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Stratigraphy of the Late Paleozoic Rocks of the Ouachita Mountains, Oklahoma

By

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STRATIGRAPHY OF THE LATE PALEOZOIC ROCKS OF THE OUACHITA MOUNTAINS, OKLAHOMA

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ABSTRACT

This paper describes some of the stratigraphic features of the Ouachita geosyncline of Oklahoma as they are believed to have been during Late Mississippian and Early Pennsylvanian time. There is considerable evidence that pre-Atoka sediments were deposited in rather deep water. The lithologic characteristics of the Late Mississippian and Early Pennsylvanian Stanley-Jackfork-Johns Valley-Atoka stratigraphic sequence are comparable to the typical black-shale flysch facies of the Eocene of the Alps and the Eocene and Cretaceous of the Carpathians. The conclusion is reached that a predominantly deep-water dark-shale and radiolarian-chert environment was periodically interrupted by turbidity currents flowing down the steep slopes of the depositional trough and that these currents brought in sands foreign to the black-shale environment. The presence of convolute bedding, graded contacts of sandstones and overlying shales, of abundant flow casts and groove casts on the under surfaces of the sandstones, the general lack of cross-bedding and ripple marks, and the scarcity of fossils except for planktonic and nektonic forms, support this thesis.

INTRODUCTION

THE OUACHITA FACIES

The arcuate pattern of folds which comprises the Ouachita Mountains (fig. 1) of southeastern Oklahoma and southwestern Arkansas is but one portion of a sinuous foldbelt which extends from western Texas eastward to within approximately 60 miles of the buried extension of the southern Appalachian Mountains. The foldbelt is now largely buried beneath relatively undisturbed Mesozoic and Cenozoic rocks but it is exposed in two arcuate uplifts, the Marathon uplift of Trans-Pecos Texas and the Ouachita Mountains. The Ouachita facies has been encountered in the subsurface by numerous deep wells which start in Mesozoic or Cenozoic rocks (Morgan, 1952, p. 2266-2274; Flawn, 1959, p. 20-29). Notwithstanding

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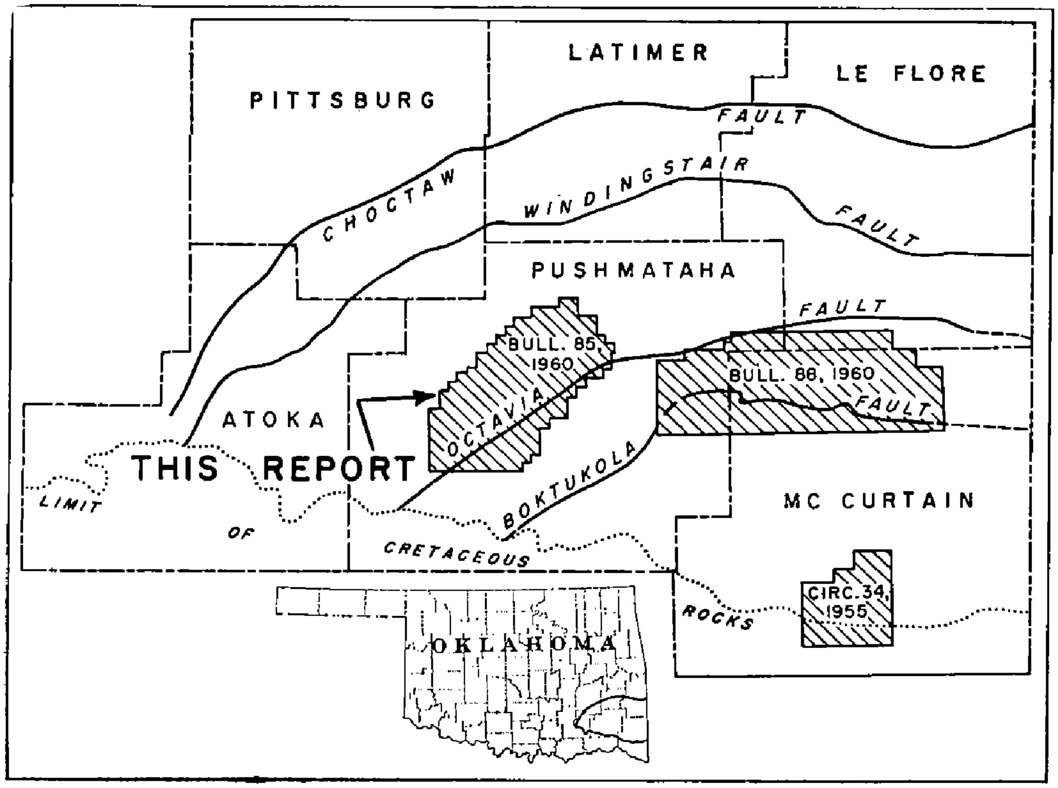

FIGURE 1. Index Map, Ouachita Mountains, Oklahoma.

the fact that the Ouachitas and Marathons are several hundred air-line miles apart, and much farther apart when measured along the winding course of the folds, the two geographic provinces have so many things in common that their rocks are collectively referred to as *Ouachita facies,* in contrast to shelf or platform types of sediments which comprise the *Arbuckle facies* to the north or west, as the case may be. The stratigraphic column within the foldbelt also shows some vertical variations in facies, the pre-Stanley section being relatively thin; in fact, it is considerably thinner than the Arbuckle facies and is characterized by cherts and dark graptolitic shales (fig. 2). The Stanley-Jackfork-Johns Valley-Atoka sequence is much thicker than the Arbuckle facies and contains much sandstone (fig. 3). In the minds of some geologists the pre-Stanley section with the cherts and novaculites constitutes the Ouachita facies, whereas, in the opinion of others, the abnormally thick shale and sandstone sequence of the Stanley and later rocks characterizes the Ouachita facies. The writer regards all portions of the Ouachita stratigraphic column as belonging to the Ouachita facies because at all levels the lithology differs appreciably from the Arbuckle facies, although there are

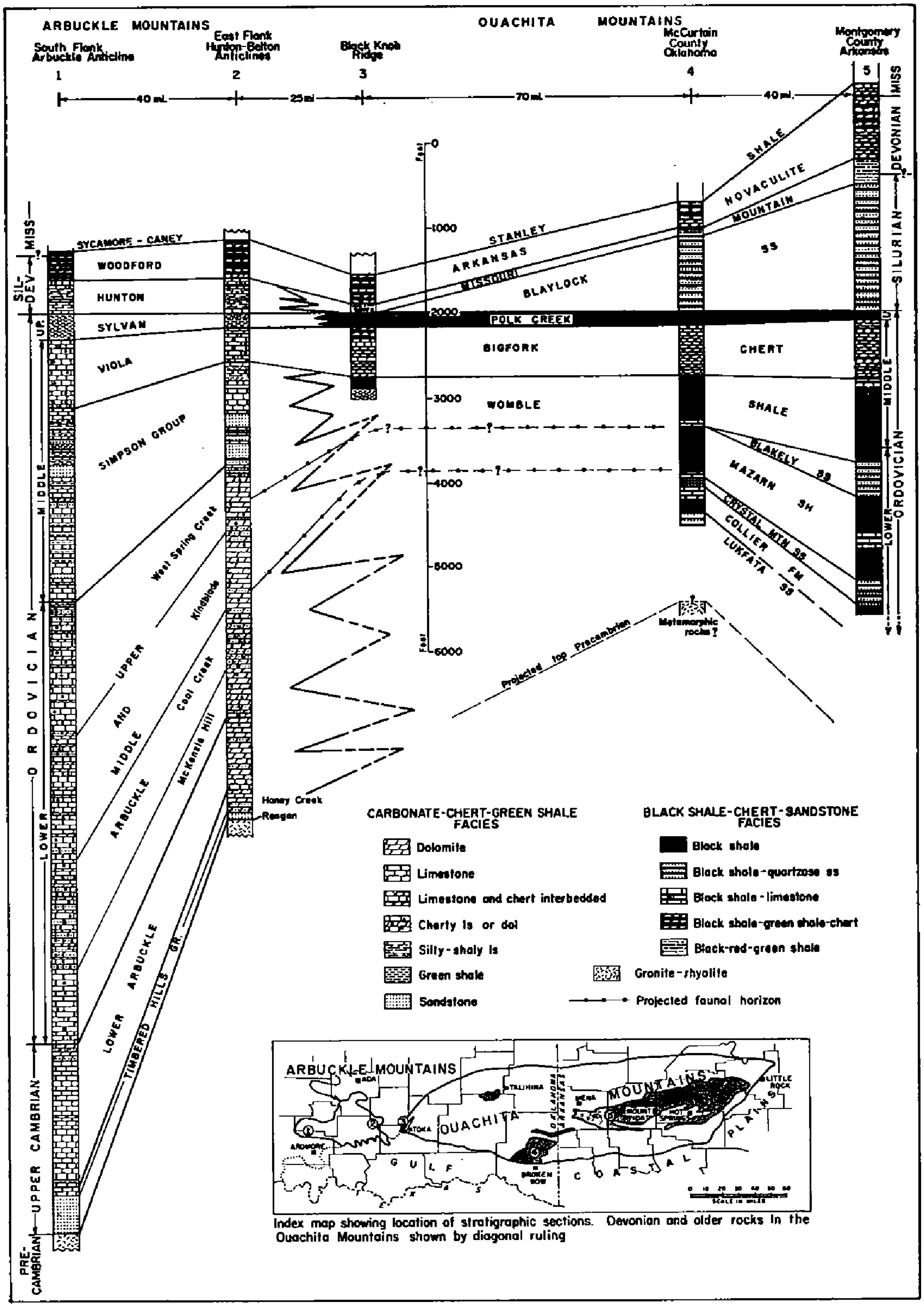

FIGURE 2. Correlation and facies of pre-Stanley rocks in Ouachita and Arbuckle Mountain regions. Observe that the Ordovician section is thinner in the Ouachitas than in the Arbuckles.

(From Ham, 1959)

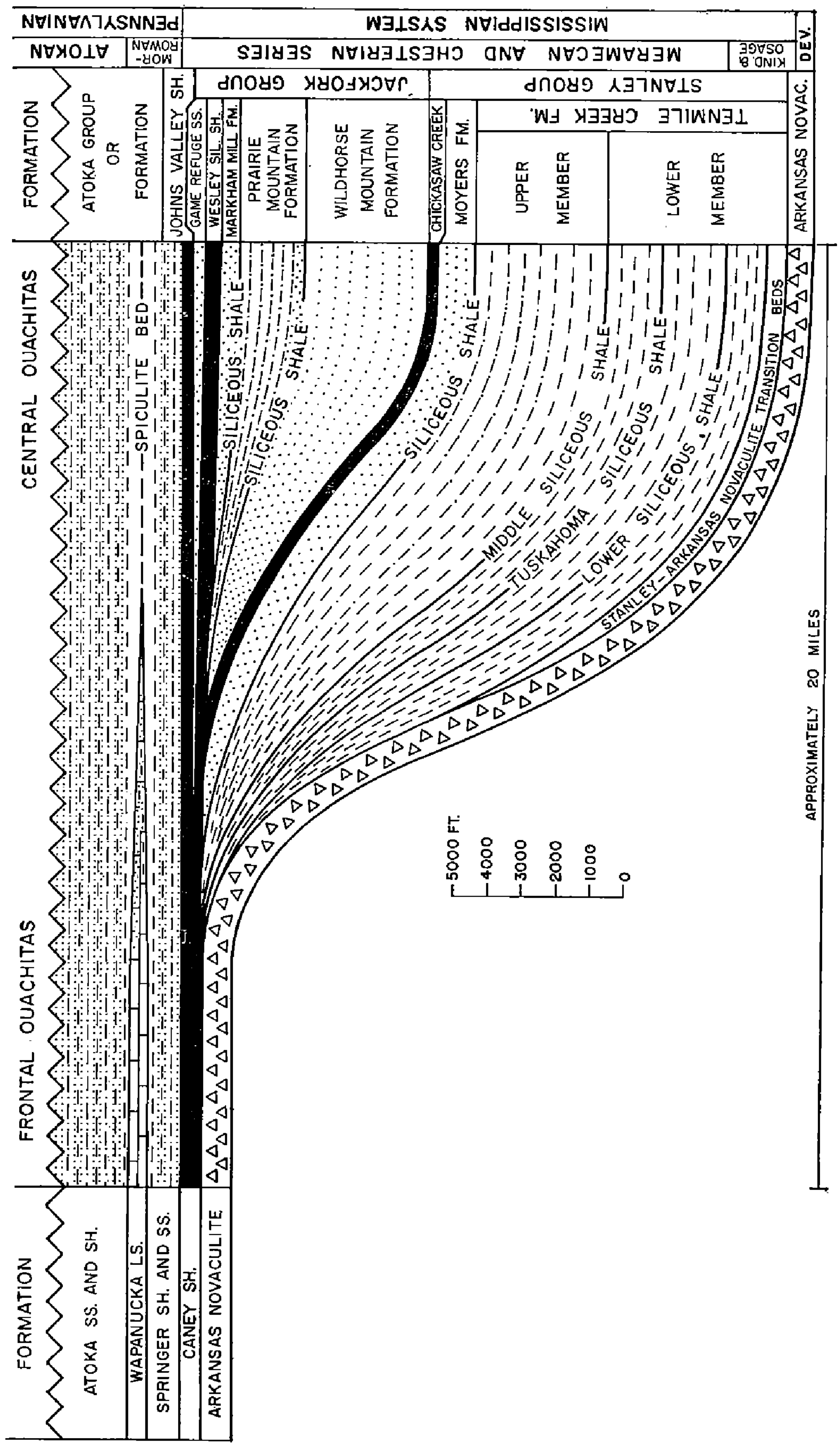

FIGURE 3. Diagrammatic cross section showing facies changes and correlations of the Late Mississippian and Early Pennsylvanian formations from the frontal Ouachitas to the central Ouachitas, southeastern Oklahoma, with thrust faults eliminated.

transitional zones coinciding approximately with the faulted belt of the frontal Ouachitas. The earlier Ouachita deposits seem to represent a period of slow sedimentation in essentially a starved trough whereas the post-Arkansas-novaculite sequence represents a much more rapid period of sedimentation during a period of more active tectonism.

Sedimentation appears to have been initiated in both the Ouachita and Marathon areas in deep arcuate troughs. One is tempted to suggest that the arcuate troughs were in relatively deep sea trenches lying at the south margin of a stable continental area which supported the shallow seas in which the miogeosynclinal Arbuckle carbonate-bearing facies accumulated. If such was the case, we should then note that the Marathon and Ouachita arcs were convex *toward* the continent. However, we should not overlook other possibilities—the possibility that a stable platform area existed to the south of the Ouachita-Marathon geosynclinal belt and the possibility that deep drilling south of the present foldbelt will encounter relatively undisturbed rocks of shallow-water origin, but not necessarily belonging to the Arbuckle facies.

Relatively flat-lying fossiliferous rocks of early Paleozoic age are known to occur beneath Mesozoic and Cenozoic rocks in nearly 50 wells in the coastal plain of southeastern Georgia and northwestern Florida (Applin, 1951, p. 1-28). It is noteworthy that this area of relatively undisturbed Paleozoic rocks lies southeast of the crystalline rocks that constitute the Piedmont province. Several recent workers (e.g., King, 1950) regard the Piedmont as including metamorphosed Paleozoic sediments, if indeed the bulk of the metamorphics are not Paleozoic. It is thus entirely possible that Paleozoic rocks exist south of the Ouachita foldbelt and that ultimately they will prove to be connected with the Paleozoics southeast of the Piedmont in Georgia and Florida. To the writer's knowledge, the relationship of the southern Appalachians to the eastern Ouachitas has not been definitely established, either by geological or geophysical methods. One cannot help speculating as to whether they meet approximately at right angles in the manner of the arcuate Palau and West Caroline trenches of the western Pacific or whether the two join by virgation, with the eastern Ouachitas curving southward to parallel the buried southern Appalachians.

The Ouachita facies contains some characteristic rock types that contrast strongly with the lithology of the Arbuckle facies, with the gradation taking place in a relatively narrow belt marking the junction of the northern and western margin of the Ouachita geosyncline and the south and east margin of the platform or shelf. Thin but laterally persistent cherts, such as the Bigfork chert and Arkansas novaculite, characterize the early Paleozoic rocks of the Ouachita geosyncline, whereas their equivalents on the platform, the Viola and Hunton formations, are limestones.

Dark graptolitic shales, which occur separately and also interbedded with siliceous sediments, are perfectly at home in the Ouachita environment, although they also occur in shales and in fine-grained carbonates (some horizons of the Viola and Bromide) in the Arbuckle facies.

At higher stratigraphic levels black siliceous shales, such as the Chickasaw Creek and Wesley, some including thin beds of radiolarian chert, occur at numerous horizons as high as the lower part of the Atoka.

In the heart of the Ouachita Mountains in southeastern Oklahoma, Late Mississippian and Early Pennsylvanian strata embraced in the Stanley-Jackfork-Johns Valley-Atoka sequence have an aggregate thickness of approximately 22,000 feet. The rocks are almost entirely of clastic origin with shale predominating in the Stanley, sandstone being the more important in the Jackfork, and with the two rock types being in subequal proportions in the Atoka. Carbonate rocks are noticeably absent in this upper part of the Ouachita section, whereas they are fairly common in its stratigraphic equivalents on the platform to the north and west. The Ouachita equivalents of this part of the stratigraphic column are substantially thinner on the platform area of northeastern Oklahoma.

The most characteristic lithologic feature of the Stanley-Jackfork stratigraphic sequence is the repeated alternation of dark shales and gray sandstones. Details of lithology and sedimentary structures closely resemble the black-shale flysch facies of the Alps and Carpathians of Europe.

HISTORY OF INVESTIGATION

In the summer of 1953 Cline began a study of the Late Paleozoic strata of the central Ouachita Mountains under the sponsorship of Dr. C. W. Tomlinson and the work has continued during the summer months and vacation periods since that time. Cline's initial interest in the area stemmed from his interest in Mississippian and Pennsylvanian stratigraphy and in the belief that the Ouachita geosyncline should contain strata transitional to the two systems. Mapping by Cline has shown that most of Harlton's map units (Harlton, 1938) of the Tuskahoma syncline are also present in the Lynn Mountain syncline northeast of Antlers and that they extend almost to the Arkansas line, some 70 air-line miles to the east (Cline, 1956a, p. 427). Persistent beds were traced principally by surface mapping aided by aerial photographs. Cline and Moretti (1956) described two complete and unfaulted stratigraphic sections of the Jackfork sandstone near the east end of Kiamichi Mountain and showed several of Harlton's map units to be present. Shelburne mapped the Boktukola syncline in the summers of 1956 and 1957 and his map was published by the Dallas Geological Society in 1959.

At this writing, that portion of the Lynn Mountain syncline lying west of Oklahoma Highway 2 (which crosses the syncline between Clayton and Nashoba Junction) and extending west-southwest to Antlers has been mapped in some detail by the author (plate I) and reconnaissance mapping has extended eastward almost to the Arkansas line. South of the Lynn Mountain syncline the next major syncline is the Boktukola syncline, which contains a Stanley-Jackfork-Atoka sequence that correlates with a similar sequence in Kiamichi Mountain (Cline, 1956b, p. 50-53). Shelburne's mapping has proved the persistence of several stratigraphic markers in the Boktukola syncline east of Little River and he has successfully traced them into Johnson's (1954) map area in the syncline west of Little River.

ACKNOWLEDGMENTS

I am grateful to the late Dr. C. W. Tomlinson for sponsoring the work and for his continued interest in the geology of this area. He reviewed many of the more controversial problems in the field with the writer, offered many helpful suggestions, but he at no time sought to impose his own ideas, rather allowing the writer complete freedom to do the type of work that seemed most expedient at each stage of the project. Dr. M. K. Elias has contributed substantially to the work, principally through the identification of fossils. Mr. Bruce Harlton was kind enough to aid me in a restudy of some of his type sections in the Prairie Mountain and Lynn Mountain synclines and in checking some of my correlations along the Indian Service road. Dr. Carl C. Branson, Director of the Oklahoma Geological Survey, has encouraged me in my work and reviewed some of the field work on two occasions. Dr. Thomas A. Hendricks, who has done so much map work in the frontal Ouachitas, spent several days in the field with me in the summer and fall of 1958 and has made some very helpful suggestions; I appreciate the encouragement he has given me. Several men interested in Ouachita geology have accompanied me in the field at various times and made helpful observations; among them are: Dr. Norman Williams, Director of the Arkansas Geological Survey, Mr. Hugh Miser and Dr. Chalmer Cooper of the United States Geological Survey, Mr. Horace Griley, Mr. B. W. Miller, Dr. Allan Bennison, Dr. Norman Johnson, Mr. E. C. Parker, Mr. William Hilseweck, Dr. Daniel Feray, Dr. William Jenkins, Mr. H. A. Sellin, and others. Finally, I wish to acknowledge the contributions of Dr. William E. Ham in editing the map and of Dr. Carl C. Branson in editing the manuscript.

STRATIGRAPHY

The rocks which crop out to form the main portion of the Ouachita Mountains in southeastern Oklahoma belong principally to the Stanley shale, Jackfork sandstone, Johns Valley shale, and Atoka sandstone. This stratigraphic succession of Late Mississippian and Early Pennsylvanian age attains an aggregate thickness of nearly 22,000 feet in contrast to the thin pre-Stanley section (about 5,000 feet) exposed in the Choctaw anticlinorium in the "core" of the Ouachitas. Pre-Stanley rocks crop out in only a few areas. The principal areas are: (1) the Choctaw anticlinorium, which lies at the south edge of the Ouachita outcrop belt and just north of the overlapping Cretaceous rocks; (2) the Potato Hills (fig. 4), an anticlinorium lying between the Kiamichi and Winding Stair ranges; and (3) along some of the thrust faults in the frontal Ouachitas, along the western and northern margins of the Ouachita foldbelt (figs. 5, 6, 7).

There are some important facies changes between the carbonate-bearing shelf deposits of the northeast Oklahoma platform and

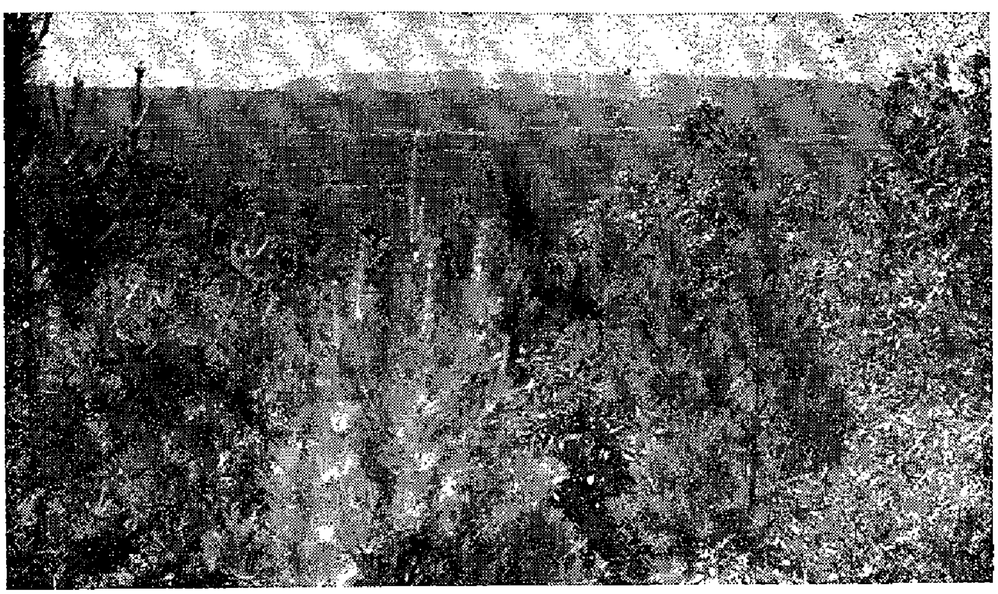

FIGURE 4. The Potato Hills, as seen from Kiamichi Mountain, southeast of Albion, form the ridge in front of Buffalo Mountain (on the distant skyline). Cherts of the Arkansas novaculite as well as older Paleozoic rocks are exposed in the Potato Hills. The complete thickness of the Stanley shale is exposed in the valley between Kiamichi Mountain and the Potato Hills. Buffalo Mountain is a syncline in which the Jackfork sandstone is preserved.

their more clastic equivalents in the Ouachita geosyncline. The changes may be seen to develop between the Arkoma basin* and the frontal Ouachitas, which province has several major thrust faults. The faults interfere with the tracing of individual formations with the inevitable result that there is a different stratigraphic terminology for each of the major thrust blocks. These differences are brought out in table 1.

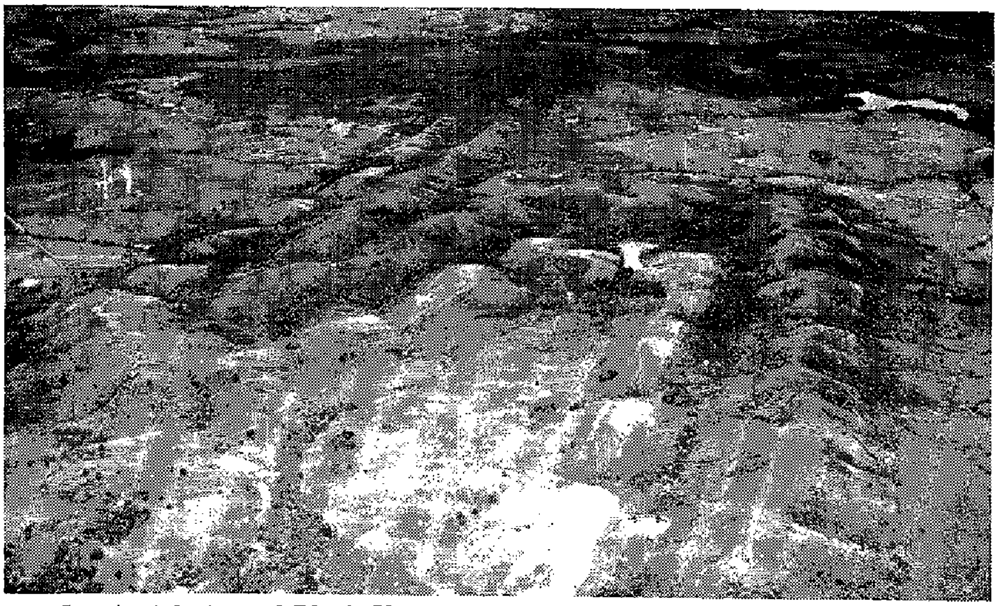

FIGURE 5. Aerial view of Black Knob Ridge, looking southwest from a point midway between Stringtown and Atoka. The sigmoidal fold lies in sec. 6, T. 2 S., R. 12 E., in Atoka County. Cherts and graptolitic shales of the Ouachita facies are exposed in the ridge. The rocks dip from 60 to 88 degrees to the left (southeast). The Ti Valley fault lies along the right margin of the photograph. The lighter ridge on the left is underlain by the Bigfork chert, the darker ridge on the right is held up by the Arkansas novaculite.
(Photograph courtesy of Socony Mobil Oil Company)

The greatest change in facies and thickness takes place at the Ti Valley fault, which has been a sort of Chinese Wall for Ouachita stratigraphers. North of the fault the stratigraphy is not too dissimilar from that of the Arkoma basin, the greatest change being in the gradation of the Wapanucka limestone into the silty Chickachoc chert (figs. 8, 9, 10, 11). South of the Ti Valley fault the Stanley and Jackfork groups take their place in the section between the Woodford chert and the Johns Valley shale and they thicken rapidly southeastward into the central Ouachitas. The Johns Valley shale is not greatly different from the Springer formation north of the

* The name Arkoma basin refers to the structural basin which flanks the Ouachita Mountains on the north. This compound name, derived from the names Arkansas and Oklahoma, has been suggested to do away with the current practice of using two names (Arkansas basin in Arkansas and McAlester basin in Oklahoma) to designate the same unit. Ed.

TABLE 1

CORRELATION OF WESLEY-JOHNS VALLEY STRATIGRAPHIC SEQUENCE BETWEEN THE CENTRAL AND FRONTAL OUACHITA PROVINCES, SOUTHEASTERN OKLAHOMA

Belt southeast of Choctaw fault	Belt southeast of Katy Club fault	Belt southeast of Pine Mountain fault	Belt southeast of Ti Valley fault	Central Ouachitas
Atoka formation	Atoka formation	Atoka formation (spiculite zone —200 feet above base)—	Atoka formation —(spiculite zone)—	Atoka formation —(spiculite zone)—
Wapanucka limestone	Chickachoc chert	Springer formation	Johns Valley shale	Johns Valley shale
Springer formation	Springer formation			
Caney shale	Caney shale	Caney shale		Game Refuge sandstone
			Wesley shale	Wesley shale
			Jackfork sandstone (undifferentiated)	Jackfork sandstone
			Stanley shale	Stanley shale
		Woodford shale and chert	Woodford chert	Arkansas novaculite
		Pinetop chert		

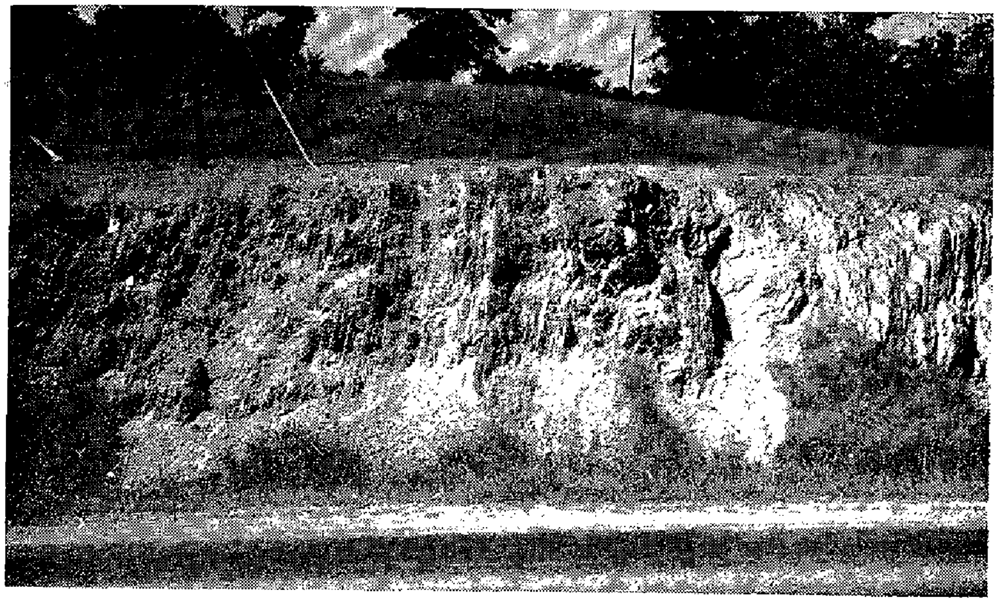

FIGURE 6. Arkansas novaculite exposed in roadcuts of Oklahoma State Highway 3, in sec. 14, T. 2 S., R. 11 E., one-half mile east of Atoka. Exposure is in Black Knob Ridge, east side of Ti Valley fault.

fault and the Wesley shale and Game Refuge sandstone formation of the upper Jackfork are partial Caney equivalents, the Game Refuge pinching out somewhere north of the Windingstair fault.

Both the Stanley and Jackfork groups thicken rapidly to the southeast, from zero near the Ti Valley fault to nearly 16,000 feet in the Tuskahoma syncline, in a distance of 20 miles or less. The writer believes that the thickening is primarily depositional and that the

FIGURE 7. Aerial view of Southwest Stone Company quarry in Black Knob Ridge. Womble shale, Bigfork chert and Arkansas novaculite, all of the Ouachita facies, are exposed in the quarry.
(Photograph Courtesy of Socony Mobil Oil Company)

FIGURE 8. Aerial view looking southwest at Limestone Gap in sec. 31, T. 2 N., R. 13 E., Atoka County. The Wapanucka formation in Limestone Ridge dips 42 degrees to the southeast and is overlain by shales in the Atoka formation, which in turn are in fault contact with Springer shales along the Katy Club fault just northwest of the right-of-way of the Missouri, Kansas and Texas Railroad. The Choctaw fault is to the northwest (right) of Limestone Ridge and lies just off the photograph.

(Photograph courtesy of Socony Mobil Oil Company)

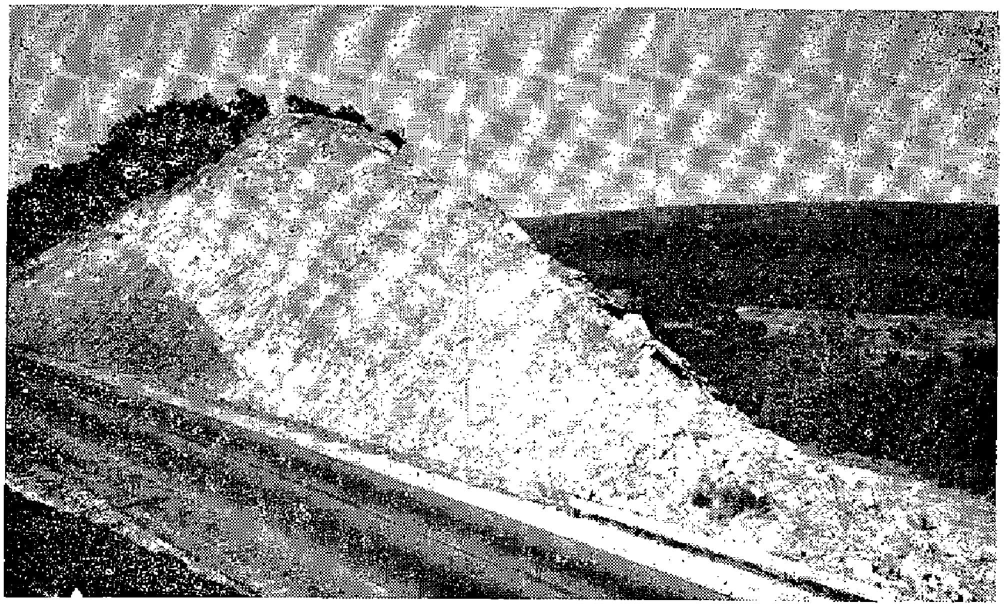

FIGURE 9. Southeast-dipping spiculitic limestone and shale in upper part of Wapanucka formation in sec. 1, T. 1 N., R. 12 E., one-half mile north of Chockie, Atoka County. The limestone is bioclastic and contains many sponge spicules. This facies is characteristic of the outer edge of the shelf deposits.

thick Stanley-Jackfork sequence south of the Ti Valley fault is the direct lateral equivalent of the main body of Caney shale north of the fault. This interpretation is shown diagramatically in figure 3, which is drawn so as to eliminate several thrust faults. From a study of the geologic map, it appears to the writer that the rate of northward thinning in the Stanley and Jackfork is not significantly interrupted by the Windingstair, Jackfork Mountain and other thrust

FIGURE 10. Limestones and shales in lower part of Wapanucka formation in road-cut of United States Highway 69, one-half mile north of Chockie, Atoka County. The limestones are bioclastic and seem to be discontinuous.

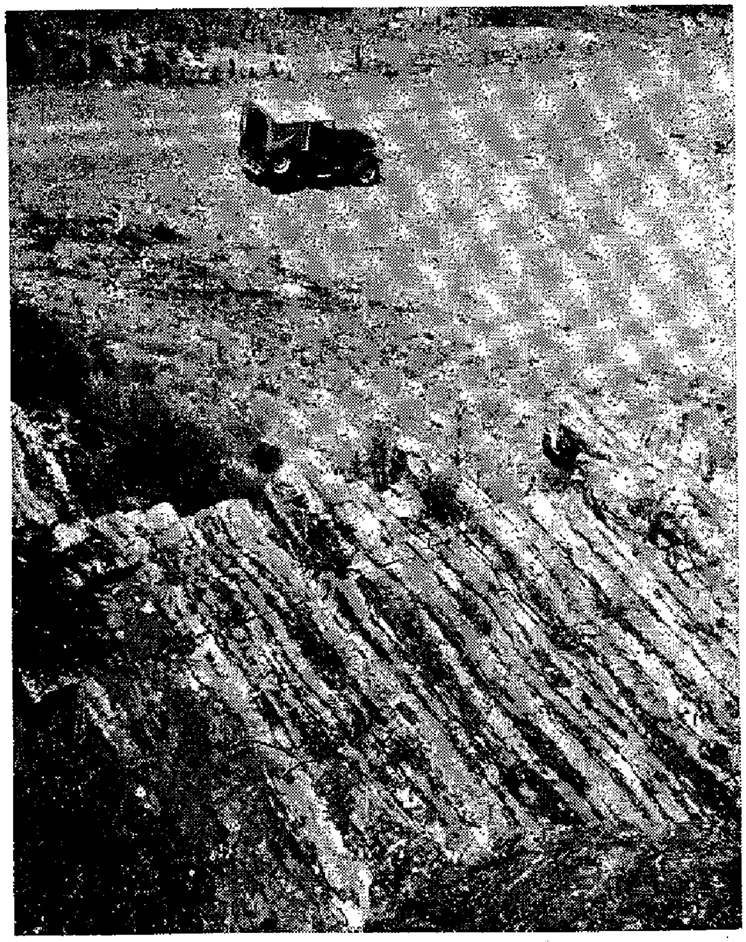

FIGURE 11. Spiculitic limestone in upper part of Wapanucka formation in quarry one-half mile north of Chockie, Atoka County. The dark bands are silty and contain abundant sponge spicules.

faults lying south of the Ti Valley fault. One might conclude, therefore, that the thinning is more a function of original deposition than of later faulting.

It can be demonstrated that there is considerable horizontal displacement to the northwest along the faults of the frontal Ouachitas (Hendricks, 1959, p. 44-56). Enthusiasts for long-distance low-angle overthrusting have explained the differences in stratigraphy on opposite sides of the Ti Valley fault as the result of faulting which moved the Stanley-Jackfork strata many miles from the original depositional basin. But one does not have to look very far to see another example of rapid convergence in a structural province where faulting does not interfere with the tracing of beds. It is in the Arkoma basin, just north of the Ouachitas. In northern Le Flore County, the Atoka formation thins from 6,500 feet on the south to 1,850 feet only 21 miles away to the northwest (Knechtel, 1949, p. 15). The Tesnus formation of the Marathon uplift of West Texas, which is the facies analogue of the Stanley and probably is of the same age, is reported by Fan and Shaw (1956, p. 258) to thin from 6,800 feet in the southeast part of the uplift to 300 feet in the northwest part of the uplift, only 24 miles distant. Fan and Shaw attribute the difference in thickness to differential subsidence during sedimentation.

It seems likely that the Ti Valley fault developed along what had been a hinge line during Stanley-Jackfork sedimentation, and that the fault marks approximately the northern depositional limit of that sequence. Thus, following the deposition of the Arkansas novaculite there was a time of active tectonism in the Ouachita geosyncline and the Stanley and Jackfork were deposited in a rapidly subsiding trough.

MISSISSIPPIAN SYSTEM

STANLEY GROUP

The Stanley group attains its best development in the central Ouachitas where it comprises approximately 11,000 feet of strata, prevailingly shaly but with sandstone becoming prominent in the upper 1,500 feet. This thick body of shale is weak, both from the standpoint of topographic expression and structural competence. It is the great valley maker of the Ouachitas, characteristically forming the flat floors of long, linear anticlinal valleys such as the Stanley and McGee valleys, large areas of which are covered by alluvium. This great mass of relatively incompetent shale, lying between the more competent Arkansas novaculite and the Jackfork sandstone, absorbed much of the punishment inflicted by Ouachita folding. Consequently, it is badly deformed and drag folds are commonly developed even where the structure of the enclosing competent rocks is relatively simple; in some intensely deformed areas it seems to have yielded in part by plastic flow. Because of this unfortunate combination of poor outcrops and complicated structure, a complete and undisturbed stratigraphic section of the Stanley has not been described, notwithstanding the fact that it directly underlies about 40 percent of the Ouachita Mountains.

History of Nomenclature

The Stanley shale was named by Taff (1902, p. 4) for outcrops in the valley of the Kiamichi River near Stanley in Pushmataha County, Oklahoma. The community of Stanley (formerly spelled Standley) is on the north side of the Kiamichi River in sec. 24, T. 1 N., R. 17 E. and can be reached by a good gravel road from Clayton, which is 8 miles northeast. Taff regarded the Stanley as a formation and assigned it to the Silurian. Unfortunately only the upper one-half of the Stanley is exposed at Stanley where it is brought to the surface by the Kiamichi River anticline.

In his report on "The slates of Arkansas," Purdue (1909, p. 40 and the facing plate) spelled the name Stanley as it is spelled today and he referred the formation to the Carboniferous. This procedure was also followed by Miser (1917, p. 66) in a report on the "Manganese deposits of the Caddo Gap and DeQueen quadrangles, Arkansas."

Little additional progress was made on partitioning the thick Stanley succession until Harlton published his significant paper on the "Stratigraphy of the Bendian of the Oklahoma salient of the Ouachita Mountains" in 1938. Making use of several distinctive and thin, but persistent, dark siliceous shales as stratigraphic markers, Harlton divided the Stanley into three formations; named in upward order they are: the Tenmile Creek, Moyers, and Chickasaw Creek. He demonstrated the persistence of the formations by mapping them at the south end of the Tuskahoma syncline, near Moyers, and in the Round Prairie syncline northeast of Atoka, about 25 miles west of Moyers. Harlton raised the Stanley to group rank and, together with the overlying Jackfork group, he included it in the Pushmataha series of his newly proposed (and ill-fated) Bendian system. He regarded the Bendian as intermediate between the Mississippian and Pennsylvanian systems. Harlton redefined the upper boundary of the Stanley to include 600 feet of beds formerly included in the Jackfork by Taff and others.

Hendricks, Gardner, Knechtel and Averitt (1947) mapped the western and northwestern portions of the frontal Ouachitas with considerable thoroughness, using some of Harlton's siliceous shales as key beds but they did not use his terminology and Harlton's uppermost Stanley Chickasaw Creek formation was restored to the lower Jackfork and included in the Pennsylvanian.

In 1953, Cline began geologic mapping in the central Ouachitas and differentiated (1956a, 1956b, 1956c) most of Harlton's map units in the western portion of the Lynn Mountain syncline (Cline and Shelburne, 1959) and succeeded in recognizing most of them in Kiamichi Mountain eastward almost to the Arkansas line (Cline and Moretti, 1956).

In connection with field work on master's theses, several University of Oklahoma students, working under the direction of Dr. Kaspar Arbenz, used Harlton's zonation in the Finley (McCollough, 1954), Snow (Willis, 1954), Medicine Springs (Johnson, 1954), and Potato Hills (Miller, 1955; Roe, 1955; Seeley, 1955) areas. In doctor's theses at the University of Wisconsin, Shelburne (1959) differentiated and mapped most of Harlton's units in the Boktukola syncline, the next syncline south of the Lynn Mountain syncline, and Laudon (1959) made a regional study of the Stanley of the central Ouachita Mountains. Shelburne's thesis is slated for early publication as Bulletin 88 of the Oklahoma Geological Survey and it is hoped that Laudon's paper also will be published at an early date.

Classification Used in this Report

The nomenclature used in this report (table 2) is principally after Harlton (1938), an exception being that the Stanley group is referred to the Meramecian series of the Mississippian system.

The Chickasaw Creek formation is included in the Stanley group for the following reasons: (1) Harlton, who was the first geologist to successfully partition the Stanley and Jackfork groups, included it in the Stanley, (2) the Chickasaw Creek is predominantly shale and logically can be included in the Stanley, and (3) the Stanley and Jackfork are completely gradational and there is no compelling reason why the Chickasaw Creek should be included in the Jackfork.

Thickness and Distribution

Attaining a maximum thickness of about 11,000 feet in the central Ouachitas, the Stanley thins rapidly westward and northward toward the frontal Ouachitas. The Stanley is not present north of the Ti Valley fault and it is possible that the fault marks the approximate original depositional limits of the group, and for that matter, the Jackfork group. The rocks on the south side of the fault have

TABLE 2

SUBDIVISION OF STANLEY GROUP, OUACHITA MOUNTAINS, OKLAHOMA

System	Series	Formation	Member	Bed
Mississippian	Meramecian	Chickasaw Creek		
		Moyers	Siliceous shale member at base	
		Tenmile Creek	Upper member	Middle siliceous shale bed at base
			Lower member	Tuskahoma siliceous shale bed
				Lower siliceous shale bed

been displaced northward and westward, although the magnitude of the horizontal movement is conjectural. Incomplete exposures of the Stanley do not permit accurate measurements of it between the central and frontal Ouachitas, but rapid northwestward thinning in the interval from the base of the Moyers to the top of the Chickasaw Creek is quite evident, and one would logically suppose that the Tenmile Creek formation thins at an equal rate.

From a study if the geologic map, it appears to the writer that the *rate of thinning* in the Stanley is not significantly interrupted by the Windingstair, Jackfork Mountain and the other thrust faults lying south of the Ti Valley fault, and one might conclude that the thinning is more a function of original deposition than of post-depositional faulting. Disregarding the arguments concerning the amount of horizontal displacement along the faults, the fact remains that the Stanley group thins from approximately 10,500 or 11,000 feet at the south end of the Tuskahoma syncline to zero north of the Ti Valley fault, a distance of not more than 23 miles. The Stanley is conformable with the overlying Jackfork sandstone, so the northwestward thinning in the Stanley was accomplished before Jackfork time. It is just possible that there is an unconformity at the base of the Stanley, particularly near the Ti Valley fault, but the writer is of the opinion that there is northwestward convergence at all stratigraphic levels within the Stanley in the western part of the Ouachitas. Consideration of all of the evidence leads to the conclusion that rapid subsidence in the Stanley-Jackfork depositional trough resulted in rapid thickening of the sediments from the margin of the trough inward toward its axis. It may be that the Stanley is too poorly exposed to permit one to determine from outcrops whether the convergence is at all stratigraphic levels but if this could be determined from surface geology it would be a major step in solving many problems of Ouachita geology.

Discontinuous outcrops and structural complications render it impossible to describe and measure a continuous stratigraphic section of the Stanley. The best place to compute the total thickness of the Stanley on the outcrop seems to be between the Potato Hills and Kiamichi Mountain in the vicinity of Albion in southeastern Pushmataha County. The Stanley is gradational with the underlying Arkansas novaculite in the Potato Hills and it is conformable with the overlying Jackfork in the lower slopes of Kiamichi Mountain a few miles to the south. Laudon (1959) calculated the Stanley to be about 11,000 feet thick in this area. The writer believes that the

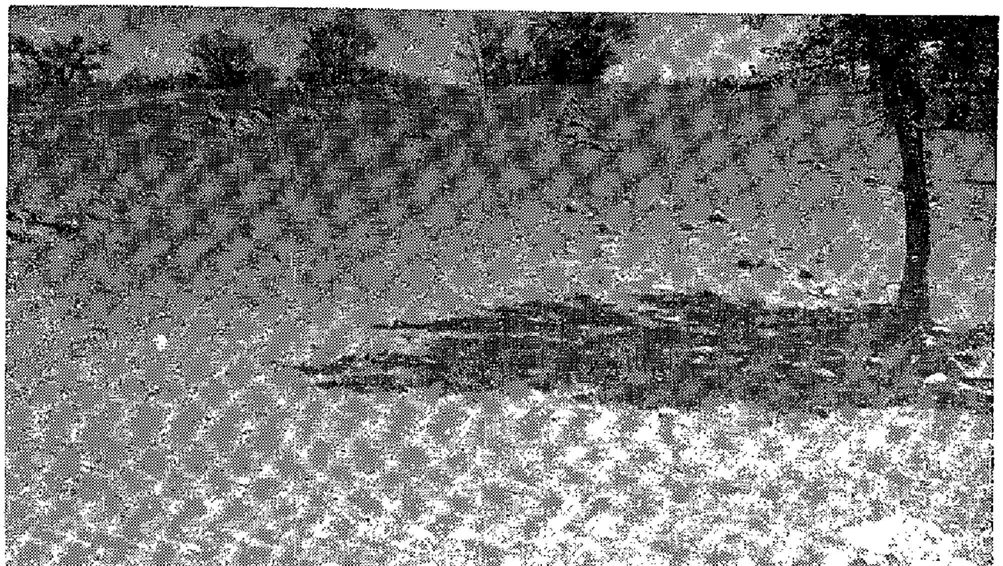

FIGURE 12. Typical outcrops of Tenmile Creek formation of Stanley group, southeast of Albion in northeastern Pushmataha County.

Stanley is relatively undisturbed in this belt and that any faulting that may be present on the south side of the Potato Hills (which according to Miser is a fenster) does not significantly interfere with calculation of the thickness of the Stanley group. Honess (1924) estimated the thickness of the Stanley to be 10,000 feet on the Pickens anticline, which lies between the Boktukola and Bethel synclines and north of the Choctaw anticlinorium. Thus it seems that the Stanley does not diminish in thickness in its southernmost outcrops.

Lithologic Characteristics

The Stanley group is predominantly composed of shale but sandstone is common and siltstone occurs in subordinate amounts (figs. 12, 13). There are no persistent limestones and the small amount of carbonate that is present occurs principally in cone-in-cone concretions that occur at several levels. Bokman (1953, p. 155) calculated the percentages of common rock types in several fresh exposures of the Stanley and found these outcrops to contain 61 percent shale, 32 percent graywacke sandstone, and 7 percent siltstone. The exposures represent only a partial Stanley section and the writer would estimate that sandstone comprises considerably less than 25 percent of the rock of the complete stratigraphic sequence of the Stanley. In the lower five-sixths of the group, in which thin sandstones alternate with thicker shales, the sandstones comprise about 15 percent of the interval according to Laudon (1959, p. 32). Sand-

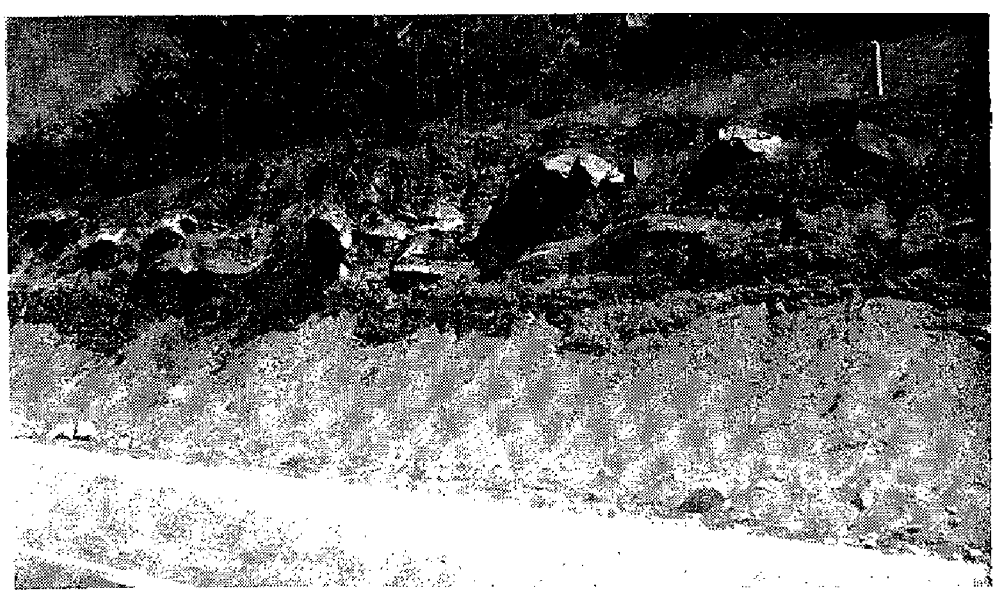

FIGURE 13. Freshly exposed dark gray shales and interbedded sandstones of Tenmile Creek formation in cutbank along Oklahoma State Highway 2, near Buzzard Creek northeast of Snow, Pushmataha County.

stone becomes increasingly important upward in the Stanley and, in the 1,000 to 1,700 feet of strata comprising the Moyers formation, sandstones constitute an estimated 35 to 40 percent of the rock. Several thin but persistent blue-gray to black siliceous shales occur in the group and form valuable stratigraphic markers. One or more tuff beds have been observed in the lower part of the Stanley in widely distributed areas in the Ouachitas.

The shales of the Stanley are characteristically thin-bedded, laminated, dark-gray to green-gray when fresh, but a moderate amount of weathering results in an olive-green, fissile product which upon more severe weathering becomes more yellowish. These shales are devoid of megascopic fossils but probably contain spores and other microscopic plant materials.

The dark siliceous shales are from a few inches to several feet thick, are thin-bedded, and microscopic examination reveals that they have exceedingly fine lamination. The dark color is produced by sapropelic organic material and some finely divided pyrite, but fine particles of silica make up a large part of the rock. All of the siliceous shales contain abundant sponge spicules, conodonts, and radiolarians and seem to have been so much the product of the same type of environment that the individual shales of the Stanley cannot be distinguished, the single exception being the Chickasaw Creek siliceous shale which has some diagnostic white-mottled siliceous areas in the dark matrix.

Stanley sandstones typically are composed of angular fine-grained quartz grains embedded in a clay matrix. They are poorly sorted, and have been classed as graywackes by Bokman (1953) and Cline (1956b). Most of them are dirty, containing pieces of shale and other rock fragments, including clay pockets and macerated plant fragments, but some are fairly clean, even orthoquartzitic in composition, and are harder and better cemented than the more typical friable varieties. The fresh, unaltered sandstones are gray but they become successively green-gray, yellowish, and under some conditions buff, as weathering becomes more advanced. Individual strata appear to average between two and six inches in thickness but some beds are as thick as twenty feet, are massive, essentially devoid of bedding and tend to weather somewhat spheroidally. Some of the beds exhibit good convolute bedding, a feature which seems to be independent of bed thickness, and many of them have remarkably well-developed sole markings.

The Stanley exhibits the bedding characteristics of a black-shale flysch facies, the chief feature being a remarkable alternation of thin sandstone beds with somewhat thicker shales. Aggregates of several closely spaced sandstone beds occur at several levels in the Stanley, but their lateral persistence has not been studied in detail. Laudon (1959) states that he was unable to trace any group of sandstones for any considerable distance, but this may have been because of poor outcrops. The writer is of the opinion that some of the thicker sandstone sequences may persist over considerable distances. The sandstone-shale contacts are clean and sharp, the contact at the base of the sandstones being especially abrupt. Graded bedding, so characteristic of some flysch sediments, is not well-developed in the Stanley, although the contact of some sandstone beds with the overlying shale is rather indefinite or fuzzy and may be thought of as a type of graded bedding. The convolute bedding of the sandstones, the numerous fine examples of flute casts, load casts, bounce casts, and groove casts, and the occasional worm borings on the undersurfaces of sandstones are typical of flysch sediments.

Stratigraphic Divisions

There are so few good key beds in the Stanley that stratigraphic partition is diffiult. This is particularly true of the lower part of the group which, according to Honess (1923), has only one persistent recognizable stratigraphic marker in the lower 3,000 feet in the southern Ouachitas. Some stratigraphic progress has been made in subdividing the Stanley of the central Ouachitas where, by making use of several persistent shales as datum planes, Harlton (1938) has defined three formations, the Tenmile Creek, the Moyers, and the Chickasaw Creek, named in ascending order. The formations are unequal in thickness, the Tenmile Creek formation comprising about 85 percent of the total thickness.

Tenmile Creek Formation

Definition.—In the type area in the central Ouachitas, the Tenmile Creek formation is defined to include the strata above the Arkansas novaculite and below the siliceous shale member of the

Moyers formation. Harlton chose the name from Tenmile Creek at the south end of the Tuskahoma syncline in Pushmataha County, designating good outcrops in secs. 11, 14, 16, 20, and 21, T. 3 S., R. 15 E., as the type section (fig. 14). There are three fairly persistent siliceous shale beds within the Tenmile Creek formation—the lower siliceous shale, the Tuskahoma siliceous shale, and the middle siliceous shale, named in upward order. We are assigning them the nomenclatorial status of beds in this report. The formation is divided into the upper shale member of the Tenmile Creek and the lower shale member of the Tenmile Creek, the division being made at the base of the middle siliceous shale bed of the Tenmile Creek, which is included as the base of the upper member.

Harlton measured more than 5,650 feet of strata at the type locality of the Tenmile Creek formation where its base is hidden by overlapping Cretaceous strata. Eight miles distant, in Jumbo Valley, the formation is 9,000 feet thick (Laudon, 1959) and it seems likely to the writer that this thickness is representative of the type area.

Lower Shale Member.—The lower shale member of the Tenmile Creek consists predominantly of olive-gray to dark-gray laminated clay shale interbedded, in certain intervals, with thin, even beds of sandstone, and containing at other levels several beds of more massive graywacke sandstone. One exceedingly persistent bed of black shale, the lower siliceous shale bed of the Tenmile Creek formation, occurs in the lower part of the formation, and another less persistent siliceous shale, the Tuskahoma, is somewhat above this. The lower part of the lower shale member of the Tenmile Creek also contains some tuff beds.

Laudon (1959, p. 40) assigned the lower shale member of the Tenmile Creek formation a thickness of 6,400 feet in the Sikes-Burkhalter and Caulkins No. 1 Denton Perrin and Southwestern Exploration No. 1 Denton Perrin wells in Jumbo Valley, and he (p. 43) computed its thickness to be between 5,000 and 6,000 feet in outcrops between the Potato Hills and Kiamichi Mountain.

The Stanley shale and Arkansas novaculite contact appears to be conformable throughout the central and southern Ouachita Mountains in Oklahoma. The unconformity reported by Purdue and Miser (1923) to occur at the base if the Hot Springs sandstone member of the Stanley in the Hot Springs, Arkansas, area does not seem

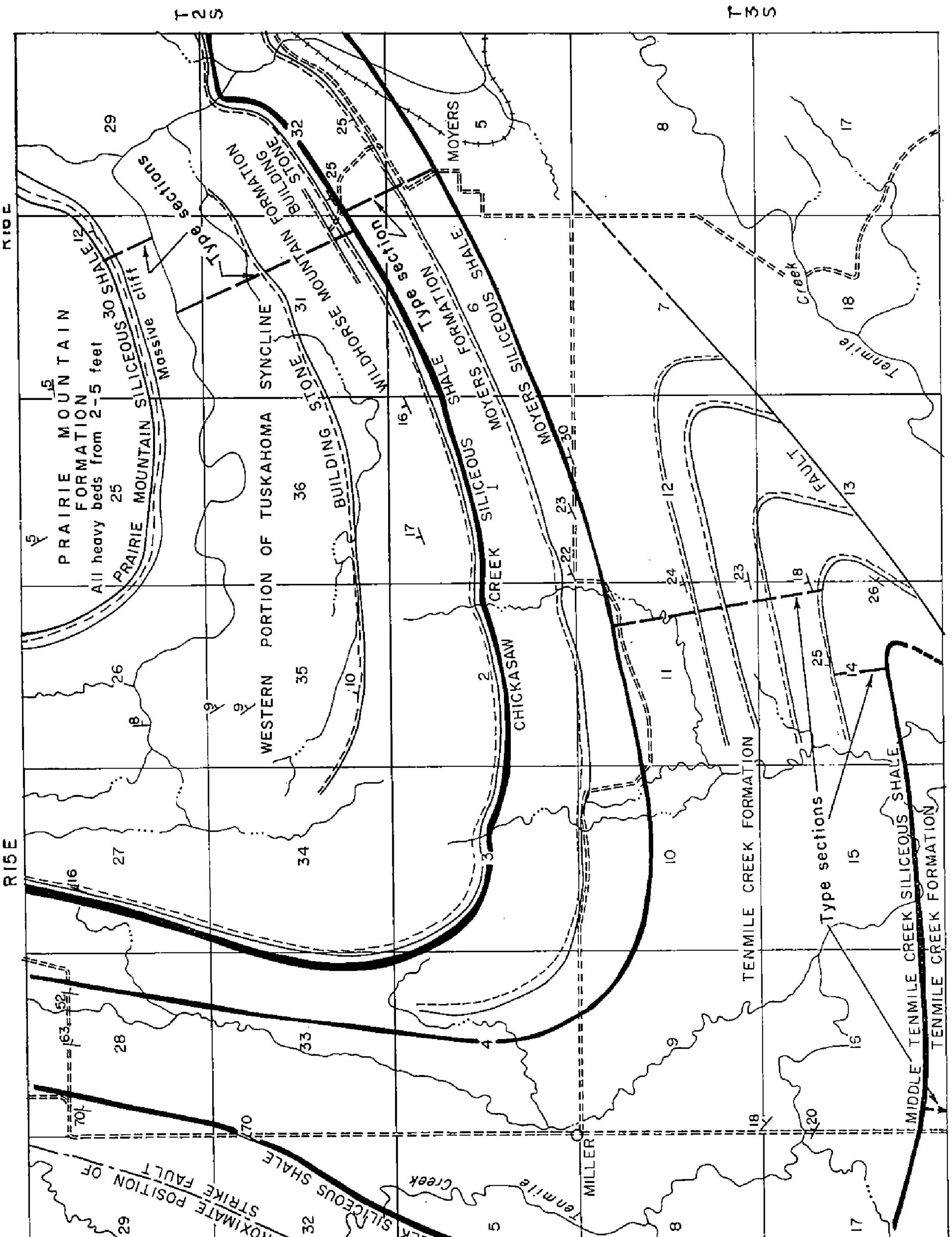

FIGURE 14. Geologic map showing type localities of Tenmile Creek and Wildhorse Mountain formations, Pushmataha County. (Modified from Harlton, 1938)

to be present around the Choctaw anticlinorium (Honess, 1923; Cline, 1956b) or the Potato Hills (Laudon, 1959, p. 27), the two areas inside the frontal Ouachitas where the contact is seen. Laudon has described a 100-foot transition sequence on the south side of the Potato Hills in which there are repeated alternations of Stanley type shales and Arkansas novaculite type cherts. Cline has reported intergradation of the two lithologies in the Beavers Bend State Park area in McCurtain County.

The Stanley-Arkansas novaculite contact is also exposed at Black Knob Ridge, which lies inside the Ti Valley fault, the boundary between the central and frontal Ouachitas. In road cuts along Oklahoma State Highway 3, in sec. 14, T. 2 S., R. 11 E., just east of Atoka, the contact is marked by green and brownish-red shales, some beds of which are siliceous and some of which contain conodonts. Hendricks (1947) and Cline (Dallas Geol. Soc., 1959b, p. 9) are of the opinion that the two formations are conformable at this locality and elsewhere in this structural belt.

The Stanley shale is not present immediately north and west of the Ti Valley fault in the northwestern Ouachitas. The possibility exists that the area immediately north of the Ti Valley fault was positive, but not necessarily above sea level, in Stanley time, in which case an unconformity may have been developed at the base of the Stanley in a belt near the outer limits of its depositional basin. Some support for this view is seen in outcrops east of Pine Top school, in a north-trending ravine in the NW¼ SE¼ sec. 4, T. 2 N., R. 15 E., in Pittsburg County. Here the contact of the Woodford chert (uppermost Arkansas novaculite equivalent) with an overlying green shale may be unconformable (fig. 15). The shale, which is only 9 feet thick, was included as the base of the Caney by Hendricks (1947) who noted that its base is phosphatic and glauconitic and suggested the possibility of an unconformity. Cline (Dallas Geol. Soc., 1959b) called attention to the similarity between this and typical Stanley shale and pointed out that at this same locality there are numerous other stratigraphically higher green-gray shales which are interbedded with the black, laminated, almost slaty shale so typical of Caney lithology. It seems more probable to the writer that this intertonguing of Caney and Stanley lithology is additional support for his belief that the Stanley shale is merely the geosynclinal equiv-

FIGURE 15. Caney shale on left in contact with vertically dipping beds of Woodford chert on right. The green shale in the gully strongly resembles Stanley shale and may represent the attenuated edge of that group. The locality is in a north-trending ravine in the NW¼ SE¼ sec. 4, T. 2 N., R. 15 E., one mile north of the Ti Valley fault.

alent of the *lower portion* of the Caney shale which accumulated on the platform bordering the geosyncline.

Twenty feet of dark blue-gray siliceous shale occur in the lower portion of the Tenmile Creek formation east of Black Knob Ridge in Atoka County (Harlton, 1938, p. 868) where its relations to the rest of the Stanley are obscured by faulting. According to Laudon (1959, p. 36) this siliceous shale lies 850 feet above the top of the Arkansas novaculite on Dry Creek southwest of the Potato Hills. Although the lower part of the Tenmile Creek formation is covered by Cretaceous sandstones at the type locality, the lower siliceous shale bed of the Tenmile Creek formation probably is present in the subsurface.

In the valley between Kiamichi Mountain and the Potato Hills a blue-gray siliceous shale is about 4,000 to 5,000 feet above the base of the Stanley. Harlton (1947, p. 41) used the name Albion in his single reference to the shale, stating that Hendricks had suggested the name orally, and that Hendricks contemplated using the name. At that time Harlton assumed the Albion to be equivalent to the lowermost siliceous shale (now called the lower siliceous shale bed of the Tenmile Creek) in the Stanley east of Black Knob Ridge. Goldstein and Hendricks (1953, p. 431) probably knew of this miscorrelation when they referred to this upper siliceous shale stating that:

> The siliceous shale of this unit has not been named previously and is herein named the Tuskahoma siliceous shale. The type locality is selected as the exposure at the center of the west side of Section 22, Township 2 North, Range 20 East, Pushmataha Co., Oklahoma, approximately 4.6 miles east of Tuskahoma on U. S. Highway 271. The type section was measured by T. A. Hendricks and Paul Averitt...

The Tuskahoma siliceous shale has not been observed outside of the Potato Hills area, according to Laudon (1959, p. 38).

UPPER SHALE MEMBER.—At the type locality of the Tenmile Creek formation the upper shale member is 3,500 feet thick according to Harlton's measurements (1938, p. 864; fig. 7, p. 867). Laudon (1959, p. 45) estimated its thickness at 2,640 feet in Jumbo Valley, a few miles northwest, and computed it to be 3,400 to 3,500 feet on the northern flank of the Tuskahoma syncline. Johnson (1954) assigned 4,400 feet to the member in the Medicine Springs area, which lies east and northeast of Antlers in a syncline between the Boktukola and Octavia faults.

The member has a persistent black siliceous shale at the base, the middle siliceous shale bed of the Tenmile Creek formation, and about 300 feet below the top of the formation there are some laminated brownish-red shales. Harlton believed the upper reddish shale to be diagnostic but Laudon thinks it is not persistent. The writer found it to be useful in mapping the southwest nose of the Kiamichi River anticline in the vicinity of Kosoma and has also observed red shale at this stratigraphic position in the outer part of the Ouachitas. It is nicely exposed about five miles east-southeast of Stringtown in ditches on the west side of the road and in adjacent glades along the center of the east line of the SE¼ NE¼ sec. 19, T. 1 S., R. 13 E.

The most widespread stratigraphic marker in the Tenmile Creek formation in the Ouachitas is the siliceous shale bed at the base of the upper shale member of the Tenmile Creek formation. This thin blue-black shale is present throughout the central and frontal Ouachitas and, on the basis of stratigraphic position and lithologic similarity, it is probably the lateral equivalent of the 25 feet of black cherty shale of the southern Ouachitas that Honess (1923 p. 152) noted as persisting eastward into Arkansas, that he (Honess, 1924) later called the "Stanley black chert," and which Miser and Honess (1927) still later named the "Smithville chert lentil." As Branson (1957, p. 102) has observed, the name Smithville has also been applied (in 1929) to a Lower Ordovician formation of northern Arkansas and southern Missouri and this usage is well established. It would seem that the best interests of stratigraphy would not be served by invoking the law of priority in this case. Shelburne (1959, p. 22) proposed to rename the Smithville. Both Shelburne and Laudon agree that the bed is equivalent to the siliceous shale described by Harlton (1938, p. 868) at the base of the upper part of the Tenmile Creek formation.

TUFF BEDS.—In the southern Ouachitas a persistent tuff lies about 270 feet above the base of the Stanley and attains thicknesses of from 90 to 228 feet. Honess' map (1923) depicts it as cropping out in narrow zig-zag bands on the numerous sharp folds of the Choctaw and Cross Mountains anticlinoria. Honess states that this is the only good stratigraphic marker in the lower 3,000 feet of the Stanley of this area. The bed is correlative with the Hatton tuff of Polk County, Arkansas, which lies just to the east. Miser and Purdue (1929, p. 63) state that the Hatton tuff is the thickest, most persistent, and stratigraphically the lowest, of three or four tuff beds in the lower part of the Stanley of Arkansas and Oklahoma. Honess (1923, p. 57, 150) stated that he had seen no place in Oklahoma where he could be sure of two or more tuffs in the Stanley and he was inclined to doubt the existence of more than one bed.

Lithologically the Hatton simulates a coarse graywacke to the unaided eye. A hand lens examination reveals fragments of plagioclase, quartz, angular pieces of sandstone, slate, and occasional bits of somewhat altered basalt, commingled with the original glassy, but now devitrified, bits of ash showing vesicular and flow structures in thin section (Honess, 1923, p. 179, 180). A few crinoid columnals have been observed, testifying to the clastic nature of the tuff.

Later workers have found lenticular, tuffaceous sandstones at several horizons within the Stanley. In addition to the Hatton tuff, Cline (Cline and Shelburne, 1959) has seen two thinner beds on the north side of the Choctaw anticlinorium that he believed to be tuffs, and Shelburne has seen two tuffs, and possibly four depending on structural interpretation, in the lower part of the Stanley on the north flank of the Cross Mountain anticlinorium.

Bennison and Johnson (1959, p. 65) called attention to a good tuff bed on the south flank of the Potato Hills, south of the old Choctaw Council House, in road ditches near the center of sec. 23, T. 2 N., R. 19 E. Here 25 feet of tuffaceous sandstone lies about 10 feet above the lower siliceous shale bed of the Tenmile Creek formation (Laudon, 1959, p. 49). The tuff has abundant lathes of kaolinized feldspar which are large enough to attract the attention of the field geologist. Bennison and Johnson report that a petrographic examination shows the bed to be a poorly sorted, argillaceous, tuffaceous sandstone with fine glass shards and coarse angular feldspars in a matrix of clay and fine quartz grains.

The writer is of the opinion that careful search will reveal additional tuffaceous beds in the Stanley group. Many of the graywacke sandstones have the weathering characteristics of tuffs.

Moyers Formation

Definition.—The type locality of the Moyers formation is in the lower slopes of Wildhorse Mountain, just north of the village of Moyers, in the NW¼ sec. 5, T. 3 S., R. 16 E., in Pushmataha County. The formation was named by Harlton (1938), who published a geologic map of the Moyers-Miller area and a diagrammatic and annotated stratigraphic column of the Moyers formation (Harlton, 1938, figs. 6, 8). The boundaries of the formation are well defined, the lower limit being drawn at the base of the hard blue-black siliceous shale member, and the upper limit being defined by siliceous shale of the overlying Chickasaw Creek formation.

Lithologic Character and Thickness.—The Moyers formation consists of 1,100 feet of alternating sandstones and shales in the type area, but the thickness is as much as 1,700 feet on the north side of the Tuskahoma syncline. The shales are soft, easily weathered, thin-bedded, and range in color from green-gray to dark-gray. The alternation of sandstones and shales produces conspicuous rock terraces and benches which rise prominently above the valley-forming shales of the Tenmile Creek formation to form the lower slopes of the synclinal mountains.

Sandstone is relatively more abundant in the Moyers formation than in the Tenmile Creek formation, comprising perhaps two-fifths of the Moyers. Individual beds are commonly several feet thick and some of them are as thick as 20 feet. On the average, Moyers sandstones are considerably cleaner and better sorted than those of the lower part of the Stanley group. Some beds are dirty enough to be called graywackes but many of them are clean enough to qualify as subgraywackes. The sandstones characteristically are massive, are about as likely to fracture across the bedding as parallel to it, and they weather spheroidally. Sole markings are numerous, flute casts being especially abundant, and convolute bedding is fairly common. Some beds are slightly micaceous and carbonized plant fragments are common.

Shales characteristically are green-gray and laminated but some brownish-red beds are present. Cone-in-cone concretions are uncommon, having a tendency to be concentrated at certain horizons.

SILICEOUS SHALE MEMBER.—A widespread 20-foot-thick dark blue-gray, green-gray weathering siliceous shale is present at the base of the formation in the central and western Ouachitas. The member is resistant and weathers to form a low ridge above the adjacent weaker gray shales. The ridge is generally at the margins of valley flats and is prominent enough to be easily mapped.

At first glance the shale appears to be unfossiliferous, but a hand lens examination reveals occasional conodonts and some white siliceous areas. Radiolaria may be seen when a thin section is examined under a high-powered microscope.

Harlton has noted that this excellent key bed appears to have great lateral persistence; in fact his second choice of a type locality was an area in sec. 26, T. 1 S., R. 12 E., which is on the northwest side of Prairie Mountain near the frontal Ouachitas and some 25 miles distant from the Moyers area. Cline (1956b) reported the Moyers as present in the eastern portion of the Lynn Mountain syncline, at the foot of Kiamichi Mountain on the north side and along the Octavia fault at Honobia on the south side. Seeley, in a written communication to Cline, dated January 26, 1959, reported that he had mapped the Moyers siliceous shale east of the Indian Service road, which is east of Albion. However, Seeley thought that the dark siliceous shale at the base of Kiamichi Mountain, which Cline (1956b, p. 54) has identified as the basal Moyers in connection with preparation of the roadlog and guidebook for the 1956 field trip of the Ardmore Geological Society, belonged higher in the Moyers formation. Laudon (oral communication to Cline, January, 1959) included this shale in the lower part of the Chickasaw Creek formation and stated (1959, p. 59) that the siliceous shale member of the

Moyers formation is not present in the eastern portion of the Oklahoma Ouachitas. We do not agree with this view because Shelburne (1959, p. 26) identified 6 feet of dark gray cherty shale at the base of the Moyers formation in the vicinity of Ludlow where it is intruded by sandstone dikes. This is on the Octavia anticline and is east of Honobia.

Chickasaw Creek Formation

Definition.—Lying stratigraphically above the terrace-forming sandstones and shales of the Moyers formation are the more easily eroded shales of the Chickasaw Creek formation. The Chickasaw Creek consists of from 80 to more than 300 feet of dark blue-gray shales interbedded with thinner, laminated black siliceous shales containing some cherty beds, and with some sandstones. Notwithstanding its thinness, the formation is widespread throughout the Ouachitas and is the best stratigraphic marker in the 17,000-foot Stanley-Jackfork interval. It has a characteristic lithology that makes for ready identification in the field and its position can be established on air photographs by a characteristic weathering pattern.

This formation was named and described by Harlton (1938, p. 874) who assigned it to the Stanley group, although Taff (1902) had originally included it in the lower part of the Jackfork sandstone. Hendricks *et al.* (1947), in mapping the frontal Ouachitas, ignored the term Chickasaw Creek but mapped the interval as a siliceous member in the lower Jackfork. Cline (1956c; Dallas Geol. Soc., 1959b) has followed Harlton's terminology and included the Chickasaw Creek in the Stanley group.

Harlton designated outcrops in the SW¼ sec. 7, T. 1 S, R. 13 E., as the type locality of the Chickasaw Creek. The locality is in the western Ouachitas and east of Stringtown in Atoka County, and is only a short distance south of the Windingstair fault. Inasmuch as the base of the formation is covered at the type locality, Harlton selected as a supplementary type section outcrops in the center of the W½ NE¼ NE¼ sec. 26, T. 1 S., R. 12 E., on the north slope of Prairie Mountain, also in the western Ouachitas.

Lithologic Character and Thickness.—Thin-bedded dark blue-gray shale is the predominating rock type in the formation but there are some subgraywacke sandstones and some of these show convolute bedding. The most distinctive rock type is black siliceous shale with intercalated thin cherty beds.

The formation is 270 feet thick at the type locality, thins eastward to where it is only a few feet thick at the south end of the Tuskahoma syncline, and then thickens eastward in Kiamichi Mountain and in the Botukola syncline. Cline and Moretti (1956, p. 10, 11) measured nearly 300 feet of Chickasaw Creek strata along the Indian Service road at the foot of Kiamichi Mountain on the north flank of the Lynn Mountain syncline and according to Laudon (1959) there are additional beds at the base which should have been included. Twenty miles east, in the cutbanks of the fine new road that winds up the north face of Kiamichi Mountain, Cline and Moretti measured 333 feet of Chickasaw Creek strata. Shelburne (1959) reports that the formation occurs throughout the Boktukola syncline, which is south of Kiamichi Mountain, and he measured sections of 131 and 140 feet in this area (p. 30).

Siliceous Shales.—Black, siliceous cherty shales occur at several levels within the Chickasaw Creek formation. The more siliceous portions occur in even beds ranging in thickness from one-half inch to six inches, are dark gray to black, and are mottled with white globular to almond-shaped areas of white silica ranging in diameter from a fraction of a millimeter to several millimeters. The white silica globules are in strong contrast to the fine-grained black matrix in which they are embedded and upon weathering produce a distinctive mottled rock. Fragments of this speckled chert, lying on weathered slopes, readily attract the attention of the field geologist who can easily trace them upslope to the outcrop. The only other siliceous shale with which these speckled cherts can be confused is in the Wesley formation in the upper part of the Jackfork group and it occurs some 5,600 feet higher stratigraphically so that there is ordinarily no chance of confusing the two. The speckled cherts occur at more than one level within the Chickasaw Creek. Along the Indian Service road, in the lower slopes of Kiamichi Mountain, there are two such zones, one a 10-foot unit at the top of the formation in which there are several speckled beds, the other a thinner zone 209 feet lower (Cline and Moretti, 1956, p. 10).

An examination of thin sections under a microscope reveals the cherty beds to contain abundant sponge spicules, numerous radiolarians, and less numerous conodonts. Individual laminae in some of the beds show a micrococoquina of tiny monaxon and tetraxon sponge spicules and one specimen showed sorting according to grain size that is suggestive of graded bedding. The distinctive globules of white silica are clearly visible to the naked eye. Harlton has suggested that radiolarians served as nuclei about which silica was deposited, and indeed some of them may have served to seed precipitation, but many globules seem to be devoid of radiolarians. Radiolarians, where preserved, show little evidence of solution. There are all gradations of these concentrations of silica from spherical masses through almond-shaped masses parallel to bedding to irregular lenses interlaminated with sapropelic material. The structure, texture, and fabric present a strong argument for syngenetic or penecontemporaneous origin for the silica. Pure, clean opaline silica appears to have been deposited concurrently with black organic-rich clays which were also rich in radiolarian tests and mechanically concentrated sponge spicules.

Age of the Stanley Group

The Stanley group is referred to the Mississippian system and the best evidence indicates that it is Meramecian in age. Except for the Radiolaria, sponge spicules, and conodonts of the thin siliceous shale members, the Stanley is essentially devoid of fossils. It has been assigned to the Ordovician, Mississippian, and Pennsylvanian systems by various workers. As the history of classification of the Stanley is long and somewhat involved, only the more important contributions are reviewed below.

Honess (1923, pp. 176-178) discovered a marine invertebrate fauna in a three-inch sandstone bed near the middle of the Stanley shale in sec. 33, T. 4 S., R. 21 E., on the west bank of Little River in McCurtain County. Another fossil locality involving lower Stanley beds was discovered in sec. 27, T. 2 S., R. 24 E. Honess collected faunas from both localities and submitted them to Charles Schuchert for study. Schuchert identified the following forms: crinoid stems, the bryozoan genera *Cystodictya, Rhombopora,* and *Fenestella,* the brachiopods *Orbiculoidea nitida* Phillips, *Chonetes* sp., and a productid suggesting *Pustula nebraskensis,* and a fish bone. Schuchert was fairly certain that the collection was of Mississippian or Pennsylvanian age. He showed the collection to Ulrich who stated that it could be Mississippian or Pennsylvanian, with the trend of the evidence pointing toward Pennsylvanian.

Plant fragments from the middle Stanley locality mentioned above were submitted to David White whose original opinion concerning their age was that they are Mississippian and probably Chesterian in age. Of plant fragments found at other localities in the Stanley, White stated that they could be either Late Mississippian or "Pennsylvanian of earlier date than I am acquainted with in the Appalachian trough" (Honess, 1923, p. 177). Later paleobotanical work by White, which was published in 1934 and 1937, led him to the conclusion that the plant-bearing Jackfork and upper Stanley are Lower Pennsylvanian, and that the non-plant-bearing lower Stanley probably also is Lower Pennsylvanian. Most subsequent workers, e.g., Miser and Hendricks *et al.*, leaning heavily on White's latest work, included the Stanley and Jackfork in the Pennsylvanian.

C. L. Cooper (1945, p. 390-397) made a thorough review of all of the published evidence concerning the age of the Stanley-Jackfork and concluded that the paleobotanical evidence supported a Mississippian age for the two groups but believed that they are younger than any known Chester in the Mississippi Valley type area. Weller *et al.* (1948, p. 106) noted that if White's correlation of the Stanley and Jackfork with the lower Namurian of Europe is correct, they "are probably of Mississippian age." Cooper made the point that at the time White had made his correlation, the lower Namurian was generally considered to be Lower Pennsylvanian (in North American terminology).

A most important contribution to the problem of the age of the Stanley was Hass' paper entitled "Age of lower part of Stanley shale," published in 1950. Conodonts collected from some of the black siliceous shales in the Stanley were identified by Hass and found to be conspecific with forms from the Caney shale of Oklahoma and the Barnett shale of Texas, both of which have long been regarded as Late Mississippian. Hass concluded that the Stanley correlates with the Caney. He considered the lower Stanley to be Meramecian (p. 1581). In 1956 Hass (p. 25-33) referred the upper division of the Arkansas novaculite to the Kinderhookian and Osagean and reaffirmed his belief that the lower Stanley is Meramecian; these correlations were also made on the basis of conodont studies.

Cline's mapping (1956c) of the Johns Valley shale in the Central Ouachitas showed that the lower Johns Valley contains a depositional tongue of the black goniatite-bearing Caney shale. Inasmuch as the Johns Valley overlies the Jackfork in normal stratigraphic sequence, the Jackfork and Stanley cannot be younger than Late Mississippian. It seems probable that Hass is correct in assigning a Meramecian age to the lower part of the Stanley group.

JACKFORK GROUP

In its typical development the Jackfork group consists of 5,600 to 5,800 feet of alternating sandstones and dark gray shales with minor amounts of black siliceous shales which include some thin chert beds. Sandstone is the prevailing rock type, hence the Jackfork is more resistent to erosion than the underlying Stanley shale and it forms the steeper slopes and higher portions of the synclinal mountains of the Ouachitas.

History of Nomenclature

Taff (1902) named the Jackfork for Jackfork Mountain in the frontal Ouachitas. Harlton (1938) studied and mapped better exposures of the Jackfork in the Tuskahoma syncline in western Pushmataha County and in the Round Prairie syncline northeast of Atoka in Atoka County. Harlton classified the Jackfork as a group and divided it into four formations; named in ascending order they are: the Wildhorse Mountain, Prairie Mountain, Markham Mill, and Wesley. He excluded the upper 400 to 500 feet of Taff's Jackfork from the group, named it the "Union Valley sandstone" in the mistaken belief that it is a correlative of the Union Valley of the type locality east of Ada, Oklahoma, and included it in the Morrow. Harlton also excluded about 300 feet of shales from the lower part of Taff's Jackfork, gave to them the name Chickasaw Creek, and referred them to the Stanley group.

Harlton made the significant observation that several black siliceous shales in the Jackfork are widespread in their occurrence and he demonstrated their value as stratigraphic markers by using them as datum planes in his mapping. Hendricks and his coworkers (1947) mapped two of the siliceous shales as members of the Jackfork but they did not use Harlton's names.

A restudy of the type sections of all of Harlton's Jackfork formations by Cline (1956a, p. 427) revealed that the lower portion of the type Prairie Mountain duplicates the upper portion of the type Wildhorse Mountain. Although this miscorrelation resulted in a 3,600-foot error in estimating the thickness of the Jackfork in the Tuskahoma syncline, the interests of stratigraphy are best served by retaining both formational names even though the thickness of the Prairie Mountain is considerably reduced and a transfer of the

Prairie Hollow shale member from the Prairie Mountain formation to the Wildhorse Mountain formation becomes necessary.

Cline (1956c, p. 103) restored the "Union Valley sandstone" of Harlton to the Jackfork group because it proved to be non-equivalent to the type Union Valley, belonging instead with the underlying Mississippian formations. Following a suggestion from Cline, Harlton (1959, p. 132, 135) renamed the sandstone between the Wesley and Johns Valley shales, calling it the Game Refuge. Unfortunately, Harlton revived his old Pushmataha series in this paper and included both the Stanley and Jackfork in it.

Classification Used in this Report

The nomenclature used in this report (table 3) is principally after Harlton but the age assignments are different.

Thickness and Distribution

The most nearly complete exposures of the Jackfork group, in its typical development, seem to be in the north face of Kiamichi Mountain, in a belt extending from Clayton eastward to the Arkansas line (fig. 16). Two complete, unbroken, and essentially unfaulted stratigraphic sequences were recently described by Cline and

TABLE 3

SUBDIVISION OF JACKFORK GROUP, OUACHITA MOUNTAINS, OKLAHOMA

System	Series	Formation	Member
Mississippian	Meramecian and Chesterian	Game Refuge	
		Wesley	
		Markham Mill	Siliceous shale member at base
		Prairie Mountain	Siliceous shale member at base
		Wildhorse Mountain	Prairie Hollow shale member below middle

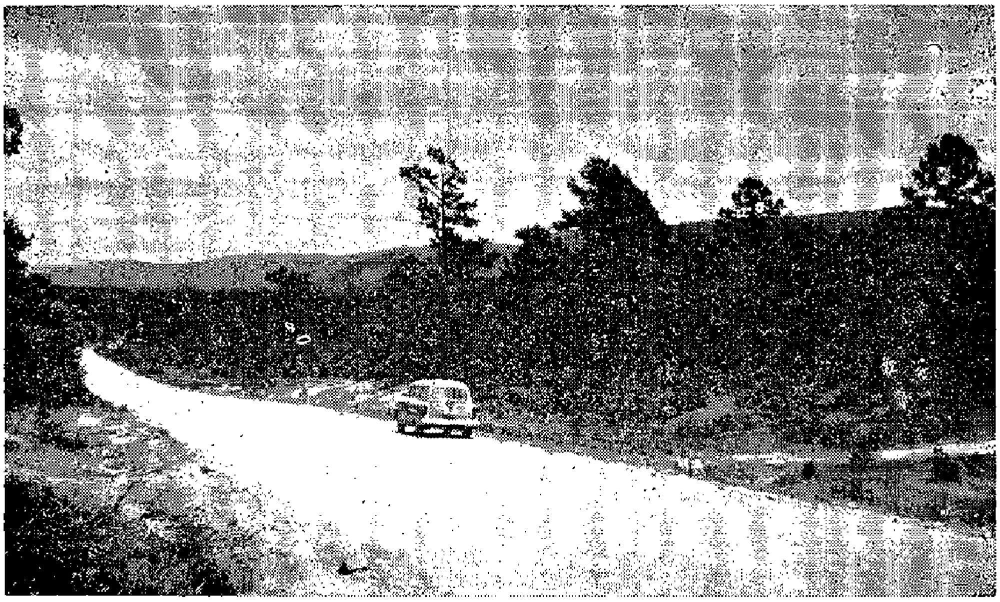

FIGURE 16. Looking east-southeast toward north escarpment of Kiamichi Mountain from a point near Kiamichi Post Office, eastern Pushmataha County. A complete, unbroken Jackfork stratigraphic section is exposed in the escarpment and the beds dip southward into the Lynn Mountain syncline.

Moretti (1956). Thus far these are the only published sections which describe more than a small part of the Jackfork group; complete exposures are almost impossible to find. The two stratigraphic sections are 22 miles apart, are structurally aligned, and probably are about on sedimentary strike. One is exposed in a series of deep new road cuts between Big Cedar and Octavia, the other in an older series of cutbanks on the Indian Service road southeast of Albion, thus affording the geologist an opportunity to compare relatively fresh strata with their somewhat weathered equivalents. These superb exposures are shown diagrammatically on plate II with zone numbers which correspond to descriptions published in Circular 41 of the Oklahoma Geological Survey. The sections are drawn to scale and one can determine at a glance that the complete thickness of the Jackfork is about 5,600 feet in one of the exposures and about 5,800 feet in the other. These thicknesses are about average for the central Ouachitas. When due allowance is made for the duplication of 3,600 feet of strata in the type sections of the Prairie Mountain and Wildhorse Mountain formations, the thickness of the Jackfork in the Tuskahoma syncline probably is on the order of 5,650 feet.

Honess (1924) reported the Jackfork to be from 10,000 to 13,618 feet in the southern Ouachitas but it must be remembered that he divided it into "Lower Jackfork" and "Upper Jackfork" separated by a fossiliferous sandstone which he reported to have a Morrow fauna. He noted that the 7,000 feet of "Upper Jackfork" is apparently a shoreward phase of the Atoka. Miser and Honess (1927, p. 21) pointed out that, inasmuch as Honess' "Upper Jackfork" is Atokan in age, it should be called Atoka and it was so mapped and labeled on Miser's 1926 edition of the geologic map of Oklahoma. Shelburne (1959, p. 33) recently estimated the thickness of the Jackfork of the southern Ouachitas (Boktukola syncline) to be from 5,400 to 6,500 feet.

An examination of Hendricks' and Harlton's geologic maps reveals that 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. Admitting that a great deal of this thinning has been accomplished by faulting, it seems that much of it was also depositional. Convergence is noticeable in all of the formations in the Jackfork group and it seems probable that its depositional limits did not extend north of the Ti Valley fault.

Examination of Hendricks' map brings out significant differences in the geology on opposite sides of the Ti Valley fault. South of the fault the Atoka group rests upon Johns Valley shale which normally is underlain by a thinned version of the Game Refuge sandstone, which in turn rests upon Wesley. North of the fault the Atoka rests upon the Springer formation which rests upon Caney shale. During the past summer the writer restudied the relations of the formations in the two fault blocks and during a part of this work he was aided by Dr. Daniel E. Feray. A restudy of the type section of the Wesley has led us to the conclusion that it is almost certainly a tongue of the Caney. We also are convinced that the Game Refuge sandstone pinches out between the Wesley and Johns Valley shales, in the SE¼ sec. 1, T. 1 S., R. 12 E. Hendricks' map shows the Game Refuge sandstone to thin southwestward along the outcrop in T. 1 N., R. 13 E., from section 23 to section 33 where it disappears and the Wesley and Johns Valley are mapped in contact. To the writer it seems likely that the other units of the Jackfork group also converge northward into the Caney shale.

Lithologic Characteristics

Sandstone is the prevailing rock type in the Jackfork group, but there is much interbedded gray shale. Sandstone is especially conspicuous in the middle portion of the group where the massive and resistant sandstones of the upper Wildhorse Mountain and lower Prairie Mountain formations combine to produce the higher elevations in the Kiamichi and other mountain ranges. The laminated dark gray shales, which include numerous thin beds of sandstone, are important components of the upper and lower thirds of the group.

The average sandstone-shale ratio seems to be on the order of 3 to 2, but it varies with stratigraphic position. Bokman (1953, p. 157) found one part of the section to have 70 percent sandstone, 27 percent shale, and 3 percent siltstone. Reinemund and Danilchik (1957) state that the upper 2,500 to 3,000 feet of the Jackfork in the Waldron Quadrangle of Arkansas is a little more than one-half sandstone.

There are several dark siliceous shales in the Jackfork group with lithology similar to the siliceous shales of the Stanley group. They are widespread and form good stratigraphic markers.

A 250- to 300-foot interval of variegated green and red shales which includes some green-gray friable sandstone, is in the lower one-third of the Jackfork. Surprising as it may seem, this variegated shale, the Prairie Hollow shale member of the Wildhorse Mountain formation, has proved to be a remarkably persistent unit and is a good datum plane in mapping.

Jackfork sandstones range in character from massive beds as thick as 8 feet to thin, even beds averaging less than 6 inches. The thicker beds are composed of angular poorly sorted grains, and range in composition from graywackes to subgraywackes. The thinner beds, which are intricately interbedded with thicker beds of dark gray shale, are hard, well-cemented, have sharp parallel bedding surfaces, and are clean enough to be classed as orthoquartzites. They are brittle and flexing has produced closely spaced joints which combine with the sharp parallel bedding surfaces to produce rhomboidal to tabular blocks where weathered. Many of the sandstone beds have thoroughly developed sole markings and some exhibit convolute bedding. Cross-bedding is uncommon except in the Game Refuge formation, which has both cross-bedding and ripple marks.

As does the Stanley group, the Jackfork group has the bedding

FIGURE 17. Thin-bedded sandstones and dark shales in lower part of Wildhorse Mountain formation in roadcut on Big Cedar-Octavia road, eastern part of Kiamichi Mountain.

characteristics of a flysch facies. The dark gray shales are intricately interbedded with thin, even beds of sandstone (fig. 17). Interlamination is so regular that it suggests a rhythmic, perhaps even cyclic, pattern, although we have not made a thorough study of this aspect of sedimentation. The abundant well-preserved sole markings, occasional worm trails, and convolute bedding are all characteristic of a flysch facies. A few readings on the directional features of the sandstones, i.e., flute casts, groove casts, and other markings, indicate that the currents transporting Jackfork sediments flowed W12°S, along the axis of the depositional trough.

Wildhorse Mountain Formation

DEFINITION.—The lowest stratigraphic unit in the Jackfork group is the Wildhorse Mountain formation, which was named by Harlton (1938, p. 878) for outcrops in Wildhorse Mountain north of Moyers in Pushmataha County, Oklahoma (fig. 18). Its lower

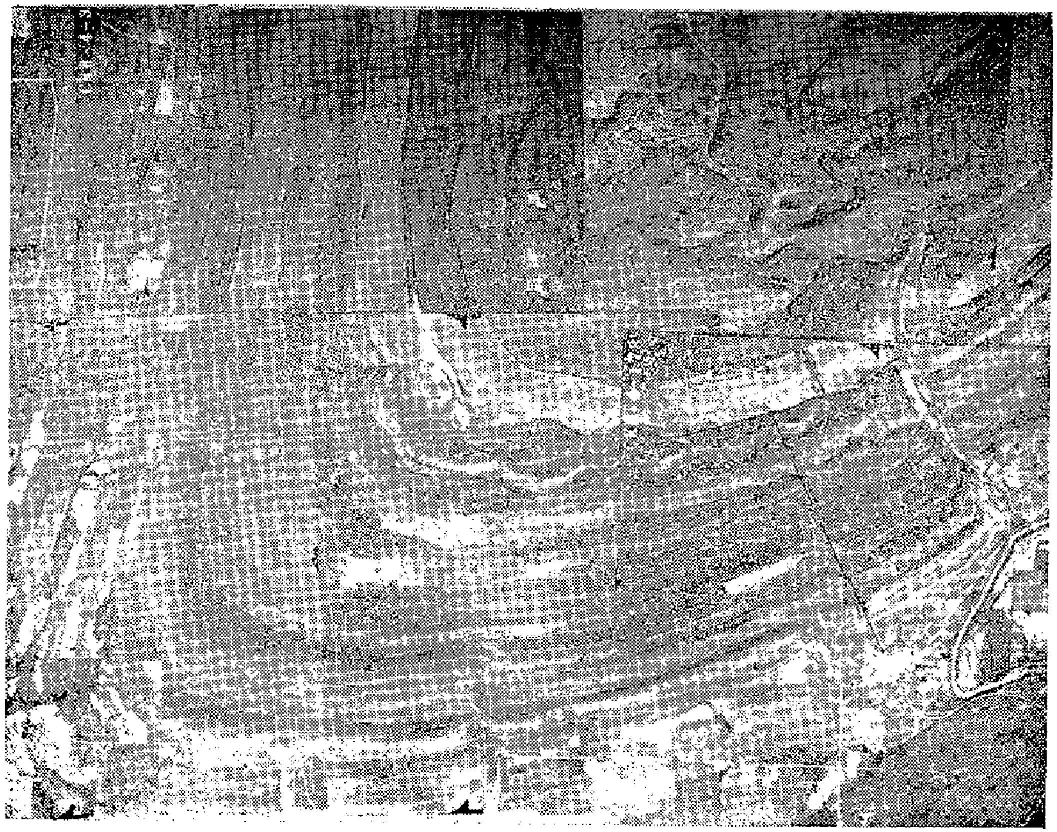

FIGURE 18. Aerial mosaic of south portion of Tuskahoma syncline showing Wildhorse Mountain and the line of traverse where Harlton measured the type section of the Wildhorse Mountain formation.
(Mosaic prepared by L. M. Cline)

boundary is drawn at the top of the siliceous shales of the underlying Chickasaw Creek formation, with which it is conformable, and its upper limit in the type area is at the base of the siliceous shale member of the Prairie Mountain formation. Harlton designated outcrops in secs. 30, 31, and 32, T. 2 S., R. 16 E., as typical and he published a diagrammatic stratigraphic section (Harlton's fig. 10, p. 879) and a geologic map (his fig. 6, p. 866) showing the traverse along which he had measured the section (figs. 14, 18).

LITHOLOGIC CHARACTER AND THICKNESS.—At the type locality the Wildhorse Mountain formation consists of 3,550 feet of massive sandstones interbedded with alternating shales and thin sandstones. The upper part of the formation contains much sandstone. Massive sandstones near the top produce a conspicuous 60-foot cliff around the south rim of the Tuskahoma syncline, and sandstones at about this same stratigraphic position produce prominent ridges and terraces throughout the Kiamichi Range to the Arkansas line. It is not to be implied that individual sandstone beds persist over any considerable distance, although we have not confirmed this one way or another, but rather that the sandstones collectively exert a strong influence on topography.

From field examinations it is evident that the sandstones of the upper part of the Wildhorse Mountain formation are whiter, cleaner, and better sorted than those in the lower part of the formation. Frank Moretti (1958) has completed a study of the mineralogy of the Jackfork sandstones under the direction of the writer. Although the writer is aware of his results, they will not not be reported here so that Moretti may have the pleasure of reporting his own research, which we hope will soon be published.

Where sandstone rests upon shale, the lower surface of the sandstone commonly has well-developed flute casts, bounce casts, groove casts, and occasional worm markings. Slabs of the sandstones have long been quarried for building stone, and many houses and business establishments in the Moyers, Antlers, and Clayton communities have been built from this attractive stone, with the base of the sandstone faced outward to reveal the numerous sole markings. Mr. Mike Emery, of Kosoma, quarries these slabs commercially.

From weathered outcrops one can easily gain the impression that the formation is composed mostly of sandstone, but fresh exposures reveal a high proportion of shale. Cline and Moretti (1956) have published a detailed description of fresh roadcut exposures of the formation in the eastern part of Kiamichi Mountain. Of the 3,524 feet of the formation, 880 feet is sandstone, 737 feet is sandstone with subordinate shale, 1,579 feet is shale with subordinate sandstone, and 328 feet is shale (figs. 19, 20). Most of the section consists of intricately interbedded dark blue-gray shale and thin, even beds of sandstone.

Shelburne's work indicates about the same thickness for the formation in the southern Ouachitas as in the central Ouachitas. From the type area in the Tuskahoma syncline the formation thins conspicuously westward into the Round Prairie syncline, and northward it thins rapidly.

Prairie Hollow Shale Member.—About 300 feet of green and maroon shale with some included green-gray sandstone forms a persistent band in the middle of the Wildhorse Mountain formation at the type locality. Harlton (1938, p. 880) named this the Prairie Hollow shale from Prairie Hollow on the west side of the Round Prairie syncline at the type locality of the Prairie Mountain formation. He considered it as a member of the

FIGURE 19. Alternating sandstones and shales exposed in newly constructed road up north face of Kiamichi Mountain between Big Cedar and Octavia. Lower part of Wildhorse Mountain formation in lower level, upper part of Wildhorse Mountain formation in upper level.

Prairie Mountain formation. Cline (1956b, p. 56) found that this maroon shale occurs within the Wildhorse Mountain formation at the type locality, and he proposed that it be regarded as a member of that formation for the following reasons: (1) the type locality of the Wildhorse Mountain formation is better exposed than the type locality of the Prairie Mountain formation, (2) the original description of the Wildhorse Mountain formation takes page pref-

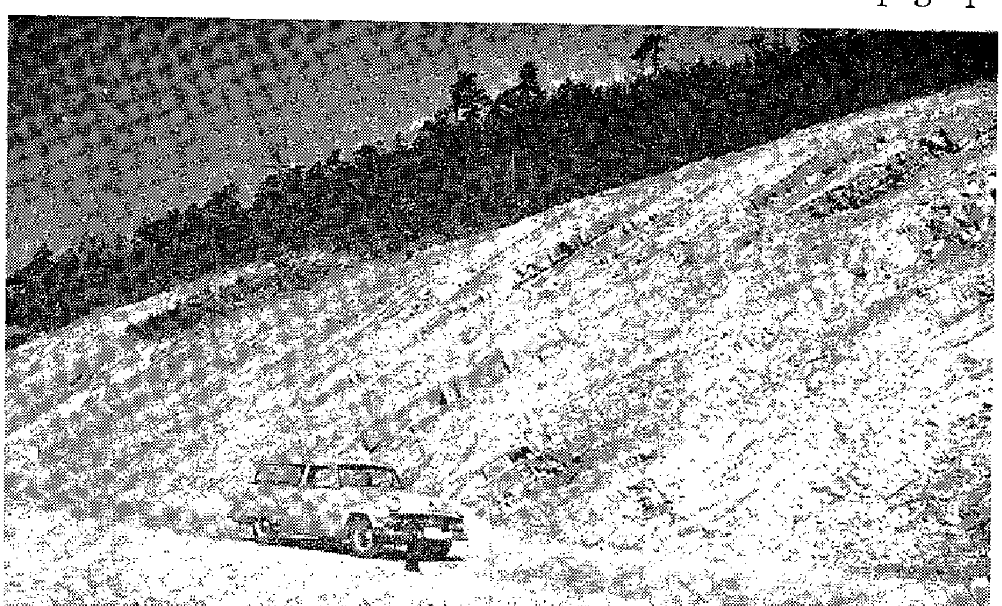

FIGURE 20. Resistant sandstones in upper part of Wildhorse Mountain formation exposed in fresh roadcut on Big Cedar-Octavia road up north face of eastern part of Kiamichi Mountain. This section was described by Cline and Moretti (1956).

erence over the description of the Prairie Mountain formation, and (3) Harlton's description of the Wildhorse Mountain formation is given in greater detail than that of his Prairie Mountain formation.

It seems noteworthy that variegated shales and sandstones of the Prairie Hollow member are so persistent, having been identified and mapped in the frontal Ouachitas by Hendricks *et al.* (1947), in the central Ouachitas by Cline (1956a, 1956b, 1956c), and in the southern Ouachitas by Shelburne (1959). The soft shales weather easily to produce a strike valley that is easy to trace in the field and its position on aerial photographs can readily be determined by the characteristic grid pattern of the steep, short gullies that come in at right angles to the prominent strike valley.

Prairie Mountain Formation

Definition.—The Prairie Mountain formation lies conformably upon the Wildhorse Mountain formation and, except for the presence of a thin siliceous shale bed at the base of the Prairie Mountain formation, can not be separated from it. The formation was named by Harlton (1938, p. 881) for Prairie Mountain, which lies in the Round Prairie syncline northeast of Atoka in Atoka County. Outcrops in the center of sec. 25, T. 1 S., R. 12 E., were designated as the type section (fig. 21). The upper limit of the formation is drawn at the basal siliceous shale member of the Markham Mill formation. Harlton's map (1938, fig. 9, p. 873), showing the distribution of the Prairie Mountain formation in the Round Prairie syncline, unfortunately includes the upper part of the Wildhorse Mountain formation in the Prairie Mountain formation, the outgrowth of an error in correlating the section with exposures in the Tuskahoma syncline.

Lithologic Character and Thickness.—Cline and Shelburne have been unable to make significant progress in zoning the Prairie Mountain formation in their mapping in the Lynn Mountain and Boktukola synclines. Sandstone and shale occur in approximately equal proportions and individual beds do not seem to be persistent. The most nearly complete exposure of the Prairie Mountain formation known to the writer is in cutbanks of a new road over Kiamichi Mountain, southeast of Big Cedar in southeastern Le Flore County (fig. 22). Here Cline and Moretti (p. 15, 16) measured 1,892 feet of strata which they assigned to the formation; this includes approximately 340 feet of sandstone, 655 feet

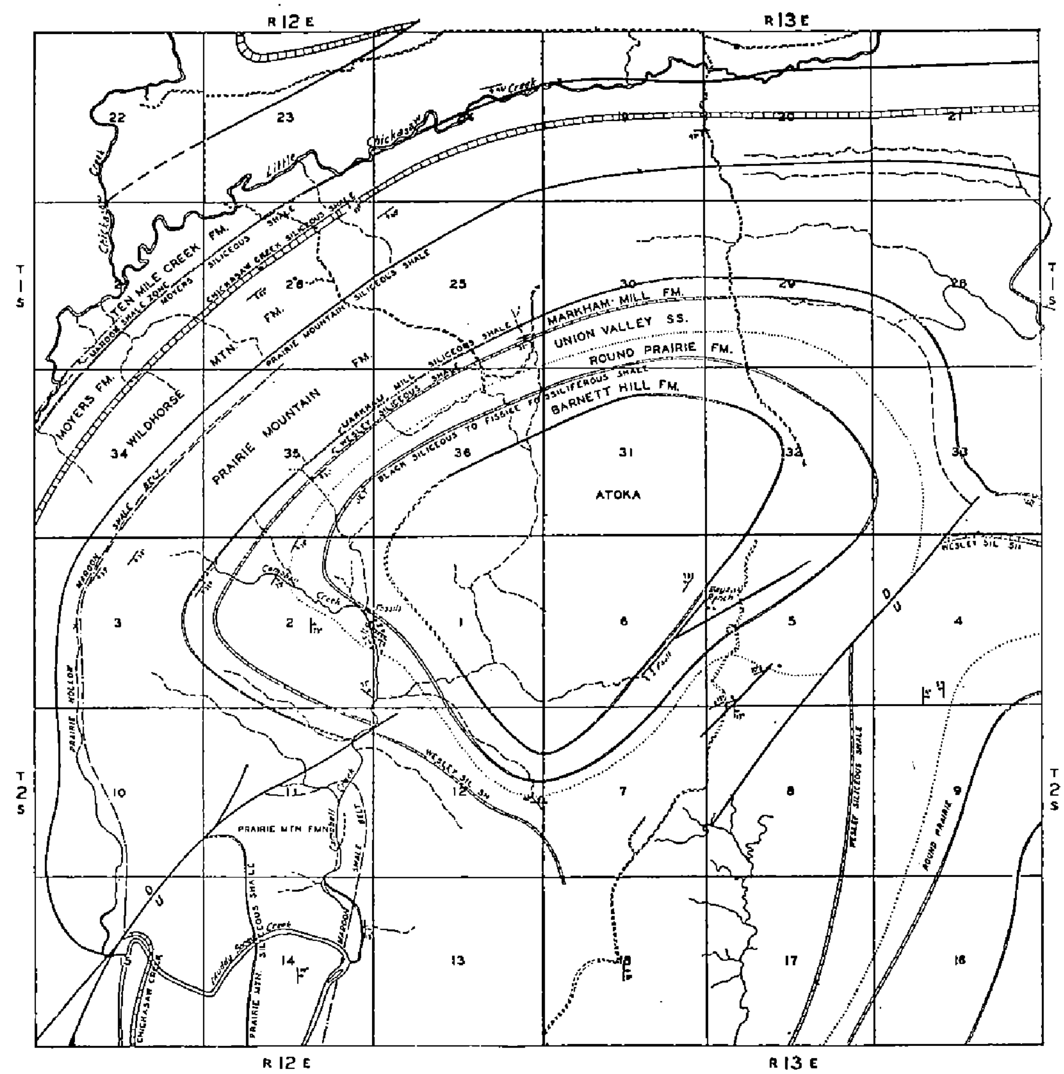

FIGURE 21. Geologic map of Round Prairie syncline northeast of Atoka, Atoka County. This is Harlton's type locality for the Prairie Mountain formation. (From Harlton, 1938)

of sandstone with some shale, 845 feet of shale with subordinate sandstone, and 52 feet of shale. A comparison with the lithology of the formation where it is exposed about 20 miles westward along the Indian Service road shows approximately the same proportions of sandstone and shale, although the rocks are somewhat weathered in these older exposures.

Harlton lists a thickness of 1,350 feet for the formation at the type locality, but when due allowance is made for his error in including the upper part of the Wildhorse Mountain with the Prairie Mountain formation, the Prairie Mountain can be scarcely more than 400 or 500 feet thick in the type area. Harlton gave a thickness of 4,300 feet for the formation in the Tuskahoma syncline

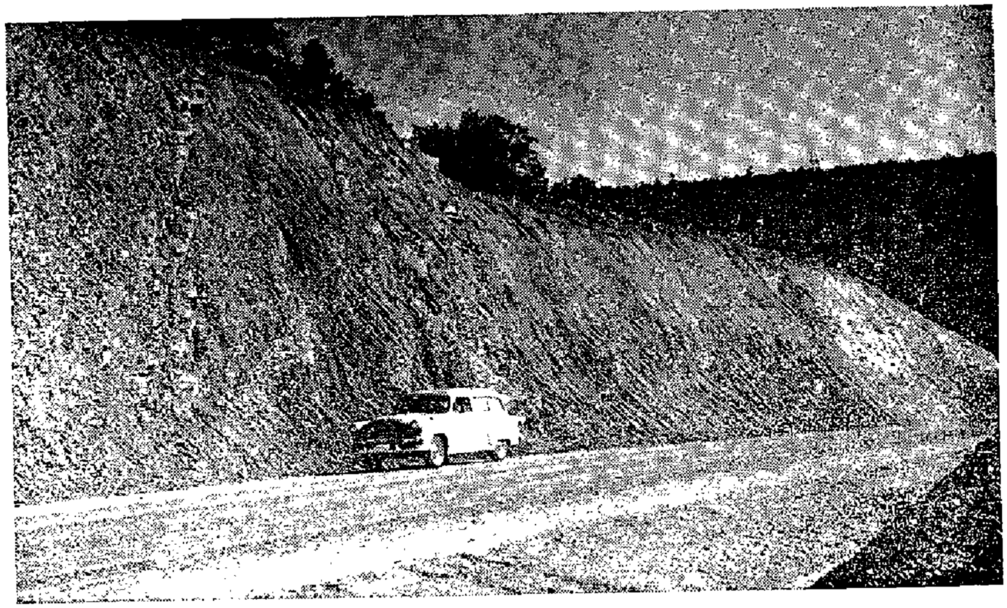

FIGURE 22. Sandstones and dark gray shales in lower part of Prairie Mountain formation exposed in fresh roadcut near crest of Kiamichi Mountain on Big Cedar-Octavia road. The stratigraphic sequence was described by Cline and Moretti (1956).

but this thickness is believed to be too great. The only published stratigraphic sections of the formation, where it has been described and measured in detail, are those of Cline and Moretti (1956) for two localities in the eastern part of the Kiamichi Range; here the maximum thickness that can be assigned the formation in the thicker of the two sections is less than 2,000 feet.

SILICEOUS SHALE MEMBER.—A one- to two-foot bed of dark gray siliceous shale marks the base of the Prairie Mountain formation in the type area in the western Ouachitas. Harlton (1938, p. 880, 881) stated that it is widespread in most of the Ouachitas. It seems to be persistent in the Round Prairie and Tuskahoma synclines where it has been used as a datum in mapping by Harlton. The writer doubts that it is as widespread as Harlton thought because his mapping in the Lynn Mountain syncline indicates that it is not present (or is too thin to be a practical key bed), and Shelburne has been unable to find it in his mapping in the Boktukola syncline farther south. Consequently we have been forced to map the upper part of the Wildhorse Mountain and the lower part of the Prairie Mountain formations as a unit.

This siliceous shale is prominently banded, the exceedingly fine laminae resulting from changes in the relative amounts of clay and iron oxides (Goldstein and Hendricks, 1953, p. 432, 433) which alternate with carbonaceous and/or sapropelic material. Harlton (p. 882) reports that a microscopic examination reveals the presence of sponge spicules and numerous capsules and spines of radiolarians; Goldstein and Hendricks report spore exines.

Markham Mill Formation

DEFINITION.—Conformably above the Prairie Mountain formation is the Markham Mill formation. The name was given by Harlton (1938, p. 884) for outcrops near the old Markham sawmill (no longer in existence) in the NE cor. SW¼ sec. 21, T. 2 S., R. 14 E., on the west side of the Farris syncline. A second type locality was chosen in sec. 2, T. 2 S., R. 12 E., on Campbell Creek in the Round Prairie syncline.

LITHOLOGIC CHARACTER AND THICKNESS.—In its type area the formation consists of 400 feet of strata chiefly composed of sandstone which is thick bedded in the lower part and is thin bedded in the upper part. The base is marked by 15 to 20 feet of dark gray siliceous shale, which is the most characteristic member of the formation.

The thickness seems to be fairly constant in the central Ouachitas. Cline and Moretti (1956, p. 5, 15) recorded thicknesses of 318 and 328 feet respectively for two well-exposed sections in the western part of the Kiamichi Range. The formation thins rapidly northward from the type section into the frontal Ouachitas. Harlton reported only 10 feet of sandstone above the thin basal siliceous shale in the fault block between the Ti Valley and Windingstair faults.

SILICEOUS SHALE MEMBER.—In the western Ouachitas 15 to 20 feet of hard, platy to blocky, dark gray siliceous shale marks the base of the formation. Some of the harder beds closely approach chert in general appearance, and on weathered outcrops float of this characteristic material is an aid in identifying and mapping the formation. The shale has inclusions of carbonized plant fragments which give it a mottled appearance. Weathered fragments of the more siliceous beds have a pinkish-gray to reddish-gray color.

Harlton (1938, p. 885) reported lenses of a cherty sandstone conglomerate in the lower part of the siliceous shale at Prairie Mountain and he noted that the conglomerate is coarser northward (presumably he meant that the individual components of the conglomerate are coarser) and includes boulders in the frontal Ouachitas. He stated that the boulders were "dropped" into the sea during deposition of the siliceous shale.

The basal siliceous shale is a valuable stratigraphic datum in the western Ouachitas. Harlton used it as a key bed in his mapping in the Round Prairie, Farris, and Tuskahoma synclines. The writer has noticed its presence south of the Kiamichi River in the north limb of the Lynn Mountain syncline, although he has not positively identified it in this range east of the Indian Service road. R. H. Johnson (1954) mapped a siliceous shale in the Medicine Springs area east of Antlers believing it to be the Markham Mill. The writer believes that this siliceous shale is in the upper part of the Wesley formation and that it correlates with a siliceous shale farther east in the Boktukola syncline which Shelburne (1959) has mapped as the Wesley. The writer mapped the Markham Mill and Prairie Mountain formations as one unit in the western part of the Lynn Mountain syncline because, in the time available, it did not seem practical to search for an obscure siliceous shale just to differentiate 300 to 400 feet of prevailingly sandstone strata from the much thicker underlying Prairie Mountain sandstones.

Wesley Formation

Definition.—Between the sandy strata of the Markham Mill and Game Refuge formations is the Wesley shale, a 150- to 500-foot unit of soft blue-gray shale containing some black siliceous shale beds. The type locality was designated by Harlton (1938, p. 886) as outcrops southwest of Wesley in the E½ SE¼ NW¼ sec. 20, T. 1 N., R. 13 E., just south of the Ti Valley fault. The formation has proved to be one of the most widespread and useful stratigraphic markers in the entire Stanley-Jackfork stratigraphic sequence.

Lithologic Character and Thickness.—At the type locality the Wesley consists of 500 feet of gray shale with some subrounded masses of dark gray to black chalcedony and many intercalated lenses of a peculiar chert conglomerate (Harlton, 1938, p. 886). Hendricks (1947, p. 17) has noted a facies change from soft blue-black and hard black siliceous shale in the northwest part of the Ouachitas to a brown clay shale containing scattered thin beds of hard black siliceous shale in the southeast. In the Lynn Mountain syncline the writer (plate I) has mapped as Wesley about 400 feet of soft gray shale containing some thin dark siliceous (cherty) layers. Eastward in this syncline, in cutbanks along the Indian Service road where it crosses the Kiamichi Range, the formation consists of about 150 feet of soft blue-gray shale with intercalated thin beds of siltstone and fine-grained sandstone and at least one conspicuous chert bed near the top (Cline and Moretti, 1956, p. 5). The chert is dark gray to black and weathering produces 6-inch rhombohedrons with a characteristic green-gray weathered surface. This chert is present in the Kiamichi Range eastward to the Arkansas line. Shelburne has also found chert beds in the top of the Wesley in the Boktukola syncline where that formation attains a thickness of at least 223 feet.

Harlton has emphasized the occurrence of the thin beds of chert conglomerate in the Wesley and has called attention to the presence of rock fragments derived from an Arbuckle facies. Hendricks (1947, p. 17) noted the presence of exotic boulders of chert and flint with diameters up to seven feet. According to Hendricks, Ordovician trilobites and graptolites have been collected from some of the exotics. From his observations that there is a progressive decrease in the size of the boulders from northwest to southeast, Hendricks concluded that they had been derived from the northwest.

STRATIGRAPHIC RELATIONS.—South of the Windingstair fault, in the central Ouachita Mountains, the stratigraphic relations of the Wesley are straightforward, but north of the fault there are some stratigraphic problems in connection with the Wesley and its correlatives. Where Harlton (1938) and Hendricks *et al.* (1947) have mapped the Wesley in the Round Prairie, Farris, and Tuskahoma synclines and adjoining areas, the Game Refuge sandstone is normally between the Wesley below and the Johns Valley shale above. The outcrop belt of the Game Refuge is ordinarily somewhat wider than that of the Wesley but the Game Refuge thins northward (and westward) and in the western part of the frontal Ouachitas the Wesley and Johns Valley have been mapped as being in contact.

In the fault block north and northwest of the Windingstair fault the Game Refuge sandstone thins rapidly and the width of its outcrop belt becomes less than that of the Wesley. The westward thinning is illustrated by Hendricks' map which shows the Game Refuge sandstone to be well developed in sec. 23, T. 1 N., R. 13 E., but thinning rapidly southwestward along the outcrop in secs. 22, 27 and 28 and disappearing altogether in sec. 33 to bring the Wesley and Johns Valley shales in contact. Farther to the northwest, adjacent to the Ti Valley fault, Harlton and Hendricks and his coworkers have mapped the Wesley in contact with the Johns Valley. An exception to this general rule is in the small fault block in which is located the type locality of the Wesley; both Harlton and Hendricks *et al.* have mapped the Atoka as resting unconformably upon the Wesley in this area.

North of the Ti Valley fault Hendricks *et al.* have employed a stratigraphic terminology that corresponds more to Arbuckle facies terminology than to that of the Ouachita facies. There are significant differences in the geology on opposite sides of the fault, the chief differences being that the Jackfork group is not recognized north of the fault and that in place of the Wesley and Johns Valley formations the Caney and Springer formations are mapped; the writer believes these differences are more apparent than real. The writer is convinced that the type Wesley represents a considerable part of the Caney shale and that the Springer formation of the frontal Ouachitas is partially equivalent to the Johns Valley (= upper Johns Valley of the central Ouachitas).

Ammonoid cephalopods have been reported to occur in many of the "siliceous masses" (Harlton, 1938, p. 889) and in some of the limonitic (sideritic) concretions of the Wesley formation (Hendricks, 1947, p. 34). According to Harlton the non-siliceous portions of the shale contain Foraminifera of which *Hyperammina, Cornuspira, Bigenerina, Haplophragmoides, Agathammina,* and *Sherbonites* are the most plentiful. Hendricks noted that conodonts and radiolarians are abundant (probably in the siliceous members); in places the radiolarians appear as spheres of clear silica approximately one millimeter in diameter.

Harlton (1938, p. 889) correlated the Wesley with the "Pennsylvanian Caney" (Goddard-Springer) and Hendricks (1947, correlation chart, p. 8) evidently intended to correlate it with the upper part of the Springer formation. Inasmuch as the basal portion of the Johns Valley shale has Mississippian Caney goniatites and typical Caney lithology (Cline, 1956c, p. 103), the Wesley shale of the central Ouachitas must be Late Mississippian in age.

Game Refuge Formation

DEFINITION.—Overlying the Wesley shale and underlying the Johns Valley shale is a persistent fossiliferous sandstone containing abundant fragments of crinoid columnals, brachiopods, bryozoans, and plant fragments. Harlton (1938) correlated this sandstone with the Union Valley sandstone (the "Cromwell" of the subsurface), which at its type locality east of Ada contains a goniatite fauna of earliest Morrowan age (Miller and Owen, 1944). Inasmuch as the lower portion of the overlying Johns Valley shale contains a Caney goniatite fauna of Late Mississippian age (Cline, 1956c, p. 103), this fossiliferous sandstone must be older than the type Union Valley. Recognizing the inappropriateness of the term Union Valley, Harlton (1959) recently substituted the name Game Refuge sandstone.

Harlton (1959) states that the best exposures of the formation known to him are along Campbell Creek* in sec. 2, T. 2 S., R. 12 E., in the Round Prairie syncline northeast of Atoka, but that the name Campbell Creek is preoccupied. He has chosen the name Game Refuge sandstone because it is available and because there are good outcrops in the State Game Refuge about 6 to 8 miles southwest of Clayton in Pushmataha County. There are good outcrops of the formation along the north side of Jerusalem Hollow in the SW¼ sec. 28 and the N½ sec. 32, T. 1 N., R. 18 E., where its relations to the Wesley and Johns Valley are quite clear.

Lithologic Character and Thickness.—The Game Refuge is predominantly sandstone, but it includes some intercalated gray shale. It contains some thin siliceous shale in the Kiamichi Range, the Boktukola syncline, and the Medicine Springs area. The sandstone has good topographic expression and produces good outcrops, lying as it does between the relatively weak Wesley and Johns Valley shales.

The Game Refuge is characterized by having zones of limonitic sandstone containing the plant *Calamites* and a fauna composed of external and internal molds of marine invertebrates. The invertebrate fossils were originally included in a quartzose sandstone as fragments of calcium carbonate but it seems that by the time diagenesis had been completed the calcium carbonate had largely been dissolved; some of the molds have since been filled with argillaceous material.

Ripple marks, including some interference ripples, and occasional small-scale cross-bedding are nearly as characteristic of the Game Refuge sandstone as the mold fauna. It seems significant that these sedimentary structures are not common in the Jackfork sandstones, whereas the flow casts, flute casts, and other bottom markings, so typical of the sandstones of the Jackfork group, have rarely been noted in the Game Refuge sandstone.

The formation is approximately 350 to 400 feet thick in the western Ouachitas, although it thins northward in the frontal Ouachitas and disappears altogether north of the Ti Valley fault. It is

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

about 500 feet thick in the Kiamichi Range and in the Boktukola syncline. It should be noted that, in their description of the Jackfork-Atoka strata of Kiamichi Mountain, Cline and Moretti (1956, p. 4, 5, 15) referred only 160 feet of sandstone to the Game Refuge ("Union Valley" of that report). Cline and Shelburne are now of the opinion that the following zones described in the Indian Service road stratigraphic section (plate II and Cline and Moretti, 1956) should also be included in the Game Refuge formation; zone 106, which was identified at that time as Johns Valley (?), and zones 107 and 108 which were included in the basal Atoka. In making the original correlation Cline and Moretti were strongly influenced by the opinion that the sandstones of zones 107 and 108 were the direct lateral equivalents of the fossiliferous sandstone in the Boktukola syncline from which Honess had obtained his "Morrow fauna." However, Shelburne has found that Honess' type "Morrow fauna" lies 800 feet above the Wesley shale and 300 feet above the Game Refuge sandstone in that area.

Because the invertebrate fossils are mostly molds it is difficult to pursue identification as far as species rank. Nonetheless, Harlton (1938, p. 893) has been able to identify the molluscs *Aviculopecten, Bellerophon, Gastrioceras,* and *Orthoceras* [more likely *Pseudorthoceras*], the brachiopod *Productus* [probably *Dictyoclostus*], and the trilobite *Griffithides.*

MISSISSIPPIAN-PENNSYLVANIAN TRANSITIONAL ROCKS

Johns Valley Shale

DEFINITION.—Lying stratigraphically above the Jackfork sandstone and below the Atoka formation in the central Ouachita Mountains is the Johns Valley shale. The formation name Johns Valley was introduced by Ulrich (1927, p. 21, 22) for outcrops in bowl-shaped Johns Valley in the trough of the Tuskahoma syncline, particularly in the north one-half of T. 1 S., R. 16 E. (fig. 23). In recent years there has been a tendency to overlook the fact that, although Taff's first mention of Caney shale was in his Coalgate folio (Taff, 1901), his type locality was in Johns Valley, which is precisely the same locality which Ulrich proposed for his type Johns Valley formation. The name was derived from Cane Creek (now Johns Creek) which drains a portion of the valley. Also, generally ignored is the fact that many of the fossils that were illustrated by Girty (1909) in United States Geological Survey Bulletin 377, *The fauna of the Caney shale of Oklahoma,* were collected from his localities 2075, 3983, 3984, and 3986 in secs. 2, 3, and 4, T. 1 S., R. 16 E., in Johns Valley.

It is now known that these collection localities are in the lower part of Taff's Caney shale, and that Taff intended that the name Caney should be applied to all of the shale between the Jackfork and Atoka in the central Ouachitas; Ulrich was well aware of this. Furthermore, all geologists acquainted with Girty's work on the Caney fauna have known that both Girty and Taff regarded the Caney fauna in Johns Valley as coming from rocks identical in age with the now better known Mississippian Caney shale of the Arbuckle facies to the west. Miser and Honess (1927, p. 11, 12, fig. 2) were firmly convinced that the Arbuckle Caney is of the same age as the shale containing the Caney fossils in Johns Valley. Ulrich acknowledged the contemporaneity of the fossils but he believed that the fossils in Johns Valley came from exotic or erratic boulders which had been ice-rafted into the enclosing shale. Inasmuch as Ulrich found what he believed were Wapanucka (Lower Pennsylvanian) fossils in a boulder-bearing portion of the Johns Valley shale, he concluded that all of the Johns Valley is Pennsylvanian in age and therefore younger than the Caney of the Arbuckle region We should note that Ulrich did not find Pennsylvanian exotic boulders in the Johns Valley at the type locality.

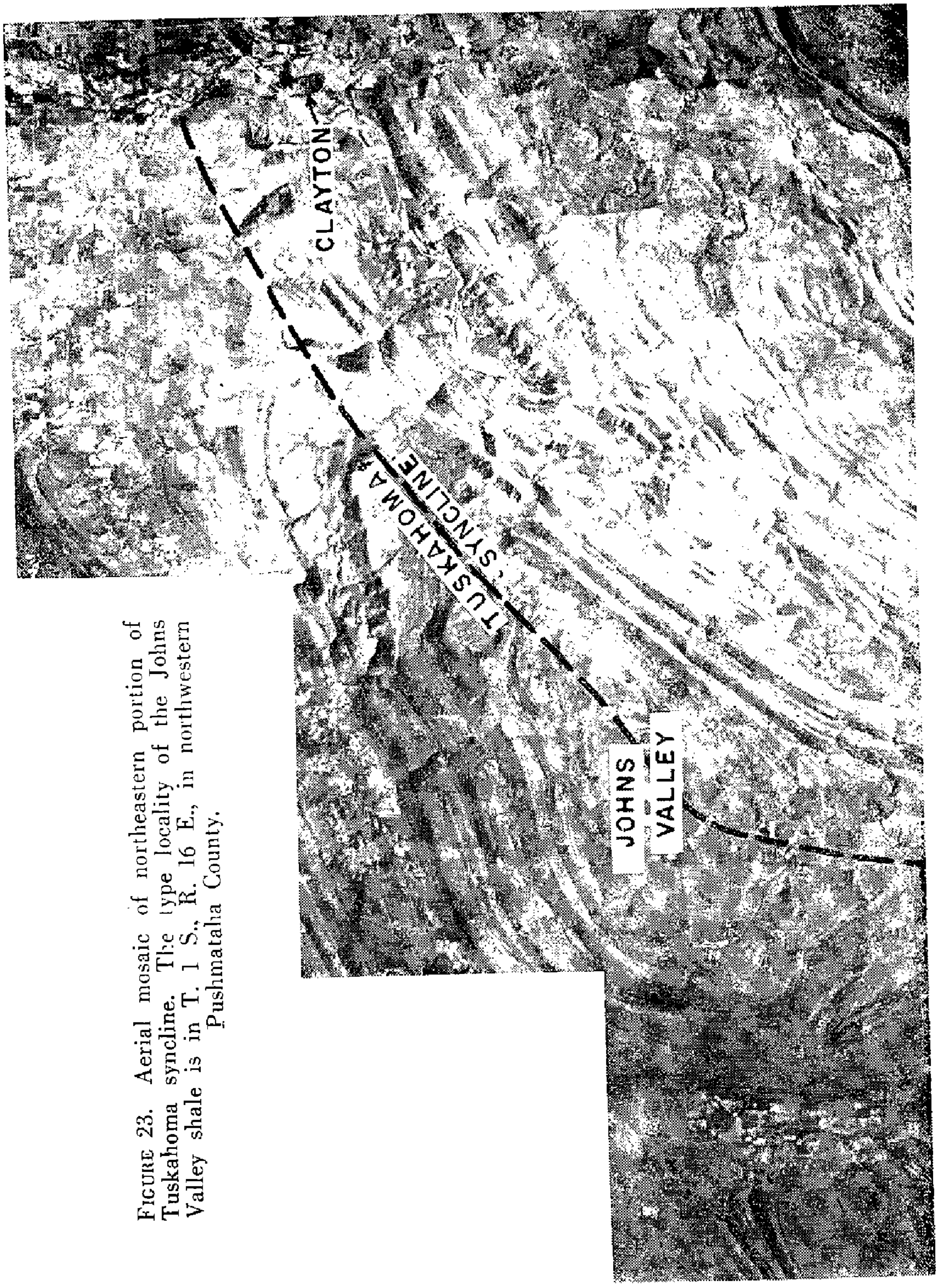

FIGURE 23. Aerial mosaic of northeastern portion of Tuskahoma syncline. The type locality of the Johns Valley shale is in T. 1 S., R. 16 E., in northwestern Pushmataha County.

The goniatite-pelecypod fauna that Girty described from the lower Caney is now generally regarded by paleontologists as Late Mississippian and as a fauna typical of a black shale facies. The upper, softer, lighter gray shale above the black Mississippian Caney in the Arbuckle facies has long been referred to as "Pennsylvanian Caney" by subsurface workers but more recently it has been named Goddard and the term seems to be coming into general use.

The presence of exotic limestone in the lower Caney in Johns Valley did not mislead Miser and Honess into correlating all of the "Ouachita Caney" with Pennsylvanian equivalents as it had misled Ulrich. Miser and Honess published diagrams (1927, fig. 2) showing two possible interpretations of the relationship of the Arbuckle to the Ouachita facies. Their diagrams are redrawn and reproduced as figures 24 and 25 in this paper. Regardless of which of their interpretations is the correct one, both diagrams show the Caney of the Arbuckles as having been physically continuous with the Caney of the Ouachitas at the time of deposition; both diagrams show the Caney of the Ouachitas as lying stratigraphically above the Jackfork. The author is convinced that Miser and Honess were correct in assigning the Caney of the Ouachitas a stratigraphic position above the Jackfork and he would like to see them given proper credit for being so discerning. Ulrich (1927) went to great lengths to convince the reader that the "Ouachita Caney" (Johns Valley shale) must be younger than Arbuckle Caney.

Because of uncertainties concerning the use of the terms Caney, Mississippian Caney, Pennsylvanian Caney, Ouachita Caney and Johns Valley, Harlton (1938, p. 896) proposed that the name Johns Valley be abandoned and that the name Round Prairie be adopted for the shale between the Jackfork and Atoka. Outcrops in the Round Prairie syncline northeast of Atoka, in the NE¼ NE¼ SE¼ sec. 2, T. 2 S., R. 12 E., were designated as the type locality. The following reasons for choosing Round Prairie over Johns Valley were given: (1) the poor exposures in Johns Valley, and (2) the chaotic mixture of the exotic boulders and the crumpled shale which precluded determination of the true character of the "normally deposited shales" in Johns Valley.

Subsequent workers, including Hendricks (1947), Hendricks *et al.* (1947), Rea (1947), Howell (1947), Cline (1956a, 1956b, 1956c), and Cline and Moretti (1956), have not followed Harlton in the use of the term Round Prairie, preferring instead the older term Johns Valley. If the law of priority were to be invoked, the name Johns Valley would be suppressed as a synonym of Caney (original usage), but in this case the name Johns Valley is so thoroughly established in the literature and so firmly entrenched in the minds of geologists working in the Ouachitas that the interests of geology are best served by the continued use of the name Johns Valley. Also, the name Caney is now generally understood to refer only to the lower, Mississippian portion, of Taff's original Caney.

Lithologic Character and Thickness.—In its characteristic development the Johns Valley formation includes from 425 to 900 feet of prevailingly shaly strata. The lower portion contains dark to black shales with typical Mississippian Caney lithology and fossils, whereas the upper portion contains considerable amounts of lighter gray clay shale with some thin interbedded sandstones, the lithology of which resembles that of the sandstones of the overlying Atoka. At the few localities where both contacts of the formation have been seen, there are zones in both the lower and upper portions of the shale in which limestone and chert exotics occur. The exotics include numerous rounded pieces ranging in size from pebbles to boulders, and less numerous angular blocks of limestone, some of which attain diameters of 40 feet or more. The boulder-bearing shales have been referred to by some geologists as the "lower boulder bed" and the "upper boulder bed." In reality, there are intervals in both the upper and lower portions of the Johns Valley in which exotics occur in several beds, some of which are shale beds separated by well-defined sandstone beds.

Johns Valley shale containing exotics is known to occur in a belt about 25 to 30 miles wide and about 125 miles long, extending from near Atoka, Oklahoma, in the western part of the frontal Ouachitas eastward to Boles, Arkansas. Hendricks, Gardner, and Knechtel did not map the Johns Valley north of the Ti Valley fault in the frontal Ouachitas but the author believes that it is almost certainly represented north of the fault by the Springer formation and by the upper part of their mapped Caney. The author recently found limestone exotics in secs. 31 and 32, T. 2 N., R. 14 E., in a belt mapped as Springer formation by Hendricks *el at.* (1947). The writer has not found boulder-bearing Johns Valley strata south of Hardy Creek in the Lynn Mountain syncline; however, farther south, in the Boktukola syncline, Shelburne (1959), on the basis of stratigraphic position, assigned the shales which lie above the Game Refuge sandstone to the Johns Valley shale.

Limestone exotics occur in the Johns Valley shale in Winding

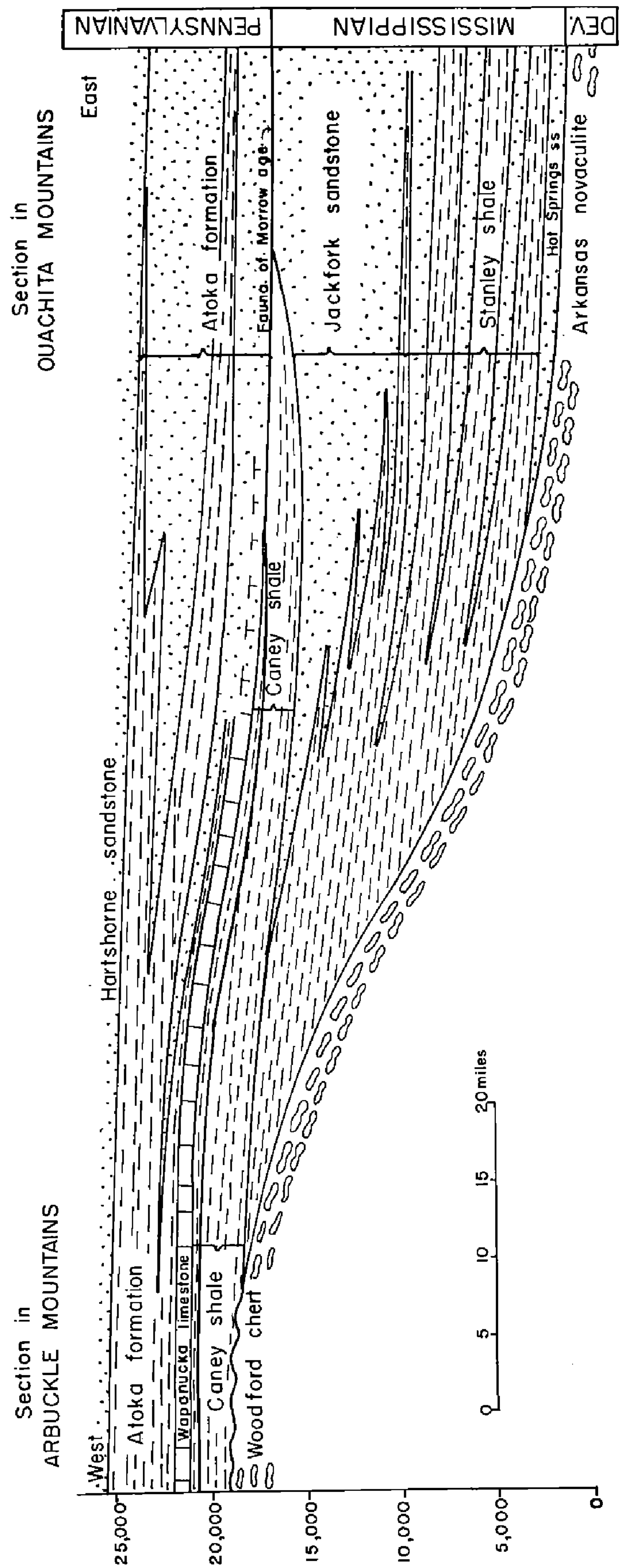

FIGURE 24. Section illustrating the hypothesis that the Caney progressively overlaps the Jackfork and Stanley groups toward the Arbuckle Mountains where it comes into contact with the Woodford chert.
(Redrawn from Miser and Honess, 1927)

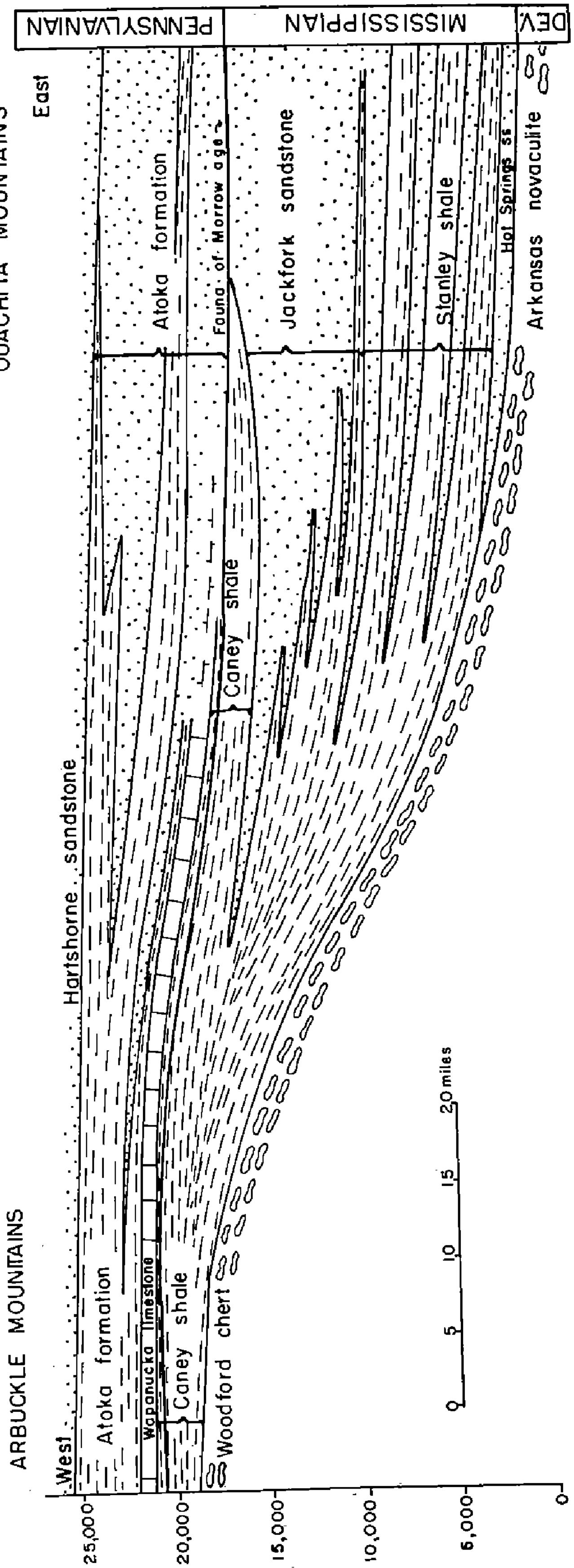

FIGURE 25. Section illustrating the hypothesis that the Caney contains beds of the same age as the Stanley and Jackfork formations.
(Redrawn from Miser and Honess, 1927)

Stair Mountain almost as far east as the state line. However, in the next ridge south, Kiamichi Mountain, the writer has been unable to find exotics east of Oklahoma State Highway 2, which crosses the range between Clayton and Nashoba Junction. Nonetheless, a well-developed strike valley, carved from soft shales which lie stratigraphically above the Game Refuge sandstone, can be traced eastward on aerial photographs. A ground check at several localities reveals that these shales have a stratigraphic position immediately above the Game Refuge sandstone, which in turn rests on easily recognized Wesley shale. Shale also occupies this same stratigraphic interval above the Game Refuge sandstone in the Boktukola syncline and the writer knows of no reason to call it anything other than Johns Valley, notwithstanding the lack of exotic boulders.

NOTEWORTHY JOHNS VALLEY OUTCROPS.—The characteristics and structural and stratigraphic relations of the Johns Valley shale are well displayed at a number of localities in the Ouachita Mountains. The six localities described below are the most suitable for a study of the formation.

Johns Valley.—Various aspects of the stratigraphy of the Johns Valley in its type area have been discussed by previous writers. The writer therefore will limit his observations to a few points which seem pertinent to this paper.

At the time Ulrich (1927) named the Johns Valley shale he stated that in the Johns Valley syncline it is underlain by the Jackfork sandstone and overlain by sandy shales of the Atoka formation. Fortunately he mentioned (p. 22) that the presence of Atoka in Johns Valley had been questioned by "recent investigators." Hendricks *et al.* (1947) did not map Atoka in Johns Valley, and the sandy shales occupying the trough of the syncline are labeled Springer and included in the upper Johns Valley by Harlton (1959, p. 134) on his map. On Harlton's map he has differentiated a wide belt of "bouldery shale" (figs. 26, 27) lying stratigraphically above the Game Refuge sandstone (uppermost Jackfork), a much thinner band of "Caney-Goddard" lying inside the bouldery shale, and an oval area of "Springer" inside this, occupying the deepest part of the Tuskahoma syncline. Although the observed dips in the inner oval area range from 20 degrees to vertical, according to Harlton, and locally are overturned, the writer believes that it is safe to say that almost the complete thickness of the Johns Valley shale is represented in its type locality. It seems like a stroke of fate that erosion

FIGURE 26. Exotic block of Silurian limestone embedded in Johns Valley shale at type locality.

should have stripped off all of the Atoka formation and possibly a small amount of the upper Johns Valley shale, but that seems to be the case. Recently discovered outcrops across the Kiamichi River, only a few miles to the east, reveal the Johns Valley shale between the Atoka formation and the Game Refuge sandstone in such simple structural relations as to leave no doubt as to its true stratigraphic position beneath the Atoka.

Farris syncline.—The Johns Valley crops out in two continuous belts on opposite sides of the Farris syncline several miles southwest

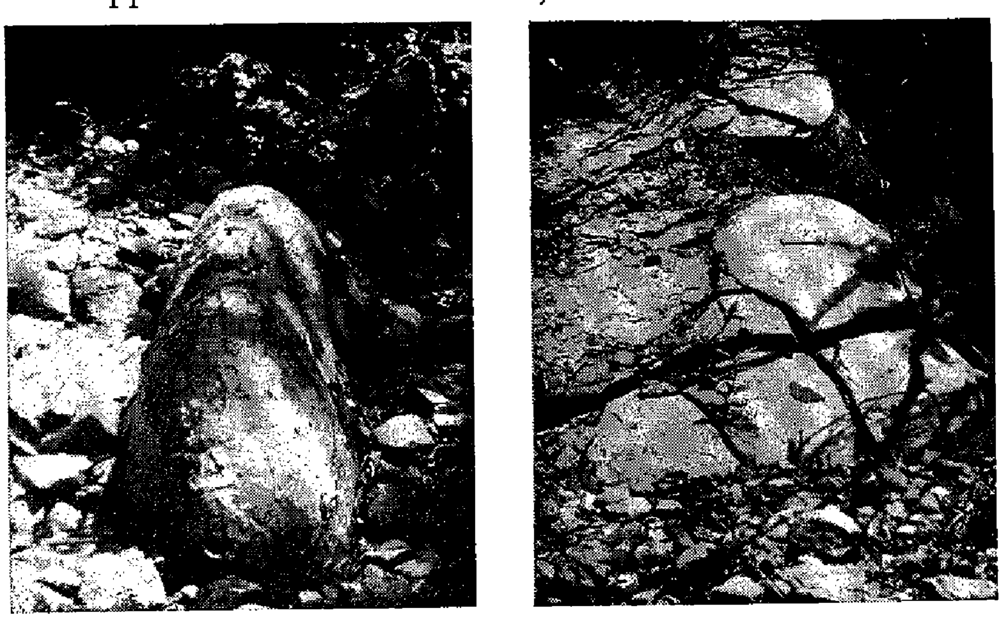

FIGURE 27. Typical dark blue-black limestone concretions interbedded with black shale of Caney lithology which is a part of the Johns Valley formation. Location is at the type section of the Johns Valley shale.

of the type locality of the Johns Valley. An interesting boulder-bearing shale outcrop, which is easily reached by automobile, lies east of the road and not far from the center of sec. 22, T. 2 S., R. 14 E., the locality being about one mile due east of the type locality of the Markham Mill formation. The stratigraphic relations of the Johns Valley shale to the Game Refuge and the Atoka formations are easily determined. There is a gentle dip-slope developed on the upper surface of the fossiliferous Game Refuge sandstone, and sandstones in the lower part of the Atoka formation form a low cuesta on the opposite side of the strike valley developed in the Johns Valley shale. Limestone exotics ranging in size from pebbles to boulders, and a few large blocks, are abundant in the dark shale matrix. Two large blocks of Ordovician limestone are shown in figure 28.

Round Prairie syncline.—The Johns Valley shale forms an almost continuous outcrop belt around Round Prairie in the inner portion of the Round Prairie syncline northeast of Atoka, being interrupted only on the south side by faulting. In 1938, when Harlton proposed to substitute the name Round Prairie for Johns Valley, he designated outcrops in the NE¼ NE¼ SE¼ sec. 2, T. 2 S., R. 12 E., as the type locality for his new formation. He recognized a lower boulder-bearing shale separated from an upper bouldery shale by two or three beds of fossiliferous sandstone. A black siliceous shale was said to mark the top of the formation. The aggregate thickness of the various members of the Johns Valley is about 800 feet in Round Prairie. Both Harlton and Hendricks *et al.* mapped the Atoka formation in the center of the Round Prairie syncline. Round Prairie is accessible by automobile by a road from Atoka which enters from the south and by another road entering from the north which is reached from Stringtown.

Hairpin Curve.—The most publicized of the Johns Valley localities is the Hairpin Curve exposure along Oklahoma State Highway 2, about midway between Clayton and Wilburton, in the south part of sec. 3, T. 3 N., R. 19 E. The locality has been visited by many geologists including those in attendance during the 1947 Tulsa Geological Society Field Conference in the Ouachita Mountains. Hendricks and Averitt published an excellent description of the Johns Valley in this exposure and reproduced two photographs of the boulder beds in the guidebook (p. 32-34). In referring to the Hairpin Curve section, Cline (1956c, p. 104) stated that "the exposures of the lower and upper Johns Valley appear to be on opposite sides

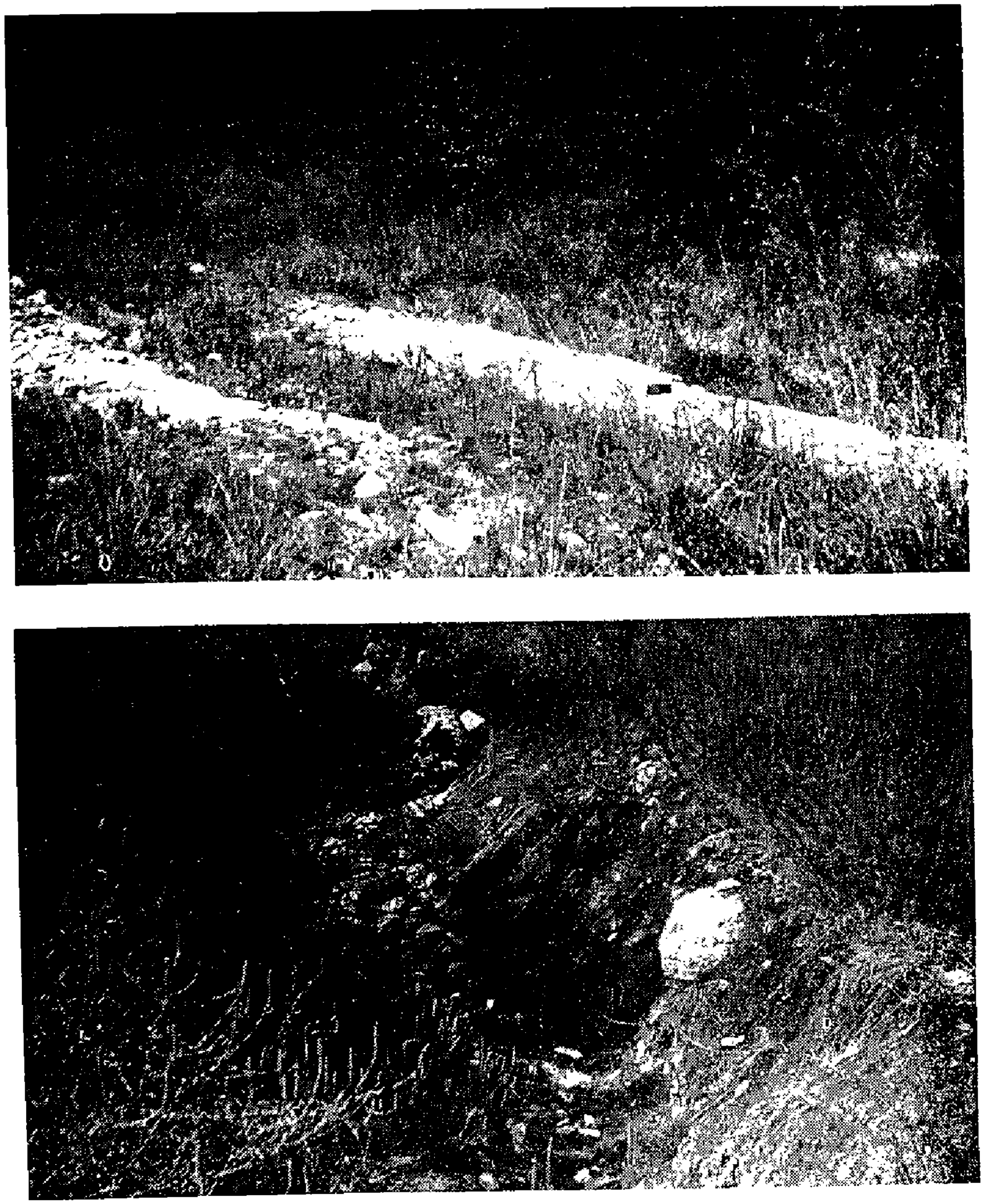

FIGURE 28. Limestone exotics in Johns Valley shale near the center of sec. 22, T. 2 N., R. 14 E., in the Farris syncline. Upper photograph shows large blocks of Ordovician limestone. Lower photograph shows boulders and cobbles of limestone embedded in soft dark gray shale.

of an anticline." In commenting on the structure at this same locality, Misch and Oles (1957, p. 1903) state that the Johns Valley shale outcrops are in an "unbroken anticline which is succeeded on the north and on the south by unbroken synclines." More recently the author has restudied the Hairpin Curve locality in greater detail than before and has found that the beds in the lower Johns Valley, which are exposed south and southeast of the sharp curve, are overturned. Near the top of the artificial cut, south of the curve, there are some sandstone beds that are nearly horizontal and a superficial examination would lead one to suppose that they are in their normal depositional position. Closer study reveals that load casts, flute casts, groove casts, and other sedimentary structures characteristic of the under surfaces of sandstones are present on the upper surfaces of the sandstone as they are now exposed; thus, the stratigraphic sequence is upside down. Confirmation that the beds south of the curve have been overturned by folding (probably accompanied by faulting) is found in a close study of the contacts of some of the sandstone and shale beds; in a normal depositional sequence the contact of a sandstone bed with the underlying shale is sharper than the contact with the overlying shale, which contact has a tendency to be somewhat gradational. As the rocks south of the curve are overturned, the structure is not that of a simple anticline as the writer formerly thought, and as Misch and Oles recently stated, but it is probably faulted in much the way that Hendricks mapped it. How much of the lower part of the Johns Valley is cut out by faulting we do not know, but probably the 200 feet of section shown as covered in the Hendricks-Averitt measured section (their zone 26) approximates the amount of missing strata. Cline and Laudon (Dallas Geol. Soc., 1959b) redescribed the section in some detail. The strata are somewhat better exposed now than at the time Hendricks and Averitt described the section and, of course, we now interpret the south part of the exposure as being overturned.

Description of lower part of Johns Valley shale exposed south and southeast of the Hairpin Curve. Note that strata are overturned and that zone 1 is at the top of the cutbank. Described by L. M. Cline and Richard Laudon (Dallas Geol. Soc., 1959b, p. 40).

	Thickness in feet
Top	
Johns Valley shale	
5. Shale; typical Mississippian Caney shale; black, laminated, includes several zones of siltstone that weather light gray; many rounded phosphatic concretions the size and shape of marbles, some contain goniatites including *Lyrogoniatites.* Exposed to road level	27
4. Shale; dark blue-gray, platy, with some zones of lighter colored clay-shale; includes some lenticular beds of clay ironstone and rolled masses of hard, fine-grained sandstone which show convolute bedding. Limestone erratics are embedded in some of the gray clay-shale. Some small drag folds	59
3. Shale and siltstone; interlaminated dark gray shale and brown-weathering siltstone with shale predominating; contains some clay-ironstone concretions	15
2. Shale; jumbled appearance; alternating gray shale and brown silty shale including some beds of hard fine-grained sandstone as thick as 6 inches. Upper surfaces of sandstones	

have meandering animal trails, the lower surfaces have prominent load casts. Lenses of conglomeratic sandstone. Rolled sandstone masses prominent. Many features of turbidity flow deposition. Beds dip 34 degrees southeastward into the hill; note that dips become successively lower in the cut; actually, the lower dips have the greatest structural disturbance because the entire section is overturned 16

Game Refuge sandstone

1. Sandstone; only the top 5 feet described. In beds from 2 inches to 3 feet thick; medium-grained to fine-grained, weathers light gray with iron-stained surfaces; contains crinoid columnals and other fragmentary fossils. Sandstone has well-developed convolute bedding; torose load casts on under surfaces. Beds are overturned but nearly flat 5

A traverse eastward along the highway substantiates the contention that the beds south of the curve are overturned. It also establishes the fact that these rocks represent the lowermost strata in the Johns Valley; the Game Refuge sandstone, also overturned nearest the curve but gradually returning to its normal structural position as it is traced eastward, underlies the Johns Valley shale and, in turn, is underlain by the Wesley shale at the place where the road curves southward.

The overturned section south of the Hairpin Curve contains some interbedded strata with typical black shale Caney lithology and with phosphatic concretions containing goniatites of Late Mississippian age, among which are *Goniatites choctawensis* and *Lyrogoniatites* (fig. 29). This tongue of Caney shale is in its proper stratigraphic position above the Game Refuge sandstone and does not represent a fault slice brought up by the fault which is present in the stream valley immediately north.

These beds with Caney lithology and Caney fossils also contain numerous exotic boulders and pebbles of limestone which were dropped into the shale at the time when it was mud. They are not tectonic boulders or part of a friction carpet. Precisely this same lithology is characteristic of the lower Johns Valley in outcrops in the State Game Refuge southwest of Clayton where the formation is found in continuous outcrops between the Game Refuge and Atoka sandstones and under such simple structural conditions as to leave no doubt that the lower Johns Valley includes beds of Mississippian Caney age and lithology.

North of the Hairpin Curve the upper Johns Valley shale occurs in its normal position and dips northward beneath the Atoka sandstone. The basal part of the exposed section of Johns Valley is composed of alternating shales, siltstones, and sandstones. Exotics have

FIGURE 29. Lower part of Johns Valley shale exposed on south side of Hairpin Curve, sec. 3, T. 3 N., R. 19 E., in cutbank along Oklahoma State Highway 2. The black shale is a tongue of Caney and contains typical rounded marble-like phosphatic concretions, some of which contain fossils. Beds are overturned and dip 35 degrees to left (south).

not been observed. Upward in the section there are scattered pebbles of limestone exotics in the shales sandwiched in between well-bedded sandstones. In the upper part of the section there is a striking concentration of limestone boulders, blocks, and cobbles and it rests in a channel which clearly bevels about 11½ feet of the underlying strata (figs. 30, 31, 32). There is a noticeable decrease

FIGURE 30. Johns Valley shale exposed beneath Atoka sandstone in road cut along Oklahoma State Highway 2 on the north side of Hairpin Curve, sec. 3, T. 3 N., R. 19 E., Latimer County. Boulder-bearing shale on left in front of automobile; north-dipping Atoka sandstones on right near curve.

FIGURE 31. Detail of Johns Valley shale shown in figure 30. Boulder-bearing shale rests in channel cut through shales and sandstones in upper part of Johns Valley group; possibly cut by mud flow or turbidity current which deposited the boulder beds.

in the size of the exotics upward in this deposit, the overall effect being not unlike that of graded bedding, but it is of course on a somewhat larger scale than the usual examples. The exotics in the lower part of the channel fill include well-rounded boulders with diameters in excess of a foot and slightly rounded blocks of similar dimensions, the whole being embedded in a clay-shale matrix. Upward the boulders give way to cobbles and they in turn give way to

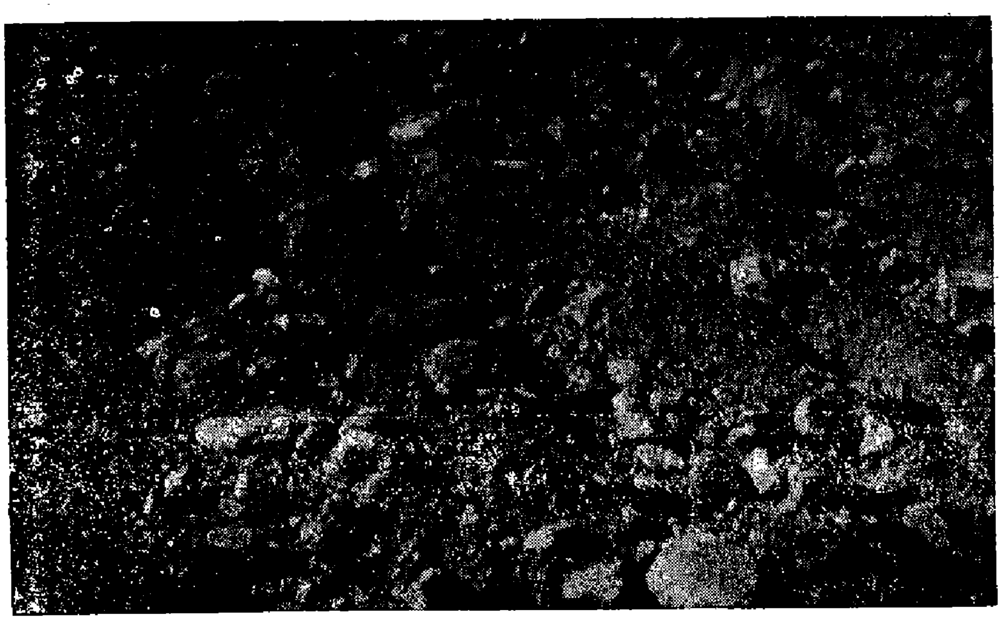

FIGURE 32. Detail of upper part of channel fill shown in figure 31. Limestone pebbles and cobbles are embedded in a clay-shale matrix in which the bedding has been obliterated. Observe that few pebbles are in contact with others.

pebbles which are so widely separated in the gray clay-shale matrix as to give the effect of plums in a pudding. Throughout this deposit there are rounded masses of a hard, brownish quartzitic sandstone. The writer interprets this particular "boulder bed" to be the product of a single submarine slide or turbidity flow. The flow initially attained a high velocity during which phase it was able to transport boulders and to scour previously deposited muds and sands. As the peak of the flow was reached and the velocity trailed off, pebbles began to drop out and were deposited with the muds of the flow and those obtained from the reworked bottom. The sandstone masses represent lenses of sand torn from the bottom and rolled along the flow. Some geologists have interpreted these rounded sandstone masses here and at other localities as "tectonic boulders" in the friction carpet of an advancing thrust sheet. The writer does not agree with this interpretation.

Description of strata exposed along Oklahoma State Highway 2, about midway between Wilburton and Clayton, in the south part of sec. 3, T. 3 N., R. 19 E., Latimer County, Oklahoma (Dallas Geol. Soc., 1959b, p. 35). Exposures in west-side cutbanks of road beginning near concrete culvert and continuing downward to covered interval. Described by L. M. Cline and Richard Laudon. August, 1958.

Top		*Thickness in feet*
Atoka formation		
23.	Shale and sandstone; dark blue-gray laminated shale comprising 60 to 65 percent of unit; interbedded sandstone in beds as thick as 6 feet. Flute casts abundant on lower surfaces of sandstones. Shale units as thick as 20 feet. Exposed below culvert	135
	About the same thickness of Atoka is exposed above culvert.	
22.	Sandstone; hard, convolute bedding near top; casts of reed-like plants on base of bed, one being nearly 5 feet long, of uniform thickness, and with longitudinal ribs	3.5
21.	Shale; medium-gray, laminated, silty	8.5
20.	Shale; gray, lower 2 feet dark-gray to black, may be siliceous	3.5
19.	Shale; medium-gray, laminated silty	3
18.	Sandstone; hard, laminated but weathers massive	0.3
17.	Shale with thin beds of sandstone; dark-gray, almost black, upper 2 feet siliceous; 4 sandstone beds in interval, each averaging only 3 inches but with prominent load and flute casts on undersurfaces; beds slightly overturned	7
16.	Shale; dark-gray to black, thin-bedded, some clay-ironstone concretions	10
15.	Sandstone; beds as thick as 3 feet; cut by small fault on north; convolute bedding and bottom markings abundant	47
Johns Valley formation		
14.	Shale; dark-gray, fissile	6
13.	Shale; poorly bedded, includes rolled sandstone masses; poorly exposed	12
12.	Sandstone; includes beds as thick as 3 feet; some shale	10.5
11.	Shale; gray	2.5

10.	Sandstone; massive, contains a sandstone mold and cast fauna of marine invertebrates; stained brown	2
9.	Sandstone; in beds 4 to 5 feet thick	19
8.	Shale; gray, thin-bedded, weathers buff	5
7.	Sandstone and shale; sandstone predominating, weathers light-gray, in massive beds the thickness of which is about 2 feet; shale, dark blue-gray, finely laminated. Some sandstone beds have flute casts and intricate convolute bedding	38
6.	Clay shale; with pebbles and cobbles of limestone exotics and masses of rolled sandstone; may be a repetition of upper part of zone 4	16
5.	Infolded sandstone and shale in small drag fold; in fault contact with underlying shale; probably belongs higher stratigraphically	32
4.	Clay shale with included limestone boulders; the lower 11.5 feet occupies a channel cut into the underlying zone 3; limestone exotics are so thick that it resembles a coarse conglomerate; some of the boulders have diameters up to 2 feet. The upper half of the zone is a drab-weathering claystone which includes large masses of rolled sandstone of depositional origin; it also contains smaller limestone exotics	45
3.	Sandstone and sandy shale; sandstone predominating, in beds as thick as 3 feet but averaging only 4 inches in upper portion; interbedded and laminated shale contains occasional limestone exotics. Abundant animal trails on upper surfaces of sandstones; a thin conglomerate 6 feet below the top	23
2.	Shale; dark blue-gray, laminated, weathers into small plates and chips; beginning 17 feet above the base numerous limestone exotics averaging 3 to 4 inches in diameter (but up to 1 foot); they appear to have undergone some weathering prior to deposition in the shale. Some thin beds of fine-grained sandstone show numerous animal trails on upper surfaces and irregular load casts on under surfaces. One massive sandstone bed 4 feet below top. Some clay-ironstone concretions in shales. Upper 4 feet of shale contains abundant exotics and is well bedded	31
1.	Shale; gray, silty; weathers drab; about 35 percent of interval composed of thin-bedded siltstone with sandstone beds up to 2 feet thick. Sandstone beds show convolute bedding and flute casts	36

Lynn Mountain syncline.—Persistent search has revealed two belts of Johns Valley shale cropping out in the Lynn Mountain syncline between Clayton and Antlers. One of the belts is 20 miles long and contains excellent outcrops of the Johns Valley under such simple structural conditions as to leave no doubt that it is part of a depositional sequence that includes the Wesley shale and Game Refuge sandstone below and the Atoka sandstone above. Equally important is the fact that black shale with typical Mississippian Caney lithology and typical Caney pelecypods and goniatites constitutes the lower part of the Johns Valley shale, a point that can be checked at numerous localities. Because these outcrops have a key role in the interpretation of Ouachita stratigraphy, the author has given

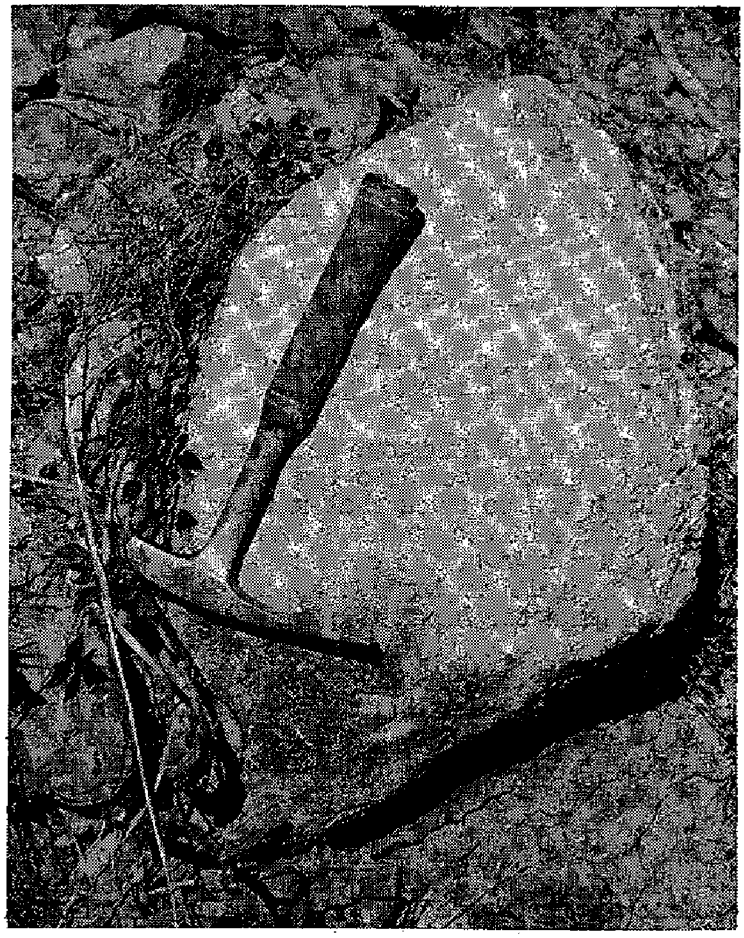

FIGURE 33. Boulder of McLish limestone in upper portion of Johns Valley shale exposed in west cutbank of Oklahoma State Highway 2 at a locality just north of Hardy Creek and north of Nashoba Junction.

them considerable attention in mapping the western part of the Lynn Mountain syncline (plate I).

The more accessible of the two outcrop belts is crossed by Oklahoma Highway 2 a few miles south of Clayton, just north of Hardy Creek and about 1½ miles north of Nashoba Junction. The Game Refuge sandstone forms the crest of an asymmetrical anticline immediately north of the creek and north of this sandstone the Johns Valley shale is exposed intermittently in ditches and cutbanks along the highway for about a quarter of a mile. Exotics are not numerous in the Johns Valley shale at this locality but a few limestone cobbles and pebbles and at least one boulder (fig. 33) of undisputed Arbuckle facies have been discovered by careful search. Rolled sandstone masses are common, some of them attaining diameters of several feet (fig. 34). This locality is noteworthy in being the southeasternmost known outcrop of boulder-bearing Johns Valley shale, although it is not the easternmost nor the southernmost occurrence.

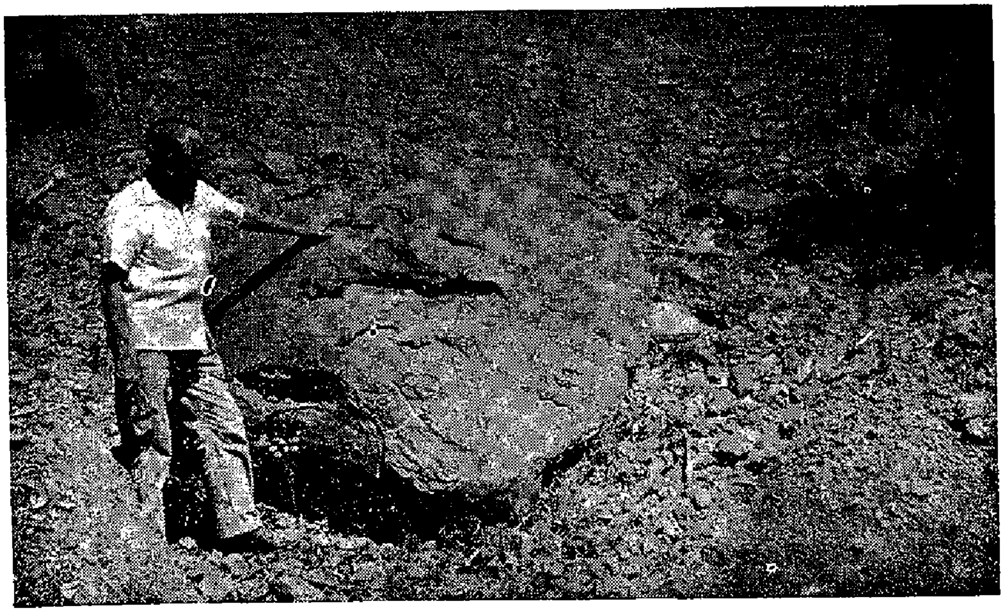

FIGURE 34. Rolled sandstone mass in lower part of Johns Valley shale in cutbank on Oklahoma State Highway 2 north of Hardy Creek between Clayton and Nashoba Junction. Dr. M. K. Elias is standing alongside.

Measured from the northwestern margin of the Stanley-Jackfork-Johns Valley depositional trough, this locality is farther out in the trough and farther from the presumed source of exotics than any other known occurrence of the boulder-bearing beds.

The best and most continuous exposures of the Johns Valley shale known at present lie in the other belt in the Lynn Mountain syncline, in the hills south and southeast of the Kiamichi River, between Clayton and Kosoma. It is most unfortunate that the three most instructive outcrop areas in this belt are comparatively inaccessible.

One interested in studying the Johns Valley shale in the Lynn Mountain syncline should first see the outcrops in the State Game Refuge southwest of Clayton and southeast of Stanley. Permission to enter should first be obtained from Conservation Headquarters in the preserve and, once this is obtained, it is possible to drive fairly close to the outcrops in a jeep or logging truck.

The steep valley wall along the south side of Jerusalem Hollow is capped by Atoka sandstones and shales dipping southeastward into the Lynn Mountain syncline at about 40 degrees. Numerous northwest-trending gullies and ravines tributary to Jerusalem Creek expose various portions of the Johns Valley shale. The writer is certain that a composite section showing the complete thickness of the formation could be pieced together by studying outcrops beginning in the SW¼ sec. 28, T. 1 N., R. 18 E., and continuing southwestward across the NW cor. sec. 33, diagonally across sec. 32, and through the south part of sec. 31 (fig. 35). The Game Refuge sandstone is well exposed in the opposite wall of the valley, the dips being about 40 degrees and the strike the same as that of the Atoka. The most significant feature of this series of outcrops is that black laminated shale containing marble-size phosphatic concretions and large black limestone concretions consistently forms the lower 200 feet (estimated) of the Johns Valley shale. The dark, dense, sideritic limestone septaria enclose numerous well-preserved *Goniatites choctawensis* and *Caneyella* and less numerous *Rayonnoceras*. The

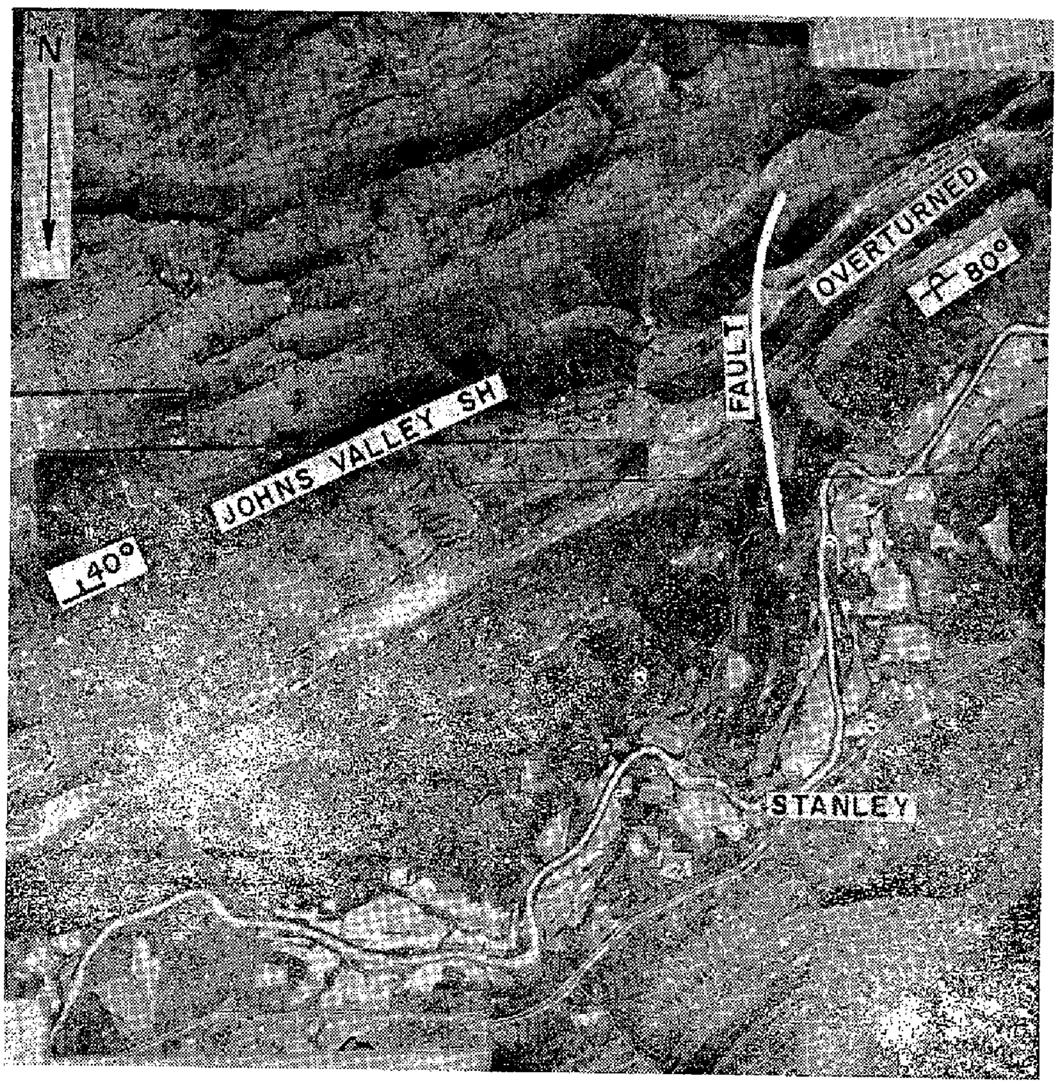

FIGURE 35. Aerial mosaic of area south and southeast of Stanley. Top of photograph is purposely oriented to south. The area southeast of Stanley and southeast of the Kiamichi River contains a normal depositional sequence of Jackfork, Johns Valley and Atoka, all dipping southeast into the Lynn Mountain syncline. In the block west of the tear fault the strata are overturned to the southeast, in opposition to the northwest movement which is prevalent in this part of the Ouachitas.

black shale in which they are embedded also contains numerous specimens of *Caneyella* flattened parallel to bedding and some of the harder more siliceous layers contain conodonts. The fauna is a typical Caney fauna and offers irrefutable evidence of the Late Mississippian age of the lower portion of the Johns Valley shale and evidence for a Mississippian age for the thick underlying Stanley-Jackfork succession, inasmuch as the upper part of the Arkansas novaculite, which underlies the Stanley, has been judged to be Mississippian on the basis of its conodonts (Hass, 1956). It is also noteworthy that there are limestone exotics enclosed in this Caney portion of the lower Johns Valley shale in these outcrops. By no stretch of the imagination can these exotics be construed to be part of a friction carpet of an advancing thrust sheet; they are as much a part of the lower Johns Valley as the black shale that contains them.

The second instructive series of outcrops in this belt lies southwest of the Jerusalem Hollow outcrops and is offset from them by a dip fault at a point almost due south of Stanley (fig. 35). Where Jerusalem Creek intersects this fault it makes an abrupt turn and flows north, following the strike of the fault. The fault is a tear fault bounding the northeast side of an overturned block which begins south of Stanley and continues southwestward to a position opposite Kosoma, an outcrop distance of about 14 miles. Throughout this distance the Jackfork sandstone and Johns Valley shale are overturned to the southeast, a direction opposed to the principal direction of movement which has been attributed to the major thrust faults in the central and frontal Ouachitas.

The first good outcrops of Johns Valley shale southwest of the tear fault lie in a strike valley excavated by the headwaters of Beuhler Creek. The outcrops are reached by fording the Kiamichi River at a point about midway between Stanley and Dunbar and following Beuhler Creek upstream to the place where it branches into two tributaries whose directions of flow are at right angles to that of the main stream. The traverse up the main stream reveals excellent exposures of the formations of the Jackfork group, each overturned and dipping northwest, the dips averaging approximately 80 degrees. The Johns Valley has the same dip and strike but it is in fault contact with the Atoka sandstone, which dips southeast at approximately 25 degrees. This strike fault merges with the tear fault at the northeast end of the block. The total horizontal movement southeastward along the fault can hardly be more than a few hundred feet; the abrupt change from the overturned beds in the Johns Valley shale to the gentle southeast dips of the Atoka formation into the Lynn Mountain syncline was accomplished principally by adjustments in the incompetent shales in the upper part of the Johns Valley shale and the lower part of the Atoka formation. The belt of Johns Valley shale strikes southwestward across the SW¼ sec. 1 and the W½ sec. 12, T. 1 S., R. 17 E. The lower part of the formation exhibits Caney lithology, including the laminated black shale containing the small marble-size phosphatic concretions and the larger limestone septaria with the Caney goniatites (fig. 36). The black shale contains numerous limestone exotics, some of which are very large; one exotic block of Ordovician limestone has a length of about 40 feet. These outcrops are instructive because the bedding planes of the laminated black shale pass over and under the exotics, demonstrating conclusively that the exotics were incorporated into the black shale at the time it was deposited (fig. 36). Large pieces of a limestone conglomerate may have been emplaced by a submarine slide. Some of the angular pieces of limestone have a lithology not unlike that of the Caney concretions and some resemble the Sycamore limestone, a feature suggesting that these shelf limestones were debouched into a black-mud environment, possibly by sliding down a slope lubricated by the accumulating muds.

Another interesting series of Johns Valley exposures lies in a strike valley in the east-central part of sec. 32 and the adjacent NW¼ sec. 33, T. 1 S., R. 17 E. The area, about 2½ miles due east of Eubanks and 3 miles southeast of Dunbar, may be reached by fording the Kiamichi River south of Dunbar and walking about 1½ miles up the canyon of a northwest-flowing stream. This traverse crosses all of the Jackfork formations, all of which are overturned to the east-southeast and dip west-northwest about 75 to 80 degrees. Just east of the watergap which cuts through the Game Refuge sandstone, the stream branches, each branch following a strike valley carved from the Johns Valley shale. The south fork has numerous exposures of laminated black Caney shale containing dark limestone concretions bearing *Goniatites choctawensis* and *Caneyella*. There are numerous limestone exotics completely enclosed by the bedding planes of the black shale. A most interesting feature is the inclusion of some large blocks of a limestone conglomerate which the writer believes may have been emplaced as a submarine slide. The bedding planes of the shale parallel the strike of

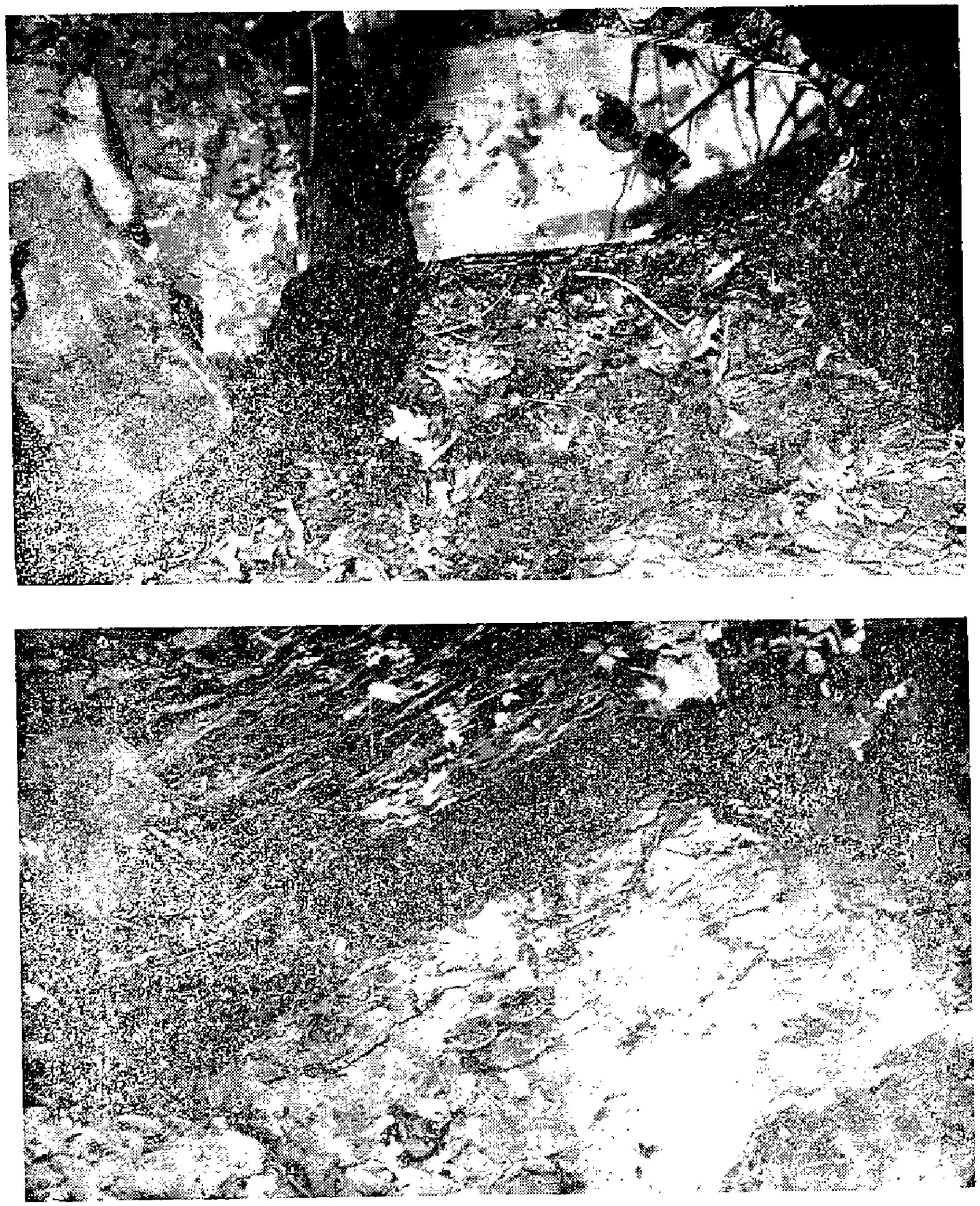

FIGURE 36. Johns Valley shale exposed in the NW¼ NE¼ sec. 12, T. 1 S., R. 17 E., in a tributary of Beuhler Creek. The top photograph shows a limestone concretion in typical black laminated Caney shale; the concretion contains Mississippian goniatites and the black shale contains *Caneyella*. The lower photograph shows the bedding planes of the black shale passing over an exotic block of limestone conglomerate. The Caney shale is in place and is a tongue which extends into the Johns Valley shale.

the underlying Game Refuge sandstone but locally the shales are badly crumpled, as one might expect in incompetent shales lying between competent sandstones in a slightly overturned section.

Boktukola syncline.—In the Boktukola syncline from 500 to 700 feet of strata have been mapped as Johns Valley by Shelburne (1959). The formation is conformable with the underlying Game Refuge sandstone and gradational with the overlying friable sandstones and gray silty shales of the Atoka formation. The Johns Valley lithology is similar to that in the Lynn Mountain syncline to the north, but limestone exotics have not been found notwithstanding a careful search for them. Rounded sandstone masses, ranging in diameter from three inches to six feet, depending on the thickness of the parent bed, are characteristic of the formation.

It is noteworthy that the fossiliferous beds from which Honess (1924, p. 23) obtained his "Morrow fauna" lie within the Johns Valley formation and about 330 feet above the top of the Game Refuge sandstone. This particular fossiliferous zone cannot be traced outside of sec. 6, T. 1 S., R. 23 E. Other occurrences cited by Honess, and presumed by him to be the same bed, range as low stratigraphically as the Markham Mill formation and as high as the lower part of the Atoka formation.

Origin of Exotic Boulders and Blocks.—The method by which the limestone exotics were emplaced in the Johns Valley shale has intrigued all geologists who have mapped in the Ouachitas. There is an extensive literature dealing with the subject, but not all of the problems have been solved. The only point on which there is general agreement is that the exotics are Arbuckle and/or Ozark types and that they must have been derived from the south, southwest, west, north, or northeast, or possibly from more than one of these directions. However, the view has also been expressed that the Ouachita facies is allochthonous and that it overlies an autochthonous Arbuckle facies from which the boulders were derived by faulting.

Tectonic emplacement.—Pointing to the large size of the Caney exotics in the Johns Valley shale in Johns Valley, at the Hairpin Curve, and in Cooper Hollow, it has been held by some geologists that they are fault slices brought up from an underlying Arbuckle facies. Enthusiasts for long-distance low-angle overthrusting have been intrigued with this idea. The exotics have been visualized by some workers as having constituted part of a friction carpet at the base of an advancing thrust sheet.

When the writer began his studies in the Ouachitas he visited Johns Valley and most of the other outcrops of the Johns Valley shale cited in the literature. His first, and lasting, impression was, and is, that the Johns Valley shale occupies a constant stratigraphic position between the Jackfork and Atoka groups. It seems odd that tectonic boulders brought up by thrusting should invariably come to rest in the same stratigraphic horizon. Howell (1947) has pointed out that the weak Johns Valley shale is a natural place for faulting to develop and that the [greasy] shales offered a lubricant for such thrusts. There are other thick and persistent shales stratigraphically lower in the Stanley and Jackfork groups. Why have the limestone exotics ordinarily bypassed these lower shales on their way to a higher plane? Along the Boktukola and Octavia faults, and the other major thrusts in the central Ouachitas, the relatively competent Jackfork sandstones are in fault contact with the thick, soft, incompetent Stanley shales. If the Johns Valley exotics are part of a friction carpet, why have not the Stanley shales stopped some of the exotics in these shear zones? Such faults surely must have served as feeders to supply the tectonic boulders of the Johns Valley shale, if indeed they are tectonic.

The writer is convinced that the supposed Caney fault slices at the Hairpin Curve and Cooper Hollow localities are a part of the normal stratigraphic succession. It is true that faulting has disturbed the beds at both localities but one familiar with the details of the stratigraphic sequence can work out the structural details.

Concurrent deposition.—In 1947 Rea (p. 47-49) stated the belief that the Johns Valley lies conformably between the Jackfork and Atoka sandstones in all of the localities in the western Ouachitas where it has been observed. From the beginning of his Ouachita studies the writer has worked on the assumption that the Johns Valley shale has constant stratigraphic position. Using aerial photographs he has traced belts of Johns Valley shale from known occurrences. Subsequent ground checks have revealed many previously unknown outcrops of the shale, some of them containing limestone exotics. In recognizing an upper and a lower boulder-bearing zone within the Johns Valley shale, Harlton (1938) expressed his faith in their having constant stratigraphic position and in their horizontal continuity. The writer has observed the Johns Valley shale at many localities (e.g., Hairpin Curve and Beuhler Creek) where the bedding planes of the shale pass over and under exotic boulders without evidence of structural disturbance. There is no doubt in his mind that the boulders were emplaced in the Johns Valley shale at the time the containing shales were being deposited. How they were transported to their depositional sites is not so apparent.

Ice rafting.—Ulrich (1927, p. 34-36, 44) put forth the theory that the exotics in the Johns Valley were transported to their depositional sites by ice floes derived from shore ice. Other writers sharing this view were Powers (1928, p. 1046), and Rea (1947, p. 49). Rea's summary of the arguments favoring this theory is especially good.

Submarine sliding.—Miser (1934a) regarded the "Ouachita Caney" as large masses possibly transported by submarine slides or slips. Although the writer likes this method of transportation to explain movement of some of the large limestone blocks, it should be pointed out that the "Ouachita Caney" masses to which Miser referred, are actually near their depositional sites and are a part of the Johns Valley shale.

Conclusions.—Of the various theories advanced to explain transportation of the exotics to their depositional sites, ice rafting seems to best explain some of the observed features. It explains the great range in size grade in the material, and in particular it offers a method of transportation for the smaller exotics, many of which are granule and pebble size; it also explains the apparent southeastward decrease in size from the shoreline. It explains the apparent concentration at particular stratigraphic levels. It explains the lack of deformation in the shales which enclose many of the exotics.

The larger blocks may have been transported in a different manner. There is a possibility that they slid down the steep western and northern slopes of the Ouachita trough on a bottom lubricated by accumulating black muds. The rapid northwestern convergence of the Stanley and Jackfork groups and their disappearance near the Ti Valley fault argues for rapid subsidence within the Ouachita trough and probably an appreciable southeastward slope into the trough. Because the Stanley thins from approximately 16,200 feet in Johns Valley to almost nothing at the Ti Valley fault about 13½ miles northwest, the bedding planes at the base of the Stanley had acquired a minimum southeastward dip of about 13 degrees at the end of Jackfork time. It could be argued that deposition kept pace with subsidence and that the depositional surface at any given time never had an appreciable slope, but the turbidity flow characteristics of the Jackfork sandstones suggest strong currents and, therefore, appreciable bottom slope during deposition. A slope of as little as one degree would have been sufficient to cause the large limestone blocks to slide over the slippery black muds.

Age of the Johns Valley Shale.—The writer's views concerning the age of the Johns Valley shale have been set forth in some detail in the preceding pages. In summary, the lower part of the Johns Valley shale includes a depositional tongue of the Caney shale and is therefore of Late Mississippian age. The middle and upper portions of the formation almost certainly contain Springer equivalents and are lithologically similar to it. At the Hairpin Curve, on the Indian Service road, and in Honess' type locality of his "Morrow fauna" in the Boktukola syncline, there are fossiliferous sandstones which probably are Morrowan in age (Dr. M. K. Elias, personal communication; also letters to Dr. C. W. Tomlinson). The writer believes that the uppermost part of the Johns Valley shale is equivalent to some part of the Wapanucka formation, possibly the lower and middle portions. Thus, it seems that the Johns Valley shale bridges the Mississippian-Pennsylvanian time line.

At the Hairpin Curve locality the boulder-bearing upper part of the Johns Valley shale occupies a channel which seems to have been scoured simultaneously with the deposition of the boulder-bearing clay shale. There is a strong suggestion that the transporting agent was a turbidity flow or submarine slide.

PENNSYLVANIAN SYSTEM

Atoka Formation

The writer has not examined the main body of the Atoka formation in any detail, but in connection with mapping the Johns Valley-Atoka contact he has studied the lower several hundred feet of the Atoka formation rather carefully. About 100 to 200 feet above the base of the formation, among the harder more siliceous beds, there is a spicular dark siliceous shale which extends from the Ti Valley fault southeastward into the central Ouachitas. Hendricks and his co-workers (1947) regard this as a good stratigraphic datum and state that it is widespread. The writer believes that the spiculite may correlate with one of the spiculitic beds in the upper part of the Wapanucka limestone in the frontal Ouachitas and in the McAlester basin. There is considerable field evidence that the upper Wapanucka grades into sandstone southeastward from the frontal Ouachitas. Thus, the lowermost Atoka of the central Ouachitas may include beds somewhat older than the lowermost Atoka of the frontal Ouachitas. The writer is of the opinion that the base of the Winslow sandstone (Atoka equivalent) of Arkansas also crosses time lines from its northernmost outcrops in Arkansas southward into the Ouachita geosyncline, its base becoming progressively lower to the south.

The writer has seen no evidence of a depositional break between the Johns Valley shale and the Atoka sandstone in the central Ouachitas. Sandstones in the upper part of the Johns Valley shale are lithologically like those in the lower part of the Atoka formation. The strike is the same in both formations. It therefore seems that the unconformity which has been reported at the base of the Atoka on the northeastern Oklahoma shelf dies out southward into the Ouachita geosyncline.

The complete thickness of the Atoka formation is not represented in the Ouachita Mountains, the upper portion having been removed by erosion. Considerable thicknesses of the formation are preserved in the Lynn Mountain and Boktukola synclines where downfolding has protected the lower part of the formation from being eroded. Shelburne (1959) estimates that 6,800 feet of the Atoka formation is present in the trough of the Boktukola syncline and the writer estimates that the Atoka formation is equally thick in the Lynn Mountain syncline. Our present state of knowledge does not permit a precise zone-by-zone correlation with the Atoka formation of the McAlester basin, so there is no way of knowing how much of the upper part of the formation has been eroded. There is no absolute certainty that the complete Atoka section was ever present in the Ouachitas because of the possibility that the central Ouachitas were somewhat elevated in pre-Desmoinesian time and thus became source areas in late Atoka time.

DEPOSITIONAL ENVIRONMENT OF STANLEY-JACKFORK-JOHNS VALLEY-ATOKA ROCKS

BLACK-SHALE FLYSCH FACIES

Definition

Lithologically the Late Mississippian and Early Pennsylvanian rocks of the Ouachita Mountains of Oklahoma are comparable to the typical *black-shale flysch* facies of the Cretaceous and Eocene of the Alps and Carpathians of Europe. Hundreds of papers have been written on the flysch of these areas and the use of the term has undergone considerable evolution. The term flysch, which literally means "gliding rock," was first used by Studer in 1827 (p. 28) for a thick sequence of interstratified shales, marls, and sandstones. Three common types of flysch, perhaps more, are now recognized by students of Alpine geology: black-shale flysch; calcareous flysch; and wildflysch. Sujkoski (1957, p. 544), in speaking of flysch, states that it is a facies designation for marine deposits composed of innumerable alternations of sharply divided "pelitic and psammitic layers," commonly thousands of feet thick and deposited in geosynclinal areas. The Late Paleozoic rocks of the Ouachita Mountains have all of these major characteristics and in addition they have many of the minor characteristics of flysch sediments. Some of these characteristics are summarized below.

Flysch Characteristics of Ouachita Sediments

ALTERNATIONS OF SHALE AND SANDSTONE.—The most characteristic feature of the 22,000 feet of Late Paleozoic rocks in the Oklahoma Ouachitas is an intricate and repeated alternation of dark gray to black shales and gray sandstones (fig. 37). In the 11,000 feet of strata in the Stanley group about 25 percent of the rock is sandstone; in the 5,700 feet of Jackfork the sandstone/shale ratio is on the order of 3:2; the writer's best estimate is that this ratio is approximately 2:3 in the Atoka formation. Interlamination is so regular as to suggest a rhythmic, perhaps even cyclic, pattern although this point is as yet unsettled. There are stratigraphic intervals in which the pattern or style seems to be fairly constant but individual beds may not be persistent. Some intervals are characterized by dark gray, almost black, laminated shale with intricately interstratified thin beds of quartzitic sandstone. Other intervals contain more massive beds of graywacke sandstone interbedded with green-gray shale. There also are other combinations.

The sandstone-shale contacts are typically sharp, indicating a sudden switch from the deposition of black mud to deposition of gray sand. However, some sandstones have a much cleaner contact with the shale below than with the shale above; the upper contact may be fuzzy, almost gradational, which is about the nearest thing to graded bedding that the writer has observed in the Ouachitas. This criterion is helpful in determining tops and bottoms of beds in structurally complex areas.

The features noted above may be explained by assuming that the normal environment in this part of the Ouachita geosyncline was one in which dark muds were accumulating. The sandstones are intruders, having been brought in rather suddenly by increased current activity, possibly by turbidity currents.

SANDSTONES.—The sandstones of this stratigraphic sequence range in composition from gray poorly sorted graywackes to firmly cemented white orthoquartzites. The graywackes are more massive than the orthoquartzites and range in thickness up to 20 feet. The quartzitic sandstones are very fine-grained, average only a few

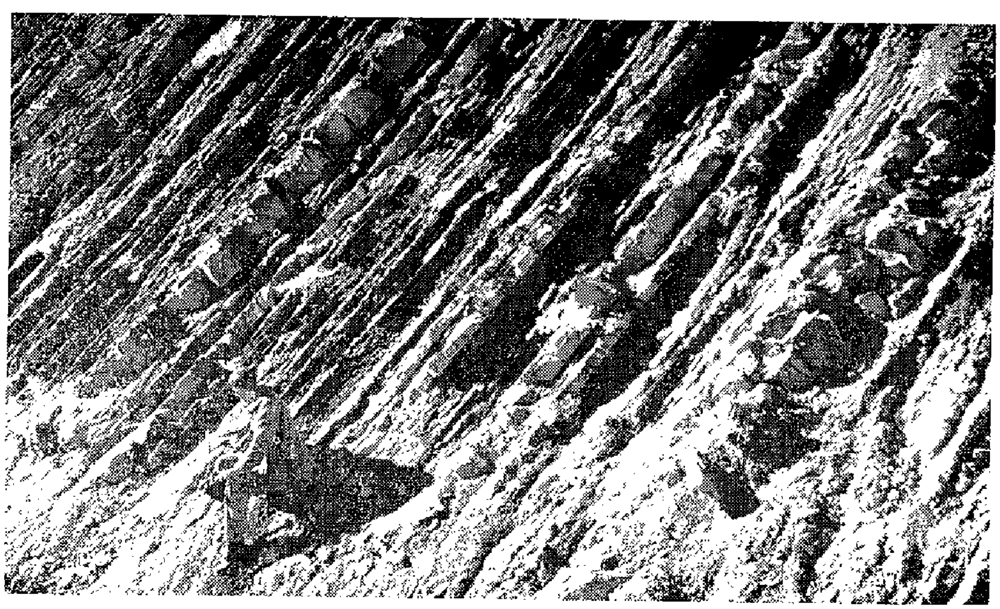

FIGURE 37. Intricately interbedded sandstones and shales in the lower part of Wildhorse Mountain formation. Exposure is in fresh road cut on Big Cedar-Octavia road in north face of Kiamichi Mountain, Le Flore County.

inches in thickness, and have clean parallel bedding surfaces cut by closely spaced joints.

Cross-bedding is rather uncommon in Stanley, Jackfork and Atoka sandstones, with the exception of the Game Refuge formation at the top of the Jackfork group. The Game Refuge sandstone exhibits some small-scale cross-bedding; ripple marks, including interference ripple marks, are common; it contains abundant well-preserved pieces of *Calamites,* and in general has the characteristic properties of sediments of a fairly stable platform environment. Some of the Stanley-Jackfork sandstones have rather large current ripples and in some cases these are associated with convolute bedding. Graded bedding is not a conspicuous feature of the sandstones.

Convolute bedding is well developed in many of the sandstones in all of the formations (fig. 38). The feature is independent of bed thickness, grain size and degree of sorting. It ordinarily affects only the internal portions of a bed, even in the strongly asymmetrical examples, and ordinarily dies out above and below as bedding surfaces are approached. The writer interprets this feature as developing at the peak velocity of a turbidity flow and then dying out upward as the flow trails off. The Stanley-Jackfork-Atoka examples do not seem to have resulted from internal gliding or flowage, but rather they seem to be related to the development of current ripple marks in the lower parts of a stratum, which in turn become

FIGURE 38. Convolute bedding in Chickasaw Creek formation in Boktukola syncline. Note fragments of siliceous shale.
(Photograph by L. M. Cline)

FIGURE 39. Flute casts, bounce casts, load casts, prod casts, and groove casts characteristic of under surfaces of sandstones of lower part of Wildhorse Mountain formation. This formation has been exploited for building stone in the vicinity of Kosoma.
(The Mike Emery dwelling, Kosoma)

asymmetrical and form convolutions during the turbulent flow at the time of maximum velocity of the current, and again they subside to form current ripple marks which may or may not extend to the top of the bed.

Sole markings such as flute casts, bounce casts, prod casts, groove casts, and load casts, are abundant on the under surfaces of many sandstones and some of them are spectacularly developed and

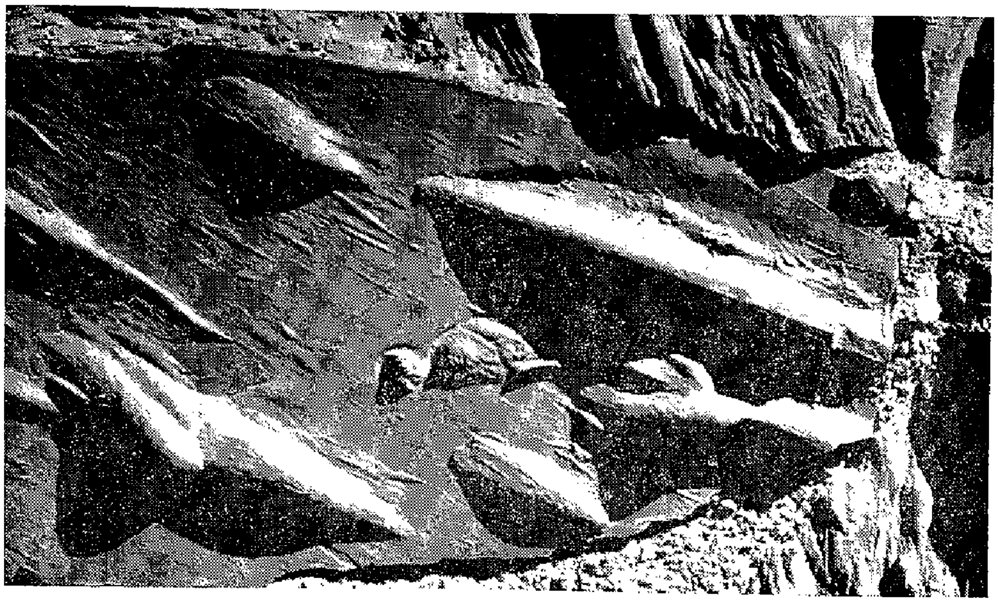

FIGURE 40. Bounce casts on base of sandstone quarried from lower part of Wildhorse Mountain formation, Kosoma, Oklahoma.

well preserved (figs. 39-41). The types of markings differ from bed to bed but they are likely to have a characteristic size and shape on any one bed and a combination of characters may persist throughout a certain stratigraphic interval and aid in stratigraphic identification.

The sole markings are developed only where sandstone rests upon shale. The linear, parallel markings obviously are the result of the scouring action of currents on a soft mud bottom—the same currents which transported the sand and dumped it into an environment in which muds were the characteristic sediment. After induration and exposure to weathering, the markings stand out as prominent ridges and are an infallible guide to the field geologist attempting to identify tops and bottoms in areas of complicated structure.

Trails made by creeping and burrowing organisms are not exceptionally abundant on the surfaces of sandstones from the Ouachita flysch but they are common on some layers. Thin siltstones and fine-grained sandstones in the middle and upper parts of the Johns Valley formation commonly have trail preservations on their upper surfaces and burrows on the under sides of the same slabs. Some of these are illustrated in figure 42. The upper photograph shows the upper surface of a fine-grained sandstone on which there are numerous meandriform trails which do not cross and rarely do they touch. In cross section the furrows show a central depression bordered on each side by parallel ridges crenulated by

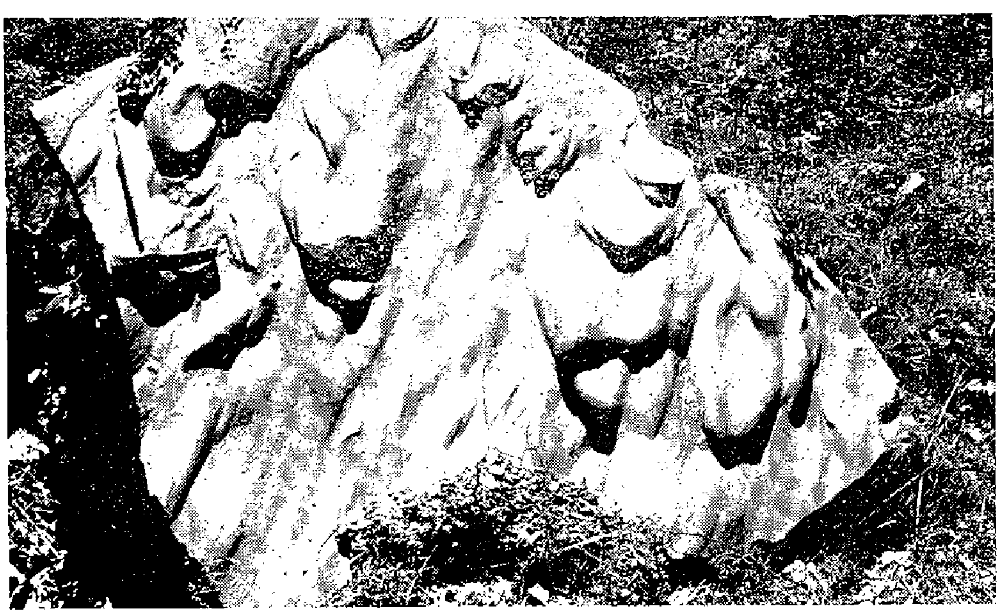

FIGURE 41. Flute casts on base of sandstone from Atoka formation, east side of Farris syncline, northeastern Atoka County.

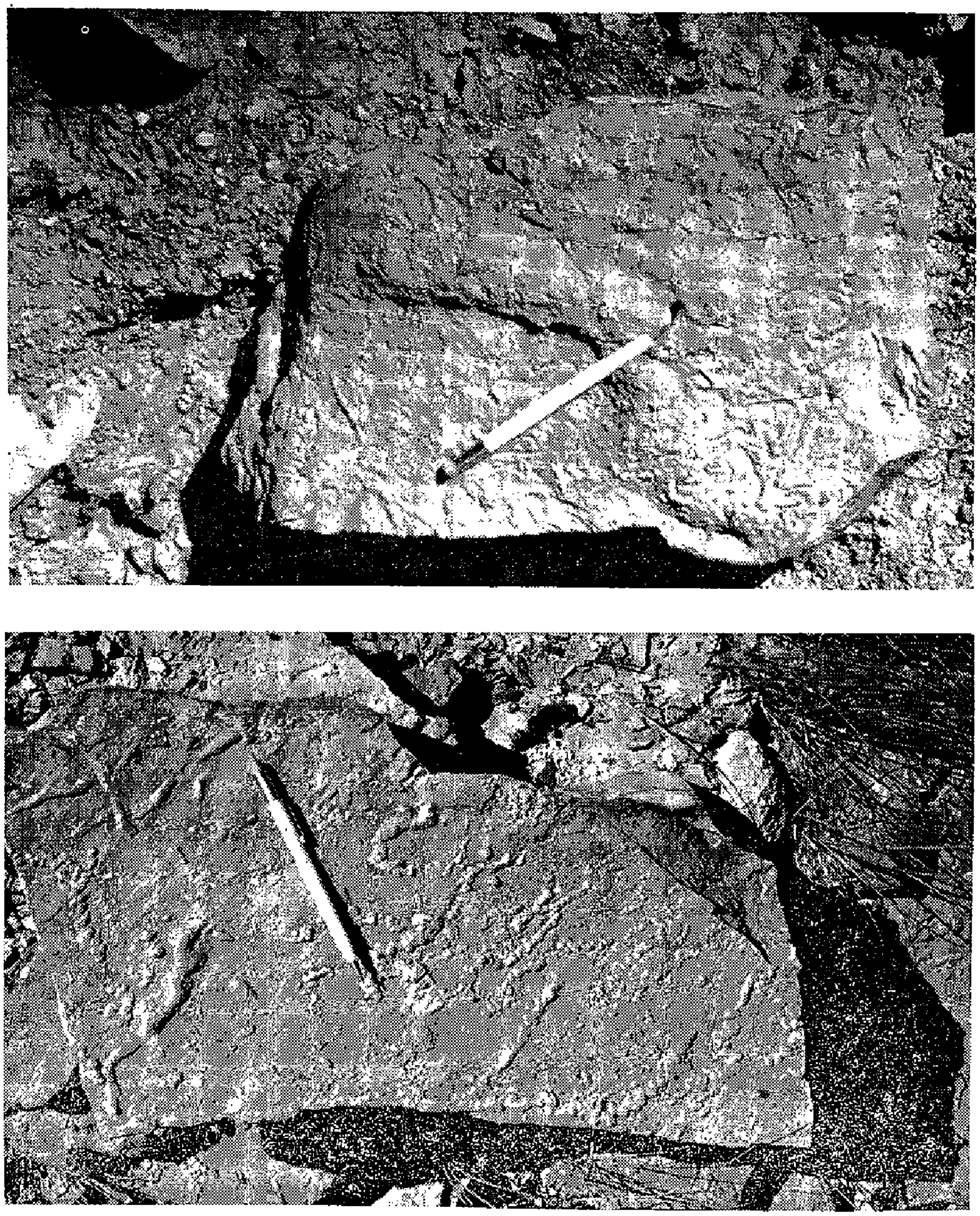

FIGURE 42. Trails and burrows on bedding surfaces of sandstone from middle part of Johns Valley formation. Upper photograph shows meandriform trails of a gastropod related to *Paleobulla* developed on upper surface of bed. Lower photograph shows lower surface of same slab on which are preserved burrows presumed to have been made by worms.

transverse grooves made by some organism that progressed slowly, leaving a crenulation to mark each bit of progress. The trails are quite similar to some described and illustrated by Goetzinger and Becker (1932) from the Upper Cretaceous flysch of Austria and believed by them to have been made by a gastropod, which they later named *Paleobulla.* The lower photograph of figure 42 shows the under surface of the same slab, revealing burrows made by some organism, probably some type of worm.

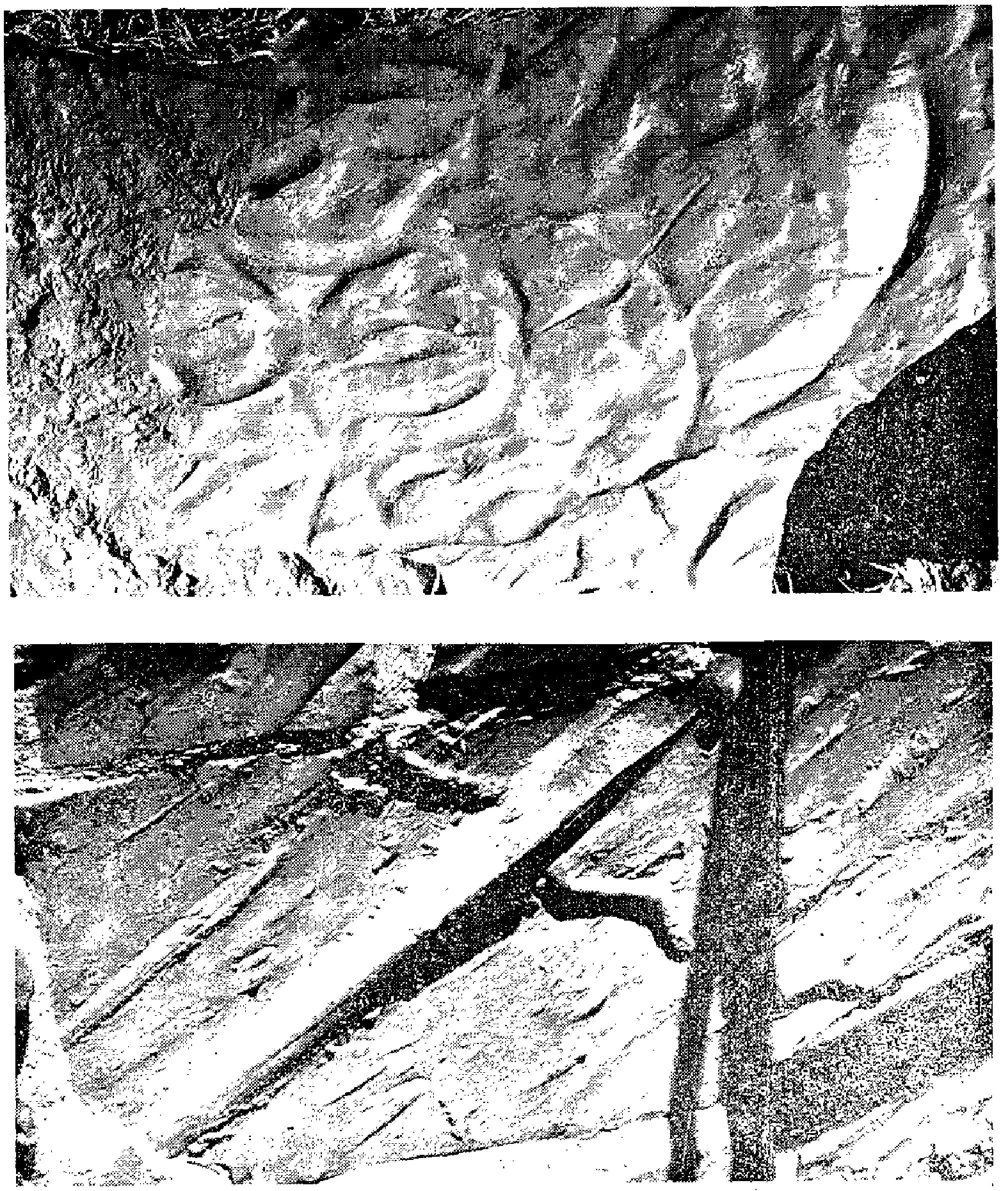

FIGURE 43. Burrows on under surfaces of sandstones from lower part of Wildhorse Mountain formation, Kosoma, Oklahoma. Upper photograph shows branching burrows. Lower photograph shows a burrow penetrating a bounce cast.

The upper photograph of figure 43 shows burrows on the under surface of a sandstone bed from the lower part of the Wildhorse Mountain formation. The burrows branch and appear to have been made by burrowing organisms, probably worms, which ate their way through the lower portion of the sand after it was deposited. The lower photograph on this figure shows a burrow penetrating a bounce cast which obviously was formed prior to the time the burrow was made.

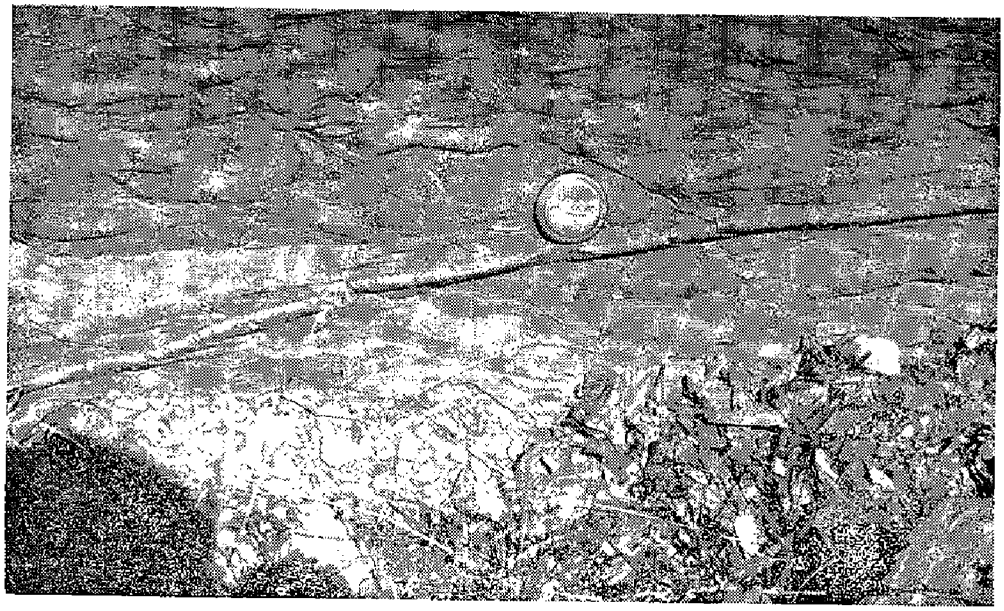

FIGURE 44. Filamentous plant on lower surface of sandstone bed in lowermost part of Atoka formation. The cross section, originally round, is somewhat elliptical. The surface is ornamented with closely spaced grooves parallel to the long dimension of the plant.

Marine invertebrate fossils other than burrows are rarely found in the sandstones. They are fairly common in the Game Refuge sandstone, which is believed to represent a temporary return to shelf conditions in the geosyncline, and they are locally abundant in the Johns Valley shale but appear to have been transported. In all cases the fossils are fragmentary; the fragments are of small size, and they appear to have been sorted according to grain size. The fragments are bits of bryozoan colonies, small brachiopods and pelecypods and fragments from larger shells, and crinoid columnals. The assemblage is from a shallow-water shelf environment and the fragments probably were sorted according to grain size, then transported from the outer edge of the shelf into the deeper waters of the geosyncline by currents. This seems to explain their absence in most of the sandstones, their local abundance in pockets in some sandstones, their fragmentary condition, and the fact that the fragments are mostly about the same size.

Small bits of carbonized plants are present in many of the sandstones but most of them are so badly macerated as to preclude identification. Pieces of *Lepidodendron* several inches long are found sparingly in the Wildhorse Mountain formation. Well-preserved *Calamites* fragments are abundant in the Game Refuge sandstone, but only in this formation. Fucoidal markings have been noted on the under surfaces of some sandstones. Whether they represent

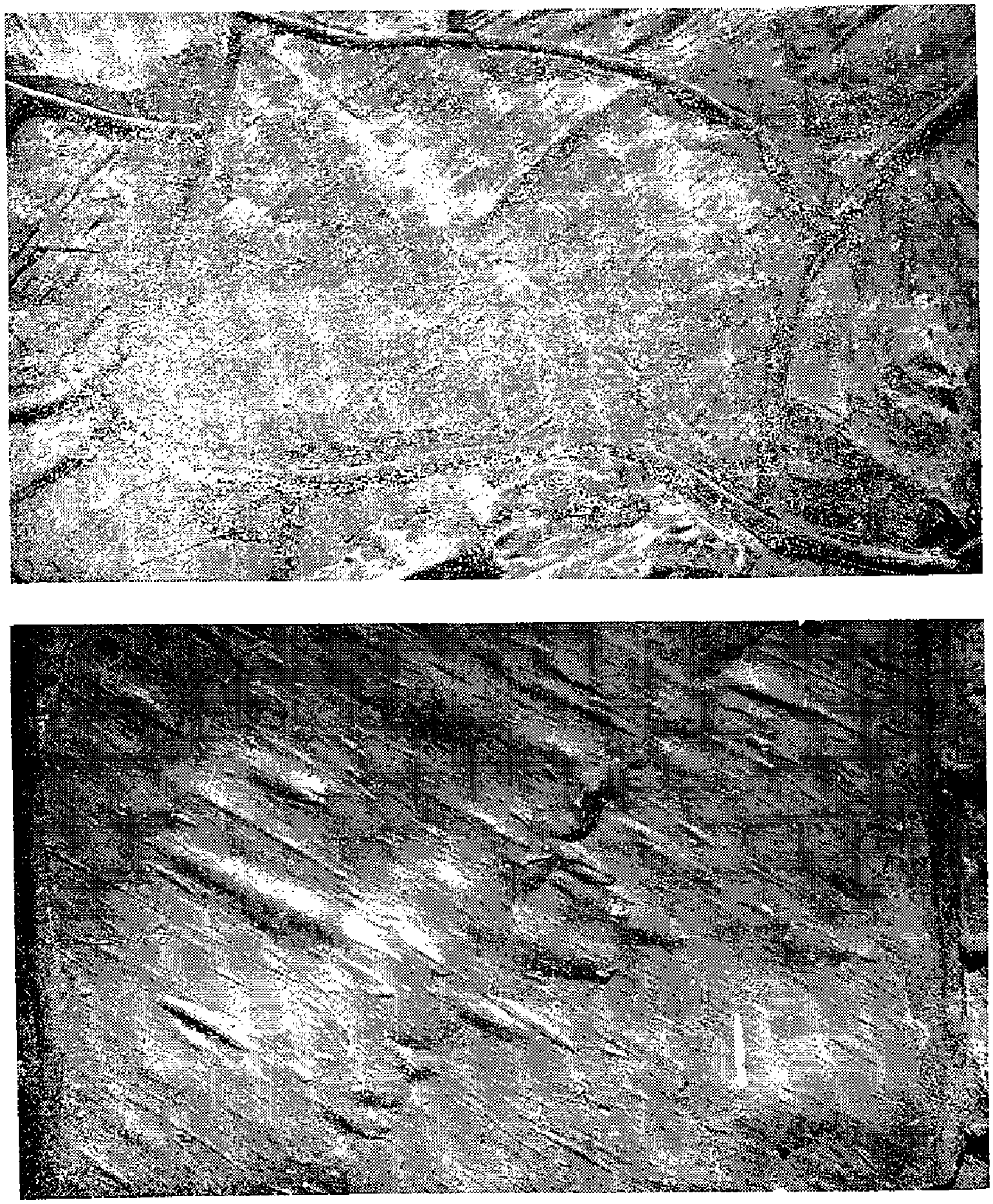

FIGURE 45. Ripple marks oriented at right angles to flute casts and bounce casts on lower surfaces of two sandstone slabs quarried from the lower part of Wildhorse Mountain formation on the lower slopes of Wildhorse Mountain north of Moyers.

algae growing on the sea floor at the time the sand was debouched into the mud environment is not known. Some of them are aligned parallel to flute casts (fig. 44), but the plants may have been transported from shallower water.

Sole markings, good examples of which are pictured in figures 39 to 41, are abundant at many stratigraphic levels and are aligned parallel to the direction of the currents which transported the sands. A few measurements indicate that the main direction of transport was W12°S, down the axis of the trough. The photographs of figure 45 show current ripples oriented at right angles to these linear structures. Filamentous plants, like the one illustrated in figure 44, are also aligned parallel to the main thread of the current. Convolute bedding, illustrated in figure 38, is a directional feature that could be used, but the writer has made few observations on their orientation. Some charcoal lineation has been observed but grain clast studies have not been made.

SHALES.—Gray shale is the most abundant rock in the Stanley; it comprises two-fifths of the Jackfork rocks and perhaps as much as three-fifths of the Atoka rocks. Green-gray colors are common but darker shades of gray are more prevalent. Most of the shales are thinly laminated and in early stages of weathering fissility is noticeable. Most of the gray shales are fairly pure clay shales and only rarely are there siltstones transitional from sandstone beds upward into shales, the contacts ordinarily being sharp. Thin, but widespread, black siliceous shales occur at a number of levels from near the base of the Stanley group upward into the lower part of the Atoka formation. Brownish-red, generally thin, shales are present at several levels in the Stanley, and one thick sandy red shale persists in the middle of the Wildhorse Mountain formation. Fossils are exceedingly rare in all but the black siliceous shales, although plant spores doubtless are present.

Laminated dark blue-gray to black siliceous shales contain some thin cherty members which range in thickness from less than an inch to 8 inches. The shales are hard and resistant to weathering, notwithstanding the exceedingly well developed laminations.

Thin sections reveal an intricate interlamination of brown and black sapropelic material and white to gray opaline silica with an admixture of sponge spicules, radiolarian tests and occasional conodonts. Some lamellae are a micrococquina of tiny monaxon and polyaxon sponge spicules, a feature best brought out by etching polished sections or thin sections in hydrofluoric acid for a short time. In several thin sections a layered arrangement of spicules has been observed and the sorting suggests minute graded bedding. Radiolarians are fairly common. The clay mineral content of the harder beds is low. Laudon (1959, p. 18) states that the silica content commonly exceeds 80 percent. This information came as a surprise to the writer who had thought that the sapropelic content would be higher.

The various siliceous shales are so similar in appearance that they obviously are the product of a similar environment. The environment was characterized by slow sedimentation in which only fine organic-rich muds settled out concurrently with radiolarian tests and tiny sponge spicules. It was a reducing environment; the waters were relatively quiet and probably, although not necessarily, deep. This environment existed simultaneously over large areas of the trough at several times. It existed during periods of essentially no tectonism when only the finest muds were transported. There probably was very little benthonic life in the oxygen-deficient areas in which the black muds were accumulating, the abundance of sponge spicules notwithstanding. The sponges probably lived in shallow shelf areas and upon death released the spicules, the finest of which were winnowed from the shelf and then transported into the geosyncline by weak currents. The spicules are microscopic, have a large surface area in proportion to their mass, and could easily have been transported by sluggish currents.

Opaline silica appears to have been deposited concurrently with black organic-rich clays. The writer has seen little evidence to suggest that the abundance of silica was related to volcanism. Sea waters may have been temporarily enriched in silica, perhaps from a distant volcanic source, but the writer has seen little affirmative evidence. Considering the intimate relationship of the sapropelic muds and the opaline silica, it would seem that the precipitation of silica was in some way related to the presence, perhaps to the life processes, of abundant small plants. Harlton (1947) has suggested the possibility that the siliceous tests of Radiolaria seeded the precipitation of some silica. The chief significance that the writer would attach to the presence of abundant radiolarian tests in the black shales in the Ouachitas is that this was an environment of exceedingly slow sedimentation, probably in deep water, and certainly one of calm water, and therefore it was ideal for preservation of the radiolarian tests which represent one of the few types of fossil material characteristic of the environment. Sedimentation was so slow that it does not seem necessary to postulate that the waters had an over-abundance of silica.

Reducing conditions prevailed in the Ouachita trough throughout most of Paleozoic time as indicated by the predominantly dark colors of the shales. However, there were times when oxidizing conditions were widespread throughout the trough and then maroon, brownish-red and variegated muds were deposited. There are laminated reddish-brown shales in the uppermost part of the Tenmile

Creek formation and in the upper part of the Moyers formation, and a remarkably persistent zone of variegated shales (the Prairie Hollow member) in the middle of the Wildhorse Mountain formation.

In many outcrops where the shales are reddish the associated sandstones are green-gray, a feature suggesting that the oxidation potential was different in the two types of sediment. The sandstones have the same type of sole markings and convolute bedding as have the sandstones which are associated with the dark gray shales. Hence it is concluded that the sandstones in both types of lithologic associations were transported by turbidity currents. The red color of the shales probably represents the original color of the accumulating muds. The original color was probably no different in the muds which were to end up as dark gray to black shales, the difference being that in the latter case the iron was reduced. The associated green-gray sandstones may have acquired most of their characteristics, including the green color, in a shelf environment before having been transported into the geosyncline. Where the sandstones are red they are dirty, poorly sorted and have a clay binder which imparts the color to the rock.

The association of red shales and green-gray sandstones is commonplace in the geologic column. The writer has observed this association in the Des Moines rocks of Iowa, in the Permian rocks of Oklahoma, in the Permian-Triassic rocks of the Great Plains and Middle Rockies (at some levels), and in the Mississippian Mauch Chunk strata of the Appalachians.

Wildflysch.—There are several stratigraphic horizons in the Johns Valley shale that contain exotic pebbles, cobbles, boulders and blocks of limestone that were derived from the Arbuckle facies and transported into the Ouachita geosyncline. The Wesley shale, the Markham Mill formation and the Springer shale and sandstone also contain exotics. The evidence is conclusive that most of the exotics are depositional, not tectonic, in origin. Most of the smaller fragments are enclosed in shales in which the bedding planes are undisturbed, and these shales in turn are interstratified with sandstones which show no evidence of structural movement other than the convolute bedding, which is a depositional feature.

The hypothesis that the exotics represent part of a friction carpet at the base of an advancing thrust sheet is untenable. Firstly, there is absolutely no evidence for bedding-plane faults in many of the "boulder beds." Secondly, it seems odd that boulders brought up from an underlying Arbuckle facies (which has been suggested, but for which there is little or no evidence) by faulting should invariably come to rest in the same stratigraphic zone. It is true that the thick Johns Valley shale is a natural place for structural adjustment to take place, and the greasy shale would offer a lubricant for such thrusts. However, there are other thick, laterally persistent shales in the underlying Stanley and Jackfork groups and they have not been similarly favored by visits from their exotic neighbors from the Arbuckle facies. Why not? Is it reasonable to expect "tectonic boulders" to bypass completely these lower shales on their way to higher shales? Along the Boktukola and Octavia faults, and other major thrusts in the central Ouachitas, Jackfork sandstones are commonly in fault contact with greasy Stanley shales. If the Johns Valley boulders are part of a friction carpet of an advancing thrust, why have not some of these boulders lodged in the shear zones of the major thrusts that are known to exist? Surely such thrusts must have served as feeders to supply the Johns Valley boulders, if indeed they are tectonic.

The writer favors ice rafting as the most plausible mechanism for transporting some of the smaller limestone exotics to their depositional sites in the accumulating Johns Valley muds. The very large limestone blocks may have had a different origin. The enclosing shales are disturbed adjacent to the blocks and this suggests the possibility that the blocks slid down a steep depositional slope lubricated by the accumulating black muds. It must be admitted however, that the weight of a 40-foot long block of limestone should have disturbed the underlying muds even if it were released gently from a melting ice floe.

SUMMARY OF DEPOSITIONAL HISTORY

Paleozoic sedimentation was initiated in the Ouachitas in a deep arcuate trough lying at the south margin of the shelf area in which the carbonate-bearing Arbuckle facies accumulated. The pre-Stanley facies of the Ouachitas is thinner than that of the Arbuckle facies and is characterized by spiculitic and radiolarian cherts and dark graptolitic shales; the Ouachita rocks are the product of slow sedimentation in a trough essentially starved for clastic sediments. In post-Arkansas novaculite time, active tectonism resulted in rapid subsidence and a stepped-up rate of sedimentation. The Late Mississippian-Early Pennsylvanian Stanley-Jackfork-Johns Valley-Atoka sequence was deposited in a rapidly subsiding trough which may have been only the northernmost of two or more parallel troughs which were a part of the developing Ouachita foldbelt. Subsidence and sedimentation were so rapid that before the end of Atoka time a minimum of 22,000 feet of Late Paleozoic shales and sandstones were trapped in this outermost trough. Some time after the deposition of lower Atoka sediments (how much of the upper Atoka was represented in the trough we do not know) the geosyncline was severely compressed, its sediments folded into long, linear folds and many of the folds were ruptured to produce thrust faults directed toward the Oklahoma platform.

The rocks of the Late Paleozoic trough exhibit essentially all of the characteristics of the black-shale flysch facies of the Late Cretaceous and Eocene rocks of the Alps and Carpathians of Europe. The environment was that of a deep trough in which dark muds were the prevailing or most characteristic type of sediment and into which sands were introduced from time to time. The sands were derived from an adjoining shelf environment and were transported down the sides of the trough by turbidity currents which then became resolved into currents flowing W12°S down the axis of the trough. The large limestone exotics of the wildflysch facies probably slid down the sides of the trough, which were lubricated by accumulating muds. There is also evidence for some slumping. The source of the sediments was probably from the southeast or south because it is inconceivable that the quartzose sands were derived from the north and dragged across the carbonate banks of the northeast Oklahoma platform.

Attaining an aggregate thickness of 16,200 feet in the Tuskahoma syncline, the Stanley and Jackfork groups thin to practically nothing at the Ti Valley fault some 13.5 miles to the northwest. Convergence at all stratigraphic levels in both groups indicates a rapidly subsiding trough with a steep northwestern margin. Some of the northwestward thinning may have resulted from the horizontal component of movement along the thrust sheets, but it seems to the writer that the rates of thinning of individual units are not significantly interrupted by the faulting. The thin but widespread black siliceous shales represent times of tectonic stability and a slow rate of sedimentation.

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(Main references are in boldface)

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