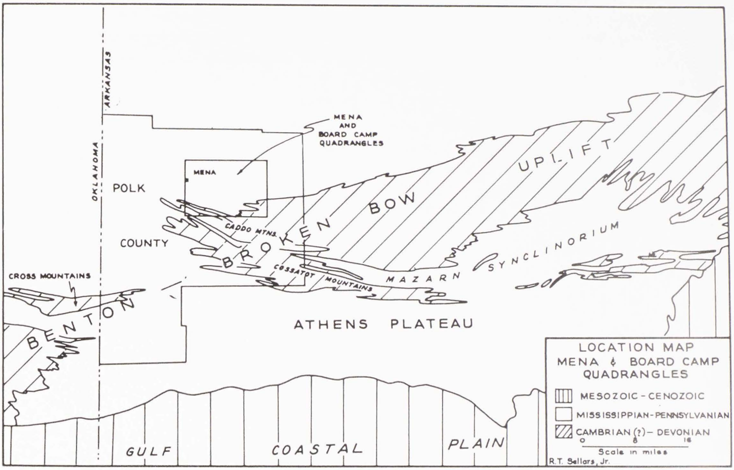



Figure 1. Location map of Mena-Board Camp quadrangles, Polk County, Arkansas.

## II. General Geology

The principal anticlinal fold of the Ouachita Mountains, the Benton-Broken Bow uplift (Miser, 1959, p. 32), extends from Benton, Arkansas, westward to Broken Bow, Oklahoma. It contains strata of Cambrian (?), Ordovician, Silurian, and Devonian age. Flanking the anticlinorium are Mississippian and Pennsylvanian strata. Outcrops within the Mena and Board Camp quadrangles, which enclose an area on the west-northwest flank of the anticlinorium, reveal sediments ranging in age from Ordovician to Mississippian. These include the Bigfork Chert (Middle Ordovician), the Polk Creek Shale (Upper Ordovician), Missouri Mountain Slate (Silurian), the Arkansas Novaculite (Devonian-Lower Mississippian), the Stanley Shale (Mississippian), and the lower portion of the Jackfork Group (Mississippian). The cumulative thickness of these formations is approximately 15,700 feet.

The Bigfork Chert-Arkansas Novaculite interval is part of the sequence of siliceous sediments, thin shales, and sandstones which comprise the Lower Paleozoic rocks of the Ouachitas. This is one of two distinct lithotopes reflecting the two major depositional environments that existed in the Ouachita trough. The other major lithotope is represented by approximately 22,000 feet of shale and argillaceous sandstones of the upper Paleozoic Stanley - Jackfork - Johns Valley - Atoka sequence. The Arkansas Novaculite-Stanley Shale contact marks the boundary between rocks formed in two distinct types of depositional environments and a sharp change in the stratigraphy of the Ouachita Mountains. The older rocks of the Bigfork Chert-Arkansas Novaculite interval within the main anticlinorium are relatively thin, siliceous sediments and intervening thin shales representing a period of relatively slow sedimentation. The younger rocks comprising the flanks are thick sequences of sand and shale which accumulated during a period of rapid sedimentation due to tectonic activity bordering the source area.

## III. Stratigraphy

### Bigfork Chert

#### *Definition*

Purdue (1909) named the Bigfork Chert for outcrops near the Big Fork post office in the northwest corner of the Caddo Gap quadrangle. It originally had been mapped as novaculite by the Arkansas Geological Survey (Griswold, 1892; see Plate 3). It is defined as those strata which lie above the

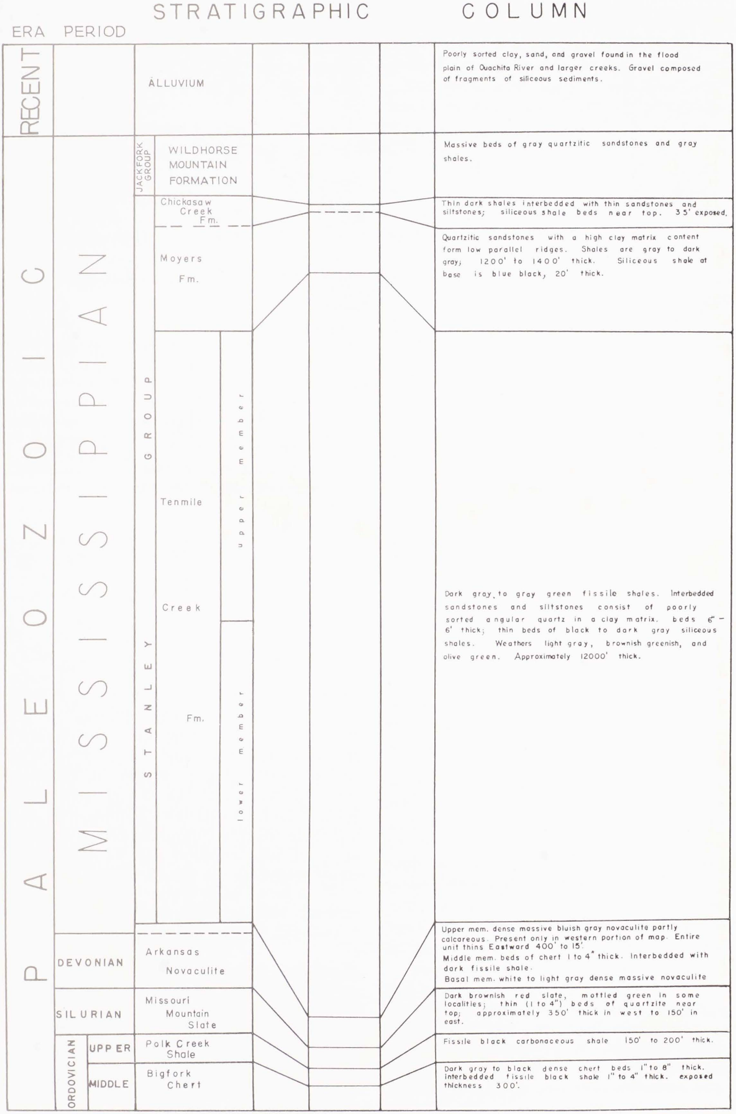



PLATE 2—Stratigraphic Column

Figure 2. Bigfork Chert (B-2). Photomicrograph of Bigfork Chert showing stratified chert and sapropelic or carbonaceous argillaceous material. Rhombohedral pseudomorphs of quartz after carbonate (and rhomb voids) are scattered throughout the slide. The layers of sapropelic or argillaceous material are warped around the rhombs. Ordinary light, X 95.

Womble Shale and below the Polk Creek Shale.

*Distribution*

Outcrops of the Bigfork Chert in the Mena and Board Camp quadrangles are limited to the southeast portion of the Board Camp quadrangle. There it crops out in two ridges which extend eastward out of the map area. Regionally, the formation crops out in the core of the Ouachita Mountains in central Arkansas and in southeastern Oklahoma. Outcrops of Bigfork Chert are also found north of the core area in Oklahoma in the Potato Hills in Pushmataha and Latimer Counties and on Black Knob Ridge, Atoka County.

*Lithology, Petrography, and Thickness*

Only the upper part of the formation is exposed in the area mapped; however, this is well shown in a road cut along Arkansas State Highway 8 in Sec. 6, T3S, R28W. Here the formation consists of individual layers of black, dense chert ranging from two to twelve inches in thickness and alternating with one to three inch layers of black carbonaceous shales. Fresh samples are difficult to obtain because the chert is brittle and breaks easily along fractures and bedding planes, and because of the depth of weathering. In places the fractures are filled with quartz. The Bigfork Chert bears a distinct resemblance to the middle member of the Arkansas Novaculite but generally is darker and nontranslucent.

A petrographic study of the Bigfork Chert shows that it consists of a mosaic of microcrystalline quartz or chalcedony, with wavy laminations of sapropelic or argillaceous material. Quartz pseudomorphs after carbonate rhombs are numerous. One sample of Bigfork contains a hash of monaxon and triaxon sponge spicules and a rhomb imbedded in a spicule, evidence that the carbonate crystallized in place. Photomicrograph B-2 (Fig. 2) shows laminations warped around carbonate rhombs, further evidence of *in situ* crystallization of the carbonate.

Miser and Purdue (1929) estimated the thickness of the Bigfork Chert to be 600 feet in the Caddo Gap quadrangle, Montgomery County, Arkansas. Ham (1959) states that in McCurtain County, Oklahoma, the Bigfork is about 600-700 feet thick. In the Mena and Board Camp quadrangles only about 300 feet of the upper portion of the formation are exposed.

*Stratigraphic Relationship*

The Bigfork Chert is conformable to the overlying Polk Creek Shale. The contact is gradational and exhibits a gradual decrease in the amount of chert and an increase in the number and thickness of chert beds. The contact with the underlying Womble Shale is not exposed in the Mena and Board Camp quadrangles.

*Paleontology, Age, and Correlation*

Graptolites, poorly preserved as gray carbonaceous films on the bedding planes of the black shale layers near the top of the formation, represent the only megafossils known from the Bigfork in the mapped area. The graptolites appear to be scandent forms similar to *Diplograptus* and *Climacograptus*. Sponge spicules have been recognized in photomicrographs of the thin sections from the Bigfork Chert.

Griswold (1892) placed the Bigfork Chert in the Ordovician on the basis of faunal evidence. Further studies of graptolite faunas have resulted in the assignment of the formation to the Trentonian Stage of the Middle Ordovician (Miser and Purdue, 1929, p. 39). Decker (1936, p. 1256) correlated the Bigfork Chert at Black Knob Ridge, Atoka County, Oklahoma, with the Viola Limestone of the Arbuckle Mountains. Harlton (1953) and Hendricks, *et al.* (1947) also noted faunal similarities with the Viola and considered the Bigfork to be its stratigraphic equivalent. The correlation of the Bigfork with the Viola Limestone of Oklahoma and the Trenton Limestone of New York now is generally accepted.

## Polk Creek Shale

*Definition*

Purdue named the Polk Creek Shale for exposures along the headwaters of Polk Creek in Montgomery County, Arkansas. It is underlain by the Bigfork Chert and, in the area where Purdue defined it, overlain by the Blaylock Sandstone. In the Mena and Board Camp quadrangles the Blaylock is absent and the Polk Creek is overlain by the Missouri Mountain Slate.

*Distribution*

The Polk Creek Shale crops out in the southern and southeastern area of the Board Camp quadrangle. In this area, valleys adjacent to the ridges supported by Bigfork Chert are formed in the Polk Creek Shale. It is exposed in one locality in the southwestern part of the Mena quadrangle.

Outcrops of this formation are found throughout the core of the Ouachita Mountains in Arkansas and Oklahoma and in the Potato Hills and Black Knob Ridge areas of Oklahoma.

*Lithology and Thickness*

The Polk Creek Shale is characteristically a black, fissile or paper-thin shale that is sufficiently carbonaceous to soil one's fingers. Pyrite is disseminated throughout the formation. Some layers are hard and dense. On weathering, the strata become softer, clayey, and dull gray. Parting along cleavage planes not parallel to bedding is fairly common. Because of the non-resistant nature of the shale, exposures of the formation are generally poor. The best of the exposures observed during this study are along Arkansas Highway 8. In addition, some weathered outcrops are present along some of the county roads and in the bed of Boggy Creek.

No complete, exposed section was found in either quadrangle. A section of Polk Creek Shale is exposed in a bluff just west of Bigfork Creek about 2,500 feet beyond the eastern boundary of the Board Camp quadrangle. From the evidence afforded by this outcrop, and from the width of the mapped belt of occurrence, the thickness of the Polk Creek Shale is estimated to be 200 feet. It is possible that it is thicker in the southeast corner of the Board Camp quadrangle, although much of the apparent increase in thickness is due to repetition by folding.

Miser and Purdue (1929, p. 39) reported a thickness ranging from a feather edge to 175 feet, but the average thickness is approximately 100 feet. Hendricks, *et al.* (1947) state that at Black Knob Ridge in Oklahoma the thickness of the formation varies and is eroded at the top, but the maximum thickness exceeds 137 feet.

PLATE 3—Stratigraphic Nomenclature Chart

| | | |
|---|---|---|
| Southern Ouachita Mountains, Ark. | Griswold, 1892 | LOWER CARBONIFEROUS: Sandstone and Shales; LOWER SILURIAN: Novaculites |
| Ouachita Mountains Atoka Quad., Oklahoma | Taff, 1902 | SILURIAN / UPPER ORDOVICIAN: Jackfork Sandstone; Stanley Shale; Not Present; Talihina Chert; Stringtown Shale |
| Caddo Gap Quadrangle, Arkansas | Purdue, 1909 | CARBONIFEROUS: Jackfork Sandstone; Stanley Shale; AGE UNKNOWN: Fork Mountain Slate; Not Present; Arkansas Novaculite; Missouri Mountain Slate; ORDOVICIAN: Blaylock Sandstone; Polk Creek Shale; Bigfork Chert; Stringtown Shale |
| Southern Ouachita Mountains, Oklahoma | Honess, 1923 | CARBONIFEROUS: PENN.: Jackfork Sandstone; PENN(?): Stanley Shale; Not Present; DEVONIAN: Arkansas Novaculite; SILURIAN: Missouri Mountain Slate; Blaylock Sandstone; ORDOVICIAN: Polk Creek Shale; Bigfork Chert; Womble Equivalent |
| Ouachita Mountains, Oklahoma & Arkansas | Miser & Honess 1927 | CARBONIFEROUS, MISSISSIPPIAN: Caney Shale; Jackfork Sandstone; Stanley Shale; Hot Springs Sandstone |
| Oklahoma salient of the Ouachita Mountains | Harlton, 1938 | PENNSYLVANIAN; BENDIAN: MORROW; PUSHMATAHA: Jackfork Group; STANLEY GROUP: Chickasaw Creek Formation; Moyers Formation; Tenmile Creek Formation; MISSISSIPPIAN |
| Western Part of Ouachita Mountains, Oklahoma | Hendricks et al. 1947 | CARBONIFEROUS, PENNSYLVANIAN: Jackfork Sandstone; Stanley Shale; DEV?, DEVONIAN: Arkansas Novaculite; SILURIAN: Missouri Mountain Slate; Not Present; Polk Creek Shale; Bigfork Chert; Womble Shale |
| Age of Arkansas Novaculite | Hass, 1951 | MISSISSIPPIAN: Stanley Shale; Arkansas Novaculite (U); DEVONIAN: Arkansas Novaculite (M, L); SILURIAN: Missouri Mountain Slate |
| Ouachita Mountains, Oklahoma | Cline, 1960 | PENNSYLVANIAN: Jonns Valley Shale; MISSISSIPPIAN: Jackfork Group; STANLEY GROUP: Chickasaw Creek Formation; Moyers Formation; Tenmile Creek Formation |
| Mena & Board Camp Quadrangles, Arkansas | Sellars, 1966 | not exposed; MISSISSIPPIAN: Jackfork Group; STANLEY GROUP: Chickasaw Creek Formation; Moyers Formation; Tenmile Creek Formation; Arkansas Novaculite (U); DEVONIAN: Arkansas Novaculite (M, L); SILURIAN: Missouri Mountain Slate; Not Present; ORDOVICIAN: Polk Creek Shale; Bigfork Chert; not exposed |

STRATIGRAPHIC NOMENCLATURE CHART

*Stratigraphic Relationship*

The Polk Creek conformably overlies the Bigfork Chert. Its relationship with the overlying Missouri Mountain Slate in the Mena and Board Camp quadrangles is not well defined, but it apparently is conformable.

Throughout much of the central anticlinorium of the Ouachitas the Polk Creek Shale is overlain by the Blaylock Sandstone (Miser and Purdue, 1929). However, in the Mena and Board Camp quadrangles the Blaylock Sandstone is not present and the Polk Creek Shale is overlain by the Missouri Mountain Slate. Miser and Purdue (1929, p. 44) have stated that in the Caddo Gap quadrangle to the southeast of the mapped area, the Blaylock thickens in a southward direction from 0 to 1,500 feet within a distance of three miles. Thus, they consider the Blaylock to be a wedge of sediments derived from an early Paleozoic orogeny to the south.

There is no record of an orogeny in the sediments of the Mena and Board Camp quadrangles, but few exposures of the Polk Creek-Missouri Mountain contact are available for study. The contact between the Missouri Mountain Slate and Polk Creek Shale is exposed in only one known locality, along Mill Creek in Sec. 8, T3S, R28W. The poorly exposed contact does not indicate the presence of an unconformity between the two formations. Therefore, in the area of study they are considered conformable.

*Paleontology, Age, and Correlation*

Poorly preserved graptolites have been found in the Polk Creek at several localities where cleavage and bedding are parallel. These carbonaceous films are indistinct but they are the only fossils found in this formation in the Mena and Board Camp quadrangles. As in the Bigfork Chert, they appear to be scandent forms similar to *Diplograptus* and *Climacograptus.* Purdue (1909) assigned the Polk Creek Shale, along with the Bigfork Chert, to the Ordovician System on the basis of contained faunas. Ulrich (*in* Miser and Purdue, 1929) correlated the Polk Creek Shale with the Upper Ordovician Hartfell Shale of Great Britain. Decker (1935) established the correlation of the Polk Creek with the Sylvan Shale of the Arbuckle Mountain region. Significant to both correlations were the Upper Ordovician graptolite faunas that occur in these formations, particularly *Dicellograptus complanatus* Lapworth.

## MISSOURI MOUNTAIN SLATE

*Definition*

The Missouri Mountain Slate was named by Purdue (1909) for outcrops on Missouri Mountain in Polk and Montgomery Counties, Arkansas. He defined it as overlying the Blaylock Sandstone, where the Blaylock is present, and overlying the Polk Creek Shale, where the Blaylock is absent. In the Mena and Board Camp quadrangles, it overlies the Polk Creek Shale and underlies the Arkansas Novaculite.

*Distribution*

The Missouri Mountain Slate crops out in the southern and east central portions of the Mena and Board Camp quadrangles along hill slopes and in valleys parallel to ridges of Arkansas Novaculite. Regionally it crops out in the Benton-Broken Bow uplift in Arkansas and southeastern Oklahoma and in the Potato Hills and Black Knob Ridge localities of southeastern Oklahoma.

*Lithology, Petrography, and Thickness*

The formation is composed of a soft slate, or low-grade metamorphosed argillite, with well developed cleavage tangent to the bedding. It is typically dark, blood red, but at some localities it is light green. Cleavage surfaces often display the sheen or glistening appearance common to low-grade metamorphosed argillaceous sediments It weathers readily and generally is seen as a rubble of light brownish red or buff slate. This is common on the slopes or ridges, particularly in the Mena quadrangle.

The Missouri Mountain Slate has consistent lithologic character and texture. It contains a few persistent silicified siltstones, 1/4 to 3/4 of an inch thick, and a few layers of quartzite, two to six inches thick. The silicified layers are typically near the top of the formation, due probably to the better exposures of this part of the formation afforded by differential weathering with respect to the overlying Arkansas Novaculite. In one locality a two- to four-inch quartzite layer was observed near the base.

The quartzites consist of well sorted, rounded grains of detrital quartz and chert. The quartz is covered by secondary enlargement which, along with interpenetration of the grains and microcrystalline mosaic-like siliceous cement, serves as a bonding agent. Well rounded detrital chert fragments are common, and recrystallization has made the boundaries indistinct between these chert fragments and the quartz.

A minor amount of clay and feldspar is present. The rock is 85 to 87 percent quartz. It is termed a protoquartzite, according to Pettijohn's classification (1957, p. 291). This and other samples of these sandstones appear to be impervious, although Goldstein (1959b) states that porosities in the Missouri Mountain sandstones are as high as 18 percent.

The formation is soft and readily weathered and, as a result, exposures are poor with no complete section available for study in the area mapped. The formation is 300 to 400 feet thick on the south slope of Dallas Mountain in the Board Camp quadrangle; in the Mena quadrangle it is only 100 to 150 feet thick.

Miser and Purdue (1929, p. 46) state that the thickness of the formation in the DeQueen and Caddo Gap quadrangles ranges from 50 feet in the southernmost outcrops to approximately 300 feet in the Missouri Mountains. In the extreme eastern Ouachitas, the Missouri Mountain is 50 to 150 feet thick (Purdue and Miser, 1923).

### *Stratigraphic Relationship*

The Missouri Mountain Slate is conformable and gradational with the overlying Arkansas Novaculite in the Mena and Board Camp quadrangles. The contact is well exposed in a number of localities. The best exposures are:

1. On the west bank of Board Camp Creek, Sec. 7, T3S, R29W (see Fig. 9).
2. The east central portion of Sec. 11, T3S, R30W.
3. In the southwest corner of Sec. 2, T3S, R29W.

The lithologic sequence exposed at the Board Camp Creek locality is like that observed in the other exposures. Here, the upper portion of the Missouri Mountain Formation is a thin, platy, greenish or reddish brown slate containing a few beds of siltstone, one-half to one inch in thickness. In the upper few feet of the sequence, two- to four-inch beds of light gray novaculite alternate with shale. Upward in the section, the percentage of novaculite to shale increases, and the individual novaculite beds are thicker.

According to Purdue and Miser (1923) these two formations are separated by an unconformity near Hot Springs in the eastern Ouachitas. This, however, they consider to be local, stating that the general relationship between these two formations is conformable. Hendricks, *et al.* (1947) report that the two formations are conformable in the Black Knob Ridge area of Oklahoma.

### *Paleontology, Age, and Correlation*

No fossils were found in the Missouri Mountain Slate in the Mena and Board Camp quadrangles. Due to the essentially unfossiliferous nature of the formation and the lack of thorough stratigraphic work at that time, Purdue (1909) did not refer the Missouri Mountain to any geologic system, stating that it might be of Ordovician, Silurian, or Carboniferous age. Hendricks, *et al.* (1947) reported a few fossils from this formation at Black Knob Ridge, Atoka County, Oklahoma. These are evidence for a Silurian age.

The Missouri Mountain Slate is equivalent in age to the basal Niagaran shaly limestones of Tennessee which change from gray to red as they approach the Mississippi embayment (Miser and Purdue, 1929, p. 49). Stratigraphically, the formation lies above the early Silurian Blaylock Sandstone and below the Devonian-Lower Mississippian Arkansas Novaculite. The evidence is that the Missouri Mountain Slate is of Middle to Upper Silurian age.

## Arkansas Novaculite

### *Definition*

The most distinctive formation throughout the central Ouachita Mountains, from the standpoint of topography and lithology, is the Arkansas Novaculite. Lithologically it is distinctive for its massive, white, basal member. Topographically it is distinctive for its steep, narrow ridges, which reflect the steepness of dip, and the thickness and resistance of the formation compared with adjacent formations. Where the formation is thicker, the ridges are broader and have not been breached by erosion.

The first discussion of the age of the Arkansas Novaculite was published by Griswold (1892) in his paper "Whetstones and the Novaculites of Arkansas." In the report he first used the term "Arkansas Novaculite or Arkansas Stone." However, he also included the Bigfork Chert in this usage. Purdue (1909, p. 39) first applied the name in a formational sense in defining rocks which lie between the Missouri Mountain Slate and the basal Stanley shales (then termed the Mountain Fork Slate). Miser (1917) divided the Arkansas Novaculite into three members. These divisions were not mapped in the present study because of the poorly exposed contacts. They were recognized where exposed, however, and used as guides to determine the proper stratigraphic sequence or relation to the adjacent formations.

The term "novaculite" was first applied to rocks of the Ouachitas by Schoolcraft (1819). Goldstein (1960, p. 139) states that the name dates back as far as 1796. The term was derived from the Latin word for razor, *novacula,* referring to the early usage of these rocks as whetstones. Tarr (1938) defined novaculite as "a very dense, even textured, light colored, cryptocrystalline siliceous rock similar to chert but characterized by a dominance of quartz rather than chalcedony."

### *Distribution*

The Arkansas Novaculite crops out in the southern and eastern portions of the Mena and Board Camp quadrangles, throughout the Benton-Broken Bow uplift in Oklahoma and Arkansas, and in the Potato Hills and Black Knob Ridge areas. Its outcrop pattern outlines the area generally termed "the core of the Ouachita Mountains."

### *Lithology, Petrography, and Thickness*

In the Mena and Board Camp quadrangles the lower member of the Arkansas Novaculite is massive with some beds eight to ten feet thick. It is predominantly white or light gray. The middle member consists of dark bluish-gray chert in beds from one to eight inches in thickness interbedded with fissile black shale. The upper member is gray and bluish gray, massive novaculite.

The lower member of the Arkansas Novaculite consists of a white or light gray novaculite. The beds vary in thickness from four to ten feet. Interbedded with the novaculite are beds of gray to black shale ranging from one to eighteen inches in thickness. Locally, quartzitic sandstone beds of similar thicknesses occur near the base of the member.

Petrographic study shows that the rocks of the lower member have a dense groundmass of microcrystalline, equigranular, mosaic quartz. The grains have a uniform size between 0.01 and 0.02 mm. Scattered throughout the microcrystalline groundmass are rhombic areas filled with mosaic quartz (identical to that of the surrounding groundmass) or unicrystalline quartz. The size of the rhombs ranged from 0.03 to 0.08 mm. These rhombic crystals indicate that a carbonate, either dolomite or siderite, was formerly present. When observed with reflected light, the red outlines observed around a few of the grains were evidence that the original carbonate was siderite.

Some areas, oval in shape, 0.10 to 0.125 mm in size and slightly darker than the surrounding groundmass, may represent radiolarian remains.

In the area mapped, the lowest member of the Arkansas Novaculite is the thickest in the Mena quadrangle, with a thickness of approximately 125 to 150 feet on Dallas Mountain and surrounding ridges. It thins sharply to the east in the Board Camp quadrangle, where a six- to eight-foot section of light bluish gray novaculite crops out in Boggy Creek. It is underlain by green shale of the Missouri Mountain Formation and is considered to be the lower member of the Arkansas Novaculite. This lower member is persistent to the eastern border of the Board Camp quadrangle and may be traced through scattered outcrops along the ridges in that region.

A quartzite is present at the base of one of the lowermost massive, light gray beds of novaculite (see Fig. 3). There are other locally occurring quartzite beds near this contact. They range from three to eighteen inches in thickness and consist of well rounded detrital quartz grains and chert fragments. A minor amount of secondary overgrowth surrounds some of the detrital quartz, and the interstices contain a mosaic of silica. Carbonate rhombs are numerous and, in one case, occur along the contact between the quartz grain and the interstitial chert, penetrating the quartz. Dark, argillaceous or clay material is present in the interstices, giving a dark color to the rock. This argillaceous material is compressed to conform to the grain boundaries.

The chert (or novaculite) of the middle

This feature, reported by various authors (Cline, 1960; Shelburne, 1960; and Morris, 1962), may be considered as a type of graded bedding. Otherwise, graded bedding is inconspicuous not only in the Tenmile Creek Formation, but also in other units of the Stanley Group. Flute and groove casts and convolute bedding are found, but they are not abundant. Cross bedding is rare but has been noted in some of the sandstones and, on a small scale, in the thin siltstones.

The sandstones are lenticular, and individual strata may be traced laterally no more than two miles. Some are as much as six feet thick, although a thickness of one to three feet is more usual. In the Board Camp quadrangle, south of the Ouachita River, the sandstones are thicker and more numerous, and they support narrow linear ridges.

Several siliceous shales in the upper portion of the Tenmile Creek Formation have been traced through the area. They are dark bluish gray in color and have conchoidal fracture. On weathering, these shales become lighter gray, softer, and appear to be more argillaceous. Associated with them are dark gray, thin-bedded shales. In one locality they occur with a thin layer of cross-bedded sandstone.

One interval of siliceous shales has been traced across the Board Camp quadrangle and the northeastern corner of the Mena quadrangle. The best exposures suggest that as many as four siliceous shale units are present with interbedded dark and light gray nonsiliceous shales in a stratigraphic interval approximately 75 feet thick. This zone is considered to be that described by Harlton (1938, p. 868) and Cline (1960, p. 34) as dividing the lower and upper members of the Tenmile Creek Formation. At most localities only one or two siliceous shale units are recognized. The soil and vegetation cover often conceal not only these distinctive lithologic markers but also any structural features which might affect their lateral extent, thus hampering mapping.

In general, the siliceous shales found at various intervals in the Stanley Group are similar petrographically. They consist of fine argillaceous material, sericite or muscovite and fine grains of quartz. In addition, they contain spherical or ellipsoidal particles of silica which consist of chalcedony with a radial fibrous texture. These particles are elongate parallel to the bedding. Bedding is compacted around the larger particles. These globules are considered remnants of some micro-organism, possibly cross sections of radiolarians or sponge spicules. The silica of which they originally were composed has been recrystallized and fills the globular shape of the original shell outline.

Numerous other forms, definitely recognizable as sponge spicules, are scattered throughout the siliceous shales. Usually they are concentrated as a microcoquina, as seen in the thin section of a siliceous shale from the Moyers Formation. This concentration is along the bedding and in the bands of sapropelic material. There is a variety of types: monaxon, triaxon (some with bulbous terminals on each spine), and some that are irregularly shaped.

No complete section of the Tenmile Creek Formation is exposed at any one locality within the Mena and Board Camp quadrangles. The monotonous lithologic character prevents accurate measurement of a composite section. Assuming an average dip of 45 degrees, and no structural complications, the thickness of the Tenmile Creek Formation along the eastern border of the mapped area is approximately 15,000 feet. Measured dips indicate that 45 degrees is too high; thus, the actual thickness would be less than the above figure.

Other authors have estimated the thickness of the Tenmile Creek Formation (Laudon, 1959; Cline, 1960; Shelburne, 1960) to be from 7,600 to 10,000 feet. Compared with these estimates, the formation is thicker in the Mena and Board Camp quadrangles.

Cline and Shelburne (1959, p. 207) state that the Stanley and Jackfork groups attain an aggregate thickness of 16,200 feet in Johns Valley in the Tuskahoma syncline, Pushmataha County, Oklahoma. Thirteen and one-half miles to the northwest at the Ti Valley fault, these groups thin to practically nothing. They suggest that the rapid thinning is primarily depositional, and that the convergence is at all stratigraphic levels in both groups.

## Moyers Formation

The Moyers Formation was named by Harlton (1938, p. 870) for outcrops north of the village of Moyers, Pushmataha County, Oklahoma, on the south flank of the Tuskahoma syncline. Its lower limit is defined as the base of the Moyers Siliceous

Figure 4. The massive beds of the lower member of the Arkansas Novaculite overlying dark red shales of the Missouri Mountain Formation (lower left). Locality is just west of Board Camp Creek, Sec. 7, T3S, R29W.

by a few thin beds of dark novaculite of the middle member and some beds of white novaculite of the lower member. A rubble of brecciated novaculite found along a ridge just east of the map area is the only evidence for its presence. The exact thickness of the Arkansas Novaculite in the eastern section is difficult to determine because of soil and vegetation covers. In many instances the extent of the novaculite must be mapped on the presence of its rubble.

Miser and Purdue (1929, p. 50) report that the Arkansas Novaculite attains its greatest thickness in the Caddo, Missouri, and Cossatot Mountains, where it is approximately 900 feet thick. These areas are ten to fifteen miles south and southeast of the Mena and Board Camp quadrangles. In the Cross Mountains, approximately fifteen miles southwest of the Mena quadrangle, the formation is 300 to 550 feet thick.

### *Paleontology, Age, and Correlation*

No megafossils were found in the Arkansas Novaculite within the Mena and Board Camp quadrangles. Figure 5, a photomicrograph of the middle member, illustrates some ellipsoidal forms, evidence for the presence of organic material, probably radiolarians. Miser and Purdue (1929, p. 58) report finding only silicified wood and a single collection of conodonts. Goldstein and Hendricks (1953) found sponge spicules, radiolarians, and spores.

Griswold (1892) referred to the rocks of the "novaculite area" and considered them to be of Lower Silurian age, equivalent to what is now the Trenton portion of the Ordovician. Purdue (1909), in his discussion of the Arkansas Novaculite, did not assign an age to these rocks. Miser and Purdue (1929, p. 57-59) concluded (based largely on the opinions of Ulrich, 1911) that the lower division is Middle Devonian and the other two members are of Middle and Upper Devonian age.

The Arkansas Novaculite was considered to be entirely Devonian by most workers until Hass (1951), on the basis of conodonts collected at the Caddo Gap locality, placed the lower division of the formation in the Lower or Middle Devonian. All except the

Figure 5. Arkansas Novaculite (A-2). Middle member of the formation containing fine clay in a matrix of microcrystalline silica, finer than that of the lower member. Ellipsoidal forms contain a higher concentration of silica than the surrounding matrix. These forms suggest the former presence of radiolarians. The maximum long axis in the photomicrograph is about 0.15 mm. The ellipsoids and the fine clay particles are oriented parallel to bedding or to foliation. Ordinary light, X 137.

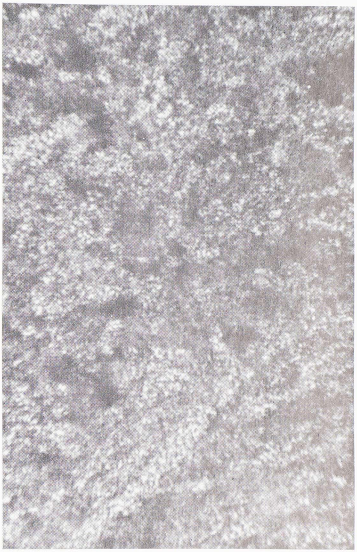


Figure 6. Arkansas Novaculite (A-6). Upper member of the formation, consisting of carbonate and carbonate rhombs dispersed in a matrix of microcrystalline silica. Crossed nicols, X 48.

upper 30 feet of the middle member and all of the upper member were defined as Kinderhook or possibly Osage age. Hass also provided a summary of previous work leading to the determination of the age of the formation.

## Comparison of Arkansas Novaculite and Bigfork Chert

The Bigfork Chert and the middle member of the Arkansas Novaculite are similar both microscopically and megascopically. The Bigfork is somewhat more argillaceous, generally darker, and nontranslucent. Both are slightly finer grained and contain a higher percentage of clay than the upper and lower members of the Arkansas Novaculite. These two factors contribute to their darker color. Evidence of organic remains is much more common in the Bigfork and, in one rock, sponge spicules provide the major portion of the silica present.

King (1937, pp. 54 and 55), in comparing the cherts and novaculites in the Caballos Formation of the Marathon Basin of west Texas, noted that novaculites are white, massively bedded, uniformly fine grained with no evidence of lamination, and appear to have a somewhat porous texture. The cherts are dark, in layers only several inches thick, laminated, and contain more clastic and organic material than novaculites. Goldstein (1960) suggests that it is not possible to draw a rigid distinction between chert and novaculite.

## Stanley Group

### *Definition*

Taff (1902) originally defined the "Standley Shale" as the thick shale beds which lie between the Talihina Chert and the Jackfork Sandstone. It was described from outcrops along the Kiamichi River valley near the village of Stanley (spelled Standley prior to 1900) in Pushmataha County, Oklahoma. Purdue (1909, p. 40), in describing this sequence, initiated the spelling "Stanley," which has become the accepted form.

Harlton (1938) made a significant contribution to the understanding of the stratigraphy of the Stanley, which he interpreted as a depositional "group." Using thin, persistent siliceous shales as stratigraphic markers, he then divided it into three formations: a lower, Tenmile Creek; a middle, Moyers; and an upper, Chickasaw Creek. Harlton's type section for these subdivisions of the Stanley Group is at the south end of the Tuskahoma syncline, near Moyers, Pushmataha County, Oklahoma. The Stanley Group now includes the strata lying between the Arkansas Novaculite and the Jackfork Group.

He also considered that the overlying Jackfork represented a depositional "group" and placed it and the Stanley in the Pushmataha Series of his proposed Bendian System. The Bendian was regarded as intermediate between the Mississippian and Pennsylvanian. Although the Bendian System is not now considered to be valid, Harlton's lithologic subdivisions have been recognized by subsequent workers in Oklahoma (Cline and Shelborne, 1959; Laudon, 1959; Cline, 1960; Shelborne, 1960; and several other workers) and in the Mena and Board Camp quadrangles.

### *Distribution*

Sediments of the Stanley Group are found throughout the Ouachita Mountains in Arkansas and Oklahoma. They underlie almost all of the northern two-thirds of the Mena and Board Camp quadrangles. Structurally and topographically incompetent, the Stanley forms a valley, broken only by a few ridges supported by the more resistant sandstones. Most of the prominent valleys in the Ouachitas are underlain by the shales and sandstones of the Stanley Group.

### *Lithology, Petrography, and Thickness*

In the Mena and Board Camp quadrangles, the Stanley is represented by an estimated 12,000 feet of shale with minor amounts of sandstone which become more common in the upper 1,500 feet of the group.

## Tenmile Creek Formation

The Tenmile Creek Formation includes the strata between the Arkansas Novaculite and the basal siliceous shale of the Moyers Formation. It is predominantly shale but contains sequences of sandstone, some of which are massive-bedded and form prominent ridges. Individual beds of sandstone also are scattered throughout the formation. The shales are usually dark gray to dark olive green on a fresh surface and weather to a lighter olive green or buff. The olive-green color is generally distinctive of weathered Stanley shales. Persistent, thin-bedded siltstones are interbedded with the shale.

Most of the sandstones are poorly sorted, argillaceous, micaceous, and contain shale fragments. They are gray on fresh surfaces, weathering to an olive green, brownish green, or tan. Occasional beds, however, consist largely of quartz with a siliceous cement. These may contain a mafic constituent, making them appear darker than the typical argillaceous Stanley sandstones.

Six specimens, considered on the basis of hand sample examination and field observation to be typical of Tenmile Creek sandstones, were examined petrographically. These consist of angular to subangular quartz in a clay matrix. The quartz is medium to very fine grained, and constitutes from 53 to 78 percent of the rock. Therefore, these rocks are graywackes according to Pettijohn's classification (1957, p. 291), for they contain more than 15 percent detrital matrix. Although quartz is the predominant detrital mineral and there is an abundance of mica, chert fragments, rock fragments, feldspar, and magnetite are present but are not common. Chlorite is common.

Bedding, perceptible in some thin sections as an alignment of the long axes of quartz grains and parallel elongation of clay particles in the rock, is seldom recognizable within the sandstones in the field. Some have sharp contacts with underlying shales but become gradually more argillaceous as they grade upward into the overlying shales.

This feature, reported by various authors (Cline, 1960; Shelburne, 1960; and Morris, 1962), may be considered as a type of graded bedding. Otherwise, graded bedding is inconspicuous not only in the Tenmile Creek Formation, but also in other units of the Stanley Group. Flute and groove casts and convolute bedding are found, but they are not abundant. Cross bedding is rare but has been noted in some of the sandstones and, on a small scale, in the thin siltstones.

The sandstones are lenticular, and individual strata may be traced laterally no more than two miles. Some are as much as six feet thick, although a thickness of one to three feet is more usual. In the Board Camp quadrangle, south of the Ouachita River, the sandstones are thicker and more numerous, and they support narrow linear ridges.

Several siliceous shales in the upper portion of the Tenmile Creek Formation have been traced through the area. They are dark bluish gray in color and have conchoidal fracture. On weathering, these shales become lighter gray, softer, and appear to be more argillaceous. Associated with them are dark gray, thin-bedded shales. In one locality they occur with a thin layer of cross-bedded sandstone.

One interval of siliceous shales has been traced across the Board Camp quadrangle and the northeastern corner of the Mena quadrangle. The best exposures suggest that as many as four siliceous shale units are present with interbedded dark and light gray nonsiliceous shales in a stratigraphic interval approximately 75 feet thick. This zone is considered to be that described by Harlton (1938, p. 868) and Cline (1960, p. 34) as dividing the lower and upper members of the Tenmile Creek Formation. At most localities only one or two siliceous shale units are recognized. The soil and vegetation cover often conceal not only these distinctive lithologic markers but also any structural features which might affect their lateral extent, thus hampering mapping.

In general, the siliceous shales found at various intervals in the Stanley Group are similar petrographically. They consist of fine argillaceous material, sericite or muscovite and fine grains of quartz. In addition, they contain spherical or ellipsoidal particles of silica which consist of chalcedony with a radial fibrous texture. These particles are elongate parallel to the bedding. Bedding is compacted around the larger particles. These globules are considered remnants of some micro-organism, possibly cross sections of radiolarians or sponge spicules. The silica of which they originally were composed has been recrystallized and fills the globular shape of the original shell outline.

Numerous other forms, definitely recognizable as sponge spicules, are scattered throughout the siliceous shales. Usually they are concentrated as a microcoquina, as seen in the thin section of a siliceous shale from the Moyers Formation. This concentration is along the bedding and in the bands of sapropelic material. There is a variety of types: monaxon, triaxon (some with bulbous terminals on each spine), and some that are irregularly shaped.

No complete section of the Tenmile Creek Formation is exposed at any one locality within the Mena and Board Camp quadrangles. The monotonous lithologic character prevents accurate measurement of a composite section. Assuming an average dip of 45 degrees, and no structural complications, the thickness of the Tenmile Creek Formation along the eastern border of the mapped area is approximately 15,000 feet. Measured dips indicate that 45 degrees is too high; thus, the actual thickness would be less than the above figure.

Other authors have estimated the thickness of the Tenmile Creek Formation (Laudon, 1959; Cline, 1960; Shelburne, 1960) to be from 7,600 to 10,000 feet. Compared with these estimates, the formation is thicker in the Mena and Board Camp quadrangles.

Cline and Shelburne (1959, p. 207) state that the Stanley and Jackfork groups attain an aggregate thickness of 16,200 feet in Johns Valley in the Tuskahoma syncline, Pushmataha County, Oklahoma. Thirteen and one-half miles to the northwest at the Ti Valley fault, these groups thin to practically nothing. They suggest that the rapid thinning is primarily depositional, and that the convergence is at all stratigraphic levels in both groups.

### MOYERS FORMATION

The Moyers Formation was named by Harlton (1938, p. 870) for outcrops north of the village of Moyers, Pushmataha County, Oklahoma, on the south flank of the Tuskahoma syncline. Its lower limit is defined as the base of the Moyers Siliceous

Shale Member and its upper limit by the basal siliceous shale of the Chickasaw Creek Formation. At the type section it is approximately 1,100 feet thick.

Lithologically, the Moyers Formation differs from the underlying Tenmile Creek by the increase in the amount of sand in relation to shale. The sands are more massive and slightly less argillaceous than those which characterize the underlying Tenmile Creek strata. They are gray on a fresh surface and weather, often spheroidally, to brown or tan hues. Bottom markings and convolute bedding are common. The shales are gray, gray-green, or black, and are similar to the shales in the Tenmile Creek Formation. The resistant sands form low parallel ridges which are easily recognized on topographic maps or aerial photographs.

In the Mena quadrangle the Moyers Formation crops out east of Rich Mountain directly north of the town of Mena. In the Board Camp quadrangle it crops out immediately south of Goldsberry Mountain and Lamb Mountain. In both of these areas the low, narrow, parallel ridges are easily discernible on the topographic map. Below this sequence lies a bed of siliceous shale ten to twenty feet thick. This unit is considered to represent the Moyers Siliceous Shale Member which defines the lower limit of the formation as described by Harlton (1938, p. 872) and mapped by Cline (1960) and Shelburne (1960). Below this siliceous shale is the Tenmile Creek Formation, which forms topographic lows.

East of Rich Mountain the Moyers Formation has an average westward dip of 17 degrees. Its calculated thickness is between 1,200 and 1,400 feet.

### Chickasaw Creek Formation

The name Chickasaw Creek Formation stems from Harlton's division of the Stanley Group. Some geologists (Hendricks, *et al.*, 1947) have placed it in the Jackfork Group. Others (Cline and Shelburne, 1959; Laudon, 1959) follow Harlton in including it within the Stanley Group. The base of the formation is defined by the basal Chickasaw Creek siliceous shale, and its upper limit is defined by a siliceous shale which lies below the massive sandstones of the Jackfork Group.

The best exposure of the Chickasaw Creek Formation is in the creek bank below the Ward Lake Spillway at the base of Rich Mountain, where 35 feet of strata are referred to the formation. The stratigraphic section consists of black shale, with a few beds of siltstone one to two inches thick. Dark bluish black siliceous shales occur in two thin intervals. The lower one is two feet thick and the upper one approximately five feet thick. Overlying this upper group of siliceous shales is twelve feet of soft, black shale with intercalated sandstone beds one to three inches in thickness. Faulting truncates the top of the shale zone, and the Stanley and Jackfork groups are in fault contact at this locality.

A siliceous shale bed may be traced around the eastern tip of Rich Mountain. This bed appears to be in the same stratigraphic position as those found below the Ward Lake Spillway, and is considered to be equivalent to the shale present there near the top of the formation. Poor exposures prohibit detailed study.

#### *Stratigraphic Relationship*

The relationship between the Stanley and the underlying Arkansas Novaculite normally is conformable, although the break is sharp. Local unconformities are present along the contact between these two formations. Several hundred feet south of Bethesda Lake in the southeast 1/4 of Sec. 31, T2S, R30W, the basal bed of the Stanley contains a thick breccia of novaculite. This breccia grades up into a quartzose sandstone (see Fig. 7). Along the creek draining Bethesda Lake to the north and in outcrops just west of the lake, the contact is conformable. This abrupt change in the relationship between the Arkansas Novaculite and the Stanley shales occurs within a distance of less than one-half mile. Other possible local unconformities between these two units are recognized by the occurrence of brecciated novaculite not *in situ*. Their occurrence is more common in the east central area of the Board Camp quadrangle.

The Stanley and Jackfork groups are considered conformable throughout the Ouachitas.

#### *Paleontology, Age, and Correlation*

In the Mena and Board Camp quadrangles no megafossils were found in the Stanley Group. A few microfossils (monaxon and triaxon sponges spicules and radiolarians) were recognized in photomicrographs of

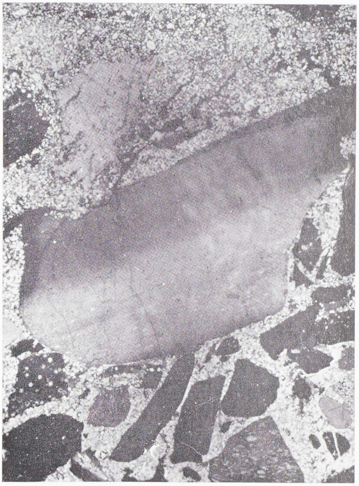


Figure 7. Tenmile Creek breccia (S-13B). Breccia near the Stanley-Arkansas Novaculite contact. The large fragment in the center is chert. There are other fragments of chert and siliceous shale throughout the breccia. The sandstone in the upper portion of the photomicrograph is stratigraphically above the brecciated layer and consists of angular to subrounded quartz. Crossed nicols, X 5.

siliceous shales from the Stanley. Honess (1923) collected crinoid stems, brachiopods, and a single bryozoan from two localities in McCurtain County, Oklahoma. Studies of this fauna indicated a Mississippian-Pennsylvanian (?) age. Plant fragments have been found in the Stanley from other areas in the Ouachitas (Miser and Purdue, 1929; Cline, 1960). Conodonts also have been used in determining the age of the Stanley.

The age of the Stanley Group has been the subject of much discussion during the last half century. In his original definition, Taff placed the Stanley "formation" in the Upper Ordovician division of the Silurian. In later studies it has been assigned to various positions within the "Carboniferous System." Miser and Honess (1927, p. 10) placed both the Stanley and the Jackfork in the Mississippian. This assignment was based on the occurrence of Mississippian fossils in the lower portion of the Johns Valley Shale overlying the Jackfork at Johns Valley, Oklahoma. From his study of conodonts from siliceous shales, Hass (1950, p. 1580) regarded the lower part of the Stanley as Meramecian. He correlated the Stanley with the Caney Shale of the Arbuckle Mountain area and the Barnett Formation of Texas, formations that have long been referred to the Mississippian System. Cline (1960, p. 85), mapping in the central Ouachitas of Oklahoma, recognized a depositional tongue of the Caney Shale in the lower part of the Johns Valley Shale. This tongue of the Caney contained late Mississippian goniatites. As the Johns Valley Shale lies stratigraphically above the Stanley-Jackfork sequence, the Meramecian age of the Stanley Group appears to be confirmed. More comprehensive discussions of the age of the Stanley-Jackfork-Johns Valley-Atoka sequence have been presented by Miser and Purdue (1929, pp. 65-75) and Cline (1960, pp. 40-41).

## Jackfork Group

### *Definition*

Taff (1902) named the Jackfork "formation" from exposures on Jackfork Mountain in southern Pittsburg County, Oklahoma. Harlton (1938), from his studies of the Round Prairie syncline in Atoka County, Oklahoma, divided Taff's unit into four formations and gave it the status of a "group." In ascending order, these formations are: the Wildhorse Mountain, Prairie Mountain, Markham Mill, and Wesley. Subsequently, in 1959, he named the Game Refuge Formation and placed it in the Jackfork Group above the Wesley. The Game Refuge originally had been correlated with the Pennsylvanian Union Valley Sandstone (Harlton, 1938), and this name was introduced for the upper formation of the Mississippian Jackfork Group.

### *Distribution*

The Jackfork Group crops out prominently throughout the Ouachita Mountain area in Arkansas and Oklahoma. It is a sequence of massive, resistant sandstones and interbedded shales, supporting many ridges including Rich Mountain, Irons Fork Mountain, and Fouche Mountain. Only the lower beds of the Jackfork are exposed in the northern parts of the Mena and Board Camp quadrangles. These overlie the Moyers-

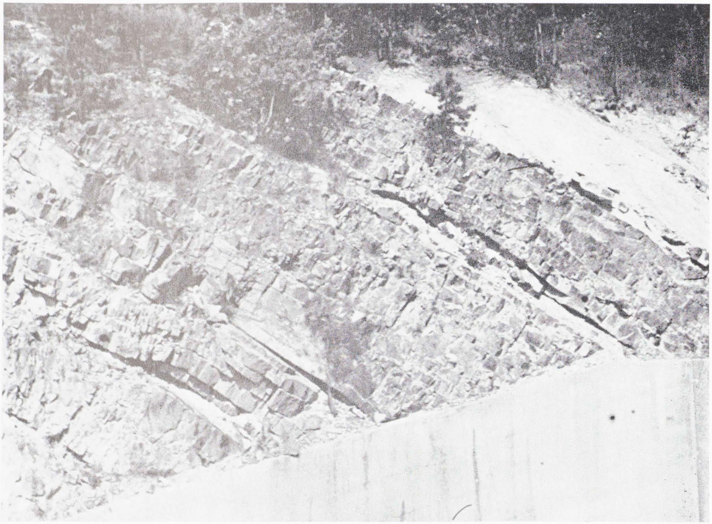


Figure 8. Lower beds of the Wildhorse Mountain Formation, exposed on the south Bank of Ward Lake Spillway. The strata dip north.

Chickasaw Creek sequence of the Stanley Group at the eastern end of Rich Mountain (see Fig. 8) and on the south flank of Goldsberry Mountain (a "foothill" of Irons Fork Mountain).

*Lithology, Petrography, and Thickness*

The Wildhorse Mountain Formation (the only portion of the Jackfork Group exposed in the Mena and Board Camp quadrangles) contains a higher percentage of sandstone than is found in the underlying Stanley Group. These sandstones are massive, occur in thick sequences, and generally contain a higher percentage of quartz in relation to the clay matrix than do those of the Stanley Group. Most could be classed as protoquartzites (see Pettijohn's classification, 1957). They are dark gray to off-white on fresh surfaces and weather to a brown or light tan. The darker sands contain a larger fraction of clay material. Current features including flute casts, groove casts, and load casts are fairly common. Plant remains are abundant in some beds and several fragments of *Calamites* were found in the basal beds.

The cut for the spillway at the west end of Ward Lake exposes 230 feet of the Wildhorse Mountain Formation. Interference ripple marks are present on the top of several beds of quartzose sandstone. Near the top of this exposure some graded bedding is observed in one of the massive sandstones. Coarse grains of angular quartz are suspended in a matrix of medium to fine grained quartz and clay. The amount of coarse grained material becomes less abundant near the top of the bed. At this locality the Jackfork is in fault contact with the underlying Chickasaw Creek Formation. Around Rich Mountain and along the south side of Goldsberry Mountain the contact is considered to be depositional.

Individual sandstone strata in the Wildhorse Mountain Formation range from a few inches to fourteen feet in thickness. The formation is thick bedded and, because of the high quartz content and jointing, appears blocky. The shales of the lower part of the formation are black to light gray in color. Soft and fissile, they weather to light gray tones, although the most intensely weathered shales are light tan. Near Ward Lake several

50- to 100-foot sequences of shales are exposed.

Several specimens of sandstones from the Jackfork Group were studied petrographically. They consist of quartz ranging in size from medium to very fine grained. The grains are subangular to subrounded and secondary overgrowth is well developed. Clay fragments are concentrated in the interstices or mashed along the contacts between grains. There are a few scattered fragments of chert. Bedding may be noted in the thin sections by the subparallel elongation of the quartz grains.

Quartz ranges from 93 to 98 percent, bordering on the limit between orthoquartzite and protoquartzite, according to Pettijohn's classification. Bokman (1953) terms the Jackfork sandstones subgraywackes and Goldstein (1959b) considers them "dirty" quartzose sandstones and subgraywackes.

Seely (1962), who mapped the Rich Mountain area to the west of the Mena quadrangle, assigned 3,378 feet of strata in the lower part of the Jackfork Group to the Wildhorse Mountain Formation. Only these lower strata occur within the Mena-Board Camp area, and their assignment to the Wildhorse Mountain Formation is here accepted. The lower Jackfork strata exposed on Goldsberry Mountain are considered to belong also to the same formation.

### *Paleontology, Age, and Correlation*

As mentioned in the discussion of the age of the Stanley Group, the Jackfork lies below the Johns Valley Shale, the lower part of which contain late Mississippian goniatites. Based on these data, the Jackfork Group is older than Upper Chesterian and is younger than the Meramecian Stanley sediments. A more precise age assignment of the Wildhorse Mountain Formation cannot be made on present evidence.

## IV. Structure

### *Regional*

The Benton-Broken Bow uplift is an anticlinorium approximately 200 miles long and 30 miles wide extending from central Arkansas westward into southeastern Oklahoma. It can be divided into several prominent structural features (Miser and Purdue, 1929, p. 1): the Crystal Mountain anticline, the Mazarn syncline, the Cassotot anticline, and the Cross Mountains anticline (see location map, Fig. 1). Along the axis of the anticlinorium are exposed Cambrian, Ordovician, Silurian, and Devonian strata. Mississippian and Pennsylvanian strata crop out along the flanks and are referred to as the frontal Ouachitas.

In the frontal Ouachitas the strata have been broken by a series of thrust faults. The major thrusts dip to the south, and have similar strike generally parallel to that of the sediments and the axis of the Benton-Broken Bow uplift. They separate the frontal Ouachitas into structural blocks. The amount of displacement of these thrusts has been the subject of much speculation and disagreement.

In the Benton-Broken Bow uplift the faulting is commonly high-angle reverse, although there are examples of low-angle thrusts. The folds in the Benton-Broken Bow uplift are closely compressed. They are commonly asymmetrical, one limb vertical or overturned, but some are isoclinal. There are also compound folds, some of which are normal or inverted fan folds.

The frontal Ouachitas are characterized by folds that are broader than those in the Benton-Broken Bow uplift. The mountains are synclines, five to ten miles in width, and composed of Jackfork and Atoka strata. The intervening anticlinal valleys are formed by shales of the Stanley Group.

The Mena and Board Camp quadrangles lie on the northwest flank, near the "nose," of the Benton-Broken Bow uplift (see Fig. 1). The structural features recognized within these quandrangles are characteristic of those found elsewhere in the Ouachita Mountain area.

### *Folding*

A portion of the Benton-Broken uplift, consisting of Devonian and older strata, is referred to as the "core" of the Ouachitas. The structure of these rocks differs from that of the Mississippian and Pennsylvanian strata on the flanks of the uplift. There are two factors to which this difference may be attributed. One is the stratigraphic change from the relatively thin beds of the core sediments to the thicker strata on the flanks. The other factor is that the flank strata are farther from the center of the uplift and were not subjected to the same degree of compressive stress.

Folds within the core area are commonly isoclinal (Miser and Purdue, 1929, pl. 15).

An example of isoclinal folds forming an inverted fan fold is illustrated on cross section A-A′ (Fig. 10). This isoclinal fold axis extends into the southeast area of the Mena quadrangle and trends northwest-southeast (see geologic map, Pl. 1). The axis has been mapped in the area south of the Mena and Board Camp quadrangles for several miles along the strike of the strata (Miser and Purdue, 1929, pls. 13 and 15). North of the central axis of this fan fold the axial planes of the isoclinal folds dip to the north and the south limbs are overturned: southward, the north limbs are overturned and the axial planes dip to the south.

The oldest formation exposed in the Mena and Board Camp quadrangles, the Bigfork Chert, forms the crest and flanks of two anticlines which extend into the mapped area from the east. The axes of these anticlines can be traced to the west through the Stanley shales into the Mena quadrangle. The remainder of the narrow linear ridges in the southern portion of the area are supported by the Arkansas Novaculite. To the south and southwest of the "Bigfork" anticlines, the folds are sharper and more elongate. The Missouri Mountain Slate is exposed in the crests of most of these folds. North of the "Bigfork" anticlines the folds are broader, and the ridges are not as high as those to the south. The reduction in topographic prominence is attributed to the north and northeastward thinning of the Arkansas Novaculite. That the folds are broader is due to the relative flank position on the axis of the anticlinorium.

One of the folds in which Bigfork Chert is exposed in its crest occurs in a road cut on State Highway 8 in Sec. 6, T3S, R28W. The south limb of the fold is overturned with faulted and tightly folded strata of the Bigfork dipping steeply to the north (Fig. 9b). The crest is concealed by overburden and, on the north limb, the Bigfork strata dip to the north at angles of 20 to 50 degrees. These exposures clearly exhibit the complexity of folding in the area. The details of the folding usually cannot be observed because of soil and vegetation cover. In the interpretation of such structures, fracture cleavage proved to be a useful tool in determining the tops and bottoms of beds. It was particularly useful in the east central portion of the Board Camp quadrangle, where the shales above and below the Arkansas Novaculite are very similar, in determining the proper stratigraphic sequence and, thus, the identification of these similar strata.

A large regional fold, the Rich Mountain syncline, extends into the northwest corner of the Mena quadrangle. Seely (1962) traced this fold as much as 20 miles to the west into Oklahoma. In the Mena quadrangle the axial plane dips to the south at an angle of about 45 degrees (Seely, 1962). The plunge of the fold is to the northwest. This is one of several similar structural features in the frontal Ouachitas. The major folds recognized in the Stanley shales may be traced to folds mapped in adjacent, more competent rocks. Minor folds, faults, dip and strike variations, and contorted bedding may also be seen in outcrops, but soil cover, vegetation, and the similarity of lithologies prevent tracing most of these structural features.

### *Faulting*

The frontal Ouachitas are cut by several regional thrust faults, one of which, the Windingstair fault, has been traced into the Mena quadrangle. Seely (1962), while mapping the geology of an adjoining area, traced the Windingstair fault from eastern Oklahoma into the portion of the Mena quadrangle north and west of U.S. Highways 71 and 59 (see Fig. 1). During the present study this fault has been mapped for an additional four miles to the northwest corner of Mena Lake. Its trace is delineated by the abrupt change in strike (Secs. 6 and 7, T2S, R30W) where the Tenmile Creek Formation, striking east-west, is thrust against the north-south striking Moyers Formation. Associated with this abrupt change in strike are minor faults and contorted bedding. Although this abrupt change in strike direction converges to a southeast-northwest direction, there is additional evidence that the fault extends farther to the east. From the northwest corner of Sec. 15, T2S, R30W, Brier Creek and Prairie Creek follow almost a straight line to where they empty into the Ouachita River, which also continues to flow in an easterly direction for several hundred feet. Further extension of the line to the east would mark roughly the termination of the two siliceous shale beds. On the evidence cited above the Windingstair fault definitely can be traced to Sec. 15, T2S,

Figure 9a, b. Photographs of outcrops of Bigfork Chert on the south limb of an anticline exposed along Arkansas Highway 8, northwest corner Sec. 6, T3S, R28W. Photograph 9a: tightly folded beds; plunge to the west. Photograph 9b: steeply dipping beds near the contact with the Polk Creek Shale.

R30W, and it is suggested that it extends at least to Sec. 16, T2S, R29W.

Movement along the Windingstair fault displaced the Tenmile Creek Formation against uppermost beds of the Moyers Formation (cross section B-B′, Fig. 11). The total missing section is approximately 1,900 feet. The Moyers Formation, which elsewhere has a total thickness of 1,300 feet, is missing on the upthrown side of the fault. The remaining approximately 300 feet of missing section is from the upper portion of the Tenmile Creek Formation. This amount was calculated by estimating the thickness of the Stanley Group along the eastern boundary of the map using an average dip of 45 degrees, based on field measurements, and the outcrop width. Similar measurements along the western boundary indicate that not more than a few hundred feet of the upper portion of the Tenmile Creek Formation are missing south of the Windingstair fault.

Seely (1962) has estimated the dip of the Windingstair fault to be less than 42 degrees. He based this estimate on the dip of the axial plane of the Rich Mountain syncline. He also suggests that the dip is probably steeper to the east. Hart (1963) estimated the Windingstair fault plane to have a dip of 60 to 70 degrees.

A northward striking thrust fault located in the northwest portion of the Mena quadrangle is related to the Windingstair fault. It has thrust the beds forming the east end of Rich Mountain (in the northwest corner of the map) to the northeast over those of the Tenmile Creek Formation. The northeast direction of thrusting along this fault is evidence that the downthrown block has several hundred feet of right lateral movement. This northward striking thrust probably can be traced to the north of Rich Mountain to connect with the Honess fault (Seely, 1962, pl. 1). It is here named the Brier Creek fault.

The Honess fault (Seely, 1962) has been mapped along the south side of Irons Fork Mountain (Morris, 1962) in the Y City quadrangle (borders the Board Camp quadrangle on the north). It extends into the Board Camp quadrangle (Sec. 35, T1S, R29W) where it is truncated by a tear fault. The conclusion that the Honess fault is truncated by a tear fault is based on two lines of evidence: (1) the abrupt termination of the Moyers Formation and (2) the conformable stratigraphic relationship between the Stanley and Jackfork strata on the south flank of Goldsberry Mountain.

Other tear faults which truncate and offset thrust faults have been mapped in the Ouachita Mountains (Hendricks, *et al.,* 1947). It is postulated that faulting associated with the Honess fault has truncated two siliceous shale beds which crop out in Sec. 35, T1S, R29W. This is based on the discontinuity of the two siliceous shales. They cannot be traced to the west either due to truncation by faulting or because they are lost under the cover of vegetation. These siliceous shales have been placed in the Tenmile Creek Formation.

Morris (1962) mapped the Acron fault in the Acron quadrangle to the north. It is based on the presence of crumpled distorted bedding which he observed to be consistent along the north side of the Ouachita River. This fault has not been traced into the Mena quadrangle. The Acron fault, however, may truncate the siliceous shales which have been traced to the east bank of the Ouachita River in Sec. 2, T2S, R30W, in the north central part of the Mena quadrangle.

Faulting also is common in the tightly folded strata of the Benton-Broken Bow uplift of the Ouachita Mountains. Although some of the faults in this area have been traced for as much as fifteen miles (Miser and Purdue, 1929, pl. 3), they are not regional in extent as compared to the thrust faults in the frontal Quachitas. The majority of these faults are high-angle reverse faults. The fault planes generally dip in the direction of the dip of the axial planes of the folds they cut. Exceptions to this general pattern are illustrated on cross section C-C′ (Fig. 12).

Three anticlinal folds in the east central portion of the Board Camp quadrangle are cut by reverse faults which have a right lateral strike-slip component. The strike of these faults approximates that of the bedding in the Stanley shales until they cross the folds flanked by the more resistant Arkansas Novaculite. Here the trace of the fault bends and strikes obliquely across the outcrop.

The Sulphur Creek fault, about two miles southwestward of the southernmost of the three faults mentioned above, has left lateral strike-slip movement of approximately


FIGURE 10

CROSS SECTION A-A′

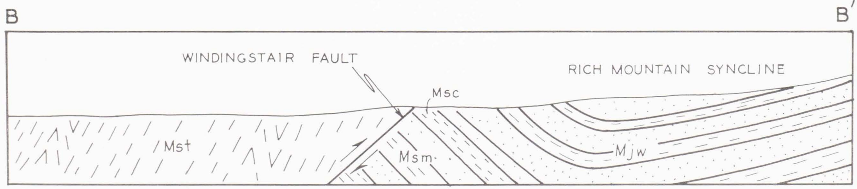
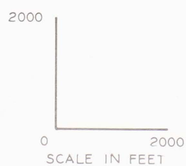



FIGURE 11

CROSS SECTION B-B′




WILDHORSE MTN. FM..Mjw
CHICKASAW CREEK FM..Msc
MOYERS FM. .........Msm

TENMILE CREEK FM.____Mst
ARKANSAS NOVACULITE..DMa
MISSOURI MTN. SLATE___Sm

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2,500 feet. The total displacement of the three right lateral strike-slip faults is closely in accord with the amount of movement along the left lateral strike-slip Sulphur Creek fault. Thus, the block which lies between the Sulphur Creek fault and the three right lateral strike-slip faults has been moved to the west.

In contrast to the relative abundance of high-angle reverse faults, thrust faulting is not common in the Benton-Broken Bow uplift. The Tower Mountain fault in the southwest portion of the map, however, is a low-angle thrust (see cross section D-D′, Fig. 13). Its trace cuts the east side of Tower Mountain at approximately a uniform elevation. Evidence for the fault is based on (1) abrupt changes in strike and dip direction between the Stanley Group and the Arkansas Novaculite, (2) the brecciation of some of the massive novaculite, and (3) the Stanley in contact with, or close to, beds of the lower member of the Arkansas Novaculite. The novaculite has been thrust to the east, and on Round Top Mountain the lower member of the novaculite rests on the Tenmile Creek Formation. To the south and southwest the Tower Mountain thrust steepens and connects with the Dallas Mountain fault.

There is a possible relationship between the high-angle reverse faults in the core and the thrust faults in the frontal Ouachitas. During deformation the sediments exposed in the core were deeply buried by the overlying Mississippian and Pennsylvanian formations. The structural features in the core were extended into the overlying sediments. Therefore, the faulting would be the "roots" of faults which extended into the Stanley shales, and were deflected to form thrust planes. Erosion of these overlying sediments has removed the traces of these faults and exposed their "roots" in the core. Evidence for this exists in the Mena and Board Camp quadrangles where the Tower Mountain fault, a low-angle thrust, joins the Dallas Mountain fault, a high-angle reverse fault.

## V. Geologic History

### *Introduction*

Two distinct depositional phases may be recognized in the strata exposed in the Mena and Board Camp quadrangles. The recognition is based on the stratigraphic characteristics, which are determined by the tectonic stability of the Quachita trough during its depositional history. The early phase includes the Bigfork Chert, Polk Creek Shale, Missouri Mountain Slate, and Arkansas Novaculite, and is termed the "tectonically stable phase." The interval in which they were deposited is upper Middle Ordovician to Lower Mississippian. During this time the rate of deposition was relatively slow, the Ouachita trough was tectonically stable, and the influx of coarse detrital sediments was comparatively small. As a result, it has been termed a sediment-starved trough (Cline, 1960).

The second phase began with the deposition of the Stanley Group and includes the younger strata exposed in the Ouachitas. The Stanley consists of a thick sequence of dark shales with graywackes in lesser amounts. The lower Jackfork beds are massive quartzose sandstones and gray shales. These strata were deposited in a rapidly filling and subsiding trough during the Middle Mississippian. This is the "tectonically unstable phase."

The ratio of thickness between the strata in the early phase of deposition and the strata of the later phase is approximately one to four, when considering the Quachitas as a whole. In the Mena and Board Camp quadrangles, the ratio is three times as great, although the complete section is not exposed. These ratios illustrate the rapid and abrupt changes in the rate of deposition in the Ouachita trough area.

### Tectonically Stable Phase

#### *Bigfork Chert-Polk Creek Shale Deposition*

In the late Middle Ordovician the silica content of the waters of the Ouachita trough increased and the bedded cherts and interbedded dark shales of the Bigfork Chert were deposited. The origin of the Bigfork cherts and of other bedded cherts has been the subject of wide discussion. There are three principal theories of origin: biochemical, metasomatic, and primary precipitation. A large number of geologists have discussed siliceous sediments from various localities, and there is abundant evidence to give definite support to a polygenetic origin of chert.

At least a part of the silica which formed the bedded siliceous deposits comprising the Bigfork Chert is of a biochemical origin.

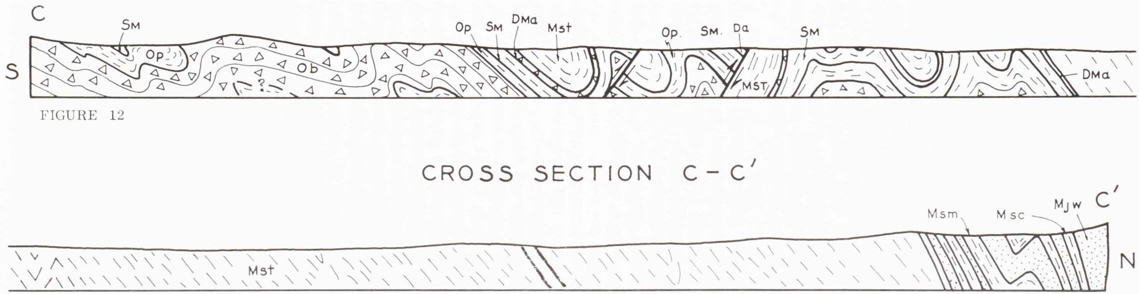



FIGURE 12

CROSS SECTION C-C'

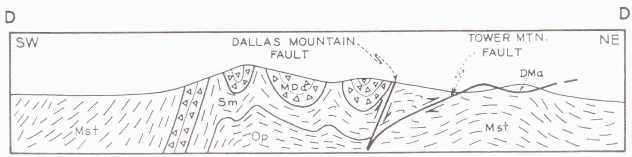
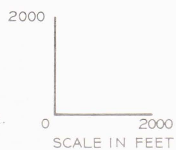



FIGURE 13

CROSS SECTION D-D'

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WILDHORSE MTN FM. ___ MJw
CHICKASAW CREEK FM __ Msc
MOYERS FM. _________ Msm
TEN MILE CREEK FM. ___ Mst
ARKANSAS NOVACULITE _ DMa
MISSOURI MTN SLATE __ Sm.
POLK CREEK SHALE ___ Op
BIG FORK CHERT _____ Ob

One thin section of the Bigfork Chert from the Board Camp quadrangle shows a hash of monaxon and triaxon sponge spicules; other sections contain none. However, not all of the rocks studied petrographically show definite evidence of organic contributions to their formation. In these rocks recrystallization is more thorough, thus leaving little evidence of any fossils they might have contained originally. How much of this evidence has been destroyed is conjectural.

Geologists who have worked in other areas (Robey, 1929; Taliaferro, 1933; Bramlette, 1946; Bissell, 1959) have noted the association of chert with volcanism and proposed that volcanic ash contributed at least a part of the silica. Bramlette (1946, p. 28) presents data from chemical analyses to show that the loss of silica from beds of vitric volcanic ash is characteristic of the Monterey Formation of California. Rubey (1929, p. 100) notes the same association in the Mowry Shale of the Black Hills region. He states that the silica in the shale is derived from altered volcanic ash. Goldstein and Hendricks (1953) are of the opinion that the siliceous sediments of the Ouachitas are of primary origin and that the source for the silica was extensive volcanism. Evidence for widespread Ordovician volcanism is noted by Ross (1928) who has quoted other authors on the occurrence of bentonite in the Ordovician rocks of the Appalachian area. From these reports Trenton age volcanism is well documented.

No direct evidence of volcanism was noted within the chert and novaculite of the Mena and Board Camp quadrangles, and to the author's knowledge none has been described from these rocks throughout the Ouachita area. Submarine volcanic activity to the south of the present core of the Ouachitas and submarine weathering of extensive deposits of volcanic ash, thus releasing silica, is a possible explanation for the silica. Because of the slow rate of precipitation, silica could have been dispersed throughout the waters of the Ouachita trough. Additional volcanic emanations could have raised the silica content above the solubility equilibrium, ultimately leading to the precipitation of bedded siliceous deposits.

Furthermore, the occurrence of carbonate rhombs, or remnants of carbonate rhombs, replaced by silica in the Bigfork Chert, indicates that this formation may also be in part the product of replacement processes. Under conditions of an euxinic environment, carbonate can be deposited simultaneously with silica (Krumbein and Garrels, 1952). That the Bigfork Chert was deposited in an euxinic environment is supported by the presence of black carbonaceous shales interbedded with the chert and the carbonaceous character of the chert itself.

The direct evidence observed in the Bigfork deposits within the Mena and Board Camp quadrangles indicates that two processes were responsible for their origin. Siliceous sponges spicules give evidence of biochemical origin and the replacement of carbonate by silica lends evidence of a replacement origin, although the latter accounts for only a small portion of any one rock.

Based on the uniformity of lithologic and petrographic characteristics, as seen in the Mena and Board Camp quadrangles, it is concluded that the cherts of the Bigfork are in part replacement and biogenetic but largely primary deposits. It is suggested that volcanic activity is a possible source for the silica.

The inferred euxinic environment which prevailed during the deposition of the Bigfork Chert persisted into the Upper Ordovician. The supply of silica was decreased and the resulting deposits were the black, carbonaceous Polk Creek shales. The rate of sedimentation was slow because the source area was of low relief or at such a distance that it supplied only argillaceous material. With restricted circulation, characteristic of the euxinic environment, coarse material would not have been moved into the basin of deposition.

### *Missouri Mountain Slate Deposition*

During Missouri Mountain time the muddy Silurian sea was widespread throughout the Ouachita trough. The argillaceous sediments of this formation are a product of slow sedimentation in an area receiving little clastic material. The intermittent influx of detrital quartz resulted in the deposition of the thin quartzite beds in the upper portion of the formation. Currents winnowed out argillaceous material after deposition.

Goldstein (1959b) described heavy mineral suites from Paleozoic sandstones of the Ouachita Mountains. He noted a change in heavy mineral content between the Missouri Mountain and the older sediments. Garnet is a common heavy mineral in the sandstones of the Missouri Mountain but it is virtually absent in sandstones in the older formations. This suggests a change in provenance from older sedimentary rocks to rocks of basement complex type.

The deposition of the Missouri Mountain Slate was characterized by environmental change from that which prevailed during the deposition of the Polk Creek Shale. The red color of this formation, due to presence of hematite, suggests oxidizing conditions and deep chemical weathering in a source area of low relief.

In the Black Knob Ridge area and in the Potato Hills in southeastern Oklahoma, the top of the Polk Creek Shale is eroded and in one locality the Polk Creek has been completely removed, with the Missouri Mountain lying on the Bigfork Chert (Hendricks, *et al.,* 1947). Miser and Purdue (1929, p. 44) report the local occurrence of a conglomerate at the base of the Missouri Mountain Slate. The rapid northward thinning of the Blaylock and the presence of the conglomerate suggest an unconformity between these two formations. However, Miser and Purdue (1929, p. 44) do not recognize a general stratigraphic break at this interval and suggest that the Blaylock grades upward into the Missouri Mountain. Honess (1923, p. 109) also states that in the Oklahoma Ouachita area the Blaylock Sandstone and the Missouri Mountain Slate are conformable. The absence of a widespread unconformity between the Polk Creek Shale and the Missouri Mountain Slate may indicate that some of the lower beds of the Missouri Mountain in the Mena and Board Camp quadrangles were deposited contemporaneously with the Blaylock, which is limited to areas south of the quadrangles. This supports a source area south of the Ouachitas and that the Blaylock was a near-shore (or near-source) deposit.

Post-Blaylock deposits (specifically the Missouri Mountain Slate and Arkansas Novaculite) thin to the north and northeast in the Mena and Board Camp quadrangles. During the Silurian-Devonian interval a subaqueous positive area present in central Arkansas tended to reduce the thickness of the sediments deposited in this area. This feature also may be reflected in the northward thinning of the Blaylock Sandstone.

*Arkansas Novaculite Deposition*

Except for a bed of quartzite sandstone near the base of the novaculite, beds of the lower member of the Arkansas Novaculite are relatively free of coarse detrital material, Sediment sources were distant enough that this portion of the Ouachita trough remained "sediment starved."

Throughout the period of deposition of the lower and middle Arkansas Novaculite members the euxinic environment prevailed, the supply of silica was replenished, and argillaceous material was introduced which formed thin beds of carbonaceous shales. The increased supply of argillaceous material resulted in the deposition of alternating beds of dark shale and chert in the middle member. Petrographic studies have shown that the cherts of this member contain fine argillaceous material, indicating either that the argillaceous sediments were deposited continually and the supply of silica was intermittent or that intermittent increases of argillaceous sediments masked silica deposition.

During Lower Mississippian time the calcareous upper member of the novaculite was deposited, and it is exposed in the western portion of the Mena quadrangle. The petrographic studies provided no evidence of replacement. Calcareous material occurs disseminated within the chert in rhombs and irregularly shaped patches, and there is no reason to suggest anything other than that primary carbonate was deposited contemporaneously with the silica unless the original rock was a limestone which was partially replaced by silica, leaving only remnant carbonate rhombs.

No macrofossils have been recognized in the Arkansas Novaculite within the Mena and Board Camp quadrangles. There is indirect evidence of micro-organic remains and radiolarians. Conodonts and siliceous sponge spicules have been reported in this formation (Goldstein and Hendricks, 1953; Hass, 1950). Silicified wood, including stumps two feet in diameter, has been found in the upper member of the Arkansas Novaculite (Miser and Purdue, 1929, p. 32) in Pike County to the southeast of the area here described.

The upper member of the Arkansas Novaculite is not present in the Board Camp quadrangle. Its absence in this area is the result of nondeposition and erosion. Likewise, all members of the Arkansas Novaculite thin to the east. In a few isolated localities there is a breccia of novaculite near the contact between the Arkansas Novaculite and the Stanley Group. Although seen only at scattered localities, this brecciated novaculite is more common in the eastern portion of the area, where the formation is thinnest. The thinning of the lower and middle members continues eastward into the Oden quadrangle.

Near Lake Bethesda in the western part of the map a quartzitic sandstone grades down into a breccia of light and dark chert at the base of the Stanley. This is the only locality where a breccia was observed in place. The remainder of the contact is gradational and the two formations do not reveal evidence of an unconformity. It is concluded that, although erosion did contribute to part of the thinning of the Arkansas Novaculite, as signified by the presence of breccias, the majority of this thinning is due to non-deposition, based on thinning of all units of the Arkansas Novaculite and the Missouri Mountain. This resulted from the subaqueous positive area which existed in central Arkansas during the Silurian and Devonian.

Other workers have noted conglomerate at or near the contact of the Arkansas Novaculite and the Stanley Shale. Miser and Purdue (1929, p. 132) discussed the occurrence of a local conglomerate at the base of the Stanley in the DeQueen and Caddo Gap quadrangles. In the Hot Springs quadrangle there is a widely distributed conglomerate at the equivalent stratigraphic level (Purdue and Miser, 1923) which is overlain by a pure quartz sandstone, the Hot Springs Sandstone. In the same area there is northward thinning of the Arkansas Novaculite from 800 to 100 feet.

There appears to be a general opinion among geologists that bedded siliceous deposits are products of an environment restricted from current circulation or wave action. This restriction mainly is considered to be the result of deep-water environments. The evidence presented above indicates that the depth of water was not as great as previously believed. A general lack of coarse clastic sediment is due to the distance from the source areas and low relief of the areas, and the lower Paleozoic sediments of the Ouachita trough were deposited in a restricted portion of the basin. The occurrence of the breccias in a few isolated localities indicates that erosion was at least partially responsible for the northeastward thinning of the Arkansas Novaculite.

King (1937, p. 54) and Miser and Purdue (1929, p. 51) have expressed the view that novaculite is of shallow-water origin. King notes that some of the bedding surfaces show fine corrugations that have the appearance of ripple marks. Miser and Purdue describe them as large, uneven ripple marks.

### Tectonically Unstable Phase

In Middle Mississippian time there was an abrupt change in the depositional environment of the Ouachita trough. The "starved basin" environment which had prevailed during the lower Paleozoic terminated. The source area was uplifted and streams were rejuvenated, supplying an influx of clastic detritus to the trough.

The Stanley sandstones consist of angular to subangular, fine to medium grained quartz in a clay matrix. They also contain chert fragments, rock fragments other than chert, feldspar and mica. Bedding is massive, and there is some graded and convolute bedding. The features of the Stanley sandstones are indicative of rapid deposition and burial. Turbidity currents have been suggested as the transporting and depositional mechanism (Cline, 1960, p. 88).

Kuenen (1953), pp. 1045-1047) summarizes the main arguments in favor of turbidity currents as the ultimate transporting agent for marine graywackes. Some of the sedimentary features characteristic of these deposits, such as graded bedding, absence of ripple marks, absence of autochthonous benthonic life, and current features on the underside of graywackes, have been noted in the Stanley. Of these features, graded bedding is the most inconspicuous in the Stanley sandstones, commonly observed as beds in sharp contact with the underlying shale, but in indistinct or gradational contact with the overlying shale. Graded bedding was noted also in some of the sandstones of the lower Jackfork on Rich Mountain.

A combination of the size of material, the distance from the source, and the length of time of flow formed a graywacke with a uniform texture but which graded into the overlying shale, such as that observed in the Mena and Board Camp quadrangles. Turbidity currents, therefore, are considered to have moved the sediments to the site of deposition, where they were buried before being sorted by current or wave action.

The concept of Llanoria, a hypothetical Paleozoic landmass situated to the south of of the present site of the Ouachita Mountains, has long been a subject of controversy and speculation. It is considered by some to be the source of the majority of the clastic sediments deposited in the Ouachita trough. In recent years, studies of paleocurrent directions based on measurements of sole markings have revealed a general west-southwest current direction within the trough area (Reinemund and Danilchik, 1957; Scull, Glover, and Planalp, 1959; Shelburne, 1960; Cline 1960; Briggs and Cline, 1962). This direction is generally in alignment wtih the axis of the trough.

Studies of the relationships of tectonic strike and current direction as indicated by sole markings have been discussed by Pettijohn (1962). In the Appalachian Basin it has been shown that there is both longitudinal and transverse filling (McBride, 1962). Kuenen (1957) and Dzulynski, *et al.* (1959) note current directions parallel to the tectonic strike of troughs in Europe.

It has been suggested by some workers (Morris, 1962; Shelburne, 1960) that the source area for the Jackfork-Atoka sediments lay to the northeast. These sediments would be transported along the margin by longshore currents. Potter and Pryor (1961) have shown a southwesterly direction for Mississippian sediment movement in the Mississippi Embayment and Illinois Basin, providing a source for sediments entering the Ouachita trough from the approximate area of northeast Arkansas. During the deposition of the Stanley-Atoka sequence, sediments transported into the basin would be moved down the slope and along the bottom of the trough into its deepest portions, somewhere in the area that is now south central Oklahoma.

The paleocurrent features noted in strata of the Ouachitas were formed by the last medium to transport the sediments before they were deposited and lithified, but are not necessarily indicative of the direction to the initial dispersal center. Similar paleocurrent patterns measured in the Appalachian trough have not precluded the possibility of a sediment source to the east. The similarities in the development of the two fold belts strongly indicate that a major source of sediments could have existed south of the Ouachita trough at various times during the Paleozoic. These sediments were transported down the side of the trough and then moved westward along the axis.

Several siliceous shale beds are found in the Stanley in the Mena and Board Camp quadrangles. They consist largely of a matrix of fine mud and organic material and contain sponge spicules. Cline (1960) and others have reported radiolarians and conodonts in other siliceous shale beds throughout the Ouachitas. The preservation of fragile, fine elements in the matrix material must have been the result of slow sedimentation, as suggested by Cline (1960). That they are thin deposits which may be traced laterally for long distances in the Ouachitas indicates deposition during a period of general quiescence in the trough. Also, the fact that they are identified throughout the Ouachitas indicates that the process of their formation was uniform throughout the trough.

The decrease in the rate of influx of sediments during relative quiescence is indicated by a cross-bedded sandstone associated with the Moyers Siliceous Shale in Sec. 26, T1S, R29W. Wave and current action formed cross bedding in this three- to four-inch layer before it was buried by additional sediments.

The sediments of the Stanley and Jackfork groups are comparable to the flysch facies in the Cretaceous and Eocene of the Alps and Carpathians of Europe (Sujkowski, 1957; Dzulynski, *et al.*, 1959; Trumpy, 1960). According to Sujkowski (1957) and Cline (1960), the term flysch, meaning literally "gliding rock," was introduced into the literature by Studer in 1827 for describing a sequence of interstratified shales, marls, and sandstones. It was restricted at first to a formation name for lower Tertiary sediments in northern Switzerland. The term has undergone some changes in meaning, but now is held to represent a lithologic facies and has been applied to a number of similar rock sequences.

Although there are lithologic variations in the different suites of rocks described as flysch, there appears to be general agreement on its definition. The sediments of the Stanley and Jackfork groups observed in the Mena and Board Camp quadrangles fit the broad descriptions of flysch facies.

In the Stanley, the sandstones apparently do not continue for distances greater than two to three miles, and normally do not attain very great thicknesses. Lack of continuous outcrops and structural complications are partially responsible for these observations. Sole markings are not common in the Stanley but they are rather characteristic of the Jackfork. The Stanley is predominantly shale, 70 to 80 percent, but the percentage of sandstones and the over-all grain size increases in the Jackfork. The addition of coarser material in the Jackfork indicates an increase in the strength and number of sediment-transporting agents. The increase in current activity produced more sole markings in Jackfork sandstones than those in the Stanley. They are considered to belong to the black shale flysch facies with the Jackfork being more arenaceous than the Stanley.

## VI. Summary

The cratonic, or stable, phase of geosynclinal development in the Ouachita Mountains includes not only the Bigfork Chert and younger rocks but also an older sequence not represented in the mapped area, which includes the Lukfata Sandstone, the Collier Shale, the Crystal Mountain Sandstone, the Mazarn Shale, the Blakely Sandstone, and the Womble Shale. This stable geosynclinal phase (the Lukfata Sandstone-Arkansas Novaculite sequence) consists of black shales, sandstones, and bedded siliceous sediments, with an approximate thickness of 5,000 feet, deposited between Cambrian (?) and Lower Mississippian time. Ham (1959) and other authors have called it the black shale-sandstone-chert facies because it contrasts with the carbonate-chert-green shale facies of the stratigraphically equivalent section in the Arbuckle Mountains of Oklahoma.

In addition to the Stanley and Jackfork groups, the tectonically unstable or trough-filling phase in the Ouachitas consists of the Johns Valley Shale (Mississippian-Pennsylvanian age) and the Atoka Sandstone (Pennsylvanian).

Pettijohn (1957) outlined a tectonic cycle and described the sedimentary assemblages which characterize the various stages in the cycle. The early phase of geosynclinal development is characterized by deposition of quartzose sandstones and carbonates, followed by a series of black carbonaceous shales, with associated bedded chert. This latter portion of the sequence is termed the euxinic facies. The entire early phase is considered tectonically stable. It is succeeded by the tectonically unstable phase, which results in the deposition of large amounts of clastic material, mainly graywackes and dark shales of the flysch facies. The flysch is followed by the molasse facies, and subsequent conversion to a nonmarine environment. Deformation and uplift may, or may not, follow.

This cycle, with its petrographically distinct sedimentary facies, may be applied, with slight adjustments, to the Ouachita geosyncline. The quartzose sandstone units (Lukfata, Crystal Mountain, and Blakely) are interbedded with black graptolitic shales. The shales are in the place of carbonates, as carbonate rocks are rare in the Ouachitas. The overlying Bigfork Chert-Arkansas Novaculite stratigraphic interval, consisting of dark carbonaceous shales and bedded siliceous deposits, is characteristic of the restricted euxinic environment. The post-Arkansas Novaculite succession of dark shales and intervening graywackes of the Stanley-Jackfork-Johns Valley units are the flysch representatives. These deposits are succeeded by the Atoka sands of the molasse facies. Beginning during the period of the deposition of the Atoka, the sediments in the Ouachita trough were folded and faulted. This completed the tectonic cycle of the Ouachita trough.

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