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# GEOLOGY OF THE EASTERN PART OF THE LYNN MOUNTAIN SYNCLINE LE FLORE COUNTY, OKLAHOMA

**Garrett Briggs**

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# GEOLOGY OF THE EASTERN PART OF THE LYNN MOUNTAIN SYNCLINE LE FLORE COUNTY, OKLAHOMA

Garrett Briggs[1]

**Abstract**—The Lynn Mountain syncline, like the Octavia fault which bounds it on the south, extends from the vicinity of the Arkansas line westward across Le Flore County and then southwestward through Pushmataha County in an arcuate configuration consistent with the structural grain of the southwardly concave salient of the Ouachita Mountains in Oklahoma. The Late Mississippian and Early Pennsylvanian rocks of the syncline consist of approximately 22,000 feet of alternating thin layers of sandstone and shale. The predominance of sandstone layers in the synclinal sequence causes the syncline to stand in bold relief above the predominantly shale sequence of the valleys to the north and south. The northern limb of the syncline exhibits an almost complete and undisturbed stratigraphic section representing, in ascending order, the Stanley and Jackfork Groups and possibly some younger units.

Few of the dark siliceous shales used in the western Ouachitas to subdivide the Stanley and Jackfork Groups extend into the area of investigation. The rocks of the southern limb of the syncline were overturned by northward thrusting along the Octavia fault. The marker beds used to correlate the rocks of the northern limb are buried beneath the overturned rocks on the southern limb. Slices of lower Jackfork rocks have been dragged upward along several bifurcations of the Octavia fault. One such slice in the eastern part of the mapped area is itself a tightly folded syncline forming a prominent ridge that stands above the less resistant Stanley shales which surround it.

## INTRODUCTION

### Regional Setting

The Ouachita fold belt is a long, sinuous structural belt extending from eastern Mississippi through central Arkansas and southeastern Oklahoma southward and southwestward through the Marathon and Solitario uplifts of Texas into northeastern Mexico. Most of the fold belt's course is concealed beneath Mesozoic and younger sediments of the Gulf Coastal Plain, but it exhibits several mountainous exposures, the largest of which is the Ouachita Mountains of central western Arkansas and southeastern Oklahoma.

The general framework of the Ouachita Mountains in Oklahoma is that of a broad salient, concave gulfward. The grain of the salient is reflected by prominent, resistant sandstone ridges separated by valleys underlain by relatively incompetent shale. Consistent with the arcuate grain of the salient are several exceptionally long fault traces along which thrusting has occurred in a northward and northwestward direction (fig. 1).

The Ouachita Mountains of Oklahoma are generally divided into three regions: the frontal Ouachitas, the central Ouachitas, and the Choctaw anticlinorium.

The frontal belt, the northernmost of the three regions, lies between the Choctaw and Ti Valley faults and is complexly folded and faulted. The lithology of the predominantly Lower Pennsylvanian rock sequence in the frontal belt is intermediate between that of the Ouachita geosyncline, known as the Ouachita facies, and that of the shallower, shelf-type sediments of the Arbuckle facies to the north and west.

The central Ouachitas, of which this area of investigation is a part, consists of rocks that are mainly Late Mississippian and Early Pennsylvanian

[1] Associate professor and interim head, The University of Tennessee, Knoxville.

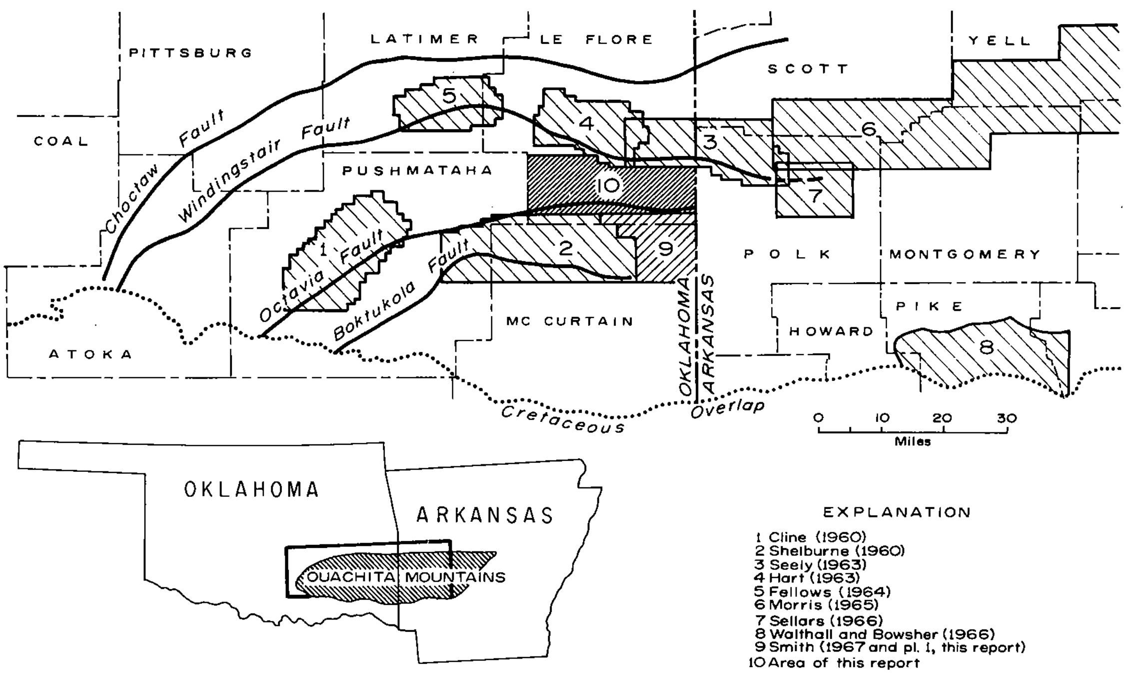


Figure 1. Index map of Oklahoma and Arkansas showing Ouachita Mountains and areas mapped by Briggs and Smith (pl. 1, in pocket). Other recently mapped areas are also shown.

in age. The structure of the central Ouachitas is generally typified by broad synclines whose southern limbs have been overturned and (or) truncated by northward-moving overthrusts that have cut out the intervening anticlines (fig. 1).

The Choctaw anticlinorium is the southernmost of the three belts. Its central portion, known as the core (Pitt, 1959, p. 88), is a region of strong deformation and incipient to low-grade metamorphism (Flawn, 1969, p. 23).

After the geologic map (pl. 1, in pocket) and text for this report had been completed, staff members of the Oklahoma Geological Survey recommended certain changes in age assignment based on palynological determinations by L. R. Wilson and field work by the late W. E. Ham, both of the Survey. These findings have been generally substantiated by the independent work of Gordon and Stone (1969) in the Arkansas Ouachitas. Thus, instead of following established usage (e.g., Cline, 1960; Miser and Hendricks, 1960), this report reflects the current usage of the Oklahoma Geological Survey—not necessarily in agreement with the author.

The new usage (which is largely comparable to that of Ulrich, 1927) differs from previous usage mainly by placing the Mississippian-Pennsylvanian boundary much lower in the section. The exact systemic boundary has not been determined but is now tentatively placed at the Stanley-Jackfork contact instead of within the Johns Valley Formation, several thousand feet higher (fig. 2). Therefore, the Stanley Group is considered essentially Late Mississippian (Chesterian, with the lower part possibly Meramecian) and the Jackfork Group Early Pennsylvanian (Morrowan).

Another departure from established usage is the removal of the Chickasaw Creek from the Stanley Group as the uppermost formation and its transfer to the Jackfork Group as the lowermost formation. This redefinition coincides with the original Stanley-Jackfork boundary established by Taff (1902).

## Location of Area and Access

The boundaries of this 243-square-mile area of investigation are mostly common with those of workers who have mapped or are mapping in adjacent areas (fig. 1). These boundaries are approximated by Oklahoma Highway 63 on the north, the road from Honobia to Zafra on the south, and the Pushmataha County and Arkansas lines on the west and east, respectively. U.S. Highway 259 between the communities of Big Cedar and Octavia traverses the area in a north-south direction and provides an exceptional exposure of an essentially complete and undis-

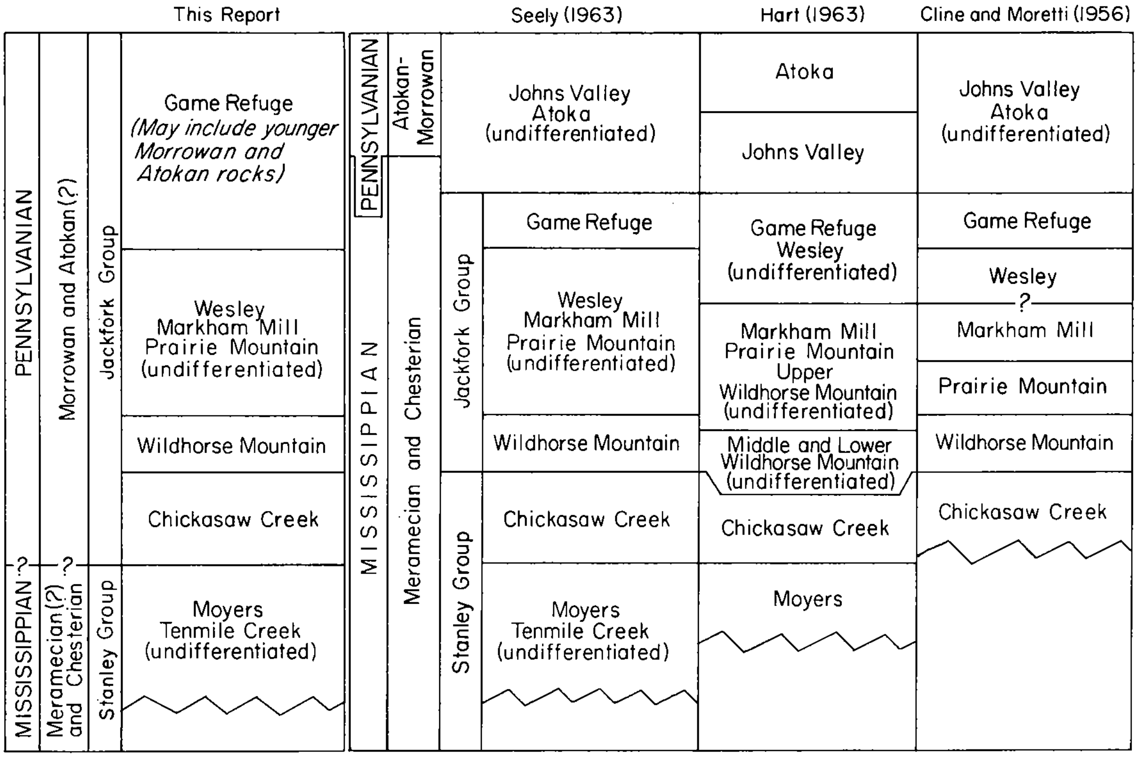


Figure 2. Correlation of Mississippian and Pennsylvanian units in area of investigation with those in adjacent areas. Cline and Moretti section (1956, section I) was described along Indian Service Road on north limb of Lynn Mountain syncline in Pushmataha County, Oklahoma. Their section, as shown above, reflects changes made by Cline (1960, p. 58, 59).

turbed sequence of strata from the shales of the lower Stanley Group up to and perhaps including rocks of late Morrowan and Atokan age. In addition to Highway 259 and the roads bounding the area on the north and south, access to the area is furnished by an improved road which skirts the nose and much of the rim of the Lynn Mountain syncline.

## Previous Work

The first significant contributions to the geology of this area of study were those of Honess (1923, 1924), who, using the Stanley and Jackfork Formations proposed by Taff (1902), recognized the principal structural elements of the Lynn Mountain syncline and adjacent areas. The late Dr. Lewis M. Cline of The University of Wisconsin had been mapping the westward continuation of the Lynn Mountain syncline from the subject area into Pushmataha County up to the time of his death in March 1971. Cline (1960) had previously mapped the western portion of the syncline in that same county. Students under Cline's direction have mapped the areas immediately adjacent to the subject area in Oklahoma (Laudon, 1959; Shelburne, 1960; Hart, 1963; Smith, 1967). Smith's (1967) map has been incorporated with the geologic map of the present report in plate 1 (in pocket). Cline and Moretti (1956) described the exceptionally good exposures of Stanley and Jackfork strata provided by U.S. Highway 259, which cuts across the Lynn Mountain syncline in the mapped area. Their measured section is included in the Appendix of this report for the reader's convenience.

## Acknowledgments

The field work for this investigation was done in the summer of 1966 and early spring of 1968 under the auspices of the Oklahoma Geological Survey. I am grateful to the Survey, and especially to Dr. Carl C. Branson, Director of the Survey when the study was begun, for providing the opportunity to map the area. Dr. Charles J. Mankin, the present Director of the Oklahoma Geological Survey, was helpful in all phases of the preparation of the manuscript for publication.

The late Dr. Lewis M. Cline introduced me to

Ouachita Mountain geology in 1959, and it was under his enthusiastic direction that I made a paleocurrent investigation of Mississippian and Pennsylvanian rocks in the Ouachita Mountains and Arkoma basin areas of Oklahoma for a Ph.D. dissertation at The University of Wisconsin. My greatest pleasure in making this study derived from continuing my association with him. He and several of his students were working in adjacent areas at the time, and I profited greatly from discussions with them. I am privileged that Dr. Cline reviewed this manuscript prior to his untimely death in March 1971. Realizing that any expression of tribute is woefully inadequate, I nonetheless wish to acknowledge the help and enthusiasm I received from my revered professor and friend, Lewis Cline.

I am grateful also to John H. Byrne and Richard Dinkel, who, as undergraduate geology majors at Tulane University in 1966, assisted me in the field.

# STRATIGRAPHY

## Stratigraphic Setting

The sedimentary sequence of the central Ouachita Mountains is composed principally of Upper Mississippian and Lower Pennsylvanian sediments referred to as the Ouachita flysch facies. Comparable to the black-shale flysch facies of Europe (Waterschoot van der Gracht, 1931, p. 998; Cline, 1960, p. 87), the Ouachita flysch facies consists of a monotonous rhythmical alternation of thin dark layers of sandstone and shale punctuated by a few sporadic thin layers of black siliceous shale or bedded chert. The flysch facies comprises four principal stratigraphic units (from oldest to youngest), the Stanley Group, Jackfork Group, Johns Valley Formation, and possibly rocks equivalent to the Atoka Formation, which together form a northward-thinning wedge of clastic sediments conforming areally to the arcuate structural grain of the Ouachita Mountains (fig. 1).

The cumulative thickness of the entire flysch sequence is estimated to be about 22,000 feet, but the absence of much of the Atokan(?) rocks and the concealment of an unknown thickness of lowermost Stanley rocks have reduced the total thickness in the subject area to approximately 17,500 feet.

The almost total absence of megafossils in the Ouachita flysch sequence and the inability to trace the rock units to their fossiliferous counterparts in adjacent regions have made age determinations difficult. On the basis of palynology, however, L. R. Wilson of the Oklahoma Geological Survey has recently determined that the Jackfork Group is Early Pennsylvanian (Morrowan) in age (R. O. Fay, Oklahoma Geol. Survey, pers. comm., 1972), although Cline (1960) considered the Jackfork Group to be Late Mississippian (Meramecian and Chesterian) in age. It is possible that the uppermost part of the Jackfork Group of this report may contain rocks of younger Morrowan and Atokan age equivalent in part to the Johns Valley and Atoka Formations of previous usage.

## Mississippian System

The Mississippian rocks of the Ouachita facies are represented, in the current usage of the Oklahoma Geological Survey, by the Stanley Group. From a cumulative thickness of about 11,000 feet in the central Ouachitas, the Stanley thins markedly northward across strike toward the frontal Ouachitas where it terminates along the Ti Valley fault. According to Cline (1960, p. 24), this fault trace probably marks the approximate northern depositional limit of the Stanley Group, inasmuch as the Stanley is not found north of the fault.

The Stanley is composed predominantly of dark fissile shales. The incompetent nature of the shales and the sparsity and friability of the sandstone layers have resulted in the Stanley's being typified by long, flat-bottomed valleys. The upper one-fifth of the Stanley Group exhibits an increased number of sandstone beds, which, like the resistant sandstone layers of the overlying Jackfork Group, alternate rhythmically with the shale layers. The greater resistance to weathering afforded by the sandstone beds has caused the upper Stanley sequence to stand in moderate relief as a topographic transition between the incompetent shale valleys of the lower Stanley and the resistant, ridge-forming sandstones of the overlying Jackfork (fig. 3).

Although shales of the Stanley Group are very thick and widespread in the central Ouachitas, the almost total absence of megafossils has made age determination difficult. From a study of conodonts from the upper Arkansas Novaculite and the black siliceous shales of the Stanley, the age of the novaculite was determined to be late Kinderhookian or Osagean, whereas that of the Stanley was designated as Meramecian (Hass, 1950, 1956). Radiometric dates obtained from the Hatton Tuff 50 to 100 feet above the base of the Stanley also indicate a Meramecian or early

Figure 3. Exceptionally good exposures of Stanley-Jackfork sequence visible along U.S. Highway 259, seen here traversing steep north-facing escarpment of Kiamichi Mountain. View is westward along strike. Valley of Kiamichi River, right background, is underlain by shales of Stanley Group. Greater resistance afforded by increased abundance of sandstone in lower Jackfork Group causes these rocks to stand in marked relief above valley-forming Stanley shales.

Chesterian age for the lower part of the group (Mose, 1969). For a comprehensive review of the development of thinking regarding the ages of the Stanley and Jackfork Groups and the Johns Valley Formation, the reader is referred to Miser and Hendricks (1960) and Cline (1960).

Gordon and Stone (1969) determined that the upper 500 feet of the Stanley Group in Arkansas may be Morrowan in age. This is one reason why the Oklahoma Geological Survey has recommended placement of the Chickasaw Creek Formation in the Jackfork Group, in accordance with Taff's (1902) original definition, rather than in the Stanley Group following usage of the recent past.

## Stanley Group

### *History of Nomenclature*

The name "Stanley" was used by Taff (1902, p. 4) to designate a clastic sedimentary sequence, consisting primarily of shale, in the Kiamichi River valley near the community of Stanley in Pushmataha County. Taff's concept of the thick Stanley Formation was adopted by subsequent workers and used without modification until Harlton (1938) raised the Stanley to group rank and subdivided it into three formations by means of several persistent thin black siliceous shale units. Harlton's type section is at the south end of the Tuskahoma syncline in Pushmataha County and consists of (from oldest to youngest) the Tenmile Creek, Moyers, and Chickasaw Creek Formations. In this report the Chickasaw Creek has been assigned to the Jackfork Group in conformance with Taff's (1902) original definition, as recommended by the Oklahoma Geological Survey.

### *Local Distribution*

Harlton's several siliceous shales have been traced eastward from the type section with varying degrees of success by subsequent workers. Cline (1960) demonstrated the persistence of most of the Stanley marker units eastward from the Tuskahoma syncline into the western part of the Lynn Mountain syncline. South of the Lynn Mountain syncline, several of the units have been recognized in the Boktukola syncline (Shelburne, 1960) and traced eastward to the Arkansas line (Smith, 1967), but workers in Kiamichi Valley north of the Lynn Mountain syncline (Cline and Moretti, 1956; Laudon, 1959; Seely, 1963; Hart, 1963) found it difficult to trace most of the units eastward to the Arkansas line. This difficulty is reflected in their geologic maps by the lumping together of the Moyers and Tenmile Creek Formations as undifferentiated Stanley.

Correlations in the Stanley have been made difficult by the fact that the siliceous shales are thin, sporadic, easily obscured by vegetation and alluvium, and similar in appearance. Because of their relative incompetence, the Stanley shales reflect the ravages of tectonism much more than do the Arkansas Novaculite and Jackfork sandstones, between which they are confined. The aforementioned difficulties in correlation are thus compounded by structural complexities.

*Tenmile Creek Formation*

The Tenmile Creek Formation is the lower of the two formations of the Stanley Group. It is bounded conformably by the basal siliceous shale of the overlying Moyers Formation and by the underlying Arkansas Novaculite. Of the estimated 11,000 feet of Stanley in the central Ouachitas, the Tenmile Creek Formation constitutes almost 9,000 feet (Laudon, 1959, p. 34). This thickness can only be estimated because no complete unfaulted section of the Stanley Group is known.

The Tenmile Creek is composed predominantly of shale which is typically dark gray to olive green when fresh but weathers to a light olive green or buff on the outcrop. The shales are interbedded with poorly sorted, light-gray to olive-green argillaceous siltstones and fine- to medium-grained sandstone layers, which, according to Laudon (1959, p. 32) account for only 15 percent of the sequence. Some of the sandstone layers are 6 to 8 feet thick and stand out as long, low, narrow ridges traceable for several miles on aerial photographs, but more commonly the layers are less than 3 feet thick. Many of the sandstones contain large amounts of clay as interstitial matrix and (or) as isolated clay pockets. The predominance of shale and the friability of the sandstones, resulting from their high clay content, have caused the Tenmile Creek to be characterized topographically as long, flat-bottomed anticlinal valleys in the central Ouachitas.

The Tenmile Creek Formation has been divided into two subequal members by the widely recognized uppermost unit of three siliceous shale units known as the middle siliceous shale. The middle siliceous shale apparently has not been brought to the surface in the Kiamichi River valley in the area of study; thus, only the upper shale member of the formation crops out.

The middle siliceous shale of the Tenmile Creek Formation, as described by Harlton (1938, p. 868), is probably correlative with the "Stanley black chert" of Honess (1924), the "Smithville chert lentil" of Miser and Honess (1927), and the "Battiest chert member" of Shelburne (1960). This unit is shown in plate 1 (in pocket) in the area mapped by Smith, where it is designated "Battiest Chert Member." The name "Smithville" was abandoned in 1957 by the Oklahoma Geological Survey as an invalid name for this unit (Branson, 1957, p. 102).

Laudon (1959) traced the middle siliceous shale eastward along the north rim of the Lynn Mountain syncline to the Pushmataha-Le Flore County line, where it apparently fades out. He observed and traced the continuation of the same unit along the south flank of the Rich Mountain syncline, and Morris (1962) and Sellars (1966) mapped the siliceous shale's continuation into Polk County, Arkansas.

Laudon measured and described the Stanley Group on the north-facing escarpment of Kiamichi Mountain along U.S. Highway 259. He estimated that less than 1,000 feet of the upper member of the Tenmile Creek remains unbreached along the axis of the Kiamichi River anticline. Absence of the basal siliceous shale of the Moyers necessitated Laudon's having to combine the Moyers Formation with the Tenmile Creek for a cumulative thickness of 4,075 feet. The Moyers and Tenmile Creek Formations have similarly been mapped as a single unit on the geologic map covering this report (pl. 1, in pocket).

*Moyers Formation*

The Moyers Formation is the upper formation of the Stanley Group. Its upper boundary is marked by the basal siliceous shale of the overlying Chickasaw Creek Formation of the Jackfork Group and its lower boundary by a basal siliceous shale. The sandstone and shale layers of the Moyers are similar in appearance to those of the underlying Tenmile Creek Formation and bear no distinguishing features with which to differentiate the two formations in the field. The most distinguishing characteristic of the Moyers is its increase upward in the number and thickness of sandstone layers relative to the shales. Whereas the Tenmile Creek Formation consists of only about 15 percent sandstone, the Moyers is composed of 35 to 40 percent sandstone, a ratio more in keeping with the lithology of the Jackfork Group. The greater resistance to weathering afforded by the more numerous and cleaner sandstones of the Moyers has produced a line of fluted terraces that are easily recognized on aerial photographs of the northern lower slopes of the Kiamichi Mountains. The increase in sandstone from the upper Tenmile Creek through the Moyers is not a distinct change coincident with the contact but is gradual, producing a transition in relief between the soft, incompetent Tenmile Creek shales of Kiamichi Valley and the resistant sandstone ridges of the Jackfork Group.

The basal Moyers siliceous shale was defined by Harlton (1938) as the boundary separating the Moyers and Tenmile Creek Formations. Its persistence in areas adjacent to the subject area has been demonstrated by Cline and Moretti (1956), Laudon (1959), Cline (1960), Shelburne (1960), Seely (1963), Fellows (1964), Sellars (1966), and Smith (1967), who recognized and traced the unit eastward into Arkansas. Although laterally persistent over a wide area, the marker unit is not present everywhere within the known limits of the formation. Laudon (1959) was unable to trace the siliceous shale eastward along the north flank of the Lynn Mountain syncline of Le Flore County, and Shelburne (1960, p. 19) described it as thin or discontinuous in the area of the Boktukola syncline immediately southwest of the Lynn Mountain syncline.

At its type locality at the southern end of the Tuskahoma syncline the Moyers is 1,100 feet thick (Harlton, 1938), but Laudon (1959, p. 52) and Cline (1960, p. 36) reported a thickness of up to 1,700 feet on the north side of the same syncline—the greatest thickness yet reported for the Moyers. Two factors have hindered accurate measurement of the Moyers in areas adjacent to that of this investigation: (1) structural complexity and (2) the absence of the basal Moyers siliceous shale. Estimated thicknesses by the aforementioned workers have ranged from 1,000 feet (Seely, 1963, p. 15) to 1,400 feet (Sellars, 1966, p. 156).

The absence of the Moyers siliceous shale from Laudon's measured section of U.S. Highway 259 necessitated his having to combine the Moyers and the exposed portion of the Tenmile Creek Formation for a total thickness of 4,075 feet. The writer found a 2-foot shale interval (SW¼NW¼ sec. 23, T. 2 N., R. 25 E.) within Laudon's measured section that contained scattered 1- to 2-inch ellipsoidal, black siliceous shale masses with ash-gray to light-buff clayey surfaces resembling those described by Seely (1963, p. 24) from beds of the Jackfork Group. Similar masses were observed in the float at the same stratigraphic position on the south limb of the Lynn Mountain syncline in the NE¼SE¼ sec. 24, T. 1 N., R. 26 E. It was initially believed that the masses perhaps represented a poor development of the Moyers siliceous shale and that the zone of siliceous shale masses marked the top of the Tenmile Creek Formation. However, estimates of formation thickness based on the zone of siliceous shale masses yield thicknesses greater than those normally estimated for the Moyers and less than those for the Tenmile Creek. The concentration of siliceous shale masses is thus regarded only as an additional, but poorly developed, siliceous shale in the Tenmile Creek Formation.

Smith (1967, p. 29) discovered a black siliceous shale unit on the south limb of the Lynn Mountain syncline (center sec. 28, T. 1 N., R. 26 E.) which he identified as the basal Moyers unit. He calculated the thickness of the Moyers Formation to be 1,250 feet.

The absence of the basal Moyers unit from the area of study precluded separation of the Moyers from the Tenmile Creek for mapping purposes. The two formations are thus combined on the geologic map. Smith (1967) mapped the rocks directly south of the Octavia fault as Tenmile Creek, and his designation is reflected in plate 1 (in pocket). A black siliceous shale is exposed in the roadcut along the north line of sec. 25, T. 1 N., R. 23 E. This exposure was observed by Shelburne (1960, p. 21, 22) who identified the unit as the basal siliceous shale of the Moyers Formation. Such an assignment indicates that the shales and sandstones of the Stanley Group that extend northward from Shelburne's area to the Octavia fault belong to the Tenmile Creek Formation.

## Pennsylvanian System

Although some workers (e.g., Cline, 1960; Miser and Hendricks, 1960) have considered the Mississippian-Pennsylvanian boundary in the Ouachita Mountains to occur within the Johns Valley Formation, which overlies the Jackfork Group, recent unpublished research by L. R. Wilson and the late W. E. Ham of the Oklahoma Geological Survey indicates that this systemic boundary actually occurs much lower in the section (R. O. Fay, Oklahoma Geol. Survey, pers. comm., 1972). This conclusion is corroborated by the determinations of Gordon and Stone (1969).

Although it cannot be placed with certainty, the Mississippian-Pennsylvanian boundary is tentatively placed at the base of the Jackfork Group, on the recommendation of the Oklahoma Geological Survey.

### Jackfork Group

*History of Nomenclature*

The name "Jackfork formation" was used by Taff (1902, p. 4) to designate a thick sequence of alternating sandstone and shale layers he observed on Jackfork Mountain in Atoka County, Oklahoma. Harlton (1938), from a section in the Round Prairie syncline northeast of the town of Atoka, elevated the sequence to group rank and subdivided it into four formations on the basis of several laterally persistent siliceous shale units. In so doing, he excluded the lower 300 feet of Taff's Jackfork sequence and, naming it the Chickasaw Creek Formation, assigned it to the Stanley Group. It is here reassigned to the Jackfork Group. Harlton also excluded the upper 400 to 500 feet of Taff's Jackfork, but later (Harlton, 1959, p. 132, 135) restored it to the Jackfork Group and named it the Game Refuge Formation. The Jackfork Group as here defined thus consists of six formations (from oldest to youngest): Chickasaw Creek, Wildhorse Mountain, Prairie Mountain, Markham Mill, Wesley, and Game Refuge (fig. 2).

Harlton's subdivisions have been generally, but not universally, agreed upon or used. Hendricks and others (1947) preferred to retain the rank of formation for the Jackfork because they found that the subdivisions proposed by Harlton could not be recognized in complexly faulted areas, especially in the absence of the siliceous-shale units used for boundaries. Like the black siliceous shales and cherts used to subdivide the Stanley, the black siliceous shales of the Jackfork fade out toward Arkansas, necessitating the lumping of some of the formations by workers mapping the eastern Ouachitas of Oklahoma (Cline and Moretti, 1956; Cline, 1960; Shelburne, 1960; Seely, 1963; Hart, 1963). Morris (1965) reported that the black siliceous shale marker units disappear altogether in the frontal belt in Arkansas, making recognition of Harlton's divisions extremely difficult if not impossible. On the south side of the Benton-Broken Bow uplift in Arkansas, Walthall and Bowsher (1966) subdivided the Jackfork into Harlton's five formations in the Athens Plateau area of Pike County.

The absence of several of Harlton's boundary markers in the area of this investigation has necessitated the combining of two or more formations into a single mappable unit. The Wildhorse Mountain Formation is readily distinguishable by its bold relief. The Prairie Mountain, Markham Mill, and Wesley Formations were combined for lack of any persistent boundary markers with which to separate their otherwise monotonous alternating layers of sandstones and shales. A widespread and easily traced siliceous shale unit near the top of the Wesley Formation was used in mapping to separate the Wesley from younger beds. Similarly, the top of the Game Refuge Formation is uncertain, and the formation as here defined may contain younger Morrowan and Atokan rocks, including the Johns Valley equivalent.

*Distribution and Character*

The two sections measured and described by Cline and Moretti (1956) in the Kiamichi Mountains of Pushmataha and Le Flore Counties of Oklahoma include the most complete and undisturbed sections of the Jackfork Group yet recognized. Their Jackfork thicknesses of 5,600 to 5,800 feet are about average for the central Ouachita Mountains of Oklahoma and vary little from those recorded in the Tuskahoma syncline to the west or the Boktukola syncline to the south where Shelburne (1960, p. 26) reported Jackfork thicknesses ranging from 5,600 to 6,500 feet. Jackfork thicknesses of 5,000 to 6,600 feet have also been reported in Arkansas by Miser and Purdue (1929, p. 75) in the Caddo Gap quadrangle in Pike and Howard Counties, by Reed and Wells (1938, p. 27) in the Quicksilver district of Pike County, and by Morris (1965, p. 31) south of the community of Kirby in Pike County.

The Jackfork Group thins northward toward the frontal Ouachitas from the central Ouachitas. This fact is perhaps best explained by Cline (1960, p. 45), who stated:

> . . . the Jackfork group thins rapidly from the Tuskahoma syncline northwestward toward the frontal Ouachitas. In the Round Prairie syncline northeast of Atoka the Jackfork is less than a mile thick and a few miles north, in the vicinity of the Wesley type section, the complete thickness of the Jackfork group cannot be more than 1,700 feet. The Jackfork is not recognized north of the Ti Valley fault.

That the Jackfork thins northward from this area of study is subject to some doubt. An anomalous thickness of more than 8,000 feet of Jackfork was estimated from aerial photographs by Hart (1963, p. 20, 21) of the Winding Stair Mountain area of Le Flore County, a thickness that suggests northward thickening rather than thinning.

The Jackfork typically thickens southward, as already evidenced by Shelburne's reported 6,500-foot section of Jackfork in the Boktukola syncline area. Similarly, Walthall and Bowsher (1966, p. 128, 129) reported a Jackfork thickness of approximately 10,000 feet in the Athens Plateau region in southeastern Pike County, Arkansas, on the south side of the Benton-Broken Bow uplift.

The Jackfork Group consists of rhythmically alternating layers of sandstone and shale in which sandstone predominates over shale in a ratio of about 3:2. The predominance of sandstone layers renders the group more resistant to weathering than the units containing more shale above and beneath it. The Jackfork is thus topographically characterized by long, sharp ridges in the area of investigation.

The rhythmical alternation of layers of sandstone and shale, the abundance of sole marks, graded bedding, and the sporadic occurrence of a black siliceous shale unit and chert units are generally accepted as being typical of a flysch sequence. Eastward within the frontal Ouachitas of Arkansas, Morris (1965) observed that shale increases and eventually becomes predominant, sandstones become more massive, sole marks become increasingly scarce, and the black siliceous shales and cherts disappear. At the same time, features more indicative of shallower water conditions, such as crossbedding and ripple marks, increase and become abundant. It is undoubtedly this change from sediments produced in a flysch environment to sediments indicative of more normal marine-shelf conditions that causes Harlton's flysch-based nomenclature to become untenable in the Jackfork of the frontal Ouachitas in Arkansas. The area of this investigation is well within the realm of flysch sedimentation, but the absence of the siliceous shale and chert boundary markers is perhaps a subtle reflection of an eastward change in depositional environment.

### *Chickasaw Creek Formation*

*Character and thickness.*—The Chickasaw Creek Formation is the lowermost of the six formations of the Jackfork Group. The relatively incompetent shales of the formation are bounded by the terrace-forming sandstones of the underlying Moyers Formation of the Stanley Group and the ridge-forming sandstone layers of the overlying Wildhorse Mountain Formation. In the area of this investigation the formation consists of about 330 feet of dark-gray, olive-weathering shale interbedded with lesser amounts of thin-bedded argillaceous sandstones. Even though it is a comparatively thin formation composed primarily of easily weathered shale, the Chickasaw Creek is widely recognized in the field by its thin-bedded black siliceous shale or chert layers, the persistence of which makes it one of the best stratigraphic markers in the Ouachita Mountains.

Originally included in the sequence assigned to the Jackfork by Taff (1902), Harlton (1938, p. 874) named and placed the Chickasaw Creek in the Stanley Group. The Chickasaw Creek is here reassigned to the Jackfork Group, on the recommendation of the Oklahoma Geological Survey.

The Chickasaw Creek Formation was named from outcrops in Atoka County, Oklahoma, near Stringtown. From a thickness of 270 feet in the type locality, the formation thins to only a few feet at the south end of the Tuskahoma syncline (Cline, 1960, p. 39), but it increases to thicknesses greater than 300 feet as it is traced eastward along the north flank of the Lynn Mountain syncline to a maximum thickness of 333 feet in the study area. Cline and Moretti (1956, p. 15-18) described and measured an uninterrupted 333-foot section of the Chickasaw Creek in the Lynn Mountain syncline from the excellent, fresh outcrops provided during the construction of U.S. Highway 259 up the north-facing escarpment of Kiamichi Mountain (*see* Appendix). To the south, Shelburne (1960, p. 25) traced the Chickasaw Creek throughout the Boktukola syncline, where he measured complete sections 131 and 140 feet thick. In the Windingstair syncline area to the north, Hart (1963) measured a thickness of at least 75 feet of primarily black shale between two siliceous shale units which, for convenience in mapping, he used as the top and bottom boundaries of the Chickasaw Creek Formation. Seely (1963, p. 166) described at least 70 feet of Chickasaw Creek shale in the vicinity of Ward Lake at the east end of the Rich Mountain syncline in Arkansas, but he estimated (p. 17) that the shale sequence above the Moyers Formation in the Rich Mountain area is generally between 150 and 200 feet thick. The sporadic variations in thickness from one area of study to another are probably more a reflection of the lack of established upper and lower boundaries of the formation than an outcome of inconsistencies in the formation's depositional environment.

*Siliceous shales.*—Despite the fact that they make up only a small percentage of the total Chickasaw Creek section, the siliceous shale and chert units are the hallmark of the formation. In this area, and in most of the immediately adjacent areas of study, two units of siliceous shale and chert are recognized. The thickness of the interval separating the two units is curiously sporadic. Cline and Moretti (1956), for example, showed the 2 units in this area to be separated by 55 feet of clastic sediments, but in adjacent areas Hart (1963, p. 18) found the 2 units to be 75 feet apart, Fellows (1964, p. 31) 35 feet, and Shelburne (1960, p. 75) 27 feet. The position of the chert layers within the formation varies similarly. As Hart (1963, p. 18) suggested, the variable position of the 2 units indicates that more than 2 units are involved.

As described in adjacent areas, the chert units occur in even beds of 1 to 6 inches in thickness. The finely laminated chert layers, usually brown stained in outcrop, are dark gray to black when freshly broken. The upper of the two units commonly contains abundant white specks described as being characteristic of Chickasaw Creek cherts in most other areas. The specks, composed primarily of siliceous sponge spicules and radiolarians, are generally about 2 mm in diameter and vary in concentration. The spots become increasingly vivid with weathering and are thus more conspicuous on the surfaces of chert samples found in float than on freshly broken surfaces. The lower chert unit exhibits few spots but is characterized by light-blue-white cloudy patches on freshly broken surfaces.

*Distribution.*—Along strike from the excellent exposure on U.S. Highway 259, the chert units are increasingly valuable as identifying marker units; consequently, for convenience in mapping, the chert units were used as the upper and lower boundaries of the Chickasaw Creek Formation. In so doing, it was found that the formation could be traced without appreciable change in lithology or thickness eastward from the described section on Highway 259 around the nose of the Lynn Mountain syncline. Westward along the southern limb, the formation dips more steeply northward and eventually becomes overturned in response to northward thrusting along the Octavia fault. The formation becomes buried in the N½ sec. 22, T. 1 N., R. 25 E., and is obscured by structural complexity along the remainder of the southern limb. Its continuation westward along the overturned southern limb is marked primarily by the upstream limit of black chert in the float. Some of the black shale and chert observed in the float contains abundant white specks reminiscent of the upper chert layer, whereas others exhibit the light blue-white cloudy patches characteristic of the lower unit.

Chert was also observed in the fault slices produced by the several bifurcations of the Octavia fault. A 5-foot interval of siliceous shale containing six or seven 2- to 3-inch layers of gray-green to black siliceous shale and chert crops out in the middle of SE¼NW¼ sec. 20, T. 1 N., R. 23 E. The layers are finely laminated and contain white specks. The unit was again observed to crop out within the same fault slice beyond the limits of the mapped area along the Indian Service Road in Pushmataha County (NE¼SE¼ sec. 24, T. 1 N., R. 22 E.).

A 9-mile slice of the Octavia fault, credited previously with burying the Chickasaw Creek Formation by its northward thrust over the southern limb of the Lynn Mountain syncline, is itself a tightly folded syncline herein named the Octavia syncline. Cherts were found in outcrop and abundantly in the float on both flanks of the fold. The partially covered outcrop, on the west side of the road in the SE¼NE¼ sec. 24, T. 1 N., R. 24 E., consists of at least four 2- to 3-inch layers of buff to black chert containing abundant white spots. Large angular blocks of black chert in the float along the northern slope of the slice testify to the proximity of a chert layer along the northern limb of the tightly folded syncline.

### *Wildhorse Mountain Formation*

*Character and thickness.*—The base of the Wildhorse Mountain Formation in the area of study rests upon the upper siliceous shale of the underlying Chickasaw Creek Formation. The top of the formation coincides roughly with the crest of Kiamichi Mountain, from which the dip surface slopes southward to the base of the next ridge. The basal siliceous shale of the overlying Prairie Mountain Formation is absent, and the boundary between the two formations is marked by the topographic break at the base of the ridge.

The Wildhorse Mountain Formation in this area consists of about 3,750 feet of alternating thin layers of sandstone and shale in which the cumulative thickness of sandstone subequals that of the shale (Cline and Shelburne, 1959, p. 187). The greater percentage of sandstone in the sequence causes it to stand out in sharp relief above the more easily weathered, valley-forming shales of the underlying units of the Jackfork and Stanley. All along the north limb of the Lynn Mountain syncline, therefore, the Wildhorse Mountain Formation forms a high northward-facing escarpment extending westward from the Arkansas line across Le Flore County and well into Pushmataha County.

From a thickness of 3,550 feet in the type locality, the formation gradually increases in thickness eastward into the Lynn Mountain syncline in Pushmataha County (3,828 feet; Cline and Moretti, 1956, p. 6-9) and Le Flore County (3,745 feet; Cline and Moretti, 1956, p. 15-18) and into the Boktukola syncline in McCurtain County (3,880 feet; Shelburne, 1960, p. 27). Morris (1965, p. 15) measured an additional increase in thickness of nearly 500 feet (relative to the section in this area of investigation) in the lower part of the formation in the frontal Ouachitas in Polk County, Arkansas, whereas Walthall and Bowsher (1966, p. 128) reported 5,000 feet of Wildhorse

Mountain on the south side of the Benton-Broken Bow uplift in Pike County, Arkansas.

An analysis of the sandstone layers in the lower part of the Wildhorse Mountain Formation by Luttrell (1965, p. 23) revealed a general composition of 85 to 95 percent quartz; 3 to 5 percent feldspar; 2 to 3 percent rock fragments; minor amounts of detrital mica, carbon, heavy minerals, and opaque metallics; and a low effective excess matrix. The sandstones become more massive, cleaner, and better sorted upward, a fact that is further reflected by a corresponding change in color from dark-grayish browns to lighter grays, yellows, and whites. Although the sandstone units have been variously classified all the way from graywacke to orthoquartzite, the author agrees with Luttrell (1965, p. 24) that the coarser clastic units are best defined as protoquartzites—75 to 95 percent quartz, rock fragments exceeding feldspar, and a clay matrix of less than 15 percent (Pettijohn, 1957, p. 291).

*Prairie Hollow Shale Member.*—The middle of the Wildhorse Mountain Formation is marked by a regionally persistent variegated shale interval named and described by Harlton (1938, p. 880) as the Prairie Hollow Shale Member of the Prairie Mountain Formation. Cline, however, discovered that the 300-foot shale occurred within the type section of the Wildhorse Mountain Formation and proposed that it be designated a member of the latter (Cline, 1956b, p. 56).

The shale interval is usually easily recognized as a friable green and maroon clay shale which forms a strike valley or saddle within the relatively resistant Wildhorse Mountain sandstones above and below. The member includes some sandstone and silt layers that are typically less than 6 inches thick, but in the area of this investigation some of the coarser units tend to be more massive. The 130-foot interval of Prairie Hollow Shale measured in this study area by Cline and Moretti (1956, p. 17) is thin compared to other areas: 300 feet in the Round Prairie syncline (Harlton, 1938, p. 880), 208 feet in the Lynn Mountain syncline of Pushmataha County (Cline and Moretti, 1956, p. 8), 300 to 700 feet in the Winding Stair Range of Le Flore County (Hart, 1963, p. 23), 320 feet in the Boktukola syncline (Shelburne, 1960, p. 71), 1,560 feet in the frontal Ouachitas of Polk County, Arkansas (Morris, 1965, p. 12). The variability in thickness of the member from area to area is undoubtedly more a function of the ill-defined nature of its boundaries than fluctuations in rate of deposition. Seely (1963) and Walthall and Bowsher (1966) did not positively recognize the Prairie Hollow Shale Member in their respective areas of study in Polk and Pike Counties, Arkansas.

*Distribution.*—The Wildhorse Mountain Formation is the most resistant formation in the area of study and, as such, forms the highest, most prominent, and outermost ridges within the Lynn Mountain syncline. It is easily traced along the northern limb and around the nose of the syncline. On the southern limb it becomes overturned as a result of northward thrusting along the Octavia fault. Westward along the southern limb from sec. 21, T. 1 N., R. 26 E., the overturned formation becomes a thrust sheet which buries overlying younger units. Based on its resistant nature and conformable contact with the several outcrops of the Chickasaw Creek siliceous shale, the overturned and northward-thrust rocks of the southern limb are identified as Wildhorse Mountain. For the same reasons, the rocks in the fault slices are similarly designated.

The Prairie Hollow Shale Member is easily traced along the northern limb of the syncline by its characteristic topography and maroon color. Around the nose and westward along the southern limb, the shale changes from maroon to green and, like the formation as a whole, is buried beneath the overturned and northward-thrust strata. The member was not positively identified in the Wildhorse Mountain Formation where it crops out in the overturned limb or fault slices.

### *Prairie Mountain–Markham Mill–Wesley Formations (Undifferentiated)*

*Character and thickness.*—The Prairie Mountain, Markham Mill, and Wesley Formations are the upper 3 of the 4 formations named by Harlton (1938) when he raised Taff's "Jackfork" from formation to group rank and subdivided it on the basis of several persistent thin black siliceous shale units. Like those of the Stanley and lower Jackfork, the black siliceous shale boundary markers fade out progressively eastward from Harlton's type exposures in the Tuskahoma and Round Prairie synclines. Of the black siliceous shales at the base of the Prairie Mountain and Markham Mill Formations and the top of the Wesley Formation, only the siliceous shale of the Wesley persists into the study area. In the absence of the siliceous shales it was necessary to combine the three formations into a single mapping unit consisting of an otherwise inseparable sequence of alternating layers of yellow- to brown-weathering sandstones and light-blue-gray shales, the sand-shale ratio of which is approximately 4:6. The base of the unit is marked by a strike valley formed where the upper Jackfork strata overlap the dip slope of the Wildhorse Mountain Formation of the lower Jackfork. This lower boundary is consistent with that used by Cline and Moretti (1956, p. 14). The upper limit of the Prairie Mountain–Markham Mill–Wesley unit is marked by the persistent Wesley siliceous shale.

In describing the Jackfork sequence exposed along U.S. Highway 259 through the Lynn Mountain syncline, Cline and Moretti (1956, p. 15, interval 59) distinguished 150 feet of Wesley shale from the units above and below, which contain numerous sandstone layers (*see* Appendix). In spite of its clear definition along the highway, the Wesley Formation's boundaries could not be traced in the field.

U.S. Highway 259 was under construction at the time Cline and Moretti measured their section. The route of the road as it descends toward the axis of the syncline south of the Prairie Mountain-Wildhorse Mountain contact (secs. 32 and 33, T. 2 N., R. 25 E., and secs. 4, 5, and 9, T. 1 N., R. 25 E.) was changed slightly, subsequent to their description. Because of insufficient time, the writer did not remeasure the section to fit the new route.

*Exotic boulders.*—A boulder-bearing shale interval is exposed along U.S. Highway 259 in the SE¼ sec. 32, T. 2 N., R. 25 E. The sequence corresponds to the 105-foot sandy shale described by Cline and Moretti (1956, p. 15, interval 55). The flaky dark-gray to olive-weathering shale yields an abundance of light-brown-weathering boulders ranging from an inch to several feet in diameter (fig. 4). The boulders are not concentrated at any particular horizon(s) but appear to be randomly distributed throughout the shale. Most of the boulders are composed of sandstone, but the sandstone boulders vary considerably in size, color, matrix content, and induration. Ironstone concretions and a few small chert cobbles were also observed. No limestone boulders were found.

The random distribution and varying composition of the boulders suggest that most of them are exotic inclusions in the shale. How the boulders were emplaced in the shale has not been firmly established, but more than one mode of emplacement is recognized. Many of the boulders were probably incorporated into mud flows which derived their coarse debris from several different sandstone or chert zones. The ironstone concretions show no evidence of transport and are regarded as having been formed in place. Some of the larger sandstone boulders, however, are thought to have been derived from local deformation of the overlying bedded sandstones.

The shale unit in which the boulders are

Figure 4. Boulder-bearing shale along U.S. Highway 259 in SE¼ sec. 32, T. 2 N., R. 25 E., believed to be part of Markham Mill Formation of Jackfork Group.

contained is directly overlain by a sequence of well-indurated, bedded sandstone layers. The contact between the two lithologies underwent local deformation, as evidenced by the incorporation of the lowermost beds of sandstone into the underlying shales. The other sandstone layers remained undisturbed, but several of the basal units penetrated deeply into the shale as they became sharply folded. The sand was concentrated in the crests of tight folds but thinned and pinched out on the limbs (fig. 5). Continued distortion of the isolated concentrations of sand produced rolled masses not unlike some of those observed as boulders lower in the shale sequence. The entire surface of one of the boulders observed in the interval of greatest boulder concentration was covered with sole marks, indicating that the boulder resulted from the pulling apart and rolling up of a sandstone layer. The layer was apparently unconsolidated at the time of deformation but was cohesive enough to remain intact and preserve the sole features.

Exotic boulders are not uncommon in the upper Jackfork Group elsewhere in the Ouachita Mountains. Harlton (1938, p. 885) reported the occurrence of lenses of cherty sandstone conglomerate near the base of the Markham Mill siliceous shale at Prairie Mountain. Northward into the frontal Ouachitas the conglomerates coarsen to boulders, which Harlton interpreted as having been "dropped into the sea during the time the basal siliceous shale was laid down" (p. 885). Harlton (1938, p. 888) also described rounded "chalcedonic masses which are irregularly intermixed in the shale matrix" of the Wesley Formation. Seely (1963, p. 24) found "discoidal sandstone masses" isolated in the shales of the Prairie Mountain–Markham Mill–Wesley section, which, like the same interval in the area of this report, could not be readily subdivided into separate formations. He also reported (p. 24) the occurrence of "ellipsoidal siliceous masses . . . and similarly shaped masses of limonite" near the top of the sequence in the Rich Mountain area. Hart (1963, p. 25, 26) described a 40-foot gray clay shale in the Winding Stair Mountain area that contained many exotic cobbles of bedded chert "remarkably similar to Wesley cobbles described by Goldstein and Hendricks (1962, p. 395)." Hart tentatively correlated the cobbles with those assigned to the basal Markham Mill by Harlton (1938, p. 886) because of their stratigraphic position.

Hendricks (1947, p. 17) observed Ordovician graptolites and trilobites from some of the exotic boulders in the frontal Ouachitas. Hammes (1965, p. 1671, 1672) suggested that the chert masses could have been derived from the Bigfork or Polk Creek cherts of Ordovician age or from the Woodford or Caney formation of Devonian-Mississippian age. Several fossiliferous limestone boulders collected by Hammes from the Wesley Formation on Jackfork Mountain were probably derived from the Viola Limestone (Ordovician) of the Arbuckle facies to the north and west. A northerly or northwesterly source was also interpreted by Harlton (1938, p. 885), Hendricks (1947, p. 17), and Hammes (1965, p. 1675), who observed that boulders are largest (up to 25 feet long) in the northern Ouachitas near the Ti Valley fault and become progressively smaller southward and eastward. However, it is probable that their observations applied to chert and other exotic boulders and may not have included sandstone masses that may be indigenous to the boulder-bearing beds. The abundance and large size of the boulders in the upper Jackfork exposed on U.S. Highway 259 do not appear to be consistent with the regional trend described by the aforementioned workers. Boulders were not observed in the upper Jackfork to the west in the Lynn Mountain syncline (Cline, 1960), in the Boktukola syncline to the south (Shelburne, 1960), nor elsewhere within the area of this investigation. Furthermore, the boulders in the subject exposure are composed primarily of sandstone in contrast to the predominance of chert boulders described in areas to the north and west. Compatibility with the regional trend of a progressive decrease in boulder size away from the northerly and westerly source is perhaps best illustrated by the few small chert masses found in the boulder-bearing shale outcrop. The abundance, large size, and restricted areal distribution of the sandstone boulders indicate that they were derived from a different and more local source than those to the north and west. Their local extent augments the idea that the boulders are rolled sandstone masses produced by local deformation.

*Wesley siliceous shale.*—The top of the Prairie Mountain–Markham Mill–Wesley unit is marked by a widespread thin sequence of black siliceous shales and cherts. The cherty unit, like the Chickasaw Creek siliceous shales, persists throughout most of the Oklahoma Ouachitas and serves as one of the most important stratigraphic markers in the Stanley-Jackfork sequence. In the Lynn Mountain syncline area it is best observed in the roadcut of U.S. Highway 259 (NE¼NE¼ sec. 5, T. 1 N., R. 25 E.), where it crops out as a 2-foot sequence consisting of eight to ten 1- to 3-inch finely laminated, dark-gray to black cherts that become

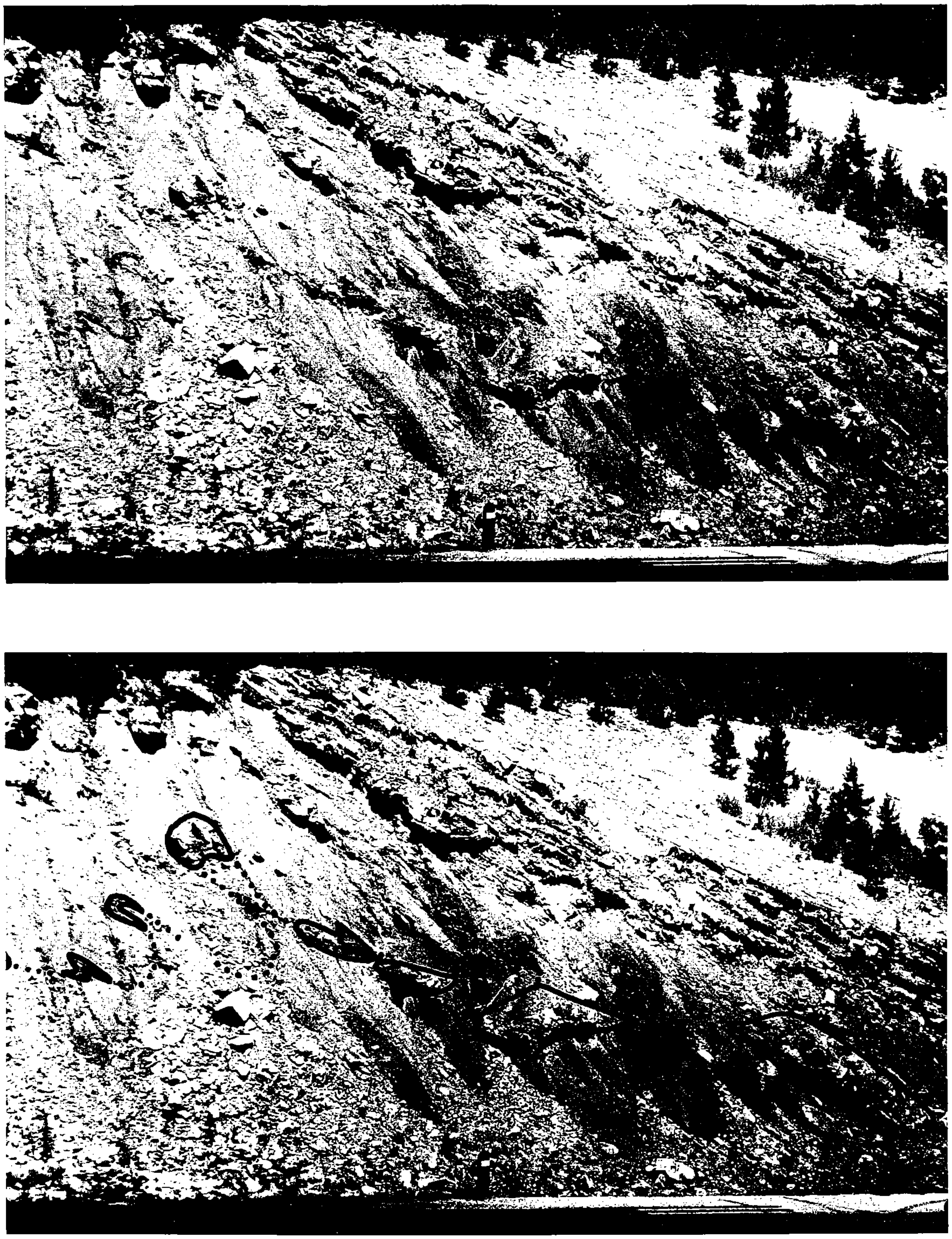

Figure 5. Rolled sandstone masses in shale sequence in undifferentiated upper Jackfork Group on U.S. Highway 259 (SE¼ sec. 32, T. 2 N., R. 25 E.). Basal unit of well-bedded sandstone sequence, which overlies shale, became folded while unconsolidated as result of local shearing. Sand thus concentrated in troughs and crests of folds and pinched out on limbs. Continued deformation caused concentration to develop into rolled sand masses. In lower photograph, concentrated masses are outlined by solid lines; limbs of folds, though now devoid of sand, are easily traced on outcrop and are illustrated by dotted lines.

siliceous shales upward (corresponding to interval 59 of Cline and Moretti, 1956, p. 15). The exposure is not conspicuous because, even though the Wesley sequence of which it is a part is predominantly shale, it is extensively fractured in a rhombic pattern. As the siliceous layers are undermined by removal of the less resistant shale, the fractured blocks of chert and siliceous shale tumble down the steep face of the cut. The foot of the slope is littered with rhombohedral blocks ranging is size from 1 to 3 inches along the maximum intercept (fig. 6). The blocks exhibit a light-gray to buff clayey exterior in outcrop and in the fresh rubble immediately adjacent, but the light-colored surface is quickly removed by abrasion. The resulting black rhombohedral blocks persist in the float far downslope or downstream from the outcrop. Their conspicuous dark color and characteristic shape greatly facilitate the identification of the blocks.

The dark siliceous marker unit occurs about 30 feet beneath a ridge-forming sandstone unit at the base of the overlying Game Refuge Formation. The Wesley siliceous shale thus follows a second ridge that is concentric to the ridge formed by the Wildhorse Mountain sandstones. It was traced eastward along the northern limb of the Lynn Mountain syncline and around the nose to the southern limb. West of U.S. Highway 259 the siliceous shale becomes overturned and then is concealed beneath overturned and northward-thrust Wildhorse Mountain strata (NE¼NE¼ sec. 13, T. 1 N., R. 24 E.). The persistent siliceous unit was also observed along the banks of Eagle Creek east of U.S. Highway 259 where, because the stream gradient exceeds the westward plunge of the syncline, the upper Jackfork sequence is dissected by the creek.

Hammes (1965) noted several trends in the Wesley Formation. Northward and westward toward the frontal Ouachitas the number and thickness of siliceous shales and cherts increase. The thickness of the formation in Oklahoma likewise increases toward the north from 150 feet in the area of investigation to 400-500 feet along the Ti Valley fault. Conversely, the number and thickness of sandstones in the Wesley, like the Game Refuge above and the Markham Mill beneath, increase toward the south and east. In Arkansas, neither Morris (1962, 1965) nor Walthall and Bowsher (1966, p. 129, 130) recognized the siliceous shale unit, but Walthall and Bowsher described the Wesley Formation in the Athens Plateau of Pike County as consisting of

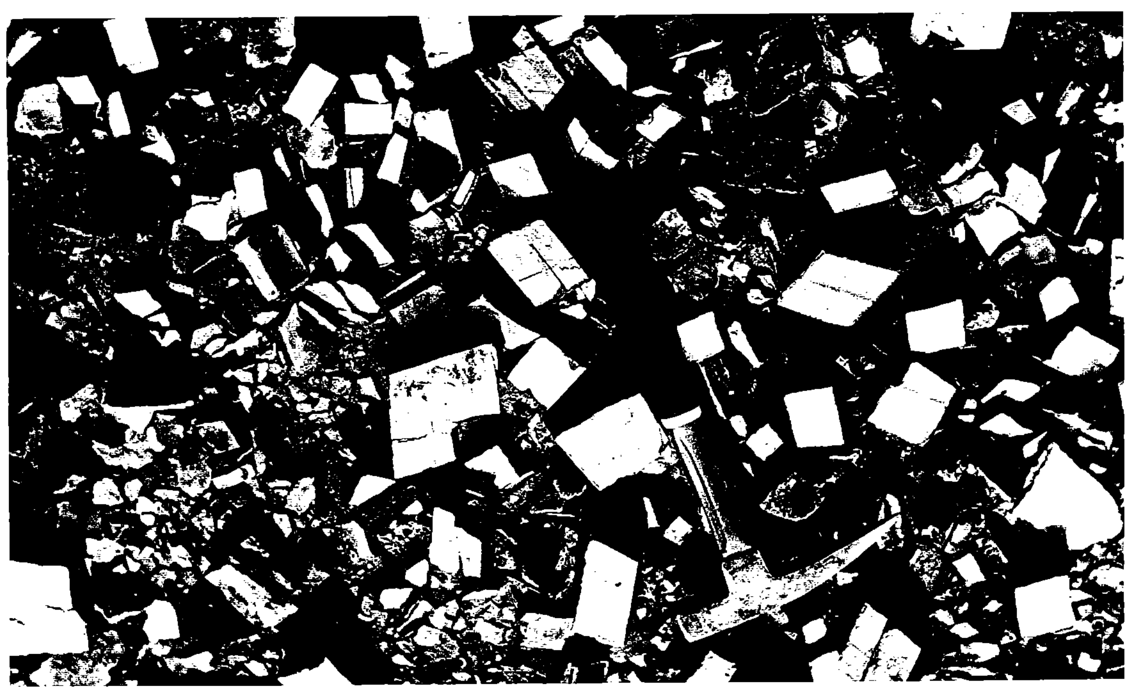

Figure 6. Rubble derived from siliceous shale of Wesley Formation, Jackfork Group, is composed typically of dark-colored rhombohedral to rectangular blocks. Light-colored exteriors seen in this photograph testify to proximity of rubble to outcrop. Removal of clayey exterior after only short transport renders blocks dark gray to black. Photograph taken near Wesley siliceous shale outcrop on U.S. Highway 259 in SE¼SE¼ sec. 32, T. 2 N., R. 25 E.

900 feet of clay shale, subgraywacke, and graywacke.

The siliceous unit of the Wesley in the area of this investigation is similar to that described in adjacent areas. To the west, in the Lynn Mountain syncline along the Indian Service Road, Cline and Moretti (1956, p. 5) reported 100 feet of Wesley shale, and 30 feet from the top of this shale they found a chert unit that weathers to characteristic rhombohedrons. Shelburne (1960, p. 31) found the Wesley shale to be 211 to 300 feet thick and to include a chert unit 35 feet below the top of the formation. He also noted the occurrence of white spots in the black chert, a feature reminiscent of the upper siliceous shale of the Chickasaw Creek Formation. Hart (1963, p. 27) was unable to find the diagnostic siliceous unit in the Winding Stair Mountain area to the north.

The variations in thickness reported by various workers are perhaps due in part to the fact that thrust faulting has placed units of different thickness in juxtaposition and the increase in number and thickness of sandstone units in the basal portion of the formation has made the assignment of the formation's lower limit rather arbitrary.

*Distribution.*—The upper formations of the Jackfork Group form a second or inner ridge concentric with that produced by the Wildhorse Mountain Formation. Like the Wildhorse Mountain Formation, the upper Jackfork is easily traced as a single unit eastward along the north limb and around the nose to the southern limb of the Lynn Mountain syncline. Westward along the southern limb, the undisturbed northward-dipping upper Jackfork rocks become progressively concealed beneath the overturned and northward-thrust rocks of the Wildhorse Mountain Formation. In secs. 18 and 19, T. 1 N., R. 25 E., the sequence containing the Wesley siliceous shale becomes overturned immediately prior to its disappearance beneath the overturned rocks of the thrust sheet. The upper Jackfork was not observed to reappear from beneath the overturned southern limb westward within the mapped area.

### *Game Refuge Formation and Younger(?) Paleozoic Rocks (Undifferentiated)*

The Game Refuge Formation is the youngest identifiable unit in the area of study, although younger rocks may be present, possibly including the equivalents of the Johns Valley Formation and the lower part of the Atoka Formation as recognized elsewhere. In any case, the lack of exotic boulders in this area precludes the positive recognition of the Johns Valley. Thus younger rocks, if present, are lithologically similar to the sandstones and shales of the Game Refuge. For mapping purposes, therefore, this entire sequence has been assigned to the Game Refuge.

*History of nomenclature.*—When Harlton (1938) raised the Jackfork to group rank, he subdivided it into four formations, of which the Wesley Formation was the youngest. At that time he considered the overlying, predominantly sandstone unit to be equivalent to the Union Valley Sandstone of Pennsylvanian age in the Arbuckle Mountains. Harlton (1959, p. 132) added this unit as the uppermost formation of the Jackfork Group and changed its name from "Union Valley" to "Game Refuge."

*Character, thickness, and distribution.*—The Wesley Formation is abruptly overlain by basal massive sandstone beds of the Game Refuge Formation, which form the crest of a second ridge concentric to that held up by the Wildhorse Mountain Formation. The several basal sandstone units of the Game Refuge are generally 6 to 8 feet thick, light buff to brown, and well indurated; locally they exhibit thin lentils of quartz-pebble conglomerate. The remainder of the formation consists primarily of rapidly alternating thin layers of light-colored sandstones and dark-gray shales. The estimated thickness of the entire sequence assigned to the Game Refuge Formation in this report is 3,000 feet.

Stratigraphically, the formation thickens westward down plunge from an erosional feather edge terminus on the nose of the Lynn Mountain syncline. Eagle Fork Creek has eroded its channel through the Game Refuge Formation to expose the underlying Wesley along the syncline's axis east of U.S. Highway 259. Cline and Moretti (1956, p. 15) measured a 500-foot interval of well-bedded, hard, white sandstones and gray shales that they tentatively assigned to the Atoka Formation. Neither the Game Refuge (known at that time as the Union Valley) nor the Johns Valley was recognized. The assignment of the interval to the Atoka by Cline and Moretti was based on the discovery of a mold fauna in the sandstone float near the top of the interval which they believed might have been Honess' "Morrow fauna." The writer now holds that the entire interval assigned to the Atoka by Cline and Moretti is Game Refuge and that the mold fauna, a feature not uncommon to the Game Refuge, is not the "Morrow fauna." The opinion that the mold fauna is not the "Morrow fauna" is consistent with Cline (1960, p. 59).

In the area mapped by the writer as Game Refuge, a few outcrops were observed that may represent the Johns Valley interval. These consist primarily of dark-gray to black friable, silty shale. In addition, rolled sandstone masses, characteristic of the Johns Valley, were observed in the float derived from shales along Big Eagle Creek.

The uppermost part of the sequence mapped as Game Refuge may represent rocks that have been assigned to the Atoka Formation in other areas, although no Atokan fossils have ever been identified in the Ouachita Mountains (R. O. Fay, Oklahoma Geol. Survey, pers. comm., 1972). This part of the sequence consists of dark-gray to olive, silty, micaceous shales alternating with brown- to gray-weathering, fine- to medium-grained sandstone beds. The character and vertical distribution of the sandstones and shales are similar to those of the underlying beds. Upward in the sequence the sandstones are 5 to 10 feet thick and are topographically more prominent, having formed an additional concentric ridge that parallels the previously mentioned ones formed by the resistant sandstone beds of the Wildhorse Mountain Formation and the basal sandstones of the Game Refuge. A 3- to 4-foot interval of dark-gray to black silty, siliceous shale characterized by 5- by 1- by 1/3-inch tabular rhombs parallels the crest of the aforementioned ridge about 80 feet down its steep north slope. The siliceous unit was traced eastward from the SE¼ sec. 33, T. 2 N., R. 24 E., to and around the nose of the ridge whereon it is concealed beneath the overturned and northward-thrust rocks of the syncline's southern limb. This distinctive unit was not encountered west of sec. 33, T. 2 N., R. 24 E., so its westward continuation can only be inferred. The unit is probably correlative with the black siliceous shale described by Cline and Moretti (1956, p. 4) along the Indian Service Road in Pushmataha County (NE¼ sec. 1, T. 1 N., R. 21 E.).

## SEDIMENTATION

### Ouachita Facies

Although the Ouachita fold belt extends for 1,300 miles along a sinuous course from east-central Mississippi into northern Coahuila, Mexico, only about 280 miles of the belt is exposed at the surface. The remainder is buried beneath relatively undisturbed younger rocks of the Gulf Coastal Plain. The major exposure of the deformed belt is in the Ouachita Mountains of central western Arkansas and southeastern Oklahoma. The sedimentary sequence observed in the Ouachita Mountains shows little change as it is traced in the subsurface south and southwestward to less extensive exposures in the Marathon Mountains and Solitario uplift of southwestern Texas. The remarkably persistent sequence is referred to as the Ouachita facies and is composed of relatively thin, dark lower Paleozoic graptolitic and siliceous shales and cherts and a thick upper Paleozoic, predominantly clastic, sequence of alternating layers of sandstone and shale.

In marked contrast to the rocks of the Ouachita facies is the shelf or platform type of deposits on the continent side of the trough that constitute the Arbuckle facies. Rocks of the Arbuckle facies are composed of carbonates and clastics indicative of shallower water and a more stable sedimentary environment. The Arkoma basin of Oklahoma contains sediments of the Arbuckle facies deposited on the northern limb of the Ouachita geosyncline. The southern limb has been severely deformed and (or) concealed beneath relatively undisturbed Cretaceous sediments of the Gulf Coastal Plain. Many of the Oklahoma Ouachita structures terminate southward along strike against the buried Arbuckle Mountains and Criner Hills and do not extend into Texas.

### Flysch Facies

Prior to deposition of sediments of the Stanley Group, the sedimentary environment of the Ouachita geosyncline was one of slow deposition of chert and dark graptolitic shales in a deep-sea trough deprived of clastic sediments. The relatively thick clastic sequence, beginning with the deposition of the shales of the Stanley Group, presumably signifies an increase in tectonism marked by a sudden and continuing influx of clastic sediment into the rapidly subsiding trough. The normal deposition of mud was frequently interrupted by the sudden incursion and rapid deposition of coarser clastics deposited from deep-water turbidity currents. The resulting 22,000-foot clastic sequence of Stanley-Jackfork-Johns Valley and later Paleozoic sediments, consisting almost entirely of a monotonous alternation of sandstones and dark shales, is now commonly referred to as a flysch facies.

The term "flysch" was first applied to the clastic Ouachita sequence by Waterschoot van der Gracht (1931, p. 998), who noted its similarity to the flysch facies of the Alps and Carpathian Mountains of Europe. Cline (1959, p. 1582) revived the term for use in describing the Stanley-Jackfork-Johns Valley and higher strata of the Ouachita facies and, more recently, made a comprehensive comparison of the sequence with those of the classic flysch localities of Europe (Cline, 1966).

*Sole Marks*

Typical of turbidites, the sandstone layers throughout the Ouachita flysch sequence exhibit a sharp disconformable lower boundary with the underlying shales, a property which testifies to the scouring capabilities of the passing turbidity currents from which the sands were deposited. Upon lithification of the sands, scour features of all types were preserved as sole marks on the bottom surface of the turbidite layers. Consistent with observations made elsewhere in the Ouachitas of Oklahoma, the writer found that the sandstone layers of the Stanley Group reveal fewer sole marks than do the younger sandstone layers of the flysch sequence. The many sole marks found on the sandstone layers of the flysch sequence above the Stanley were of exceptional value in determining sediment transport directions in an earlier study by the writer (Briggs, 1963). In the absence of fossils and other stratigraphic markers, the sole marks were of paramount importance to the present study in the recognition of tops and bottoms of beds.

*Graded Bedding*

Many of the sandstone layers in the flysch sequence display graded bedding. The grading, however, is very subtle in that there is no conspicuous decrease in grain size upward through a given sandstone unit. At a few places, the coarsest grained sands within the turbidite unit were found at the points of greatest relief on the sole marks. That graded bedding indeed exists is most clearly indicated by a sandstone's gradational or "fuzzy" contact with the overlying shale. From the gradational contact it is assumed that, as the turbidity current passed and its competency waned, the particles being deposited from it became finer and finer until the normal environment of shale deposition was resumed. Recognition of graded bedding by a gradation from sand to shale, rather than by an observable decrease in grain size upward, has become so common in studies of the Ouachita flysch facies that this type of bedding is referred to as "Ouachita-style" graded bedding (fig. 7).

The gradational upper boundary of the sandstone units was found to be most pronounced in the lower Stanley Group of the subject area and least pronounced in the upper member of the Wildhorse Mountain Formation of the Jackfork Group. The gradational nature of the sandstone-shale contacts is interpreted by the writer to be a function of variation in grain size of the suspended material carried by the turbidity current. When sorting is relatively poor, the diminishing velocity of the current is reflected by a continuous,

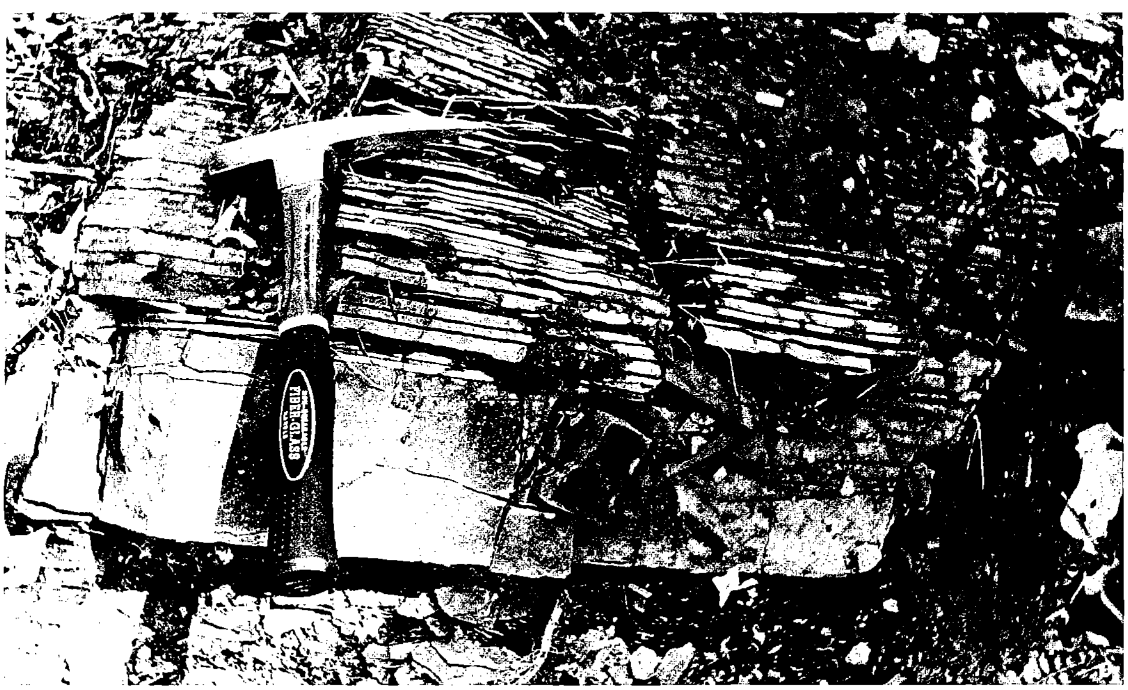

Figure 7. Turbidite bed in Stanley Group exhibiting "Ouachita-style" graded bedding. Graded bedding is evidenced by gradual increase in fissility upward.

progressive grain-size decrease upward through the deposit. If, on the other hand, the suspended sediments of the current are approximately the same size (i.e., within 2 or 3 Wentworth size grades), the particles will be deposited nearly simultaneously, leaving only matrix material in suspension. The remaining suspended particles are subsequently included in the deposition of silts and muds indigenous to the normal sedimentary environment. It has been stated previously that the sandstone units of the upper Wildhorse Mountain Formation are relatively well sorted, a fact that is further underscored by their thin gradational contacts with the overlying shales (fig. 8). The poorer sorting of the turbidites of the Stanley Group is revealed by thick gradation zones within which the sandstones grade imperceptibly into the overlying shales (fig. 7). In the latter case it is suspected that sorting improves upward through the sandstone as the heterogeneous assortment of coarser clastics and fine-grained matrix material grade upward into relatively uniform clay-sized sediments. In sandstones of both the Stanley and Jackfork Groups, the subtlety of the grading indicates that the sands were fairly well sorted prior to their deposition in the trough. It is thus concluded that the unstable accumulations of shelf sands, from which the sediment load of the turbidity currents was derived, were themselves fairly well sorted.

*Sequence of Sedimentary Features*

A turbidite layer may exhibit a vertical sequence of sedimentary features. Bouma (1962, p. 49) described an ideal sequence as consisting of five zones which, in ascending order, are: (1) a graded interval, (2) a lower interval of parallel laminations, (3) an interval of current ripple lamination (micro-cross laminations and convolute bedding), (4) an upper interval of parallel laminations, and (5) a pelitic (shale) interval. The writer regards the Bouma sequence as a composite sequence which, as far as the turbidites of the Ouachita flysch facies are concerned, seldom appears in its entirety in any one sandstone layer. Luttrell (1965, p. 46) was able to apply the Bouma sequence to the sandstones of the upper Stanley Group and the lower sandstones of the Wildhorse Mountain Formation of the Jackfork Group in the study area along U.S. Highway 259. Cline (1966, p. 100) remarked that more often than not, one or more zones of the series are missing. Briggs (1963, p. 11) observed that one

Figure 8. Alternating sandstone and shale layers of upper Wildhorse Mountain Formation of Jackfork Group along U.S. Highway 259 near crest of Kiamichi Mountain (SW¼ sec. 26, T. 2 N., R. 25 E.) Predominance of sandstone in sequence makes it prominent ridge former. Relative to sandstone layers of valley-forming Stanley Group, as seen in figure 7, sandstones of Wildhorse Mountain are cleaner, less argillaceous, and exhibit sharper upper contacts with interbedded shale layers.

sequence of features may be truncated and another sequence begun during the passage of a second turbidity current.

*Spheroidal Weathering*

Spheroidally weathered boulders were observed at several localities on the southern limb of the Lynn Mountain syncline. The boulders are about 4 feet in diameter and protrude conspicuously out of the sandstone units in which they are enclosed (fig. 9). Five boulders were observed in the proximity of the Octavia fault in secs. 13, 14, 22, and 23, T. 1 N., R. 24 E., and one was discovered on the edge of the northward-thrust block of Jackfork sandstones in the SE¼NE¼ sec. 18, T. 1 N., R. 23 E. Those adjacent to the Octavia fault protrude from what appeared to be rather gently inclined dip surfaces, but closer examination revealed that the gently inclined surfaces are actually the eroded edges of vertical to overturned thick sandstone beds within which the boulders are wholly confined (fig. 10).

That the boulders have undergone spheroidal weathering is clearly indicated by concentric fractures that become more numerous near the boulders' outer edges. Some of the boulders are flat on top as a result of spalling of tabular plates of sandstone along horizontal to gently inclined partings (fig. 11).

The nature of the sandstones in the boulders is not exactly like that of the sandstones which surround them. At one locality the sandstone of the boulder was well indurated and gray in color, whereas the surrounding sandstone was relatively more friable, slightly lignitic, and buff colored. That the boulders were formed in place is indicated by fractures that extend from the surrounding sandstones into the boulders. Vacant pits where boulders might once have been were not observed.

*Shale*

The 22,000-foot sequence of Stanley-Jackfork-Johns Valley and younger Paleozoic rocks in the Ouachita Mountains is composed primarily of alternating thin layers of sandstone and shale, with shale the dominant rock type. Typical of studies involving sequences consisting of sandstone and shale layers, the sandstones of the Ouachita facies have received more attention than have the shales. The origins and depositional environments of the sandstones have been studied in considerable detail. The shales, on the other hand, are generally and simply regarded as the product of normal deposition that was periodically interrupted by a sudden influx of coarser material via a turbidity current (Sujkowski, 1957, p. 550). Presumably, the axis of the Ouachita trough would have been filled almost exclusively with shale had there been no turbidity currents.

The abundant clay matrix in most of the turbidite layers is considered to be as much a product of the turbidity current as are the sands and silts. As the sands and silts disappear upward in the graded turbidite layer, the finer grained matrix blends with and becomes indistinguishable from the overlying clay-sized particles of the overlying shale. The overlying shale is commonly interpreted as reflecting a return to normal deposition. The writer submits, however, that much of the overlying shale may represent late-stage deposition from a waning turbidity current. The deposits from a single turbidity current may extend upward beyond the gradational contact between the sandstone and shale, in some cases to the disconformable contact with the next overlying sandstone layer.

A turbidity current must undoubtedly leave in its wake an appreciable quantity of fine-grained material in suspension, which, although slow to settle, is hardly normal for the invaded depositional environment. Ewing and Thorndike (1965) observed clouds of suspended lutite ("nepheloid layers") in the lower parts of the water column on the Atlantic continental shelf and slope. Such clouds could represent late-stage deposition following the passage of turbidity currents. The aforementioned authors suggested that the suspended material was sufficient in quantity to induce downslope flow.

Finally, the writer suggests that some of the unlaminated mudstones might have been transported to their present location as a density current or mud flow that contained no appreciable coarser material. Certainly, the presence of exotic boulders within some of the shale sequences suggests transport by mud flows.

*Siliceous Shale and Chert*

The siliceous shales and cherts of the Ouachita flysch facies are generally dark gray to black, 1 to 6 inches thick, irregularly laminated, and, in the case of the upper siliceous shale of the Chickasaw Creek Formation of the Jackfork Group, mottled with round spots of white-weathering silica with diameters averaging about 2 mm. Shelburne (1960, p. 31) observed similar white spots in the Wesley siliceous shale in the Boktukola syncline. The dark color of the shales and cherts is attributed to the presence of carbonaceous or sapropelic material.

Figure 9. Spheroidally weathered sandstone boulder in lower Wildhorse Mountain Formation of Jackfork Group exposed in creek bed in center of SW¼SW¼ sec. 14, T. 1 N., R. 24 E. Boulder occurs within overturned massive sandstone unit that dips southward at approximately 60°.

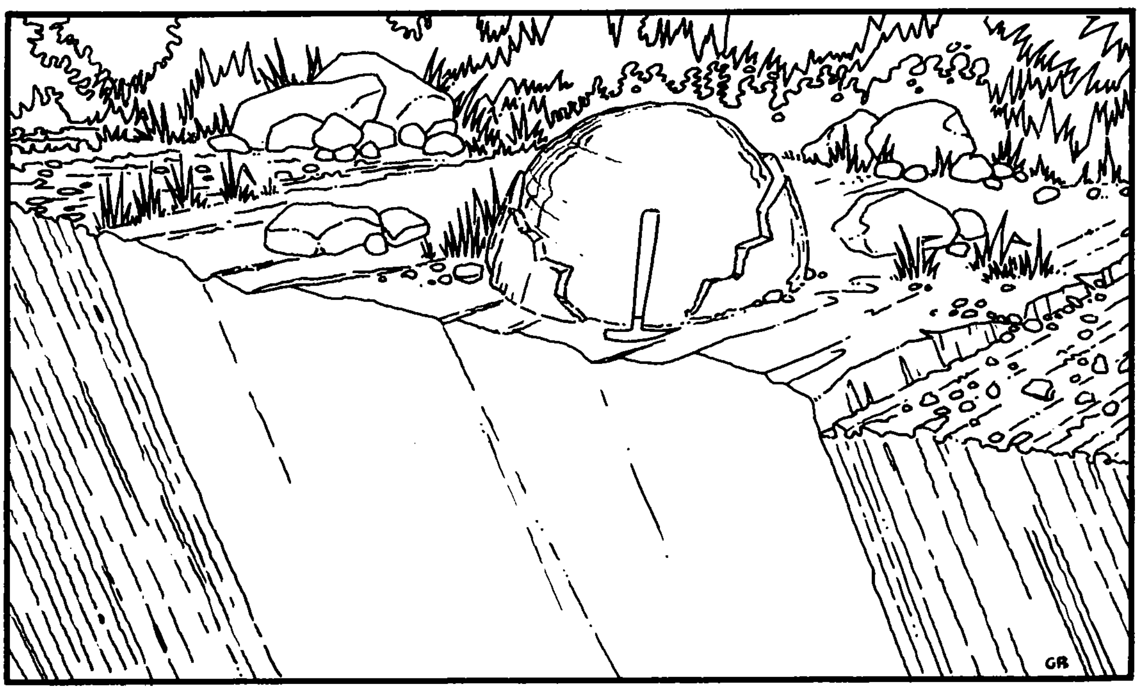


Figure 10. Diagrammatic sketch of spheroidal boulder, confined between upper and lower boundaries of sandstone unit. Gently inclined sandstone surface from which it protrudes is actually eroded edge of overturned bed.

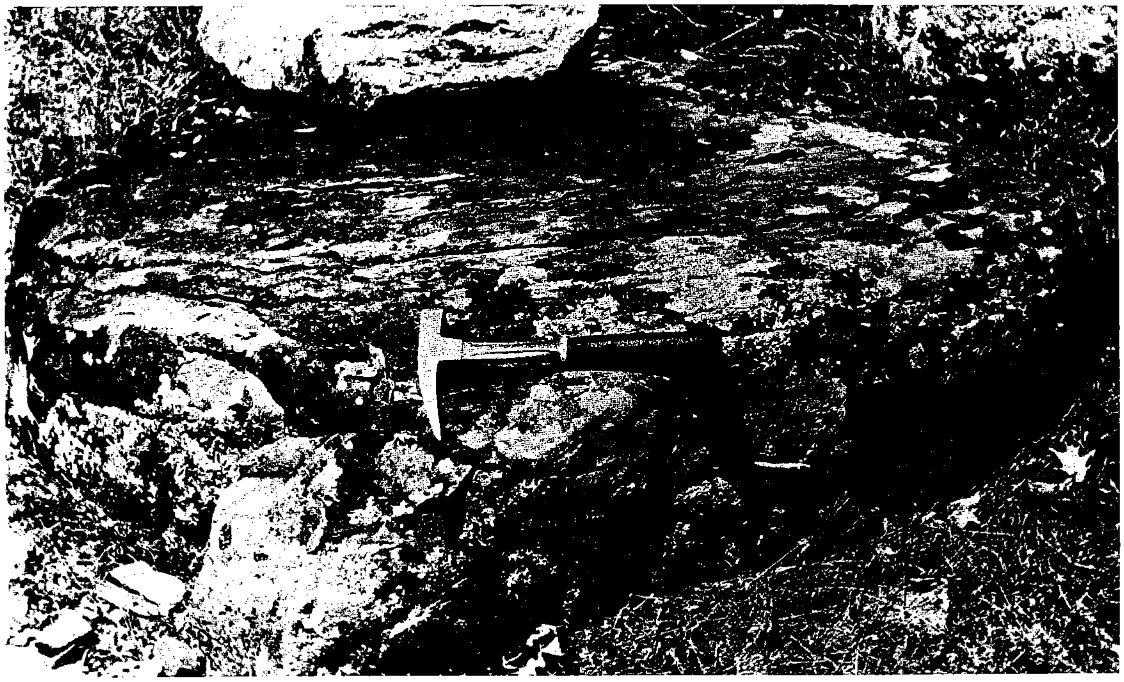

Figure 11. Spheroidally weathered sandstone boulder in relatively gently southward-dipping sandstone bed in Tenmile Creek Formation of Stanley Group directly south of Octavia fault in center of NE¼NW¼ sec. 22, T. 1 N., R. 24 E. Boulder is flat topped as result of removal of slabs produced by separation along bedding planes within boulder.

Observations of thin sections commonly reveal an abundance of sponge spicules, spore exines, and radiolarian tests and spines. Goldstein and Hendricks (1962, p. 397) reported the presence also of pyrite, silt-sized quartz, micas and chlorites, glauconite, and iron oxides in the siliceous shales of the Jackfork Group.

Studies of cherts and novaculites deposited prior to the flysch sequence of the Ouachita facies generally agree that the silica deposition was extremely slow and laterally persistent. The depositional rate of 0.01 foot/1,000 years estimated by Park and Croneis (1969, p. 109) for the Arkansas Novaculite is, as they pointed out, about half the minimum rate of accumulation for unconsolidated pelagic sediments in the Atlantic Ocean since the Pleistocene Epoch (Ericson and others, 1961, p. 274). Goldstein (1959, p. 149), in discussing the Bigfork Chert (Ordovician) and the Arkansas Novaculite (Devonian-Mississippian), stated that the siliceous sediments were derived from volcanic-ash falls during times of relative peneplanation when little detrital sediment was being supplied to the Ouachita geosyncline.

The black siliceous shales and cherts of the Ouachita flysch facies, insignificant as they are in thickness relative to the entire flysch sequence, are laterally persistent. Their wide areal distribution prompted Harlton (1938) to use them to subdivide the Stanley-Jackfork sequence into formations. Individual turbidite or shale beds, on the other hand, have not been traced for distances greater than a mile. The lateral persistence and uniform thicknesses of bundles of turbidite layers suggest that although an individual turbidite bed cannot be traced over a long distance, the turbidity-current episode of which it was a part was areally extensive. It follows that the turbidites must intertongue with the shales and that the areal distribution of the turbidites, even within a bundle, is discontinuous and sporadic.

If the same depositional environment used to explain the pre-flysch cherts and novaculites is employed to account for the thin siliceous units in the flysch sequence, one must explain how and why the dynamic sedimentary environment of the flysch facies temporarily ceased to allow the very slow and widespread deposition of the siliceous sediments. It is unlikely that the several sources of terrigenous sediments suddenly and simultaneously ceased to supply materials to the geosyncline of southeastern Oklahoma.

The writer submits that the siliceous material was introduced as a density flow or siliceous ooze, which, in seeking its own level, covered a wide area in a short period of time relative to the normal rate of silica deposition. Deposition from a waning flow is indicated by the graded bedding observed by Cline (1960, p. 39) in a specimen of siliceous shale from the Chickasaw Creek Formation.

The silica, derived primarily perhaps from volcanic activity, became concentrated near the ocean floor, where it supported an abundance of silica-utilizing organisms. The siliceous remains did not settle out, because the density of the concentration and turbulence was sufficient to maintain their suspension. The poor sorting of the siliceous shales, as illustrated by the association of clay-sized particles and sponge spicules, is perhaps a reflection of the depositing medium's high viscosity. The fine laminations and the concentration of siliceous remains of organisms within certain laminae suggest that the siliceous sediments in some areas were reworked by normal marine currents.

## Sources of Sediments

Theories on the sources of the sediments making up the Ouachita flysch facies have long been debated. Miser (1929), having observed that the sediments within the geosyncline thicken abruptly and become coarser southward, proposed a southern source which he referred to as "Llanoria." Later paleocurrent and petrographic studies have confirmed Miser's southern source for the flysch sediments but suggest additional and sometimes larger sources elsewhere at various times during Late Mississippian and Early Pennsylvanian time. The reader is referred to the recent paper by Briggs and Cline (1967) for a comprehensive study of the source areas of late Paleozoic sediments of the Ouachita Mountains.

### Stanley Group

A petrographic study by Hill (1966) and an investigation of the paleocurrents by Johnson (1966) revealed that the turbidites of the Stanley Group were derived largely from a marginal source or sources to the south. Johnson noted that northward-moving paleocurrents became westwardly directed as they approached the axis of the geosyncline. A petrographic study of the turbidites immediately adjacent to the Stanley-Jackfork contact by Klein (1966) suggested that some of the sediments were supplied from both the north and south margins of the geosyncline.

### Jackfork Group and Younger Paleozoic Units

Petrographic studies by Bokman (1953), Moretti (1958), Goldstein and Hendricks (1962), and Walthall and Bowsher (1966) suggest a southern source for many of the sediments of the Jackfork Group. A study of sole marks in the Jackfork sandstones indicated that the paleocurrents were directed westward parallel to the axis of the geosyncline (Briggs, 1963). That transport from the south margin is not suggested by the sole marks is perhaps due to the fact that Jackfork sediments, which may have contained sole marks reflecting northward transport, have been eroded away.

Axial transport of turbidites persisted during Johns Valley time, although some of the dark-gray to black shale intervals of the formation are the products of mud flows. The primary transport direction for later Paleozoic sediments was also westward and southwestward down the axis of the trough. In studying the paleocurrents of rocks assigned to the Atoka Formation, Briggs (1963) discovered that currents flowing southward across the Arkoma basin became westwardly oriented as they entered the Ouachita geosyncline; the paleocurrent pattern indicates that at least some of these turbidites were derived from northern sources.

### Sources of the Flysch Sediments

The flysch sequence thickens and becomes coarser southward (Miser, 1929; Cline, 1960; Walthall and Bowsher, 1966; Hill, 1966; Johnson, 1966) and eastward (Reinemund and Danilchik, 1957; Shelburne, 1960; Goldstein and Hendricks, 1962). Coincident with the increase in thickness and coarseness of the sediments is a progressive eastward and southward disappearance of the black siliceous shales (Hammes, 1965). The eastward disappearance of the black siliceous shales used by Harlton to subdivide the Stanley and Jackfork Groups is reflected by the lumping of formations within those groups by the writer and other workers endeavoring to trace Harlton's units toward and into Arkansas (Cline, 1960; Shelburne, 1960; Hart, 1963; Seely, 1963; Morris, 1965).

The eastward changes in facies, together with the paleocurrent data, indicate that the turbidites were derived largely from deltas somewhere east of Little Rock, Arkansas (Briggs and Cline, 1967, p. 998). Paleocurrent and facies studies of the Eastern Interior basin (Potter and Siever, 1956; Potter and others, 1958; Swann, 1964) indicate that sediments were derived from the craton to the north and transported through the basin. During Chesterian time the Eastern Interior basin was open at its southern end (Workman, 1940, p. 220-221) and served as a "sluiceway" between the Ozark dome and Cincinnati arch through which sediments were delivered to the marginal geosyncline (Potter and Pryor, 1961, p. 1229).

# STRUCTURE

## Lynn Mountain Syncline

The structure of the Lynn Mountain syncline is fairly simple. Like other synclines that characterize the central Ouachitas, it is a long, gently plunging, asymmetrical syncline whose southern limb is bounded by the trace of a large down-to-the-north thrust fault, the Octavia fault. From its nose near the Arkansas line it plunges gently westward across southern Le Flore County and then westward and southwestward through Pushmataha County in an arcuate pattern consistent with the structural grain of the southwardly concave salient of the Ouachita Mountains of Oklahoma. The axis of the Lynn Mountain syncline in the area of this report is approximated by Eagle Fork Creek east of U.S. Highway 259. From its confluence with Big Eagle Creek in sec. 8, T. 1 N., R. 24 E., Eagle Fork Creek flows southward across the southern limb.

In the area of study, southward-dipping rocks of the northern limb of the Lynn Mountain syncline extend northward to the Windingstair fault on the northern side of the Kiamichi River valley. The limb thus includes the valley-forming shales of the Stanley Group and the more resistant sandstones of the Jackfork Group which form the prominent ridges known as the Kiamichi Mountains. The incompetent Stanley shales of the Kiamichi River valley absorbed much of the mountain-building deformation, while the more structurally resistant Arkansas Novaculite below and Jackfork sandstones above emerged relatively unscathed. The northern extremity of the northern limb of the syncline constitutes the upthrown side of the Windingstair fault, along which northward thrusting produced another belt of synclines represented by the Simmons Mountain syncline (Hart, 1963) and the Rich Mountain syncline (Seely, 1963).

The relatively undisturbed upper Stanley and lower Jackfork strata of the northern limb of the Lynn Mountain syncline are easily traced around the nose of the syncline to the southern limb. Westward along the southern flank, however, the upper Stanley and lower Jackfork rocks increase abruptly in dip and become overturned in response to northward thrusting along the Octavia fault. Beginning in, and extending westward from, the SE¼ sec. 23, T. 1 N., R. 26 E., the strata of the southern limb dip steeply or are overturned. Westward, the overturned rocks themselves extend as a thrust sheet farther and farther to the north to conceal, first, the Prairie Hollow Shale Member of the Wildhorse Mountain Formation (NE¼NW¼ sec. 24, T. 1 N., R. 25 E.); next, the siliceous shale of the Wesley Formation (middle of S line SE¼ sec. 12, T. 1 N., R. 24 E.); and finally, the axis of the Lynn Mountain syncline (SW¼ sec. 8, T. 1 N., R. 23 E.). The progressive concealment of stratigraphic marker beds greatly hinders correlation westward along the southern flank. The belt of overturned rocks of the southern limb is bounded on the south by the Octavia fault and on the north by an abrupt change to relatively undisturbed, gently dipping beds near the syncline's axis.

## Octavia Fault

The southern limb of the Lynn Mountain syncline is bounded by the Octavia fault, a large down-to-the-north thrust fault which extends westward across southern Le Flore County and southwestward to southwestern Pushmataha County, where it becomes concealed by Cretaceous sediments of the Gulf Coastal Plain. Its trace is generally marked by an abrupt change in relief where valley-forming lower Stanley shales are in contact with ridge-forming upper Stanley and lower Jackfork sandstones. The fault is also marked by an abrupt change in direction of dip. Rocks on the upthrown (south) side of the fault dip relatively gently to the south, whereas those on the downthrown side are inclined steeply northward or are overturned.

The trace of the Octavia fault is rarely observed as a single line. Cline (1960) mapped the Octavia fault in Pushmataha County as two roughly parallel faults, the northern of which he called the Birdsong fault. In the area of this investigation, the Octavia fault similarly exhibits two traces which join and bifurcate to produce two fault slices. Consisting primarily of lower Jackfork sandstones, the fault slices stand out topographically in contrast to the less resistant Tenmile Creek shales of the Stanley to the south of the fault. The rock layers in each of the slices have been folded into a syncline, the axis of which roughly parallels that of the Lynn Mountain syncline. The two synclines, the Octavia and the Honobia, are named for small communities in their immediate vicinities.

## Octavia Syncline

The Octavia syncline is the eastern of two fault-slice synclines flanking the southern limb of the Lynn Mountain syncline along the Octavia fault. Its lower Jackfork sandstones have produced a 9-mile-long ridge (from the center of sec. 30, T. 1 N., R. 26 E., to the NW¼ sec. 24, T. 1 N., R. 24 E.) which stands out topographically in contrast to the less resistant Stanley shales that surround it on all sides. Its topographic expression is misleading in that the sharp crest of the ridge, rising 400 feet above adjacent valleys, approximates the axial trace of the tightly folded syncline. The structure is dissected into two subequal parts by a northwest-southeast-trending, right-handed tear fault along which the western portion of the syncline was displaced slightly farther to the north than was its eastern counterpart. The northward displacement of the western segment is further reflected by overturning of most of its southern limb. The eastern half of the Octavia syncline is symmetrical.

### Honobia Syncline

The western of the two fault-slice synclines, the Honobia syncline, is not wholly contained within the mapping area but extends an undetermined distance into Pushmataha County. The northward-thrust slice consists primarily of southward-dipping Wildhorse Mountain sandstones which override and conceal not only the overturned rocks of the southern limb of the Lynn Mountain syncline but also a portion of its axis (sec. 7, T. 1 N., R. 23 E.). A northward-dipping sequence of Chickasaw Creek siliceous shale (lumped with the Stanley on the geologic map, pl. 1, in pocket) crops out on the syncline's southern limb but does not reappear on the northern limb.

## Influence of Structure on Drainage Pattern

The drainage pattern in the area of this investigation is principally rectangular. A strong north-south orientation of streams is intersected at right angles by an equally strong east-west trend. The drainage conforms closely with the topographic expression of structure. The large streams follow the linear valleys between resistant ridges or coincide with the axis of the Lynn Mountain syncline, all of which have an east-west orientation. The north-south stream direction results from drainage down the slopes of the ridges into the east-west-trending larger streams.

Azimuthal readings were made of joints at 155 localities within the study area. Two joint directions were observed at each locality (fig. 12). Many more localities were available for observation, but the constancy of the joint pattern made additional observations unnecessary. A plot of the azimuthal directions of the fractures vividly illustrates the prominent bimodality in the north-south and east-west directions (fig. 13).

Joint control of drainage is perhaps best illustrated by the north-south orientation of tributaries to Eagle Fork Creek, which flows almost due

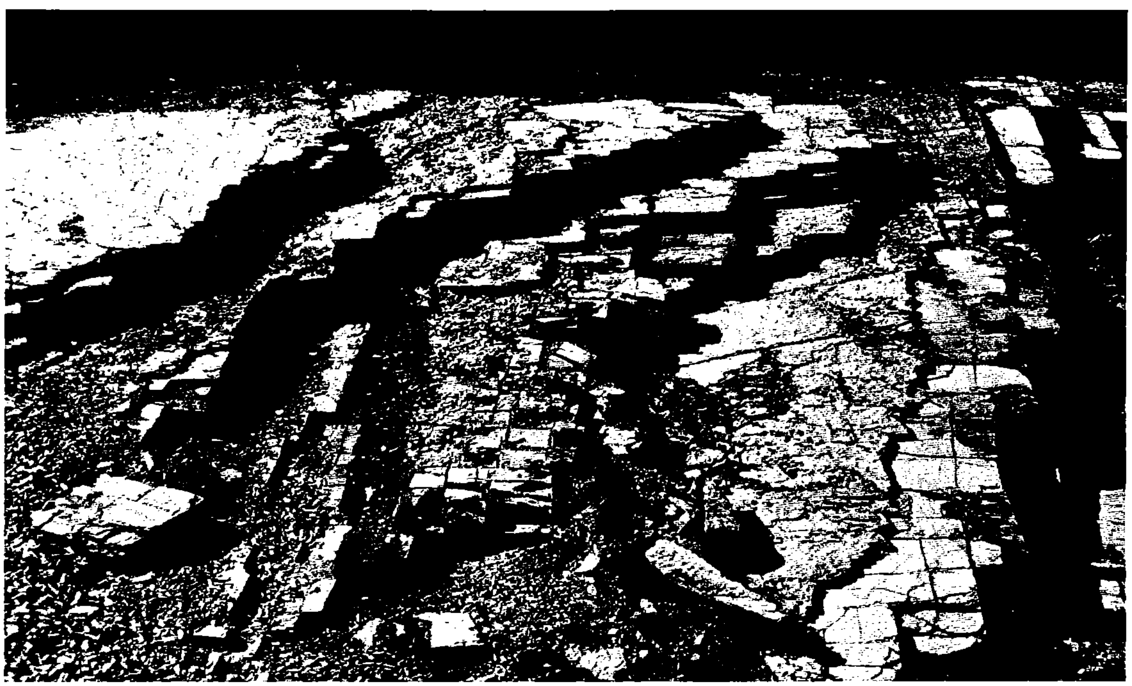

Figure 12. Joints in dip slope of sandstone layers of upper Wildhorse Mountain Formation of Jackfork Group at crest of Kiamichi Mountain (SE¼ sec. 27, T. 2 N., R. 25 E.). Joint sets parallel directions of strike and dip to produce rectangular fracture pattern.

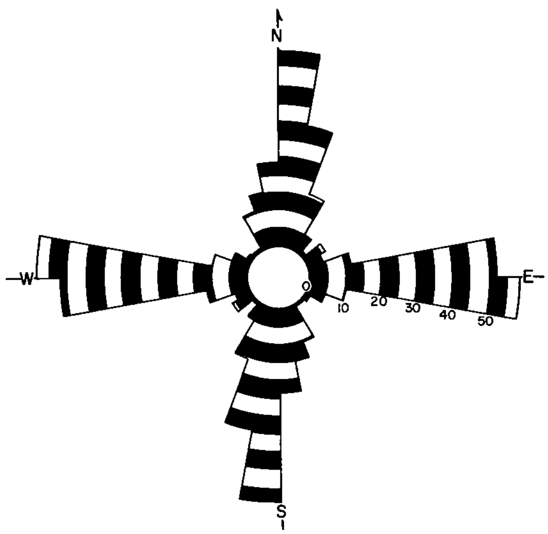


Figure 13. Circular histogram of jointing directions in area of study. Diagram is compilation of 310 compass readings of joints at 155 localities. Joint planes are at right angles to bedding planes.

west along the axis of the Lynn Mountain syncline (pl. 1, in pocket). Not only do the tributaries branch at right angles from Eagle Fork Creek, but they also branch in pairs: i.e., a southward- and a northward-flowing tributary branch from the same point on Eagle Fork Creek.

The regional slope, and hence the drainage direction, is southward. Three streams flowing along the axis of the Lynn Mountain syncline breach the overturned southern limb of the syncline at orientations anomalous to the north-south, east-west stream pattern. The streams have a northwestward orientation and are here interpreted as following the traces of three right-handed strike-slip faults. One of the streams is Eagle Fork Creek where it flows southward through secs. 17, 20, and 21, T. 1 N., R. 25 E. The other two are in sec. 16, T. 1 N., R. 24 E., and sec. 13, T. 1 N., R. 23 E.

## GEOLOGIC HISTORY

By Late Mississippian time, the entire Ouachita geosyncline had undergone active and apparently rapid downwarping as indicated by the rather abrupt transition from the "starved basin" type of sediments of the Arkansas Novaculite and older formations to the sandstones and shales of the Ouachita flysch facies. Sands and muds derived primarily from sources to the east and southeast were transported by turbidity currents westward and southwestward along and essentially parallel to the axis of the geosyncline (Briggs and Cline, 1967, p. 994). In response to the deep subsidence of the geosyncline during Late Mississippian and Early Pennsylvanian time, a geanticlinal ridge of eastern Arbuckle and Ozark facies rocks almost emerged along the northern margin of the trough, presumably as the upthrown edge of a southward-dipping normal growth-fault system (Shideler, 1968, p. 125; Buchanan and Johnson, 1968). The ridge, parallel to the strike southward to the vicinity of the Criner Hills, separated the foreland from the geosyncline.

The age and duration of the Ouachita orogeny are still subject to conjecture. According to Goldstein and Hendricks (1962, p. 427), deformation began in early Atokan time and intensified into the middle Atokan, at which time uplift and erosion of geosynclinal sediments occurred. It was probably in late Atokan time that the structural configuration of the Lynn Mountain syncline was developed. As folding intensified in the central Ouachitas, the anticlinal folds became oversteepened, ruptured, and were resolved into major thrust blocks which in their northward thrusting overturned the southern limbs of the intervening synclines.

The Ouachitas were subsequently eroded and the area inundated by Cretaceous (Comanchean) seas. The present topography is the result of differential erosion by running water during Cenozoic epeirogenic uplift and subsequent adjustment to underlying structures.

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# APPENDIX

## Measured Stratigraphic Section

The following measured section is reproduced from Cline and Moretti (1956, p. 15-18). Their description was made from roadcuts along U.S. Highway 259, which at that time was under construction. The highway traverses the Lynn Mountain syncline between Big Cedar and Octavia, Oklahoma. The section was measured and described along the highway, in secs. 23, 25, 26, 27, 32, 33, 34, T. 2 N., R. 25 E., and sec. 5, T. 1 N., R. 25 E. Subsequent to their description, the highway route was changed in sec. 5 to its present route. The section has not been remeasured to fit the new route.

The writer suggests the following changes to the Cline and Moretti section:

1. Intervals 60-63, assigned to the Atoka Formation, should be assigned to the Game Refuge Formation.
2. The siliceous shale described in interval 4 in the Chickasaw Creek Formation should be designated the upper boundary of the Chickasaw Creek instead of the top of interval 5.

The above changes are shown in italics. In addition, the Chickasaw Creek is designated the basal formation of the Jackfork Group in this report.

| Interval | Thickness in feet |
|---|---|
| *Game Refuge Formation* | |
| 63. Poorly exposed sandy shale with rectangular blocks of hard quartzitic sandstone. Sandstone float containing a sandstone cast fauna was found in this interval. The fauna may be Honess' "Morrow fauna". | |
| 62. Poorly exposed blue-gray shale | 90 |
| 61. Shale and thin-bedded sandstone. Shale predominates near the base but at the top the well-bedded, thin, white sandstone may comprise 40% of the rock | 245 |
| 60. Sandstone and sandy shale; hard, white, quartzitic sandstone comprises 60% of the interval | 165 |
| Jackfork sandstone | |
| Wesley shale | |
| 59. Shale; weathers light blue-gray; contains at least one 5-inch bed of black green-gray weathering chert | 150 |
| Markham Mill and Prairie Mountain formations | |
| 58. Sandstone; soft, green-gray, a small amount of interbedded lignitic sandy shale near top | 38 |
| 57. Shale; sandy; exposed at sharp curve in road | 27 |
| 56. Sandstone; some very hard white massive rock but toward the top becomes green and friable | 148 |
| 55. Light blue-gray sandy shale with rounded boulder-like masses of brown-gray quartzitic sandstone | 105 |
| 54. Poorly exposed, massive, yellow-weathering sandstone | 90 |
| 53. Shale and sandstone | 195 |
| 52. Massive to medium bedded, fine-grained, firm white sandstone; weathers yellow; thickness of interval hard to calculate | 230 |
| 51. Poorly exposed light blue-gray sandy shale with some intercalated hard, thinly bedded, quartzitic sandstone | 650 |
| 50. Light gray yellow-weathering sandstone and sandy shale in about equal proportions | 278 |
| 49. Shale; soft, slightly sandy at base; weathers light gray | 52 |
| 48. Massive yellow sandstone | 20 |
| 47. Covered; some poorly exposed yellow-weathering sandstone | 50 |
| 46. Poorly exposed sandy blue-gray shale and soft sandstone; exposed in the saddle where the new highway intersects the old road to Big Cedar | 327 |
| Wildhorse Mountain formation | |
| 45. Sandstone; soft, medium-grained, light gray, weathers yellow | 40 |
| 44. Shale with subordinate sandstone; dark blue-gray laminated shale with interlaminated gray siltstone and sandstone with evenly bedded white quartzitic sandstone; sandstone comprising 35% of upper portion of interval, relatively unimportant in lower portion | 120 |
| 43. Sandstone and shale; 80% of interval comprised of fine-grained, hard, well bedded, quartzitic sandstone in beds up to 1½ feet thick; dark gray sandy shale intercalated, becoming important toward the base | 55 |
| 42. Shale and sandstone; soft white sandstone at base grading upward into blue-gray laminated silty shale | 35 |
| 41. Covered; poor exposures indicate sandy shale | 310 |
| 40. Sandstone; soft, yellow-weathering; thickness hard to calculate because road parallels strike | 50 |
| 39. Sandstone; hard, white to light gray, well bedded in even beds two feet thick | 75 |
| 38. Lower one-half of interval covered; upper one-half appears to be badly | |

| Interval | | Thickness in feet |
|---|---|---|
| | weathered gray sandy shale with interbedded fine-grained quartzitic sandstone | 155 |
| 37. | Sandstone; hard, white to pink, fine-grained, quartzitic sandstone; forms crest of ridge where highway cuts through | 170 |
| 36. | Shale and sandstone; dark blue-gray sandy shale and hard to firm gray sandstone; sandstone-shale ratio 60:40 | 135 |
| 35. | Sandstone and shale; sandstone comprises 65-70% of interval; remainder composed of dark blue-black shale with alternating laminae of gray siltstone and some sandstone beds up to a foot in thickness | 117 |
| 34. | Shale; black with interlaminated gray siltstone (35%); one bed of hard, quartzitic sandstone | 9½ |
| 33. | Sandstone; predominantly hard, medium blue-gray, subquartzitic sandstone in beds averaging from 2 to 6 feet; rarely a well bedded silty shale intervenes; a fault with small displacement down to west | 265 |
| 32. | Shale and sandstone; dark blue-gray shale with interlaminated 1 to 2 inch beds of hard quartzitic gray sandstone occurring in 30% of interval; total sandstone content estimated at 45% of interval | 52 |
| 31. | Predominantly dark gray laminated shale interbedded with thin 1 to 2 inch beds of gray sandstone; occasional 2 to 5 foot beds of soft, dirty, poorly sorted, yellow-weathering sandstone; grades into zone 32 above where the sandstone merely becomes more quartzitic and better jointed; about 60% shale and 40% sandstone | 105 |
| Prairie Hollow maroon shale member | | |
| 30. | Shale and sandstone; mostly gray shale and green-gray, silty, massive sandstone that weathers yellow; some brownish-red shale and silty shale at intervals | 130 |
| 29. | Sandstone; massive below becoming bedded above and containing a small amount of shale at top; hard and quartzitic below becoming poorly sorted and brown-gray above | 30 |
| 28. | Shale; dark blue-gray laminated shale with some silty and sandy beds included | 39 |
| 27. | Sandstone; fine-grained, blue-gray, hard, quartzitic, weathers brown; well defined beds about 2 feet thick | 50 |
| 26. | Shale; dark blue-gray to black, blocky clay-shale; some rounded hard quartzitic masses near the top that may be concretionary | 52 |
| 25. | Sandstone; gray, weathers brown-gray | 73 |
| 24. | Dark laminated shale and interlaminated hard, white, quartzitic sandstone in about equal amounts | 135 |
| 23. | Sandstone; soft, white, weathers yellowish; beds up to 2 and 3 feet thick | 45 |
| 22. | Shale and sandstone; dark blue-gray laminated shale interbedded with white, well bedded, quartzitic sandstone occurring as thin laminae in the shale; sand-shale ratio 4:6 | 173 |
| 21. | Sandstone; soft, dirty, massive, weathers yellowish | 40 |
| 20. | Shale; blue-gray with beds of dirty gray sandstone | 22 |
| 19. | Covered | 20 |
| 18. | Interval 65% sandstone, 35% sandy shale; silty, poorly sorted, yellow-weathering sandstone; blue gray shale with interlaminated light gray siltstone or fine-grained sandstone; center of cut faulted; displacement unknown but not great | 115 |
| 17. | Predominantly laminated blue-gray shale with laminae of ash-gray siltstone; one 8-foot bed of yellow-weathering friable sandstone one-third the distance above the base | 60 |
| 16. | Covered; estimated | 50 |
| 15. | Sandstone; soft, friable, gray, weathers yellowish, in beds averaging about a foot in thickness; 95% sandstone in lower part of interval decreasing to 80% above | 40 |
| 14. | Shale; dark gray well-bedded shale with some light gray, hard, quartzitic sandstone in beds up to 6 inches; soft, friable, yellow sandstone begins to be prominent toward top | 100 |
| 13. | Sandstone and sandy shale; firm to friable yellowish-weathering gray sandstone and separating sandy gray shales (30%) | 80 |
| 12. | Covered | 125 |
| 11. | Sandstone with perhaps 30% purple-gray to brown-gray, sandy, lignitic shale and some laminated dark blue-gray shale; firm to friable, fine to medium-grained, ash-gray, yellow-weathering sandstone in beds averaging 1½ feet thick; many beds have ripple-marked upper surfaces | 140 |
| 10. | Shale and sandstone; predominantly dark blue-gray laminated shale with thin even-bedded sandstone layers; at top of zone about 5 feet of white, hard, ripple-marked sandstone | 25 |
| 9. | Alternating sandstone and shale in subequal proportions (ratio 6:4); sandstone is light gray, medium to fine-grained, poorly sorted, in well developed beds averaging less than 2½ feet and with some poorly developed ripple marks; dark gray to | |

| Interval | Thickness in feet |
|---|---|
| brown shale, the brown layers being sandy, lignitic, and containing many plant remains | 135 |
| 8. Covered | 35 |
| 7. About 50% of interval medium-gray, poorly sorted sandstone in beds up to 1½ feet, the units averaging 20 feet; separated by subequal amounts of dark blue-gray sandy shale; shale laminated with 1 to 3 inch beds of brown-gray lignitic sandstone | 95 |
| 6. Shale and sandstone; blue-gray shales with thin laminae of silty, poorly sorted, fine-grained sandstone with intercalated medium-grained, brown-weathering sandstone; sandstone-shale ratio 6:4 | 37 |
| 5. Shale; soft, dark gray to black when fresh, weathers light blue-gray; a few 1 to 4 inch beds of white siltstone and brown-gray poorly sorted sandstone | 205 |
| *Chickasaw Creek Formation* | |
| 4. Siliceous shale; black laminated siliceous shale containing several thin beds of blue-black chert mottled with white almond-shaped siliceous areas; the weathered chert has a characteristic speckled appearance | 3 |
| 3. Shale; poorly exposed, dark gray to black, laminated, weathers light blue-gray; includes some siliceous shale and some minor amounts of fine-grained ash-gray siltstone and sandstone | 55 |
| 2. Siliceous shale; dark gray to black laminated siliceous shale with thin 1 to 3 inch hard, ash-gray siltstones comprising about 20% of the interval; dark blue-black chert in 1 to 3 inch bands, speckled with white siliceous areas | 15 |
| 1. Dark blue gray to black laminated shale predominating (60-65%); fine-grained ash-gray sandstone in even beds up to 3 feet in thickness second in importance; sandy shale, 5% | 55 |

# INDEX

(**Boldface** number indicates main reference; parentheses indicate figure explanations)