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GEOLOGY OF THE EASTERN PART OF WINDING STAIR RANGE, LE FLORE COUNTY, OKLAHOMA

by

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CONTENTS

ILLUSTRATIONS

Figures

Plate

Geology of the Eastern Part of Winding Stair Range. Le Flore County, Oklahoma

Orville Dorwin Hart

ABSTRACT

The area of the report is 150 square miles in the central Ouachita Mountains in central Le Flore County. It is limited to the north by the Ti Valley fault and to the south by the Windingstair fault. The major rock units are the Stanley Group (Meramecian), Jackfork Group (Chesterian) and the Johns Valley (Morrowan-Chesterian) and Atoka (Atokan-Morrowan) Formations.

The Stanley Group, the lowermost stratigraphic unit in the area, consists of the Tenmile Creek, Moyers, and Chickasaw Creek Formations. The Tenmile Creek Formation was not definitely identified in the area, and the Moyers was identified principally by its stratigraphic relation to the Chickasaw Creek Formation.

The Jackfork Group (8,000 feet thick) overlies the Stanley Group and consists of the Wildhorse Mountain, Prairie Mountain, Markham Mill, Wesley, and Game Refuge Formations. Because structural complexity obscures formational boundaries, for mapping purposes the group has been subdivided into middle and lower part of Wildhorse Mountain Formation (undifferentiated), the upper part of Wildhorse Mountain-Prairie Mountain-Markham Mill Formations (undifferentiated), and the Wesley-Game Refuge Formations (undifferentiated).

The Johns Valley Shale is estimated to be 990 to 1,200 feet thick and the uppermost unit in the area is the Atoka Formation of which cnly about 5,600 feet is exposed.

Structurally the area is characterized by major east-west-trending synclines and thrust faults and local areas of more intense and complex deformation.

The rocks of the Stanley-Atoka sequence, particularly those of the Atoka, resemble flysch sediments and were apparently deposited during active downsinking of the Ouachita geosyncline, beginning in Mississippian (Meramecian) time and continuing into Pennslyvanian (Atokan) time. The characteristics of these rocks are indicative of turbidity-current deposition.

INTRODUCTION

Purpose of Study

The objectives of this investigation were to make a report of the character, distribution, stratigraphy, and structure of the Mississippian and Pennsylvanian sedimentary rocks that crop out in and adjacent to the eastern part of the Winding Stair Range in Oklahoma and to prepare a geologic map of the area. Intensely folded and faulted, the Winding Stair Range exhibits some of the most complex geology in a province that is noted for its complicated geologic structures. Lying just south of the Ti Valley fault, which marks the northern limit of the thick Stanley-Jackfork sequence of rocks, the area is stratigraphically and structurally significant.

Location of the Area

The report area is bounded on the north by the Ti Valley fault, on the east by State Highway 103, on the south by the Windingstair fault, and on the west by the north-south center line of R. 23 E., and a north-south line between secs. 5, 6 and secs. 29, 30, T. 3 N., R. 23 E. (fig. 1). The area is approximately 150 square miles and is entirely within Le Flore County. The Winding Stair Range, a high linear ridge composed mostly of thick, resistant sandstones of the Jackfork Group, attains elevations up to 2,400 feet and comprises some of the more imposing mountains in the Ouachita area.

Previous Work

Pioneer work in the area was done by J. A. Taff (Taff and Adams, 1900; Taff, 1901, 1902) in the Coalgate, Atoka, McAlester, Tuskahoma, Winding Stair, Antlers, and Alikchi quadrangles. Unfortunately only his Coalgate and Atoka quadrangle maps were published (1901, 1902), but Miser used Taff's field notes and maps to prepare his 1926 *Geologic map of Oklahoma.*

The Choctaw anticlinorium and adjacent areas were studied and mapped in detail by Honess (1923), who further continued his studies of Stanley-Jackfork sediments in an area north of the Choctaw anticlinorium and published a geologic map which embraces the area of this investigation (1924).

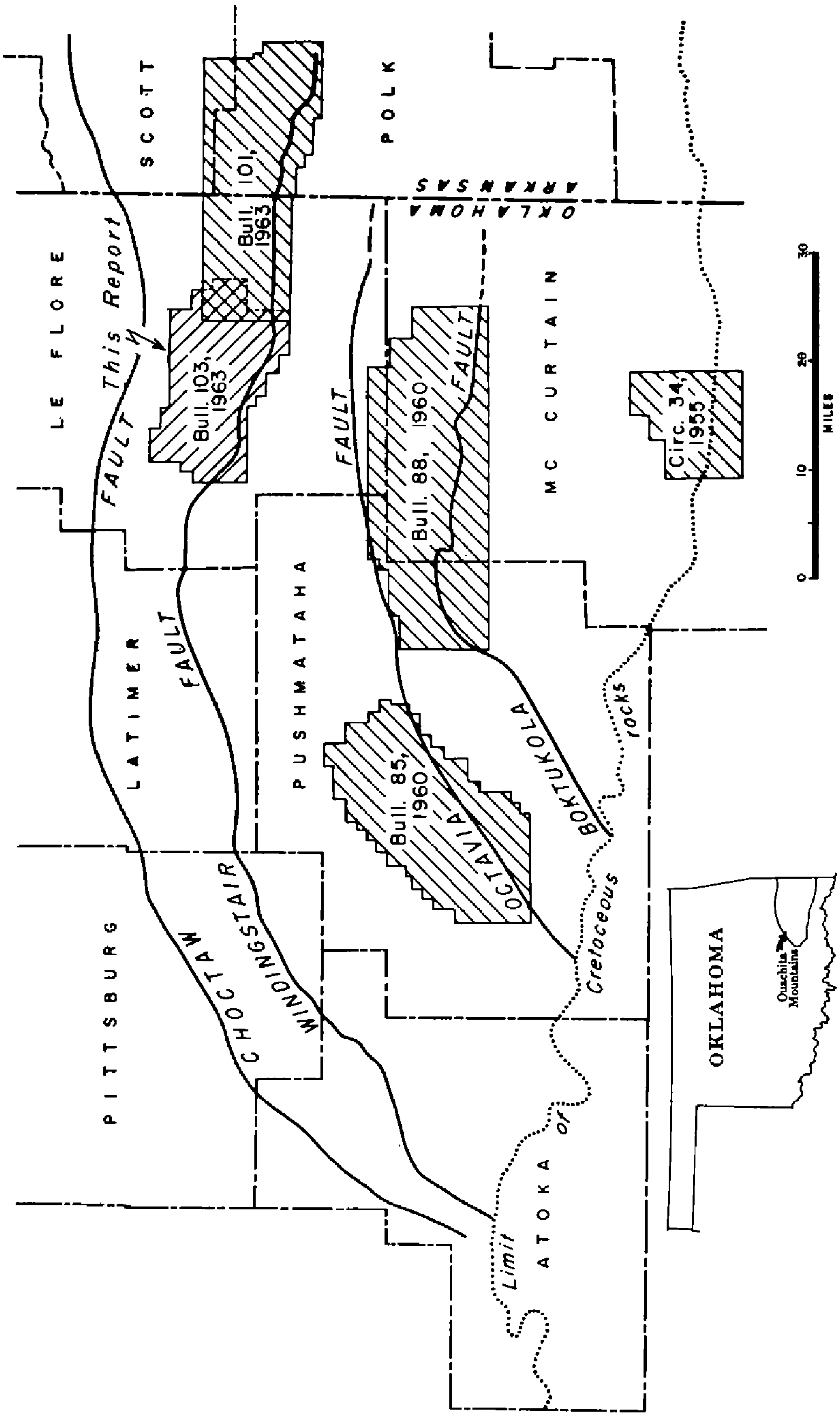


Figure 1. Index map, Ouachita Mountains, Oklahoma.

Miser's publications date from 1917 to 1960 and cover many of the puzzling problems in the Ouachitas. Through his work Miser further developed the concept of low-angle overthrusts to explain the complex Ouachita structures (1929).

The Stanley-Jackfork-Johns Valley-Atoka sequence was successfully subdivided for the first time during the decade 1934-1944 by Harlton (1938). Using thin siliceous shales as datum levels, he divided the Stanley shale, in ascending order, into the Tenmile Creek, Moyers, and Chickasaw Creek Formations. The Jackfork sandstone he divided from bottom to top, into the Wildhorse Mountain, Prairie Mountain, Markham Mill, and Wesley Formations and proposed elevation of the Stanley and Jackfork to group rank.

In 1947 Hendricks and his co-workers mapped in detail the western part of the frontal belt of the Ouachitas from Atoka east to State Highway 2. Hendricks recognized most of Harlton's siliceous shales but did not use his terminology.

Since 1953 L. M. Cline and his students have made significant contributions to the study of the geology of the Oklahoma Ouachita Mountains. Cline (1960) published a map of the western part of the Lynn Mountain syncline, and Shelburne (1960) published a map of the Boktukola syncline. They were able to recognize Harlton's units and to prove the persistence of siliceous shales and their utility as mapping units. Cline (1960, p. 87) observed that the sequence of alternating sandstones and shales of the Ouachita sediments corresponded in almost every respect to the typical black-shale flysch facies of the Cretaceous and Eocene of the Alps and Carpathians of Europe. Cline (1956, p. 103) also demonstrated that the Stanley and Jackfork Groups are Mississippian instead of Pennsylvanian in age because they are stratigraphically below the Johns Valley Shale which spans the Mississippian-Pennsylvanian boundary. Cline (1960, p. 18) is firmly convinced that rapid thickening of the Stanley-Jackfork Groups south from the Ti Valley fault is primarily depositional, and that their thick sequence south of the Ti Valley fault is the direct lateral equivalent of the main body of the Caney Shale north of the fault. Fellows (1962) has concluded work on a geologic map of the area that joins the eastern boundary of an area mapped by Hendricks and others (1947) and continues east along the Winding Stair Range almost to Talihina. Morris (1962) has completed mapping an area in the frontal belt of Arkansas. Seely (1963) published a geologic map of the Rich

Mountain area which joins the western boundary of the area mapped by the writer.

Field Methods

Aerial photographs were used both as a base map and for field observation locations. Positions of section corners and bench marks were determined by first noting their approximate locations on topographic maps and then field checking them in relation to topography by stereoscopic observation.

Outcrops are essentially restricted to stream and gulley bottoms because ridge crests and slopes are covered by colluvium, talus debris, and vegetation. Prospective creeks and gullies were noted on the photographs before they were field checked. Many structural and stratigraphic trends could be traced easily on photographs, requiring only a minimum of field checking; however, where structures terminated abruptly, extensive field work was necessary to determine the reason. Various rock types in this part of the Ouachitas have distinctive weathering characteristics that allow them to be identified on aerial photographs. For example, thick shale units weather into valleys or into a series of closely spaced fluted stream gullies down ridge slopes. This characteristic distinguishes shale sequences from sandstone units, which develop either smooth slopes if the sand beds are thin or striated slopes if the sand beds are thick and stand in relief.

Outcrops of the thin siliceous shale stratigraphic marker beds are few; however they weather into rhombohedral blocks of float scattered on the surface. The most abundant accumulation of the blocks closely locates the position of the siliceous shale in the sequence.

Complex structure makes it necessary to determine tops and bottoms of beds. Fortunately the major stratigraphic units contain many paleocurrent sole markings such as flute, groove, and bounce casts that may be used to indicate bottoms of beds. These markings are sandstone casts of primary sedimentary structures that were developed on a mud bottom by currents prior to deposition of the overlying sand unit and always indicate the bottom of the bed.

The Johns Valley Shale in this part of the Ouachitas contains many exotic blocks that range in age from Ordovician (Arbuckle) to Pennsylvanian (Morrow). Some huge masses of limestone up to 550 feet long have been found in Johns Valley, the type locality of the Johns Valley Formation (Powers, 1928, p. 1036); but in the area of this study few exotic boulders exceed four feet in diameter, although some are 20 feet long. The more common exotics are composed of various types of limestone and chert. Exotics are found in the downstream deposits at almost all Johns Valley outcrop localities. Black-chert fragments are most resistant to weathering and are carried farthest downstream; limestone fragments generally do not persist so far downstream as chert fragments. Tracing exotics upstream to their source was one of the more successful means of locating the Johns Valley Shale and was one of the more valuable mapping techniques of the investigation.

Acknowledgments

Dr. L. M. Cline of the University of Wisconsin suggested the problem, accompanied me in the field on several occasions, and offered many valuable suggestions throughout the course of this investigation. Dr. C. C. Branson, director of the Oklahoma Geological Survey, arranged for three months field expenses and loaned aerial photographs necessary for this study. The Wisconsin Alumni Research Foundation gave additional financial support to defray part of the field expenses. Mr. Henry Fisher of the Humble Oil & Refining Company made available a set of aerial photographs, which assisted in a more accurate interpretation of the geology. Dr. O. B. Shelburne, Mobil Oil Company, spent several days in the field with me and gave many helpful suggestions. D. R. Seely, who worked in the adjacent area to the east, helped clarify several mutual problems.

STRATIGRAPHY

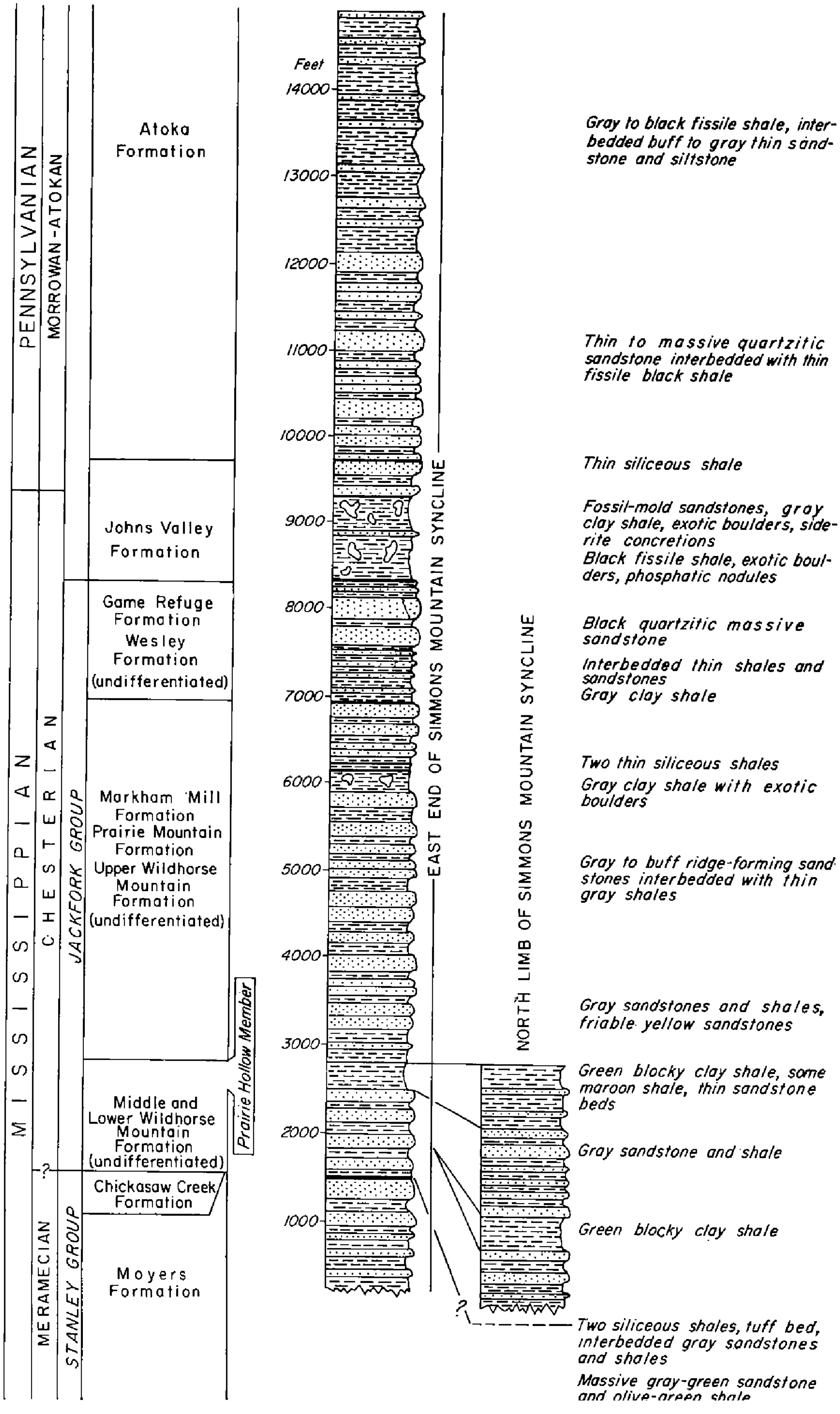
Introduction

Exposed rocks of Late Mississippian and Early Pennsylvanian age in the Ouachita Mountains of Oklahoma are more than 22,000 feet thick and belong principally to four units. From oldest to youngest these are Stanley Group, Jackfork Group, Johns Valley Shale, and Atoka Formation. The rock sequence is composed largely of thousands of feet of rhythmically alternating sandstones and shales with a few thin chert beds. The Stanley-Jackfork sediments are closely comparable to the typical black-shale flysch facies of Europe (van der Gracht, 1931, p. 998; Cline, 1960, p. 87) and were deposited in a rapidly sinking mobile geosyncline.

Pre-Stanley rocks crop out in the Choctaw anticlinorium, Potato Hills, and a few isolated areas in thrust blocks of the frontal belt, but they are relatively thin, being about 5,000 feet thick, in contrast to the tremendously thick Stanley-Jackfork-Johns Valley-Atoka sequence.

The Ouachita Mountains of Oklahoma are divided into three major geological provinces: the frontal belt, the central part of the Ouachitas, and the Choctaw anticlinorium. The frontal belt lies between the Choctaw and Ti Valley faults and is complexly folded and faulted into a series of blocks which are lithologically intermediate between rocks of typical Ouachita facies in the central zone and typical Arbuckle facies (Goldstein and Hendricks 1962, p. 387). Structure and stratigraphy of the central part of the Ouachitas are relatively straightforward. The structure is composed principally of broad synclines truncated on their south flanks by large thrust faults overthrust to the north and northwest, which have cut out intervening anticlines. The four standard rock units, Stanley Group, Jackfork Group, Johns Valley Shale, and Atoka Formation, of the central Ouachitas are widespread and have been recognized from the westernmost area near Atoka, Oklahoma, eastward into Arkansas, a linear distance of about 125 miles. This report is concerned primarily with rock units stratigraphically related to the deposits of the central part of the Ouachitas but structurally related to the frontal belt (fig. 2).

Rapid changes in lithology across the Ti Valley fault, which


PENNSYLVANIAN
MORROWAN-ATOKAN
MISSISSIPPIAN
CHESTERIAN
MERAMECIAN
JACKFORK GROUP
STANLEY GROUP
Atoka Formation
Johns Valley Formation
Game Refuge Formation
Wesley Formation
(undifferentiated)
Markham Mill Formation
Prairie Mountain Formation
Upper Wildhorse Mountain Formation
(undifferentiated)
Prairie Hollow Member
Middle and Lower Wildhorse Mountain Formation
(undifferentiated)
?
Chickasaw Creek Formation
Moyers Formation
Feet
14000
13000
12000
11000
10000
9000
8000
7000
6000
5000
4000
3000
2000
1000
EAST END OF SIMMONS MOUNTAIN SYNCLINE
NORTH LIMB OF SIMMONS MOUNTAIN SYNCLINE
Gray to black fissile shale, interbedded buff to gray thin sandstone and siltstone
Thin to massive quartzitic sandstone interbedded with thin fissile black shale
Thin siliceous shale
Fossil-mold sandstones, gray clay shale, exotic boulders, siderite concretions
Black fissile shale, exotic boulders, phosphatic nodules
Black quartzitic massive sandstone
Interbedded thin shales and sandstones
Gray clay shale
Two thin siliceous shales
Gray clay shale with exotic boulders
Gray to buff ridge-forming sandstones interbedded with thin gray shales
Gray sandstones and shales, friable yellow sandstones
Green blocky clay shale, some maroon shale, thin sandstone beds
Gray sandstone and shale
Green blocky clay shale
?
Two siliceous shales, tuff bed, interbedded gray sandstones and shales
Massive gray-green sandstone and olive-green shale

<table>
<tr><th>BELT SOUTHEAST OF CHOCTAW FAULT</th><th>BELT SOUTHEAST OF KATY CLUB FAULT</th><th>BELT SOUTHEAST OF PINE MOUNTAIN FAULT</th><th>BELT SOUTHEAST OF TI VALLEY FAULT</th><th colspan="2">CENTRAL OUACHITAS</th><th>SERIES</th><th>SYSTEM</th></tr>
<tr><td>ATOKA FORMATION</td><td>ATOKA FORMATION</td><td>ATOKA FORMATION
(SPICULITE ZONE
— 200 FEET ABOVE BASE) —</td><td>ATOKA FORMATION
— (SPICULITE ZONE) —</td><td colspan="2">ATOKA FORMATION
— (SPICULITE ZONE) —</td><td>ATOKAN — MORROWAN</td><td>PENNSYL-VANIAN</td></tr>
<tr><td>WAPANUCKA LIMESTONE</td><td>CHICKACHOC CHERT</td><td rowspan="2">SPRINGER FORMATION</td><td rowspan="3">JOHNS VALLEY SHALE</td><td colspan="2" rowspan="2">JOHNS VALLEY SHALE</td><td rowspan="10">CHESTERIAN — MERAMECIAN</td><td rowspan="10">MISSISSIPPIAN</td></tr>
<tr><td>SPRINGER FORMATION</td><td>SPRINGER FORMATION</td></tr>
<tr><td rowspan="8">CANEY SHALE</td><td rowspan="8">CANEY SHALE</td><td rowspan="8">CANEY SHALE</td><td rowspan="5">JACKFORK GROUP</td><td>GAME REFUGE SANDSTONE</td></tr>
<tr><td>WESLEY SHALE</td><td>WESLEY SHALE</td></tr>
<tr><td rowspan="3">JACKFORK SANDSTONE (UNDIFFERENTIATED)</td><td>MARKHAM MILL FORMATION</td></tr>
<tr><td>PRAIRIE MOUNTAIN FORMATION</td></tr>
<tr><td>WILDHORSE MOUNTAIN FORMATION</td></tr>
<tr><td rowspan="3">STANLEY SHALE</td><td rowspan="3">STANLEY GROUP</td><td>CHICKASAW CREEK FORMATION</td></tr>
<tr><td>MOYERS FORMATION</td></tr>
<tr><td>TENMILE CREEK FORMATION</td></tr>
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Figure 3. Correlation of Mississippian and Pennsylvanian units between the central and frontal Ouachita provinces, southeastern Oklahoma. (Modified from Cline, 1960)

divides the frontal belt from the central part, have resulted in the application of different names to rock units of equivalent ages in the two areas (fig. 3). Stanley and Jackfork sediments are recognized only south of the Ti Valley fault, whereas north of the fault they have been correlated with the Caney Shale (Miser and Honess, 1927, p. 12; Cline, 1960, p. 10; Goldstein and Hendricks, 1962, p. 410). Overthrusting of the Ti Valley fault in the critical zone between the frontal belt and the central Ouachitas obscures the exact nature of the stratigraphic change from Stanley-Jackfork to Caney. Certainly thrusting has brought the two facies more closely together than was the case when deposition took place, but no doubt there was also a rapid facies change and pinchout of the thick Stanley-Jackfork geosynclinal sediments into the much thinner Caney Shale to the north. Cline (1960, p. 18-22) showed that sedimentary thinning does take place in the western Ouachitas.

Age determination of the Ouachita sediments has been difficult and controversial because of the absence of fossils and the inability to correlate lithologic rock units from the more fossiliferous shelf deposits in the nearby Arkoma basin into the complexly faulted geosynclinal Ouachita sediments. Most recent workers now agree that the Stanley-Jackfork sequence is Mississippian (Meramecian and Chesterian) in age and that the Mississippian-Pennsylvanian boundary lies within the Johns Valley Shale. Excellent discussions of the history of the age determination of Ouachita rocks, based mostly upon the Johns Valley Shale, which contains an indigenous fauna, may be found in the following references: Tomlinson, 1959, p. 13-16; Elias and Branson, 1959, p. 3-7; Cline, 1960, p. 60-85; Miser and Hendricks, 1960, p. 1829-1832.

Mississippian System

MERAMECIAN SERIES

Stanley Group

Rocks of the Stanley Group are best exposed south of the area of this report and consist predominantly of shale, with lesser amounts of sandstone, that erodes into large anticlinal valleys such as the Kiamichi Valley south of the Windingstair fault. Because no continuous unfaulted section has been discovered, the exact thickness is unknown; however, a maximum thickness of 10,000 to 12,000 feet can be obtained by combining sections. Honess (1924, p. 6) reported 10,000 feet in McCurtain County, Hendricks and others (1947) estimated 12,000 feet in the western Ouachitas, and Laudon (1959) calculated that the Stanley is 11,000 feet thick between the Potato Hills and Kiamichi Mountain.

Most of the Stanley is composed of black, fissile clay shale that weathers to a characteristic olive gray and constitutes 60 to 75 percent of the group. Shale is quantitatively more important in the lower part, but sandstone is more abundant and thicker bedded in the upper part, where it is estimated to make up 35 to 40 percent of the section. The sandstones are generally fine grained, argillaceous, and dirty, in many places containing shale fragments and plant debris. Goldstein and Hendricks (1962, p. 392) stated that the average Stanley sandstone, on the basis of mineralogic composition, is a subgraywacke, but texturally it may be considered a graywacke because of its "mud" matrix. Normally the sandstone beds, a few inches to a few feet thick, alternate regularly with beds of shale; but bundles of sandstone units up to 20 feet are common, particularly in the Moyers Formation, which also displays some fairly clean, quartzose sandstone units that are difficult to differentiate from the overlying Jackfork sandstones.

The diagnostic olive green of weathered shale; the dirty, argillaceous, easily weathered sandstone; and the occurrence of tiny white specks, probably weathered feldspar grains, in most Stanley sandstones all contribute to the easy recognition of Stanley sediments in field observations.

The Stanley Group comprises in ascending order the Tenmile Creek, Moyers, and Chickasaw Creek Formations. Hass (1950, p. 1578), who studied a collection of conodonts from the lower part of the Stanley, determined they were Meramecian in age, correlative with the Caney Shale.

Moyers Formation

The Moyers Formation is the lowest stratigraphic unit definitely recognized and then only because it lies below the siliceous shale of the Chickasaw Creek Formation. The Tenmile Creek Formation possibly exists in the Stanley, mapped as undifferentiated south of the Windingstair fault (pl. I), but could not be determined with certainty in this structurally complex part of the Ouachitas because of inability to find the thin siliceous shales that mark boundaries of Stanley formations.

History of nomenclature.—Harlton (1938, p. 870) named the formation from two exposures, one north of Moyers, Oklahoma, in T. 2 S., R. 16 E., and the other in sec. 26, T. 1 S., R. 12 E., both in the western part of the Ouachita Mountains.

Distribution.—The Moyers Formation is best exposed in limited areas along the lower slopes of the east end of the Simmons Mountain syncline, a large synclinal structure which dominates the mapped area. The name is taken from a prominent mountain which was formed by upturned resistant Jackfork sandstones on the east end of the syncline. Three other small outcrops of Moyers rocks are in secs. 16, 22, T. 3 N., R. 23 E., on both flanks of a tightly compressed syncline formed by northeastward thrust movement of the Windingstair fault. Recognition of Moyers sediments is based entirely upon their stratigraphic position below the Chickasaw Creek Formation and their upward transition into thick, clean, quartzose sandstone beds of the Jackfork Group.

Character and thickness.—The Moyers Formation consists of interbedded greenish-gray argillaceous sandstone, dark-gray more resistant sandstone, and olive-gray shale. The formation is more sandy and thicker bedded near the top. The shales are clayey, flaky, and splintery and split into thin, smooth conchoidal fragments that are so characteristic of Stanley shales throughout the Ouachitas. Because the Moyers Formation contains thick, resistant sandstone beds, in many places it forms the lower slopes of synclinal mountains above the less resistant valley-forming Tenmile Creek Formation. Erosional weathering sculptures the Moyers into fluted terraces and ledges that are easily recognized and traced on aerial photographs. R. C. Morris (oral communication) found that the ledge-and-terrace topography of the Moyers continues into Arkansas. Although sole markings, particularly flute casts, are relatively few in most Stanley sediments as compared with Jackfork and Atoka rocks, the Moyers Formation commonly contains them.

The siliceous shale reported at the base of the Moyers in the type locality, in other areas of the central Ouachitas, and at the base of Rich Mountain to the east of the study area (Seely, 1962, p. 15) was not found because everywhere the base of the formation is truncated by faults. It is probably present in the sequence, however, because it crops out in the nearby Rich Mountain syncline, which is both structurally and stratigraphically similar to the Simmons Mountain syncline.

Thickness of the Moyers Formation in the type section was reported to be 1,100 feet. Cline (1960, p. 36) stated that it is 1,700 feet thick in the Tuskahoma syncline, and Seely (1962, p. 15) estimated that it is about 1,000 feet thick in the Rich Mountain syncline. Its thickness in the report area is unknown because of faulting, but a maximum of about 1,200 feet is exposed on the east end of the Simmons Mountain syncline.

Chickasaw Creek Formation

History of nomenclature.—Harlton (1938, p. 874) named the Chickasaw Creek Formation from a locality near Chickasaw Creek in sec. 7, T. 1 S., R. 13 E., Atoka County, Oklahoma.

Distribution.—The Chickasaw Creek Formation is exposed most extensively around the east end of the Simmons Mountain syncline above Moyers strata but is also present in three small outcrops near the west end of the syncline in secs. 16, 22, T. 3 N., R. 23 E., where, like Moyers rocks, it is present on both flanks of a small tightly folded syncline. Outcrops also may be found on the west end of the Rich Mountain syncline, but these are poorly exposed and difficult to find. Good exposures are few but the best locality is in a creek bed up the steep eastern flank of the Simmons Mountain syncline near the north end of the north-south line between secs. 10 and 11, T. 2 N., R. 25 E. Here two siliceous shales crop out with fair exposures of intervening strata.

The Chickasaw Creek Formation is one of the more valuable marker beds in the entire Ouachita clastic sequence, and its persistently widespread character has aided in correlation throughout a large part of the Ouachita Mountains. It has been reported in the following areas by various workers: Tuskahoma and Prairie Mountain synclines (Harlton, 1938); western frontal belt (Hendricks and others, 1947); Lynn Mountain syncline (Cline, 1960); Boktukola syncline (Shelburne, 1960); Kiamichi Valley (Laudon 1959); Buffalo Mountain (Fellows, 1962); Rich Mountain syncline (Seely, 1962); Acorn and Y City quadrangles, Arkansas (Morris, 1962); and southern Ouachitas by several students from The University of Oklahoma.

Character and thickness.—Rocks of the Chickasaw Creek Formation, as exposed in the best locality, mentioned above, predominantly consist of thin, black to dark-gray shales interbedded with thin, dense, quartzitic, black sandstone beds. Two siliceous shales crop out here. The lower one is a 2-foot bed of black bedded chert associated with black siliceous shale and rests directly on a massive sandstone bed 20 feet thick, considered here as the top of the Moyers Formation. The second siliceous shale bed is about 75 feet higher, where it consists of a 3-foot bed, the lower half of which is thin, platy, dense black shale, and the upper half is black bedded chert in 2- to 3-inch beds. Intervening beds consist of dirty, argillaceous, gray sandstone beds 2 to 3 feet thick with small weathered feldspar specks as in other Stanley sandstones, and of thin, dense black sandstones and dark-gray hard shale. Ten feet above the lower siliceous shale is a zone of thinly laminated, gray, carbonaceous, spiculitic soft siltstone. In this section the tuff bed, present in other Chickasaw Creek outcrops in the area, is not exposed.

In contrast to their appearance in other areas of the Ouachitas, the siliceous shales of the Chickasaw Creek in the report area lack the distinctive white specks. Seely (1962, p. 18-20) also was unable to find the large white specks in siliceous shales of the Chickasaw Creek in the Rich Mountain area, but he did report some small specks, generally less than 0.1 mm in diameter, from the upper of two siliceous shales in the Eagle Gap syncline. It is interesting that two siliceous shale zones have been described in the Chickasaw Creek Formation from elsewhere but separated by different thicknesses of sediments. Along the lower slopes of Kiamichi Mountain, Cline and Moretti (1956, p. 10) found 2 such beds 209 feet apart; Shelburne (1960, p. 73, 75) in the Boktukola syncline measured about 25 feet between 2 siliceous shales; and Seely (1962, p. 19-20) estimated an interval of roughly 250 feet between 2 siliceous shale zones in the Rich Mountain area. In the report area, however, the two zones are only about 75 feet apart. The wide differences in interval between the various reported siliceous zones suggest either a highly variable rate of deposition during Chickasaw Creek time or that more than two units are involved. In either case the problem has resulted in inconsistent determination of the top and the bottom formational boundaries. For convenience in mapping, the writer chose the two siliceous shale zones to mark the top and the bottom contacts of the Chickasaw Creek Formation even though the result-ing unit is only about 75 feet thick. Elsewhere in the mapping area, such as secs. 16, 22, T. 3 N., R. 23 E., and secs. 27, 28, T. 3 N., R. 25 E., only one siliceous shale could be found, but the general stratigraphic position and upward gradation into Jackfork sandstones established its identity.

Further proof that the 2 siliceous shale zones are indeed Chickasaw Creek is the occurrence of an 8- to 10-foot tuff or tuffaceous sandstone bed between the two siliceous shales both in the Rich Mountain area (Seely, 1962, p. 19) and in the Simmons Mountain syncline of this study. It is a massive, gray-green to dark-gray, dense bed when fresh and contains large light-colored grains up to 2 mm across, which give it a spotted appearance. In thin section the large grains were identified as quartz and weathered plagioclase feldspar within an angular fine-grained matrix. Weathering had completely altered some grains to clay minerals, whereas others were altered only around the edges. Devitrified glass shards identified in the matrix are proof of its volcanic origin; however, grains such as biotite, muscovite, zircon, and quartz were probably incorporated in the airborne volcanic debris as it settled to the ocean floor. X-ray analysis of one relatively fresh sample showed that it contained quartz and the clay mineral kaolinite (analysis made by George Asqueth, University of Wisconsin). Outcrops are normally poor because of susceptibility of the Chickasaw Creek to weathering, but the best exposures are in SW¼ SW¼ sec. 9, T. 2 N., R. 25 E., and near C S½ NE¼ sec. 10, T. 2 N., R. 25 E. Other tuff beds have been described from Stanley rocks. Honess (1923, p. 144) mapped a persistent lower Stanley tuff (Hatton tuff) in the southern Ouachitas, Cline (Cline and Shelburne, 1959, p. 182) found two thinner beds he believed to be tuffs on the north side of the Choctaw anticlinorium, and Shelburne (1960, p. 18) found westward extensions of tuffs mapped by Honess.

Lenses of chert conglomerate, chert pebbles, cobbles, and boulders reported in the Chickasaw Creek Formation elsewhere were not noted in this study.

MERAMECIAN AND CHESTERIAN SERIES

Jackfork Group

Jackfork rocks in the central Ouachitas consist of about 5,600 to 6,000 feet of alternating sandstones and shales that conformably overlie the Stanley Shale, but in the report area the Jackfork Group has a maximum thickness of about 8,000 feet. Its lower boundary is considered here to be the top of the upper siliceous shale of the Chickasaw Creek Formation in keeping with Harlton's definition (1938, p. 874-878). Hendricks and others (1947) preferred to place the contact below the two siliceous shales where a pronounced change in sandstone lithology occurs. The upper contact is at the base of the Johns Valley Formation. Taff (1902, p. 4) first named the Jackfork and considered it a formation, but Harlton (1938) raised it to group rank, dividing it from base upward into Wildhorse Mountain, Prairie Mountain, Markham Mill, and Wesley Formations, based upon thin persistent siliceous shales. Other workers have retained Jackfork as a formation because it cannot be subdivided in intensely faulted areas, particularly where the exposures do not contain one of the siliceous shale marker units (Hendricks and others, 1947). It became apparent that a similar situation exists in part of the area of this report but that the northern flank of the Simmons Mountain syncline contains almost a complete sequence of Jackfork rocks in which some of Harlton's formations can be recognized. Nevertheless, it was necessary to map as undifferentiated the upper part of the Wildhorse Mountain, the Prairie Mountain, and the Markham Mill Formations because the siliceous shales that divide them in the type section could not be definitely identified here. The Game Refuge Sandstone, which Harlton first called "Union Valley," was not originally placed in the Jackfork Group but is now included just above the Wesley Shale. The Game Refuge could be differentiated from the Wesley in the good exposures along State Highway 103, but elsewhere the two could not be separated; hence, for convenience they were mapped as undifferentiated. Generally sandstone is the prevailing rock type in the Jackfork Group, but interbedded, dark-gray shales make up to 50 percent of the section in some horizons. Consistent with exposures in other areas, massive resistant sandstones constitute a large part of upper part of the Wildhorse Mountain Formation and of the Prairie Mountain Formation near the middle of the group and are largely responsible for the high linear ridge known as Winding Stair Mountain. Because most Jackfork sandstones are cleaner, less argillaceous, better sorted, and coarser grained than the average Stanley sandstones, their differentiation in the field is readily ascertained. However, distinction of Jackfork from some Atoka sandstones is not so easy and requires careful scrutiny of structural and stratigraphic relationships. For the best description of the entire Jackfork Group, the reader is referred to the two complete Jackfork sections of Cline and Moretti (1956).

The Jackfork Group thickens from its minimum development in the northwesternmost belt of outcrop (Hendricks and others, 1947) to about 6,000 feet in the central part of the Ouachitas (Cline and Moretti, 1956). Thickening northeastward along structural and stratigraphic strike from its minimum thickness of 1,150 to the area of this study was also noted. In fact the group is considerably thicker than is reported elsewhere. Thickness, calculated from measurements of aerial photographs and observed dips of the section, from the lower part of the Wildhorse Mountain Formation, where it is truncated by the Briery fault, to the top of the Game Refuge Formation is about 8,060 feet.

Dips for the calculations were taken from exposures in the road in secs. 8, 9, 16, T. 3 N., R. 24 E., which crosses much of the Jackfork section. Only thick massive sandstone beds were measured to minimize the effect of creep. The beds dip rather consistently about 70 degrees to the south, top side up. The estimated thickness of 8,060 feet is only an approximation but is nevertheless as correct as the data permit.

The 8,000-foot Jackfork thickness is probably a minimum because an unknown amount has been cut off the lower part of the Wildhorse Mountain Formation. If the measured thickness of Wesley-Game Refuge exposures on State Highway 103 (1,421 feet) were substituted for the photographic measurements of this part of the sequence, the total exposed Jackfork thickness would become about 8,348 feet.

The age of the Jackfork Group is considered Mississippian (Meramecian and Chesterian) by most recent workers.

Lower and Middle Parts of the Wildhorse Mountain Formation

History of nomenclature.—The Wildhorse Mountain Formation was named for outcrops on Wildhorse Mountain in Pushmataha County, Oklahoma, by Harlton (1938, p. 878). Harlton regarded his Prairie Hollow Shale Member as a unit of the Prairie Mountain Formation. However, Cline (1956, p. 101) found it to be in the type locality of the Wildhorse Mountain Formation. It is here considered to be the Prairie Hollow Member of the Wildhorse Mountain Formation.

Distribution.—The Wildhorse Mountain Formation is extensively exposed in the report area along the highest ridge-forming elevations of the Simmons Mountain syncline. Its lower boundary is marked by the upper siliceous shale of the Chickasaw Creek in the eastern part of the syncline, but along the north flank, its lower part has been cut off by the Briery fault. On the geologic map (pl. I), the lower and middle parts of the Wildhorse Mountain and the Prairie Hollow Member have been delineated, but the upper part of the formation has been included with Prairie Mountain and Markham Mill Formations as an undifferentiated unit because the basal siliceous shale of the Prairie Mountain of the type section was not found. The Prairie Hollow Member, one of the better stratigraphic marker beds, is well exposed for several miles on the crest of Winding Stair Range in borrow ditches of Skyline Drive that winds the entire length of the range from State Highway 103 westward to U. S. Highway 271. This crestal position is in contrast to other areas where the soft shales of the Prairie Hollow Member weather into prominent strike valleys (Cline, 1960, p. 27). A small sliver of green shale of the Prairie Hollow is just south of the Briery fault along the road near the south center of sec. 22, T. 3 N., R. 25 E. The large anticlinal drag fold in secs. 27, 28, T. 3 N., R. 25 E., on which the Winding Stair fire tower is located, is well outlined on the geologic map by the Prairie Hollow Member.

Character and thickness.—No well-exposed sections of the part of the rock sequence occur below the Prairie Hollow, but the best outcrops may be seen in sec. 34, T. 4 N., R. 23 E., in weathered cuts of a road that runs from Holson Valley road up to Skyline Drive on Winding Stair Mountain. Within these deposits is exposed a green clay shale about 1,000 feet below the Prairie Hollow Member and resembles it in almost every respect. Because it has not been reported elsewhere, it is here included in the lower part of Wildhorse Mountain Formation. Its sinuous outcrop pattern near the trace of the Briery fault makes exact distance below the Prairie Hollow Shale difficult to determine, but it ranges from about 600 feet to 1,500 feet. This range may be only apparent owing to contortion and small-scale faulting associated with the Briery fault. Thickness of the shale also ranges roughly from 350 to 500 feet for the same reasons, whereas the Prairie Hollow Member above ranges from 300 to 700 feet in thickness. Apparently both thin to the east. The lower shale is faulted out in sec. 12, T. 3 N., R. 24 E. The Prairie Hollow Member continues east and is exposed along a road in sec. 17, T. 3 N., R. 25 E., but it too is faulted out about half a mile farther east. The Prairie Hollow Shale crops out again farther southeast in the anticlinal drag fold in secs. 27, 28, T. 3 N., R. 25 E. The lower green shale was not found because thinning and eventual pinch-out had probably terminated it. A good exposure of Prairie Hollow Shale is along the road in SE¼ sec. 35, T. 3 N., R. 25 E.

The Prairie Hollow Shale and the lower shale are almost identical lithologically. They consist of poorly fissile to blocky green, and more rarely maroon, clay shale in beds up to 15 feet thick, interbedded with olive-green to yellow, silty, fine-grained sandstones in beds 6 inches to 1 foot thick. The sandstones commonly contain weathered feldspar grains visible on the surface. Some shale units contain thin silty sandstones one to two inches thick. Weathering of the shales produces a brilliant rust-red clay soil, and the sandstones easily weather into friable, smooth-surfaced fragments. Goldstein and Hendricks (1962, p. 397) stated that the sandstone and siltstone associated with the maroon shale of the Prairie Hollow are more feldspathic than the bulk of the Jackfork sandstones. Along with high argillaceous content, feldspar content probably causes sandstones in this part of the sequence to weather readily into soft, friable, pinkish fragments that are so characteristic of this part of the section.

The lower part of the Wildhorse Mountain Formation, below the Prairie Hollow Member, consists of at least 2,780 feet of interbedded gray shale, friable, buff to mustard-colored, argillaceous sandstone, and some quartzitic sandstone along the north slope of Winding Stair Mountain. On the other hand, this part of the section is only about 1,250 feet thick around the east end of the Simmons Mountain syncline, where it overlies the Chickasaw Creek Formation. Marked northward thickening of the lower part of the Wildhorse Mountain is thus indicated, whereas a rather constant thickness of about 1,700 feet was reported for this part of the section in the central Ouachitas by Cline and Moretti (1956) and Shelburne (1960, p. 27).

Upper Part of Wildhorse Mountain—Prairie Mountain—Markham Mill Formations (undifferentiated)

History of nomenclature.—Nomenclature of the Wildhorse Mountain Formation is discussed above. Prairie Mountain and Markham Mill Formations were also named by Harlton (1938, p. 880-884) from exposures on Prairie Mountain in the extreme western Ouachitas in Atoka County.

Distribution.—Distribution of the upper part of the Wildhorse Mountain Formation and the Prairie Mountain and Markham Mill Formations is essentially the same as that for the lower part of Wildhorse Mountain and Prairie Hollow Member, discussed above. A large part of the Simmons Mountain syncline, both the east and west ends and the north flank along the south slope of Winding Stair Mountain, is composed of thick massive quartzitic sandstones of these formations. The best exposures are along weathered cuts of a road in secs. 8, 9, 16, T. 3 N., R. 24 E. Failure to recognize with certainty either the thin basal siliceous shale of the Prairie Mountain or the basal siliceous shale of the Markham Mill that characterize the type sections led the writer to map these formations as one unit. Lithology of the sequence as a whole is relatively uniform so that, without the siliceous shale marker beds, differentiation was impossible. The thin siliceous shales of the Jackfork Group apparently are not so widespread as are those in the Stanley Group. Cline and Shelburne (Cline, 1960, p. 53, 55) also were unable to find the basal siliceous shale of the Prairie Mountain, and Cline could not trace the siliceous shale of the Markham Mill east of the Indian Service road in the Lynn Mountain syncline. Seely (1962, p. 29) was unable to find either siliceous shale but arbitrarily placed the upper boundary of the Wildhorse Mountain Formation at the top of a sandstone zone. In this study the top boundary of the Markham Mill Formation is chosen above an easily traceable ridge-forming sandstone zone below the less resistant valley-forming shales and thin sandstones of the Wesley Formation.

Character and thickness.—The base of what may be considered the upper part of Wildhorse Mountain Formation contains a series of resistant, gray to buff, quartzitic sandstone zones up to 50 feet thick, with individual beds 1 to 4 feet thick. These ridge-forming sandstones support the underlying Prairie Hollow Shale along the crest of Winding Stair Mountain. Intercalated are dark-gray shales, in subequal amounts, some of which are silty and locally contain thin siltstone stringers. The rest of the sequence to the top of the Markham Mill Formation is topographically dominated by thick sandstone bundles, but shale beds are probably more numerous than would appear from surface observation. The sandstones are generally fairly clean and quartzitic, and many beds have large flute and groove casts on bottom surfaces. They weather from reddish brown to white depending upon iron-oxide content. Upon close examination tiny rust-colored specks are visible in some, probably formed by oxidation of pyrite grains. Lower contacts with shales are sharp, whereas many upper contacts are fuzzy, grading imperceptibly upward into finely laminated, argillaceous siltstones and finally into fissile shale. This type of graded bedding is common in Ouachita sandstones. Thin shaly units between thicker sandstones are in many cases no more than fissile siltstones containing much muscovite and weathering light gray to lavender. Carbonaceous plant fragments, small clay galls, and worm trails characterize the upper surfaces of some sandstone beds.

Approximately 550 feet below the top is a 2-foot zone of cherty black siliceous shale in beds 1 to 2 inches thick, best exposed on the apex of a hairpin turn in the road in NE cor. sec. 16, T. 3 N., R. 24 E. It weathers into the rhombohedral blocks so characteristic of other Ouachita siliceous shales and contains tiny white specks, but the specks are not so large as those in Chickasaw Creek siliceous shales. This thin unit was traced and mapped completely around the exposed Jackfork sediments of the Simmons Mountain syncline (pl. I) and possibly could be correlative with the basal siliceous shale of the Markham Mill Formation in the type section. Nevertheless, this relationship could not be established with certainty because in the Markham Mill type section Harlton (1938, p. 884) described a 15- to 20-foot siliceous shale, whereas this one has a maximum thickness of 2 feet. About 150 feet lower is a second siliceous shale. The writer, therefore, could not determine which of the two siliceous shales is the equivalent of Harlton's basal siliceous shale of the Markham Mill.

The lower of the two siliceous shales is about 10 feet thick and consists of dull-black, platy siliceous shale that splits into thin sheets ⅛ inch thick and weathers rust red on the surface. Immediately below the dull-black siliceous shale, also along the same road, is a 40-foot weathered gray clay shale containing many exotic cobbles of bedded chert, which are incorporated randomly in the shale and are markedly different from other Ouachita rocks of this area. The cobbles characteristically have a white rind ¼ inch to 1 inch thick, which surrounds black chert, and are commonly weathered differentially along bedding laminations. They are remarkably similar to Wesley cobbles described by Goldstein and Hendricks (1962, p. 395) and probably had the same source. Cobbles and boulders of this kind up to 4 by 4 feet were also found in the same general stratigraphic position near SE cor. sec. 3, T. 3 N., R. 23 E., associated with other exotic cobbles composed of black chert. Harlton (1938, p. 885) made a brief comment about lenses of cherty conglomerate near or at the base of the siliceous shale of the Markham Mill. He also remarked that the boulders were dropped into the sea and called them "erratics" (p. 886). Possibly the exotics in the Simmons Mountain syncline correspond to those found by Harlton; if so, it is logical to assume that the two zones are correlative.

The upper 373 feet of the upper part of the Wildhorse Mountain-Prairie Mountain-Markham Mill section is well exposed along State Highway 103. Well-developed sole markings are common (fig. 4). For more detailed description, see the stratigraphic section

Figure 4. Flute and groove casts on the lower surface of a sandstone bed in the Markham Mill Formation along a road cut on State Highway 103 in NE¼ SE¼ sec. 26, T. 3 N., R. 25 E.

in the appendix. The approximate thickness of strata from the Prairie Hollow Member to the top of Markham Mill Formation is 4,145 feet, as determined from aerial photographs.

Wesley—Game Refuge Formations (undifferentiated)

History of nomenclature.—The Wesley Formation was named by Harlton (1938, p. 886) from exposures southwest of Wesley, Atoka County, Oklahoma, in sec. 20, T. 1 N., R. 13 E; he also named the overlying Game Refuge Formation from outcrops in the Clayton Game Refuge, Pushmataha County, Oklahoma (Harlton, 1959, p. 132). He had previously considered sandstones above the Wesley as correlatives of the Morrowan Union Valley Formation in the Arbuckle Mountains and consequently extended the name Union Valley into the Ouachitas. Cline (1956, p. 103), however, pointed out that the overlying Johns Valley Formation was, in part, Mississippian in age and that the underlying sandstones could not possibly be Morrowan in age, and, therefore, could not be correlative with the Union Valley Formation. Harlton concurred in this opinion and chose the new name, Game Refuge.

Distribution.—Wesley-Game Refuge sediments are mapped as undifferentiated mainly because the siliceous shale, so diagnostic of the upper part of the Wesley elsewhere, was not found. In the well-exposed upper Jackfork sequence along State Highway 103, the Game Refuge may be arbitrarily divided from underlying Wesley based on 2 massive thick sandstones 95 and 75 feet thick. This distinction, nevertheless, could not be made in the field; so for convenience the two were mapped as one unit. By far the best exposures are in State Highway 103 road cuts and along Big Cedar Creek, sec. 26, T. 3 N., R. 25 E., and reveal the entire Wesley-Game Refuge rock section in the steeply dipping south flank of the Spring Mountain syncline. The Briery fault truncates the sequence in sec. 22 T. 3 N., R. 25 E. Extensive exposures are on both flanks of the Simmons Mountain syncline. Sycamore and Billy Creeks follow the valley-forming sequence on the north flank, and the Windingstair fault truncates it on the south flank.

Cline (1960) and Shelburne (1960) recognized and mapped the Wesley and Game Refuge Formations in Lynn Mountain and Boktukola synclines, respectively. Hendricks and others (1947) recognized rocks of both formations in the western Ouachitas but did not use Harlton's names. Seely (1962) recognized Game Refuge but mapped Wesley undifferentiated from the Prairie Mountain and Markham Mill Formations. Morris (1962) was able to differentiate both formations in Arkansas.

Character and thickness.—In the measured section of the Spring Mountain syncline, the Wesley-Game Refuge sediments are characterized by a remarkable rhythmical alternation of dark-gray to black, thin, quartzitic sandstones and black, hard, platy shales, probably somewhat siliceous (fig. 5). The basal contact is chosen at the bottom of a 165-foot dark-gray to light-brown, hackly clay shale which rests directly upon sandstones of the upper part of the Markham Mill Formation. Above the shale is about 40 feet of thick sandstones overlain by another shale bed about 100 feet thick. The upper part of this shale is covered. Balled or rolled sandstone masses are incorporated in both shales. The rest of the section, upward to the thick sandstones that may be Game Refuge, consists predominantly of dark-gray quartzitic sandstones up to 24 feet thick, but mostly 1 foot and less thick, intercalated with black silty shales of subequal thicknesses. At many places the shales contain hundreds of thin siltstone stringers commonly less than ½ inch thick (fig. 6). These may be similar to what Shelburne (1960, p. 31) ascribed to

Figure 5. Rhythmically alternating thin sandstones and shales in the Wesley-Game Refuge unit in Big Cedar Creek along State Highway 103 in NE¼ SE¼ sec. 26, T. 3 N., R. 25 E.

upper Wesley in the Boktukola syncline. Sole markings such as flute and groove casts are abundant and well developed. Clay galls and carbonaceous matter are common.

The 95- and 75-foot dark-gray, massive, quartzitic sandstone beds are separated by 19 feet of gray contorted clay shale. Approximately 200 feet of strata above the massive sandstones are also assigned to this unit and are similiar in lithology to the rest of the section. Apparently the upper contact is gradational with lower Johns Valley Shale, but much of the critical horizon is poorly exposed.

Chert conglomerates, chalcedonic masses, and exotic boulders reported by Harlton (1938, p. 888) and Hendricks (1947, p. 17) were not found, but Seely (1962, p. 33) found them in Rich Mountain and used them to correlate the soft shale in which they occur with the Wesley Shale. Cline and Shelburne (1959, p. 192-193) indicated that the Game Refuge is characterized by zones of limonitic sandstone containing molds of plants and marine invertebrates. Beds along State Highway 103 assigned to this interval do not conspicuously contain fossil molds, but some molds were noted in SW¼ sec. 25, T. 3 N., R. 24 E.

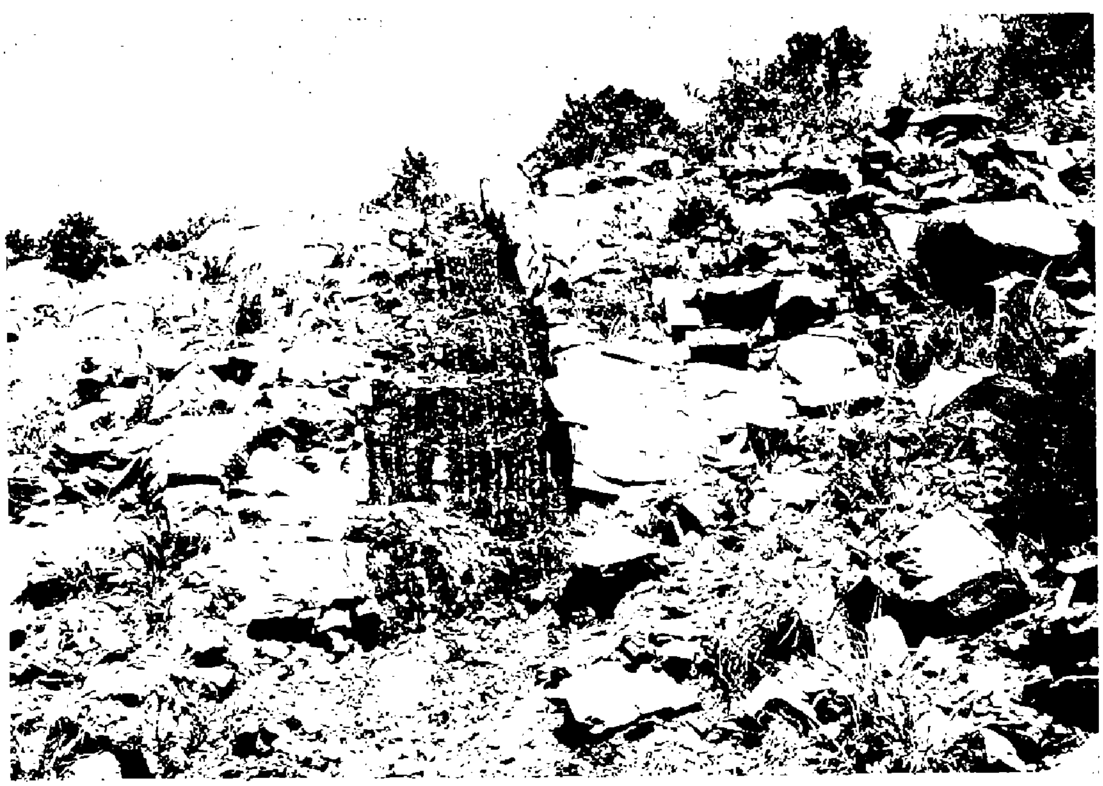


Figure 6. Thin siltstone stringers ½ to 1 inch thick in black shales of the Wesley-Game Refuge unit in a road cut on State Highway 103 in SE¼ NE¼ sec. 26, T. 3 N., R. 25 E.

Outcrops of Wesley-Game Refuge rocks are poorly exposed elsewhere in the report area. The thin sandstones and shales weather easily, developing into valleys. The easily eroded overlying Johns Valley Shale is also a valley former. At a few places along the lower slopes of the north limb of the Simmons Mountain syncline, the upper massive sandstones of the Game Refuge form a conspicuous ridge between the soft shales of the Johns Valley and the sandstones and shales of the Wesley, but the ridges cannot be traced along structure for any distance.

The thickness of the Wesley-Game Refuge sediments, as measured in the described section, is 1,421 feet. Faulting is present at some horizons but probably little duplication or elimination of section occurs.

Mississippian-Pennsylvanian Rocks

CHESTERIAN AND MORROWAN SERIES

Johns Valley Formation

History of nomenclature.—Ulrich (1927, p. 21) named the Johns Valley Formation from exposures in the Tuskahoma syncline, T. 1 S., R. 16 E. The formation had been previously named Caney by Taff (1901), who had failed to designate a type section. Ulrich proposed the name Johns Valley because he believed it to be Pennsylvanian in age and younger than Caney, which in the Arbuckle Mountains is of Mississippian age. He explained the Mississippian fossils in the Ouachita Caney as exotics eroded from rocks of Mississippian age and deposited in the Pennsylvanian sea. Fossils of Mississippian age in Johns Valley Shale are now known to be indigenous. Harlton (1938, p. 896) introduced the name Round Prairie Formation to eliminate confusion arising from using the names Caney and Johns Valley to represent the same strata, but recent workers have not accepted the term, preferring instead to retain the name Johns Valley. Elias and Branson (1959) designated a new Caney Shale type section in the Arbuckle Mountains area, proposed to abandon the original type locality in the Ouachitas, but suggested leaving the exotic-bearing shales under the name Johns Valley.

Distribution.—The Johns Valley Formation is exposed in numerous areas throughout the mapped region. It crops out most extensively around the east and the west ends and along the north and the south flanks of the Simmons Mountain syncline. The belt of exposures on the south limb is narrow and sinuous because it marks the trace of a fault. Exposures along State Highway 103 are part of a belt in the south flank of the Spring Mountain syncline that is truncated by the Briery fault in secs. 21, 22, T. 3 N., R. 25 E. Along the north slope of Winding Stair Mountain, the Johns Valley crops out immediately north of the Briery fault. Exposures in the valley west of the Stapp syncline near Stapp are characterized by structural complexity but continue westward for about five miles and mark the trace of the Stapp fault. Another narrow exposure was discovered in a fault slice along and near the east-west line between Tps. 3, 4 N., R. 24 E. Two tightly folded synclines south of the west end of the Simmons Mountain syncline contain Johns Valley outcrops around their arcuate structural outlines.

Outcrops of the Johns Valley Shale containing exotic boulders have been found in a strip 25 miles wide and 125 miles long as far west as Atoka, Oklahoma, and as far east as Boles, Arkansas. The Johns Valley Shale is not mapped north of the Ti Valley fault, but Cline (1960, p. 63) reported limestone exotics in the Springer Formation north of the Ti Valley fault, as mapped by Hendricks and others (1947), which he believed is correlative to some part of the Johns Valley Formation. Within the frontal belt Seely (1962) and Morris (1962) mapped Johns Valley Shale about 40 miles into Arkansas. South of the frontal belt the Johns Valley was mapped in the Lynn Mountain syncline by Cline (1960) and in the Boktukola syncline by Shelburne (1960), but they were unable to find the exotic boulders so common in the frontals. Other workers from The University of Oklahoma have recently traced the formation farther south to the Cretaceous overlap.

Character and thickness.—The lower boundary of the Johns Valley sediments is in depositional contact with beds of the upper part of the Game Refuge in this area, although Goldstein and Hendricks (1962, p. 398) stated that in the northwestern Ouachitas the Johns Valley ". . .overlaps strata in the upper part of the Jackfork Sandstone and rests on beds as much as 500 feet below the top of the Jackfork." That Atoka deposits conformably overlie Johns Valley beds is clearly demonstrated along State Highway 103 (fig. 7B) and along a road near C S½ SW¼ sec. 15, T. 3 N., R. 24 E.

The basal part of the Johns Valley consists of black, platy, fissile shale containing marblelike phosphatic nodules, large black limestone concretions, and exotic boulders, and closely resembles typical Mississippian Caney lithology; whereas the upper part consists of units of lighter gray, less fissile, exotic-bearing clay shale, in places alternating with thin sandstones. The above differentiation, however, is not everywhere apparent but is best shown in a small fault slice in C sec. 14, T. 3 N., R. 23 E., where the lower exotic-bearing black shale is separated from the upper gray shale by a thin sequence of interbedded sandstone and shale. Elsewhere, such as the exposures along State Highway 103, the lower black shale unit apparently is absent although the lower part is poorly exposed at this locality. Development of sandstones in deposits that both Seely (1962, p. 40) and the writer assigned to the Johns Valley Formation is well shown in a road cut along U. S. Highway 270 near the middle of the line between the NE¼ and SE¼ sec. 12, T. 3 N., R. 25 E. Sandstones in this cut are slightly overturned and exhibit excellent development of large flute casts, but their exact stratigraphic position within the Johns Valley is in doubt because of structural complexity. The sandstones resemble those in the Atoka; however, their assignment to the Johns Valley Formation gives the simplest structural interpretation.

Exotic boulders incorporated in the clay shales of the Johns Valley Formation are its most distinguishing characteristic in the report area and immediately catch the eye of the field observer. Almost all exposures contain exotics so that recognition of Johns Valley deposits is easy.

Excellent exposures of exotic boulders up to 15 feet in maximum dimension are along U. S. Highway 270 at the north end of the road cut discussed above and are those described by Harlton (1938, p. 893-895). A shale pit approximately 200 yards west of the road cut also contains large limestone exotics up to six feet in diameter. Some of the boulders are coarse conglomerate (fig. 7A) and strongly resemble the Stapp Conglomerate described by Harlton (1938, p. 889-895) from railroad cuts in SW¼ sec. 7, T. 3 N., R. 26 E. The writer is in agreement with Seely (1962, p. 40-43) that the Stapp Conglomerate probably is the upper part of the Johns Valley.

Exotic boulders composed of angular black chert, ocher-colored silty sandstone, and various types of limestone are also well exposed in the upper 100 feet of a broad road cut of State Highway 103 (unit

A. Coarse conglomerate exotic boulders that resemble the Stapp Conglomerate in the Johns Valley Shale in a road cut along U. S. Highway 270 near the middle of the line between NE¼ and SE¼ sec. 12, T. 3 N., R. 25 E. One large exotic boulder is shown in the center of the picture and another one in the lower right corner.

B. Johns Valley Shale with limestone and chert exotic boulders in a road cut along State Highway 103 in NE¼ NE¼ sec. 26, T. 3 N., R. 25 E. A four-foot limestone exotic boulder is shown in the center of the picture above the top of the jeep. The conformable upper contact with the Atoka Formation is near the top of the cut.

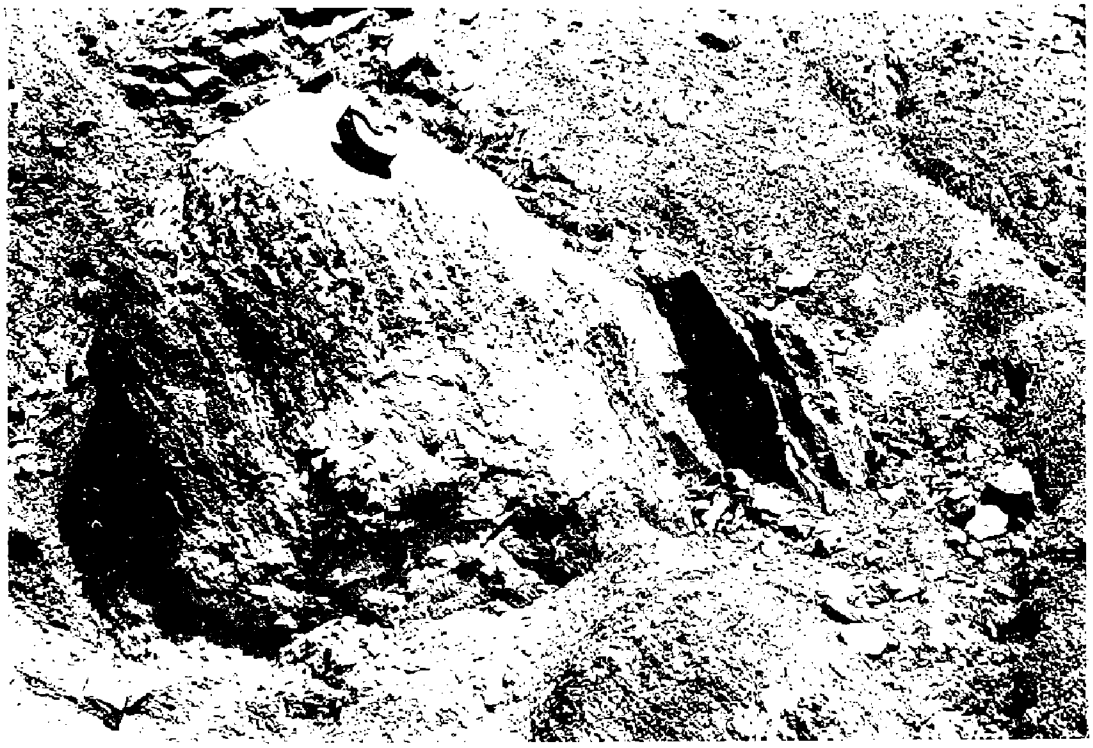
Figure 7. Exotic boulders in the Johns Valley Shale.

146 of the stratigraphic section) in NE¼ NE¼ sec. 26, T. 3 N., R. 25 E., (fig. 7B). The largest are limestone blocks up to four feet in maximum dimension, are randomly oriented in respect to bedding of the enclosing shale, and show definite effect of solution prior to deposition (fig. 8A). Throughout the map area almost every outcrop of the Johns Valley Shale shown on the geologic map (pl. I) has exotic boulders of various rock types. Some of the larger boulders were found in steep stream beds which cross the belt of the Johns Valley along the north slope of Winding Stair Mountain. One such stream bed in SE¼ NW¼ sec. 35, T. 4 N., R. 23 E., contains sandy, oölitic, fossiliferous limestone boulders up to 20 feet in maximum dimension that strongly resemble the Wapanucka Limestone that crops out to the northwest in the frontal Ouachitas. Concentration of boulders occurs randomly throughout both the lower black shale and upper gray shale, and the so-called lower boulder bed and upper boulder bed described in other areas could not be recognized in this study.

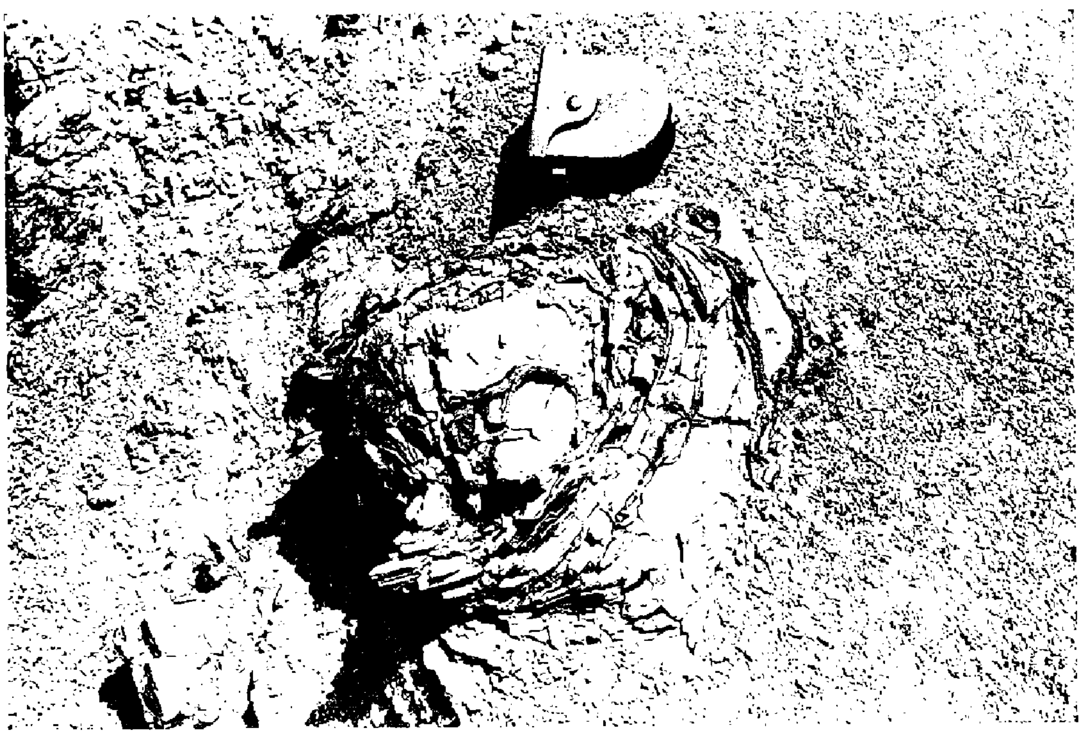
Rolled or balled sandstone masses reported in the Johns Valley Shale elsewhere are not common but are found locally. Some were undoubtedly formed by penecontemporaneous slumping soon after deposition because they have been observed between two undisturbed sandstone beds. Others, however, are structural in origin, associated with close folding and faulting.

A distinctive limonitic, friable sandstone containing molds of fossil invertebrates, bryozoans, and crinoid columnals occurs in several 2-inch to 1-foot beds at or near the Johns Valley-Atoka contact. Its character may be examined in unit 146 of the stratigraphic section of State Highway 103 where it crops out at the base of the first 2-foot sandstone above the thick boulder-bearing shale. Another bed occurs about 40 feet up in cleaner, more quartzitic sandstone. The north end of the road cut along U. S. Highway 270, discussed above, also exposes thin fossiliferous sandstone. Its consistent occurrence at the Johns Valley-Atoka contact is helpful in delineating the two formations, particularly because its distinctive appearance is easily recognized.

A dull-black, platy, siliceous shale up to 20 feet thick occurs about 275 feet below the upper Johns Valley boundary in many parts of the area, although it seems not to be present in exposures along State Highway 103. Its most accessible exposure is along a road in NE¼ SW¼ SW¼ sec. 15, T. 3 N., R. 24 E.



A. A limestone exotic boulder about 4 feet in maximum dimension in the Johns Valley Shale in the road cut of State Highway 103 in NE¼ NE¼ sec. 26, T. 3 N., R. 25 E. It is the one pointed out in figure 7B. Note the effect of solution before incorporation in the shale, particularly the right side of the boulder.



B. A sideritic concretion in the Johns Valley Shale that has weathered into a reticulate, septarian pattern and has developed concentric shells of brilliant rust red and yellow. It is in the same road cut as A above.

Figure 8. Exotic limestone boulder and sideritic concretion in the Johns Valley Shale.

Large ironstone or sideritic concretions up to 18 inches long are commonly found in Johns Valley Shale, some of them well exposed in the State Highway 103 section (fig. 8B). They characteristically weather into a reticulate, septarian pattern and develop concentric-spalling shells of brilliant rust red and yellow when weathered. Their high specific gravity and colors make them useful in recognizing the Johns Valley Shale.

Another useful identification characteristic is the presence of marblelike phosphatic nodules which are more commonly found in the lower black fissile shale but are also sparsely disseminated in the upper gray clay shale.

The Johns Valley sediments are about 990 feet thick. As measured and calculated from estimated dips on aerial photographs in SW¼ sec. 15, T. 3 N., R. 24 E., they are about 1,200 feet thick. Both thicknesses are near or above the maximum of 1,000 feet, as reported in areas farther west by Goldstein and Hendricks (1962, p. 398), who stated that the Johns Valley thickens toward the east from 200 feet to 1,000 feet. Seely (1962, p. 43) mapped the Johns Valley and the Atoka as undifferentiated in Rich Mountain east of this area but stated that 2,000 feet of strata between the Game Refuge and lower Atoka sandstones consists of shale and minor amounts of thin sandstone and siltstone. Much or all of this may, in reality, be Johns Valley Shale. R. C. Morris (personal communication, May, 1962) stated that the Johns Valley probably exceeds 2,000 feet in thickness in Acorn and Y City quadrangles, Arkansas, which is farther east. Apparently the Johns Valley Shale thickens rapidly eastward.

Shale taken from the Johns Valley outcrops has been used as fill along the eastern part of the Holson Valley road and consequently limestone and chert exotics occur along the roadside and should not be confused with a true Johns Valley outcrop. Abundant evidence of rooting by wild pigs can be seen wherever Johns Valley Shale crops out. One could almost map the Johns Valley by noting where pigs had been most active.

Origin of exotic boulders.—In the last 50 years numerous papers have been written about the origin of the exotic boulders in the Johns Valley Shale. The hypotheses that have been suggested to explain them are not here reviewed, but some of the ideas and observed facts are discussed in order to relate them to a concept of conditions that may have given rise to the exotic boulders.

Taff (1909, p. 702) attributed the presence of exotic boulders in the Johns Valley Shale to glacial movement or ice rafting. Woodworth (1912) demonstrated that the scratches on the exotics were tectonic instead of glacial in origin. Nevertheless, ice transportation was still held by many as the best method to explain the exotics (Ulrich, 1927; Powers, 1928, p. 1046; Rea, 1947, p. 49). Ice transportation does not adequately explain either the large or small boulders, either from the standpoint of weather conditions at that time or from characteristics of the boulders themselves. Cline (1960, p. 82-83) gave convincing arguments against the theory of tectonic origin. Numerous workers, on the other hand, have postulated some type of sliding or submarine land slipping down a muddy slope from a steep fault scarp to account for the exotics (Dixon, 1931, p. 344; Dixon and Hudson, 1931, p. 90; Miser, 1934, p. 1003; Kramer and others, 1936, p. 482; Goldstein and Hendricks, 1962, p. 400). Boulder-bearing shales or wildflysch in the Alpine flysch of Europe are considered products of rock slides or slumps by Kuenen and Carozzi (1953, p. 367) and Crowell (1955, p. 1370). The writer favors the submarine land-slip theory.

Examination of exotic boulders in the area of this study revealed that the surfaces of many limestone exotics are pitted and have solution channels that were formed before incorporation in the shale (fig. 9A). Other boulders have been so extensively attacked by solution that they have acquired bizarre shapes (fig. 9B), and some have delicate fossils etched out in high relief. Several boulders show solution confined mostly to one face (figs. 8A, 9B) as if they were subjected to beach or submarine action on their upper sides before detachment and debouchment into the mud. Dixon and Hudson (1931, p. 85) reported similar phenomena on exotics in Settle, England, that are known to have come from a nearby fault scarp. It therefore seems inconceivable that such delicate surficial-etched structures and bizarre-shaped boulders could have survived any kind of glacial or ice-rafting action. If, on the other hand, they were washed or slumped into soft muds of the surrounding sea, the delicate structures would be preserved.

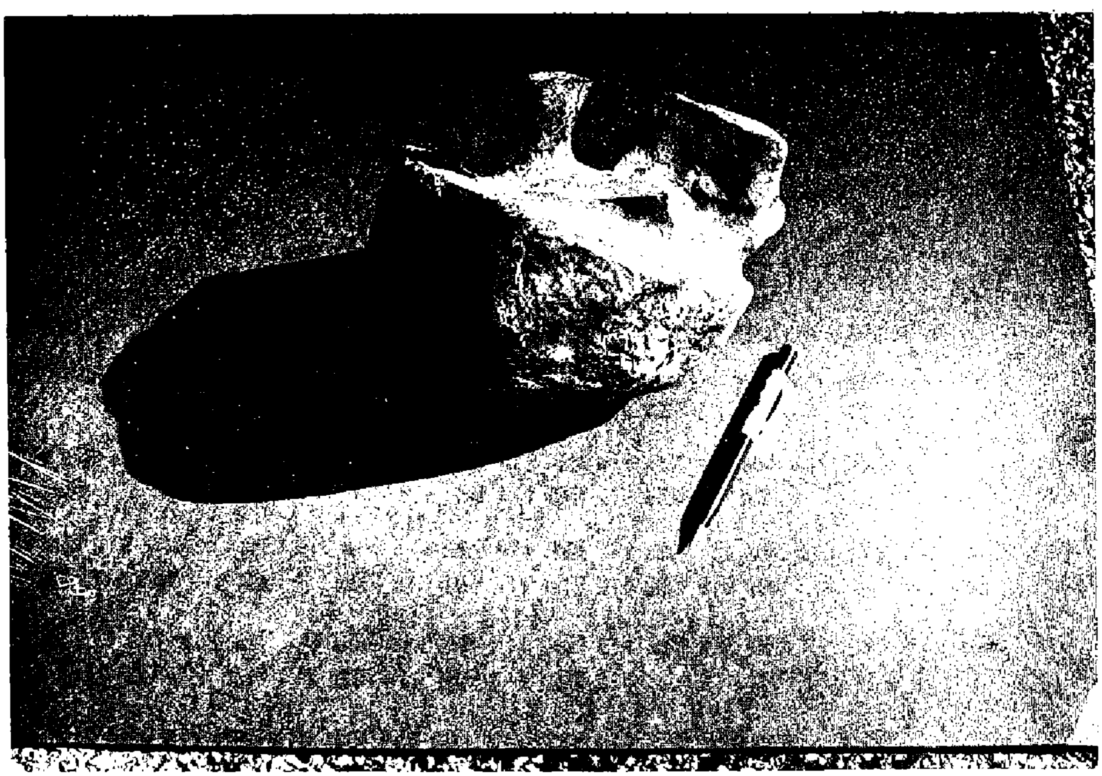
For the ice-rafting hypothesis to be valid, a suitable environment and a frigid climate are required, but the fauna and flora of the oölitic Wapanucka Limestone, a nearby partial equivalent of the Johns Valley Shale, do not suggest a cold-water climate. Also it is probable that ice could not have existed in the Wapanucka sea where oölites were forming. Paleomagnetic studies (Howell and Martinez, 1957) indicate that during Mississippian-Pennsylvanian time the equator extended northeast-southwest and was only about 300 miles to the northwest of the Ouachitas. One would not expect ice to exist so near the equator.

A combination of turbidity currents and sliding down the lubricated northern slope of the Ouachita trough is an adequate mechanism that does not require ice to transport the boulders away from the exposed source area. The Johns Valley Formation contains many structures attributed to turbidity currents, such as alternating thin sandstones and shales, well-developed sole markings, and exotics in shales between sandstone beds. Some rounded exotics occur in channel-like deposits exhibiting crude grading and are ascribed to turbidity flows or submarine slides with rather violent action (Cline, 1960, p. 72-74). Other exotics not occurring in channels, including those with the delicate surface structures, are scattered more randomly in the shale and were probably carried down the muddy slope by less violent turbidity flows and gravity sliding.

The huge masses, or blocks, of exotic limestone up to 550 feet long, reported in the Johns Valley, are much larger than any glacial erratic known to have been transported by glaciers or shore ice and could have slid easily down the same muddy slope that the smaller exotics traversed, as was postulated by Cline (1960, p. 84).

The linear nature of exotic-bearing Johns Valley Shale outcrops, the abundant occurrence of Arbuckle-type exotics at the west end, and the presence of some Ozark-type exotics at the east end nearer the Ozark uplift (Miser, 1934, p. 1003) leave little doubt that the source was linear, local, and probably steep. The fact that boulders of Arbuckle and Viola limestone occur in the lowest boulder zone of the Johns Valley Shale indicates that the entire stratigraphic section, represented by the exotics, was exposed when deposition first began. This could only mean that some tectonic feature, probably a fault scarp, could have been formed violently enough to expose the entire section rapidly. The fault scarp need not have been high enough to expose the 15,000 feet of section as found in the Arbuckle Mountains because in wells just north of the Choctaw fault the section is only about 2,500 feet thick and is probably much thinner farther south near the present position of the Ti Valley

A. A large limestone exotic boulder in the Johns Valley Shale that shows deep solution channels that developed before deposition. It is in a small road cut along U. S. Highway 270 and 59 in NW¼ sec. 18, T. 3 N., R. 26 E.



B. A small limestone exotic boulder from the Johns Valley Shale that shows extensive solution. Note how solution was mostly confined to one face as if the upper part had been more exposed to solution action of water.

Figure 9. Limestone exotic boulders in the Johns Valley Shale.

fault where the postulated exposure probably was located. Small chert exotics have been found as low in the section as the Chickasaw Creek Formation, but these are neither as large nor as common as those in the Johns Valley and probably represent incipient stages in tectonism along the structurally weak zone between the foreland and the geosynclinal trough. Uplift of the fault scarp culminated in Johns Valley time but must have continued through Wapanucka time inasmuch as exotics of this formation are also present.

Of particular interest is the common occurrence of exotics in the shale but with little sand associated with them. Dzulynski and others (1959, p. 1110), who studied the islands of Trinidad and Tobago, reported that "An island of only a few thousand square kilometers probably could not produce a rapid supply of sand during a long period. Only gravel and boulders might be delivered to submarine slopes in profusion." It might be added that the outcropping rocks were probably mostly limestone and cherts with little quartz sandstone to produce sand-size particles.

Age of Johns Valley Formation.—Most recent workers are in agreement that the Johns Valley Formation contains transitional rocks from Upper Mississippian into Lower Pennsylvanian. The fossiliferous-mold sandstones at the upper contact in this area probably correlate with those in the upper part of the Johns Valley in the Boktukola syncline reported by Shelburne (1960, p. 39) and at the Hairpin Curve of State Highway 2 described by Cline and Laudon (Cline, 1960, p. 74). These mold faunas have been considered Morrowan in age. Elias and Branson (1959, p. 3-7) described a new type area for the Caney Formation of Mississippian age from the Arbuckle Mountains, as previously mentioned, and correlated it with the lower part of the Ouachita Johns Valley Shale.

Pennsylvanian System

MORROWAN AND ATOKAN SERIES

Atoka Formation

History of nomenclature.—The first reference to the Atoka Formation was made by Taff and Adams (1900, p. 273), who named it from Atoka, Oklahoma, which is situated on outcrops of the formation; however, they gave vague descriptions and failed to designate a type section.

Distribution.—The Atoka Formation has the largest outcrop area of this study. It covers almost all the area north of the Briery fault with the exception of a thin belt of the Johns Valley and the upper part of the Jackfork on the south flank of the Spring Mountain syncline, the Johns Valley Shale around the Stapp syncline, and two other long narrow Johns Valley belts. Ridge-forming beds of the lower part of the Atoka crop out in a wide strip about eight miles long along the lower part of the north limb of the Simmons Mountain syncline and also form an arcuate outline within its western end. Other small exposures are in two tightly folded synclines south of the west end of the Simmons Mountain syncline. The best exposures are in a series of excellent road cuts along State Highway 103 that traverse the south flank of the Spring Mountain syncline and are described in the stratigraphic section in the appendix.

Character and thickness.—As previously stated, the lower contact of the Atoka Formation is conformable with the Johns Valley Shale in this area. The upper part of the formation has been removed by erosion or by faulting everywhere in the Ouachita Mountains. In the well-exposed Atoka section along State Highway 103, the lower 3,000 feet is dominantly composed of massive orthoquartzitic sandstone beds, mostly 1 to 6 feet thick, interbedded with thin dark-gray to black shales, and was referred to by Seely (1962, pl. I) as the basal sandy member (fig. 10A). The overlying sequence, also about 3,000 feet thick, is composed mostly of dark-gray shales interbedded with thin sandstone beds and was called the upper shaly member by Seely (fig. 10B). It is estimated that the lower part is about 60 percent sandstone, whereas the upper part is only about 25 percent sandstone. The sandstones are tan to buff, fine to medium grained, argillaceous, micaceous, generally finely cross laminated, and at many places have well-developed sole markings. Clay galls are common in the lower 3,000 feet. Intercalated are beds of gray to black, flaky, silty, micaceous shale beds increasing in thickness and abundance in the upper 3,000 feet. A thin, silty siliceous shale occurs in the lower part of the Atoka in NW¼ SE¼ sec. 23, T. 3 N., R. 25 E. A thin siliceous shale, also in the lower part of the Atoka, and probably the same one as above, crops out along a road in SW¼ SW¼ sec. 11, T. 3 N., R. 25 E., and is again exposed in SE¼ SE¼ sec. 7, T. 3 N., R. 25 E.

A. Sediments of the lower part of the Atoka, showing the high proportion of sandstone beds in a road cut of State Highway 103 in SE¼ sec. 23, T. 3 N., R. 25 E. The beds are slightly overturned. Lower surfaces of beds face to the right.

B. Atoka sediments above the lower 3,000 feet, showing the high proportion of shale interbedded with thin sandstones. The road cut is along State Highway 103 in SE¼ sec. 17, T. 3 N., R. 26 E.

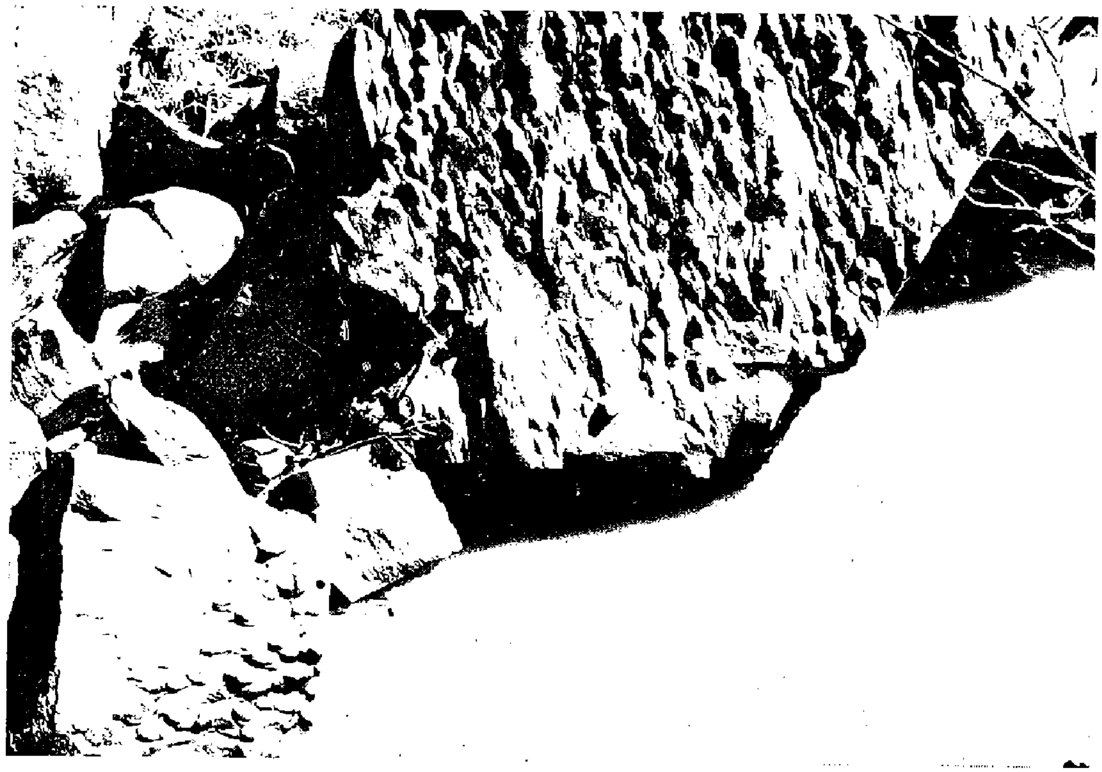
Figure 10. Atoka Formation.

Most other Atoka exposures, particularly south of the Ti Valley fault, are bounded on the north and the south by faults so that their exact stratigraphic positions cannot be determined. They are complexly folded and faulted, and only a few synclinal and anticlinal structures could be traced. They differ sufficiently in lithologic character and sedimentary structures from the exposures of strata in the lower part of the Atoka Formation along State Highway 103 to make it reasonably certain that they are stratigraphically higher. They differ in that the sandstones appear to be more argillaceous and silty and more finely laminated. Their most diagnostic features are the common occurrence of large well-formed sole markings such as flute casts (fig. 11A) and well-developed convolute bedding (fig. 11B). The upper parts of convoluted sandstone beds in many cases exfoliate concentrically to the wavy lamination, thus exposing a face showing the incipient development of the convolutions. Many such surfaces appear like symmetrical ripple marks with sharp crests and broad troughs. Some reach such large dimensions that the distance from crest to crest may be 2 feet and the crest height 8 to 10 inches. The relative abundance of convolute bedding compared with that in other units of the Ouachita stratigraphic section is a valuable characteristic in distinguishing this part of the Atoka Formation.

The Atoka sediments contain many characteristics attributed to turbidity currents and probably more nearly conform to flysch facies than do other Ouachita formations. The occurrence of rhythmic alternation of sandstone and shale, sole markings, sharp lower sandstone contact with shale, abundant convolute bedding, crude graded bedding, and shale inclusions or clay galls in sandstones are characteristic of turbidity-current deposits.

In SE¼ SE¼ NE¼ sec. 36, T. 4 N., R. 23 E., within Atoka rocks, is a small channel-like body of sandstone about 8 feet long, 4 feet wide, and 18 inches deep lying in stream float. It is interesting because well-developed flute casts occur along both sides and the bottom of the sandstone body (fig. 12). Apparently a small fluted channel was scoured into the mud bottom prior to deposition of the sandstone.

Thickness of the entire Atoka section is unknown owing to erosion and truncation by faults, but it must be enormously thick because Reinemund and Danilchik (1957) reported more than 18,500 feet in the Black Fork syncline of the Waldron quadrangle,



A. Well-developed flute casts on the lower surface of an Atoka sandstone bed in SE¼ SE¼ NE¼ sec. 36, T. 4 N., R. 23 E.

B. Convolute bedding characteristic of the upper part of the Atoka Formation.

Figure 11. Flute casts and convolute bedding in the Atoka Formation.

A. A small channel-like Atoka sandstone body with well-developed flute casts on both sides and the bottom. Flute casts are on the left side and on the bottom near the pencil end.

B. The same channel-like sandstone as above showing good flute casts on the right side and bottom. The location is in a creek bed in SE¼ SE¼ NE¼ sec. 36, T. 4 N., R. 23 E.

Figure 12. Channel-like sandstone with flute casts.

Arkansas. Only about 5,621 feet is exposed in the Spring Mountain syncline of the report area, but most of the Atoka exposed immediately south of the Ti Valley fault is probably stratigraphically higher.

Age of the Atoka Formation.—The Atoka Formation contains rocks older than Atokan age because its partial correlative, the Wapanucka Limestone of Morrowan age, grades eastward into sandstones considered there to be the lower part of the Atoka (Cline, 1960, p. 85). In fact Branson (1959, p. 121) suspected that Atoka rocks in the Ouachita Mountains may all be Morrowan in age. The only evidence of age in the mapped area is the occurrence of Morrowan sandstone-mold faunas in the lowermost part of the Atoka.

STRUCTURE

Introduction

The Ouachita Mountains in Oklahoma and Arkansas are only a small exposed portion of a more extensive structural belt that extends under the Gulf Coastal Plain and is exposed elsewhere in the Marathon region of Texas. The part in Oklahoma is structurally divided into a complexly folded and faulted frontal zone between the Choctaw and Windingstair faults; the central, structurally less complex part, to the south; and the Choctaw anticlinorium of older Paleozoic rocks near the Oklahoma-Texas border.

The area between the Ti Valley fault and the Windingstair fault is structurally related to the frontal zone owing to its complex structure but it is stratigraphically related to the central part because the lithologic units are genetically the same. Immediately north of the Ti Valley fault, however, the stratigraphic units are different and even have different names. The zone between the Ti Valley and Windingstair faults, therefore, occupies a unique and strategic location with respect to structures and stratigraphy. It is this area that the writer chose to map to show these relationships more clearly.

Major Structures

Simmons Mountain Syncline

The Simmons Mountain syncline is the largest structural element within the report area and is named for an impressive mountain of that name at its eastern end. It is a doubly plunging east-westward-trending syncline about 17 miles long, exposing a continuous sequence of rocks from the lower part of the Wildhorse Mountain Formation upward into the lower part of the Atoka Formation along its northern limb, also known as the Winding Stair Mountain. Its east end plunges about 30 degrees to the west and is truncated by a cross fault about 1,000 feet west of State Highway 103 between Simmons Mountain and Rich Mountain just north of Big Cedar. The west end extends almost to the north-south line between secs. 5, 6, T. 3 N., R. 23 E., and plunges east about 50 degrees. A large part of the south limb has been cut out by the Windingstair fault. The narrow belt of the Wesley-Game Refuge unit between the Windingstair fault and another associated fault about one-half mile farther north has been steeply folded to overturned and thrust north along the Johns Valley Shale over rocks in the lower part of the Atoka, but the stratigraphic displacement is not great. The north flank of the Simmons Mountain syncline is terminated by the Briery fault. Along the arcuate east end are continuous outcrops of the Moyers Formation upward into the lower units of the Jackfork Group.

The greatest structural complexity in the map area is south of the west end of the Simmons Mountain syncline and north of the Windingstair fault. Three tightly folded small synclines bordering the Windingstair fault have been thrust upon the south limb of the Simmons Mountain syncline. A small wedge-shaped exposure of Stanley Shale is in secs. 15, 22, T. 3 N., R. 23 E., and its presence is difficult to explain. It is surrounded on all sides by rocks younger than Stanley that are in fault contact; almost as if Stanley shales had been forced up through the younger sediments.

Spring Mountain Syncline

The Spring Mountain syncline was named by Seely (1963) for Spring Mountain, the highest ridge in the syncline where State Highway 103 makes a prominent hairpin turn. The highway completely crosses the south flank, composed of sediments of the lower part of the Atoka, and follows the axis for about a mile before crossing the north flank to join U. S. Highways 270 and 59. The Briery fault truncates the south limb, and other faults truncate the north limb. Its east end plunges gently to the west at about 10 degrees, and the west end plunges eastward but narrows as folding increases and is finally truncated by a fault. The south flank is steeply overturned and dips to the south, forming an asymmetrical overturned syncline.

Stapp Syncline

Seely (1963) named the Stapp syncline from its relationship with the Stapp Conglomerate. Only the west end of the Stapp syncline extends into the area of this report (sec. 7, T. 3 N., R. 26 E.), the greater part of the structure being in Seely's map area immediately adjacent to the east. The western end of the syncline plunges eastward and is in fault contact with the Johns Valley Shale around its complete arcuate outline. The Stapp fault truncates the northern limb and the south flank is cut by a fault with a trace that parallels the Kansas City Southern Railroad. Rocks of the Stapp syncline are composed of the Stapp Conglomerate, considered equivalent to the upper part of the Johns Valley Formation and overlying sandstones and shales of the lower part of the Atoka.

Windingstair Fault

The Windingstair fault, which trends generally east-west along the north edge of Kiamichi Valley, truncates the south limb and much of the internal structure of the Simmons Mountain syncline. Stanley sediments were thrust northward upon rocks that range from the Moyers Formation into the Atoka Formation. The Windingstair fault is not a single fault but is a zone of imbricate faults that in places is as much as 1 mile wide. The fault trace shown on the geologic map (pl. I) represents the northernmost position where a change from Stanley into younger rocks can be recognized; it can also be clearly traced on aerial photographs by its topographic expression.

Between sec. 6, T. 2 N., R. 25 E., and sec. 26, T. 3 N., R. 23 E., the Windingstair fault occurs about a mile farther north than is shown on the 1954 edition of the *Geologic map of Oklahoma*. Consequently, the fault trace forms a large reentrant between the ends of the Simmons Mountain syncline that cuts out almost all of the south flank. The mass of thick lower Jackfork sandstones in the broadly arcuate ends of the Simmons Mountain syncline were more competent and offered more resistance to forward movement of the Windingstair fault than did the less competent rocks of the south limb; consequently, the fault block moved farther along the flank and the fault cut out most of the south limb.

The Windingstair fault makes a sharp angle in sec. 24, T. 3 N., R. 23 E., but at this point the exact structural relationships are not clear because exposures are poor. Nevertheless, a small fault sliver of Atoka and Johns Valley was recognized. A remarkable exposure of a drag fold and fault in Stanley sandstones immediately above the Windingstair fault may be seen in a stream bank about 500 feet south of the center of sec. 36, T. 3 N., R. 24 E. Honess recognized its close structural relationship with the Windingstair fault and illustrated the outcrop (1924, pl. II).

Briery Fault

The Briery fault was named for Briery Creek, which follows its trace for a short distance along the north base of Black Fork Mountain (Seely, 1962, p. 105). This is one of the large faults of the Ouachitas. The writer traced it from U. S. Highway 271 for about 20 miles east to State Highway 103, and Seely (1962, pl. I) traced it an additional 40 miles to the east into Arkansas. Morris' map (1962) shows its eastern extension more accurately. Because the fault extends farther at both ends, it is at least 60 miles long and probably much longer. A good exposure of the Briery fault, one of the few faults actually to be seen in the Ouachitas, is on an east road cut where the fault trace crosses State Highway 103 (fig. 13). Here Stanley shales are in fault contact with the Jackfork Group about 373 feet below the upper contact of Markham Mill Formation. All of the lower and most of the middle Jackfork sediments are eliminated. The stratigraphic displacement at this point is at least 6,500 feet and is probably more because the Stanley shales resemble those in the Tenmile Creek Formation. Seely (1962, p. 108) reported that the maximum stratigraphic throw of the Briery fault occurs north of Black Fork Mountain and could be as great as 25,000 feet.

Along most of the length of the north limb of the Simmons Mountain syncline the trace of the Briery fault is on the steep north slope of Winding Stair Mountain where lower beds of the Wildhorse Mountain Formation have been thrust upon the Johns Valley exotic-bearing shale. Apparently the Johns Valley Shale acted as a lubrication surface along which the fault moved. Bifurcation occurs in sec. 21, T. 3 N., R. 25 E., and to the northwest in secs. 7, 17, 18, T. 3 N., R. 25 E., both faults occur in the Johns Valley Shale. At this place the faults may join in the Johns Valley Shale, but this relationship could not be determined with certainty.

Between the Briery and Ti Valley faults, 2½ to 3 miles apart, not one definitely recognizable outcrop of Stanley-Jackfork sediments was found. All exposures are either Johns Valley or Atoka, whereas south of the Briery fault practically the entire Jackfork section, at least 8,060 feet thick, is exposed, and an unknown thick-

Figure 13. Contorted sandstones and shales in the zone of the Briery fault. Markham Mill sandstones and shales are shown on the left side of the picture and Stanley Shale on the right side. The outcrop is in a road cut on State Highway 103 in NE¼ SE¼ sec. 26, T. 3 N., R. 25 E.

ness of Stanley may have been present before faulting. The significance of this fact is that if the Ti Valley fault is the northern depositional limit of Stanley-Jackfork rocks where they thin and change facies into equivalent rocks of the Caney Shale, two alternatives are possible. Either a small amount of northward overthrusting and rapid thinning of Stanley-Jackfork is within the 2½ to 3 miles or a larger amount of overthrusting and less rapid thinning occurs. Between the Briery and Ti Valley faults two other faults have been recognized, and it is probable that within the Atoka are others that could not be distinguished owing to the absence of marker units. Consequently, much horizontal foreshortening may have taken place along numerous faults within the narrow belt between the Briery and Ti Valley faults, accounting for the assumed rapid thinning in the Jackfork from at least 8,060 feet to the 525 feet reported for the Caney Shale in the western Ouachitas. The thinning of the Stanley-Jackfork sequence toward the Ti Valley fault is observed only in the western part of the Ouachitas, and it is merely assumed to thin farther toward the east. Thinning is not apparent from surface exposures. In fact a noticeable increase occurs in the thickness of the Jackfork from 5,800 feet in the Lynn Mountain syncline northward to at least 8,060 feet in the Simmons Mountain syncline, but because the latter is the last outcrop of the Jackfork before the Ti Valley fault, we have no way of knowing if it thickens farther north or begins to thin in that direction. It may well be that the deposits of Jackfork in the Simmons Mountain syncline represent the axis of maximum deposition at that time. If so, a hypothetical north-south cross section of the Jackfork would appear as a thick wedge with maximum thickness in the area of Simmons Mountain.

Ti Valley Fault

The Ti Valley fault marks the northern limit of the map area and its trace is entirely within Atoka sediments. Along the western part of the area, it can easily be traced on aerial photographs by topographic expression and truncation of major structures, but its trace eastward is not so apparent, probably because of bifurcation in sec. 24, T. 4 N., R. 23 E., and sec. 20, T. 4 N., R. 24 E., which may have absorbed much of the movement of the Ti Valley fault. As a result, the eastward continuation of the Ti Valley fault is designated on the map (pl. I) as inferred. Nevertheless, evidence shows that it continues to the east off the limits of the map area. The displacement along the Ti Valley fault decreases from west to east across the map area.

The trace of the Ti Valley fault parallels Holson Creek for several miles; consequently, much of its surficial expression is covered by stream alluvium, but an excellent exposure of contorted sandstone and shale beds within the zone of faulting is in a bank of the creek near C NE¼ sec. 24, T. 4 N., R. 23 E. (fig. 14).

Stapp Fault

The Stapp fault, which truncates the north limb of the Stapp syncline, was named by Seely (1963). The trace joins the Briery fault north of Black Fork Mountain to the east and continues westward north of a Johns Valley-Atoka ridge, where it joins another fault in sec. 7, T. 3 N., R. 25 E. North of the ridge it places the Johns Valley Shale in fault contact with Atoka beds. As in the case of Briery fault, the fissile Johns Valley Shale has acted as a zone of weakness and slippage along which the fault block moved.

Figure 14. Contorted Atoka sandstones and shales in the zone of the Ti Valley fault in a cutbank of Holson Creek near C NE¼ sec. 24, T. 4 N., R. 23 E.

Structurally it appears as if the Stapp fault at its western part occurs along an anticlinal trend that has been considerably narrowed by the fault displacement.

Minor Structures

A large anticlinal drag fold and complementary syncline in secs. 20, 21, 22, 27, 28, T. 3 N., R. 25 E., is easily seen on aerial photographs and is outlined by outcrops of the Chickasaw Creek Formation and the Prairie Hollow Member. Along its north limb, one siliceous shale of the Chickasaw Creek Formation can be traced for some distance, but its south limb reveals the siliceous shale at only one locality; therefore, most of its trace along the south limb is mapped as inferred. The Winding Stair fire tower is located on the anticlinal north limb.

The structure is a combined product of northward thrusting and right-lateral strike-slip movement of the Briery fault. Cross section F-F′ (pl. I) shows its genetic relation to the Briery fault. The writer found, as did Seely (1962, p. 155), that right-lateral strike-slip movement along Briery fault may be demonstrated by the recess around the south limb of the Spring Mountain syncline. The width of the syncline narrows considerably westward by greater northward overthrusting of the south limb at the west end of the syncline than near the middle. Some right-lateral movement is thus necessary. Right-lateral movement of the fault between Rich Mountain and Simmons Mountain is inferred because of its association with right-lateral strike-slip movement along the Briery fault where the two join.

In sec. 9, T. 3 N., R. 23 E., left-lateral movement, produced by tear along a low-angle fault, offsets the axial line of the west end of the Simmons Mountain syncline.

A synclinal structure in Atoka rocks extends from sec. 1, T. 3 N., R. 24 E., eastward for at least seven miles to sec. 6, T. 3 N., R. 26 E., where it continues out of the map area. It is truncated on the south by the Stapp fault and on the north by a lesser fault. Other anticlinal and synclinal structures entirely within Atoka sediments are designated near Cedar Lake and in secs. 32, 33, 34, 35, T. 4 N., R. 24 E.

Low-Angle or High-Angle Thrust Faults

Surficial evidence of the dip of fault surfaces in the Ouachita Mountains is not common; however, several localities permit rough approximations. Some are definitely high angle at the surface and others are low angle.

Probably the best exposed and most accessible locality where a fault surface may be examined is in the road cut where the Briery fault trace crosses State Highway 103 (fig. 13). In this road cut, a zone of fault gouge dips about 60 degrees southward, which is also the approximate dip of beds on both sides of the fault, suggesting that fault movement inflicted similar dips on its enclosing beds. By using the three-point method and assuming a generally planar fault surface over short distances, it is possible to estimate a fault-surface dip where the trace on aerial photographs can be seen to cross contour lines taken from topographic maps. This method was applied at two nearby localities in sec. 12, T. 3 N., R. 24 E., along the Briery fault where the fault trace was clearly visible. The calculated dips were both southward between 25 and 30 degrees. These data were used in construction of the cross sections of the Briery fault in this area. Dip of the Briery fault is thus seen to range widely between 25 and 60 degrees.

Dips of the Windingstair fault surface are not easily determined but the drag fold and fault about 500 feet south of C sec. 36, T. 3 N., R. 24 E., have a dip of between 60 and 70 degrees. If it is as closely associated with the Windingstair fault as it appears, the dip should reflect and closely approximate that of the Windingstair fault. In that case it, too, would have a dip between 60 and 70 degrees. Beds truncated and upfolded immediately north of the trace of the Windingstair fault have an average dip of about 60 degrees southward. If it is essentially a bedding-plane fault, as it appears, then it too should dip about 60 degrees southward.

An example of low-angle thrusting is a sinuous fault trace in secs. 2, 3, T. 3 N., R. 23 E., where Johns Valley Shale has been thrust over an uneven surface of steeply dipping Jackfork sandstone ridges. The fault trace closely follows topographic contours, moving updip where traversing hills and downdip where crossing valleys. Under these conditions, a low-angle fault surface is strongly suggested. Closer examination of the associated structural relationships reveals that the interior portion of the east end of the Simmons Mountain syncline, represented by lower Atoka and Johns Valley deposits, was first synclinally folded with the other rocks and then, upon further compression, was thrust over the already steeply dipping Jackfork beds of the north limb. Fissile shales of the Johns Valley served as an excellent gliding surface for the fault. Thrusting of the interior of the Simmons Mountain syncline also produced a clockwise rotational component around a vertical axis that was near NE cor. sec. 13, T. 3 N., R. 23 E. Stratigraphic displacement is greatest at the middle of the line between secs. 2 and 3, T. 3 N., R. 23 E., and decreases eastward, where it disappears into Johns Valley Shale at the point of the rotational axis. Movement was overthrust in nature but in reality moved down the stratigraphic column (cross section B-B′, pl. I). Presence of the siliceous shale on both sides of the Johns Valley-Atoka overthrust mass is further evidence of the low angle of the fault surface. It is estimated that the fault dips southward less than 25 degrees.

Where the Stapp fault trace crosses secs. 7, 8, 9, 10, T. 3 N., R. 25 E., it demonstrates the high-angle nature of some fault surfaces. Beds closest to the fault trace dip nearly vertically along much of its western end, and because Johns Valey Shale acted as a gliding surface, the fault is probably a bedding-plane fault. It therefore follows that the fault also dips nearly vertically.

The conclusion concerning the dips of faults at the surface is that they may be high or low angle depending upon the local structural and stratigraphic relationships.

SEDIMENTARY STRUCTURES

Kuenen and Carozzi (1953, p. 364) listed several characteristics of coarse deep-water sediments known as turbidites. Flysch-facies sediments also are believed to have been deposited by turbidity currents. Carboniferous rocks of the Ouachitas closely resemble flysch facies and they have abundant sedimentary structures that lend strong support to the argument that many of these sediments were deposited by turbidity currents.

Sole Markings

Sole markings occur on the bottoms of many sandstone beds and were extensively used to determine tops and bottoms for structural interpretation (fig. 4). They include such features as flute casts, groove casts, and load casts. Flute casts are sandstone casts of flutings which develop on the upper surfaces of underlying muds by turbulent erosion by a moving abrasive fluid, probably a turbidity current with a heavy load of silt in suspension. Turbulence excavated subconical depressions which were filled with sand by the turbidity current. Flute casts are not present on all sandstone beds because many have planar lower surfaces. In few places is more than a small surface exposed so that if one part of the bed exhibits flute casts and another part does not, the observer seldom sees enough of the surface to make this determination. More than likely the most erosive and turbulent part of the turbidity current is confined to a zone near its middle, whereas the outer flanks cause little bottom erosion. Whether a small exposed lower surface of a sandstone bed has sole markings or not probably depends upon its location in respect to the turbidity current that deposited it. Atoka sandstone beds exhibit the most abundant and best developed flute casts in the study area (fig. 11A); some are huge, as large as six inches deep and many feet long.

Grooves cut into mud by solid objects moved by currents give rise to groove casts on bottoms of sandstone beds. They too are attributed to turbidity currents. Hsu (1959, p. 533) stated that flute casts were probably formed at an earlier stage of transport when turbulence of currents was still high, in contrast to groove casts which were formed at a later stage when turbulence of currents had subsided.

Load casts are the result of differential sinking or loading of unconsolidated sand into an underlying soft mud. They show no lineation or current direction as do flute and groove casts. Rich (1950), Crowell (1955), and Hsu (1959), adequately treated the origin of various sole markings.

Convolute Bedding

Convolute bedding is of particular interest because of its common occurrence in Ouachita sediments. It was previously pointed out that it is characteristic in Atoka sandstones above the lower 6,000 feet. Convolute bedding is complexly folded and generally unbroken, with the laminae confined to the interior of a sandstone or siltstone bed (fig. 11B), in which the upper and lower bedding surfaces are normally not affected. Some convolute bedding may be the result of gravity sliding after the tops of the beds were laid down, as described by Rich (1950, p. 729). It is reasonably certain that most of the convolute bedding in Atoka sandstones of the Ouachitas formed while the sand was being deposited. Crowell (1955, p. 1364) gave several reasons for believing that they are syndepositional rather than postdepositional, all of which apply to Ouachita convolute bedding: (1) the deformed laminae if straightened out would have a length far greater than the length of the layer in which they occur; (2) the convoluted folds at the top commonly grade through gentler and gentler folds into relatively undeformed bedding surfaces; (3) no piling up of layers at one place and thinning at another; (4) where axes of convoluted folds are regular, they trend normal to direction of current in associated beds. Commonly the largest convolute bedding also occurs in the same sandstone bed with the largest flute casts, which suggests that the same current that formed the flutes also formed the convolute bedding. Haaf (1956, p. 193) stated that there are concomitant increases in grain size, thickness of bed, and magnitude of convolutions, all of which depend on the velocity of the turbidity current. It logically follows that convolute bedding and turbidity currents are genetically related. Sanders (1960) described processes of hydroplastic sedimentary flow due to increased traction and shearing stresses caused by a slowing turbidity current, and Williams (1960) discussed the phenomenon of liquefaction to explain the origin of convolute bedding. Each depended upon its being formed within the turbidity current itself at the time of deposition of the turbidite.

Ripple Marks and Cross-Bedding

Ripple marks and associated coarse cross-bedding are uncommon in the rocks of the study area, but locally they are found in Jackfork and Atoka sandstones. A paucity of ripple marks is one of the diagnostic characters of flysch sediments. Ripple marks are few, probably because most sandstone beds gradually grade upward into silt and clay grain sizes in which ripple marks are not likely to form. Small-scale cross-lamination, on the other hand, is quite common in most sandstone beds, particularly in the Atoka Formation. A freshly broken surface of sandstone generally will not show the cross-lamination, but differential etching and color banding of laminae by weathering makes it readily visible.

Graded Bedding

Although many features characteristic of flysch-facies deposition are well developed in Ouachita sediments, the classic graded bedding is not generally seen upon cursory examination; nevertheless, a type of grading is present in many cases. Sandstones exhibiting this type of graded bedding are homogeneous throughout most of their thickness, but the top surface is fuzzy and indistinct. Near the top a gradual upward increase in clay material forms thinly laminated silts and at the top is shale. In almost all cases the lower surface of the sandstone bed has a sharp contact. Possibly the source area provided only well-sorted sediments, so that there was little chance for vertical grading within the main part of the sandstone unit. In addition, although grading may not be megascopically discernible, it might be seen in thin section. Carozzi (1957, p. 281) commented on a schematic diagram by Sanders, stating that at the distal end of a turbidity current at the bottom of the basin slope grading disappears. Such a condition may also explain absence of grading in some Ouachita sandstones.

Clay Galls

Fragments of clay and shale incorporated within sandstones occur throughout the stratigraphic section but are more common in Jackfork and Atoka deposits. In many cases they are concentrated on the upper surface where weathering quickly removes the soft clay fragments, leaving the surface pitted with their molds (fig. 15). The inclusions consist of inter-layer shale material and clearly testify to active erosion by the current that transported the overlying sand.

Parting Lineation

Crowell (1955, p. 1361) described faint streaks on some bedding-parting surfaces that parallel the current direction and referred to them as parting lineation. These were observed on bedding partings of thick Jackfork sandstone units. They are small warps, creases, and grooves that are most conspicuous when sunlight strikes the surface at a low angle.

Figure 15. Pitted upper surface of a Jackfork sandstone bed; pits formed by removal of clay galls. Along road in sec. 9, T. 3 N., R. 24 E.

GEOLOGIC HISTORY

Source of Sediments

Previous work by Reinemund and Danilchik (1957), Cline (1960), Shelburne (1960), and Seely (1962), who used sole markings to determine current directions, indicate that the currents during Stanley-Atoka time came from the east and travelled longitudinally down the axis of the geosyncline. Scull and others (1959) demonstrated that Atoka sandstones thicken and increase in number eastward in the Arkoma basin. Briggs (1962) made a detailed study of the paleocurrents of Jackfork-Atoka rocks and concluded that the source area probably lay to the northeast and east in the Eastern Interior basin of Illinois and in the Black Warrior basin, and that the source rocks were preexisting sediments.

Deposition

Older Paleozoic rocks of the Ouachita geosyncline represent a period of slow deposition in a starved trough in which thin cherts and black shales were laid down. On the other hand, the thick clastic Stanley-Atoka sequence was characterized by a period of active downsinking and rapid sedimentation, and closely resemble flysch facies of Europe. Recent workers have called on turbidity currents to account for the anomalous sandstone beds in a shale-type environment which collectively may reach thousands of feet in thickness. Many features which characterize turbidite sequences are found in the Ouachitas and were discussed in detail by Cline (1960, p. 87-99). Such features as continuous parallel stratification, repeated alternation of sandstones and shales, graded bedding, oriented sole markings, sharp lower contact of sandstones, shale inclusions, convolute bedding, absence of indigenous fossils, and absence of coarse ripple marks are indicative of turbidite deposits and are common in the area of this study.

The most obvious property of the sequence is its rhythmically alternating sandstones and shales. The sandstones are laterally persistent and maintain their lithologic character over long distances; however, they eventually thin and pinch out. Haaf (1959, p. 218) stated that turbidity currents are dense but have viscosities approaching that of water; therefore they would tend to spread out in broad flat sheets, filling in bottom irregularities. Turbidity-current action, bringing sands into a dominantly mud environment, more logically explains most of the sandstone beds than does any other mechanism. It is not implied that all the sandstone beds were laid down by turbidity currents, because the characteristics of some sandstones are difficult to explain by such action. Massive sandstone beds in the Jackfork and Atoka strata are as much as 30 feet thick. At places several such beds occur in zones 50 to 60 feet thick with no apparent shale interbed. It is difficult to imagine a turbidity current large enough to account for such thick massive sand beds. Other processes must also have prevailed at different times. Conditions at the source of sand supply probably were not everywhere in the delicate state of imbalance which allowed a buildup of sandy material that could be suddenly dislodged to form a turbidity current. Times of continuous sand supply must have permitted deposition of thick beds of sand.

One of the prerequisites of turbidity currents is the presence of a slope down which gravity may provide the motive force for the current. Rich (1950, p. 734) showed that flysch characteristics meet all the criteria of slope deposits and further pointed out that the locus of most rapid deposition would be rather far from shore and in deep water rather than on the shelf. Paleocurrent studies show that turbidity currents in the Ouachita geosyncline travelled from the source down the axis from east to west; thus a long gentle slope in that direction is required. The locus of maximum deposition within the trough lies in the direction of thickening, and, as has been previously brought out, most of the Ouachita units thicken to the east. The Jackfork Group thickens eastward along strike from 1,150 feet in westernmost Ouachitas (Hendricks and others, 1947) to 8,000 feet in the Simmons Mountain syncline. Shelburne (1960, p. 61) also noted an eastward thickening of Jackfork sediments of 1,200 feet over a distance of 30 miles in the central Ouachitas. Goldstein and Hendricks (1962, p. 398) stated that the Johns Valley Shale thickens from about 200 feet in northwestern Ouachitas to as much as 1,000 feet farther east. From evidence in the area of this study and studies made farther east in Arkansas by Seely (1962) and Morris (1962), it appears likely that the Johns Valley Shale is much thicker than 1,000 feet, probably more than 2,000 feet. The Atoka Formation also thickens eastward (Scull and others, 1959). General thickening to the east up the geosynclinal trough indicates that the source of sand supply lay in that direction. The northward thinning of Stanley-Jackfork sediments in the western Ouachitas does not necessarily mean that the source lay to the south but rather that sedimentation progressed down the trough toward the west and, by gradual filling, transgressed upon the slope toward the shelf to the north.

Most workers agree that relatively quiet water at a depth beyond the reach of wave action prevailed during flysch deposition; otherwise such delicate markings as worm and gastropod trails would have been destroyed. One is led to conclude that flysch deposits are slope deposits off the edge of the continental shelf.

Deposition of the Stanley-Atoka flysch sequence began in Mississippian (Meramecian) time and continued into Early Pennsylvanian (Atokan) time, during which more than 22,000 feet of sandstones and shales filled the geosynclinal trough. Occasionally the rapid rate of deposition was interrupted by periods of quiescence during which relatively pure cherts and siliceous shales were introduced into the dominantly clastic section. Sponge spicules and radiolarians are contained in most siliceous shales, and so quiet periods in which few clastics were deposited must have occurred. During Stanley time, volcanic debris rained down intermittently to form tuff beds and tuffaceous sandstones.

Solution of the problem of origin of silica that impregnates the numerous siliceous shales in the Ouachitas probably lies in the tuffaceous beds. Volumetrically the number and thickness of tuffs heretofore reported are considered insufficient to supply the silica present in the various siliceous shales; however, it is possible that other volcanic rock types have not been discovered or recognized. Volcanic ash falling into pelagic environments would tend to be masked by other sediments and to produce deposits that, from casual outward appearance, resemble other sandstones. Goldstein and Hendricks (1953, p. 440) considered that the siliceous shales were derived from submarine weathering of volcanic ash and stated that they are locally associated with tuffaceous sandstone. The conclusions of Goldstein and Hendricks are borne out by the strategic location of the tuff bed between the two Chickasaw Creek siliceous shales in the report area.

Argillaceous sandstone and graywacke sedimentation during Stanley time was replaced in Jackfork time by deposition of more abundant, cleaner sandstones such as subgraywacke and orthoquartzites. The character of shales also changed, which fact suggests that a fundamental change in source rocks probably took place between Stanley and Jackfork time. Reducing conditions normally existed throughout most of Stanley-Jackfork time, but the maroon color of the shales of the Prairie Hollow Member probably indicates that they were oxidized before deposition and have retained their original color. Most of the clay shales of the Prairie Hollow Member considered in this study, however, are green; little maroon shale is present.

Deposition of the massive shales of the Johns Valley Formation occurred in late Chesterian and early Morrowan time and thus spanned the Mississippian-Pennsylvanian boundary. The lower black shales differ considerably from the upper gray shales and may be a reflection of the nearby uplift that supplied the exotic boulders. Slope conditions off the uplift into Johns Valley muds permitted the exotics to slump and slide to their present position. Periodically turbidity currents brought in thin sands to cover the thick Johns Valley muds. Thin limonitic sandstone mold faunas of Morrowan age were brought into the flysch environment of the upper Johns Valley and the Atoka by currents from the shallow shelf to the north. The fossils are fragmental and not indigenous to the flysch environment.

A sudden increase in sand supply terminated Johns Valley Shale deposition, and about 3,000 feet of lower Atoka sediments containing much sandstone accumulated before the sand influx began to subside. Atoka deposition above the lower 3,000 feet consisted mostly of shales with minor thin sandstones. The increase in convolute bedding and in the size of flute casts in sandstones of the upper part of the Atoka Formation may have resulted either from increase in turbidity current velocities or from a change in character of the sandstones themselves. Increased velocities would have increased the erosive abilities of suspended grains in the turbidity current. More abundant mica flakes in Atoka sandstones may have permitted a greater amount of hydroplastic slippage to produce convolute bedding.

Deformation

The age of deformation of the Ouachita Mountains has always been in doubt. Several lines of evidence indicate that it was not just one sudden period of tectonism but that it took place over a long period of time. The first stages were not strong and did not exercise profound regional influence, but the final phases caused large-scale folding and overthrusting that produced the structures as they appear today.

The occurrence of exotic boulders in the Chickasaw Creek, Markham Mill, and Wesley Formations, and in the Johns Valley Shale strongly suggests intermittent local uplift from Meramecian into Morrowan time. Uplift probably took place along the hinge line of the shallow shelf where it dropped off into the deeper basin. Influence of this local uplift affected only the rocks in the immediate area and may have accounted for the possible unconformity within the Johns Valley Shale and for the one at its base in the northwestern part of the Ouachitas reported by Goldstein and Hendricks (1962, p. 398, 410). Hendricks and others (1937) noted the presence in Atoka sediments of pebbles of Caney Shale or Springer that belong to Arbuckle facies in outcrops west of Black Knob Ridge. Uplift that provided the pebbles existed before the development of the Choctaw and Ti Valley faults because they cut Atoka rocks.

That sedimentation took place contemporaneously with deformation during Johns Valley time is shown by the presence of exotic boulders of the Wapanucka Limestone in Johns Valley Shale; however, final culmination of tectonism did not take place until after deposition of the Atoka Formation. The only evidence of final folding and thrusting revealed in the area of this study is that Atoka beds are deformed. Nevertheless, that folding occurred prior to thrusting is well demonstrated by the structural relationships within the west end of the Simmons Mountain syncline. As previously described, the Simmons Mountain syncline was synclinally folded before thrusting shoved Johns Valley and Atoka sediments up over Jackfork rocks along its northern limb. Folding must have preceded faulting in order for younger rocks to be thrust over older ones.

Goldstein and Hendricks (1962, p. 427) concluded that deformation in the Ouachita geosyncline began in early Atokan time, definitely continued as late as Desmoinesian time, and was more or less continuous throughout the Pennsylvanian, but that most of the thrusting occurred in Middle or Late Pennsylvanian time and finally culminated in major thrusting of the Ti Valley and Windingstair faults.

SUMMARY

Detailed mapping of the critical zone between the Windingstair and Ti Valley faults reveals that the area is structurally related to the complexly faulted frontal belt of the Ouachita Mountains but stratigraphically similar to the less complex central part. Most of the formations that crop out and have been described in the central Ouachitas were recognized and mapped in the area of this investigation.

Of the three formations in the Stanley Group, only the Moyers and the Chickasaw Creek could be recognized with certainty, but the Tenmile Creek Formation probably exists in the Stanley, mapped as undifferentiated. Moyers Formation is truncated by faults, exposing a maximum thickness of 1,200 feet. In the Chickasaw Creek Formation the upper and lower siliceous shales are separated by a section only about 75 feet thick.

A persistent 10-foot-thick tuff bed is present between the two Chickasaw Creek siliceous shales. It is also reported in Black Fork Mountain to the east.

The entire Jackfork Group is exposed in the Simmons Mountain syncline, a name proposed for the large syncline that dominates the map area. Not all of the siliceous shale boundary units that divide Jackfork formations are present. As a result, the following formations were mapped as undifferentiated: lower part of Wildhorse Mountain and Prairie Hollow Member; upper part of Wildhorse Mountain, Prairie Mountain, and Markham Mill; Wesley and Game Refuge.

The lower part of the Wildhorse Mountain Formation contains a green shale similar to the Prairie Hollow Member on the north slope of Winding Stair Mountain, but it is absent farther south. This part of the Wildhorse Mountain Formation thickens from 1,250 feet around the east end of the Simmons Mountain syncline northward to at least 2,780 feet on Winding Stair Mountain. The Prairie Hollow Member is an excellent marker bed and occurs extensively along the crest of Winding Stair Mountain.

Within what may be the Markham Mill Formation there occurs an exotic-bearing clay shale and two siliceous shales.

Wesley-Game Refuge strata, 1,421 feet thick, are excellently exposed along State Highway 103, and two massive Game Refuge

Sandstone beds are recognized here but could not be found in less well-exposed areas.

The total exposed Jackfork strata in the Simmons Mountain syncline is at least 8,060 feet thick, considerably thicker than described anywhere else in the Ouachitas. Marked thickening occurs northeastward over a distance of about 70 miles from a minimum of 1,150 feet in western Ouachitas to 8,060 feet in the study area. Thickening also occurs northward from 5,800 feet to 8,060 feet. The Simmons Mountain syncline area may have been the site of maximum Jackfork deposition.

Stratigraphic thinning of Jackfork strata north to Ti Valley fault could not be determined.

The Johns Valley Shale consists of a lower black fissile shale and an upper gray clay shale, each of which contains exotic boulders. A siliceous shale occurs in its upper part. The Johns Valley is 990 to 1,200 feet thick in the report area. It thickens from a minimum of 200 feet in the western Ouachitas to a probable maximum of 2,000 feet in Arkansas.

The Johns Valley exotic boulders were derived from a fault scarp and were transported by slumping, sliding, and turbidity currents to their depositional sites.

Fossiliferous sandstones, Morrowan in age, occur at and near the contact with the Atoka Formation.

The lower 3,000 feet of Atoka sediments contains a high percentage of sandstone, whereas the overlying 3,000 feet is dominantly shale. The total thickness is unknown because the uppermost part has been removed by erosion and faulting.

Sedimentary structures and general stratigraphic characteristics of Carboniferous Ouachita sediments lend strong support to the hypothesis of flysch-facies deposition by turbidity currents.

The Simmons Mountain syncline is truncated on the south by the Windingstair fault and on the north by the Briery fault. The Briery fault is one of the large faults of the Ouachitas and extends for at least 60 miles.

Dips of fault surfaces range from less than 25 degrees to vertical depending upon structural and stratigraphic relationships.

Owing to bifurcation the Ti Valley fault loses much of its throw from west to east across the map area.

Thickening of stratigraphic units eastward up the axis of the geosyncline strongly suggests that the source lay to the east or northeast.

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APPENDIX

Measured Stratigraphic Section

The section was measured from cutbanks of Big Cedar Creek and road cuts along State Highway 103. The bottom of the section is about 950 feet north of the Pipe Spring roadside picnic park in a small shale pit on the east side of State Highway 103 in NE¼ SE¼ sec. 26, T. 3 N., R. 25 E. The top is just east of an east bend in the highway near C NW¼ NW¼ sec. 19, T. 3 N., R. 26 E.

Atoka Formation	*Feet*
220. Shale, olive-gray, and gray sandstone; lower part measured in first road cut and upper part measured in second road cut to the east from the eastward turn in the road; mostly shale with thin-bedded sandstones and siltstones; trace of fossil molds in sandstone in middle of unit. Some local folding in the axis of the Spring Mountain syncline has affected nearby rocks but it is believed that this unit is continuous	85
219. Covered along roadside ditch on east side of road on eastward curve	70
218. Shale, dark-gray, and light-gray to gray sandstone; mostly blocky shale that weathers light gray, interbedded with fine-grained, dirty, micaceous sandstones and siltstones; carbonaceous plant fragments common; 25 feet from top is a thin sandstone bed with fossil molds of bryozoans and crinoid columnals	115
217. Shale, dark-gray, and light-gray to gray sandstone; blocky, waxy shale interbedded with medium-grained, dirty, micaceous, dense sandstone with black and white grains; some sandstones contain clay galls, most grade upward into soft siltstones, bedding 1 to 12 inches, good sole marks on many sandstones; shale and sandstone each about 50 percent	245
216. Shale, dark-gray, and light-gray sandstone; blocky shale; fine-grained, dense sandstone with black and white irregular grains, grades upward to buff, soft, micaceous siltstone; at top is a small normal fault visible in cut, little stratigraphic displacement	80
215. Covered in saddle on east side of road at top of hill	85
214. Shale, black, and light-gray sandstone; poorly exposed, weathered, blocky shale; very fine-grained, micaceous, dense sandstone in sparse thin beds	45
213. Covered on east side of road	60
212. Shale, dark-gray to black, and gray sandstone; blocky,	

hard shale with silty zones, some containing iron-oxide-filled joints; sparse, fine-grained, micaceous, dense, buff-weathering sandstone interbedded at wide intervals. Sandstone commonly grades upward into thin wavy bedded, soft siltstones. Carbonaceous plant fragments occur along bedding surfaces of many sandstone beds; cross-bedding exhibited by some; sole marks common. Shale about 70 percent and sandstone about 30 percent 400

211. Shale, dark-gray to black, and light-gray to dark-gray sandstone; hackly to fissile shale with gritty silt zones and some joint filling; fine-grained, thin-bedded, micaceous, carbonaceous sandstone interbedded in shale; many sandstones grade upward into soft, buff siltstone. At top is a trace of fossil molds in sandstone. Shale 65 percent and sandstone 35 percent 145

210. Sandstone, gray to fine-grained, micaceous; contains black shale and carbonaceous fragments; bedding 1 to 3 feet 15

209. Shale, black, and light-gray sandstone; bottom of unit is at culvert on northwest side of road below turnout; lower half poorly exposed hackly shale; very fine-grained, micaceous, dense, thin-bedded sandstone in beds ½ to 8 inches with white and black grains, some containing shale and carbonaceous fragments, many grading upward into thin, laminated, soft siltstones. Shale 75 percent and sandstone 25 percent 250

208. Covered 75

207. Shale, dark-gray, and dark-gray to black sandstone and siltstone; waxy, blocky, hackly shale; very fine-grained, micaceous laminae and streaks of dense sandstone and soft siltstone. Some sandstone in beds 2 to 5 inches thick. Shale about 60 percent and sandstone 40 percent 135

206. Sandstone, light-gray to buff, and dark-gray shale; lower part of unit fine-grained, micaceous, soft sandstones most common; middle part is much disturbed and broken by minor faults, alternating buff very fine-grained, micaceous sandstone with thin silty shale; upper part massive sandstone with good fossil molds at top. Sandstone about 75 percent and shale 25 percent 130

205. Covered 90

204. Shale, dark-gray to black, and gray to black sandstone; blocky shale that weathers to tan and light gray; thin-bedded, dense, micaceous sandstone. Upper 20 feet mostly very fine-grained, soft, micaceous sandstones with platy bedding and thin shale pebble zones. Shale about 70 percent and sandstone 30 percent 165

203. Covered in saddle at bottom of ridge slope 460

202. Shale, and olive-green sandstone; poorly exposed

	weathered shale; some thin-bedded resistant, fine-grained, dirty, micaceous, dense sandstone	150
201.	Shale, gray to tan, and dark-gray sandstone; mostly nodular shale with interbeds of fine-grained, dirty, micaceous, dense sandstone; basal 10 feet is composed largely of sandstone. Shale about 60 percent and sandstone 40 percent	60
200.	Shale, dark-gray to black, and gray sandstone; nodular, platy shale with silty laminae, beds 10 to 20 feet thick interbedded with thin, very fine-grained, micaceous, dirty, dense sandstone and siltstone. Shale about 80 percent and sandstone 20 percent	79
199.	Sandstone, gray, and gray shale; very fine-grained, dirty, micaceous, dense sandstone interbedded with soft nodular to platy shale with silty laminae. Sandstone about 60 percent and shale 40 percent	26
198.	Shale, black to tan, and sandstone; waxy, blocky to platy shale, some slightly olive in color; thin stringers of siltstone and fine sandstone; bottom poorly exposed	85
197.	Sandstone, light-gray, and black shale; fine-grained, micaceous, dirty, soft sandstone and siltstone interbedded with splintery shale, weathers easily. Sandstone about 50 percent and shale 50 percent	70
196.	Sandstone, gray, and dark-gray shale; very fine-grained dirty, micaceous, dense sandstone, weathers buff, mostly massive; interbedded thin, dark-gray, irregular, platy, dense shale. Sandstone about 85 percent and shale 15 percent	100
195.	Shale, dark-gray, blocky to splintery	30
194.	Sandstone, gray, very fine-grained, dirty, micaceous, hard; weathers buff	20
193.	Shale, dark-gray, waxy, blocky; with thin irregular, micaceous, platy silt zones	150
192.	Sandstone, gray, fine- to very fine-grained, dirty, micaceous, dense to quartzitic, massive; with ripple marks on top of some beds; interbedded black, hackly, gritty, carbonaceous, thin shale with silt and sand laminae. Sandstone about 80 percent and shale about 20 percent	92
191.	Several small faults in this zone	13
190.	Sandstone, gray, fine-grained, dirty, micaceous, hard; weathers buff; interbedded with dark-gray shale with thin siltstone stringers. Sandstone about 80 percent	35
189.	Shale, black, hackly, silty	14
188.	Sandstone, gray to light-gray, and black shale; lower part very fine-grained, micaceous siltstone and sandstone interbedded with silty shale; upper part mostly micaceous, dense, massive sandstone up to 8 feet thick. Some beds contain incorporated fragments of plant debris and shale. Sandstone about 80 percent	150

187.	Shale, tan to black, waxy, blocky; includes small fault with little stratigraphic throw	19
186.	Sandstone, gray, and dark-gray to tan shale; interbedded fine-grained, thin-bedded sandstone and carbonaceous, micaceous shale; shale contains silty laminae. Sandstone about 50 percent	50
185.	Shale, gray; slightly weathered with thin sandstone and siltstone stringers	40
184.	Sandstone, gray to light-gray, and dark-gray to black shale; lower 30 feet very fine-grained, micaceous, massive, dense sandstone with shale fragment inclusions; middle part interbedded very fine-grained, micaceous sandstones and fissile shale with silt streaks and stringers, sandstone about 60 percent and shale 40 percent; upper part dominantly fine-to medium-grained, micaceous, dense, massive sandstone beds	170
183.	Shale, gray to tan, carbonaceous, blocky to platy	18
182.	Sandstone, light-gray, and black shale; lower 40 feet fine-grained, rounded-grained, micaceous, dense, massive sandstone; middle part interbedded fine-grained, micaceous, dirty, thin sandstones and hackly shale with fine silty streaks; some shale contains abundant plant fragments; upper part mostly micaceous, massive sandstone. Sandstone about 80 percent	115
181.	Shale, dark-gray, silty; with balled-up silt and shale; thin sandy zones 2 to 4 inches thick	30
180.	Shale, black, hackly	6
179.	Sandstone, gray, fine-grained, micaceous, dense, quartzitic	12
178.	Siltstone, shale, and sandstone; buff-weathering thin siltstone, shaly silts, soft micaceous sandstone, and some black hackly shale	15
177.	Sandstone, light-gray, fine-grained, dirty, micaceous, dense; some shale fragments	27
176.	Siltstone, buff-weathering, and gray shale; mostly micaceous siltstones and silty sandstones interbedded with thin shale	30
175.	Sandstone, olive-weathering, and dark-gray to black shale; fine-grained, dirty, micaceous, dense, sandstone with rounded grains interbedded with thin, platy to blocky shale. Sandstone about 65 percent and shale 35 percent	35
174.	Shale, gray, waxy; with thin beds and stringers of fine sandstone and siltstone. Shale about 85 percent	67
173.	Shale, dark-gray, waxy, fissile, platy; plates 1/8 inch thick	15
172.	Sandstone, gray, and dark-gray shale; alternating thin-bedded, fine-grained, dirty, micaceous, dense sandstone, weathering lavender to olive-green, and shale. About 50 percent sandstone and 50 percent shale	35

171.	Shale, dark-gray to black, fissile to blocky	15
170.	Shale, dark-gray, and gray sandstone; alternating fissile to blocky shale containing thin sandstone and siltstone stringers with fine-grained, dirty, micaceous, dense sandstone beds up to 2 feet thick. Shale about 60 percent and sandstone 40 percent	60
169.	Shale, dark-gray to black, fissile to blocky	12
168.	Sandstone, gray, buff-weathering, and dark-gray to black shale; interbedded fine-grained, silty, dirty, micaceous, dense sandstone in beds up to 4 feet thick and irregular, platy to nodular, slightly carbonaceous, soft shale in beds up to 8 feet thick. Sandstone about 50 percent and shale about 50 percent of interval	173
167.	Shale, poorly exposed, weathered; in dozed cut near crest turn-out; interbedded thin, olive, dirty, micaceous, dense sandstone. At bottom is black, very fine-grained, recrystallized, cherty sandstone; resembles some siliceous shales	57
166.	Shale, dark-gray to black, hackly, nodular; interbedded with olive, platy, ¼-inch shale and fine siltstone laminations	35
165.	Covered in gully just north of ridge crest on east side of road	80
164.	Sandstone, light-gray, and dark olive-gray shale; lower part buff, weathered, fine-grained, dirty, micaceous siltstone and sandstone, some graded beds; middle part mostly blocky, waxy shale with thin sandstone and siltstone stringers; upper 22 feet fine-grained, micaceous, soft sandstone	115
163.	Covered	50
162.	Sandstone, light-gray; weathers buff; fine- to medium-grained, micaceous, silty, soft, massive beds up to 12 feet thick; interbedded thin buff, micaceous siltstone and soft sandstone	95
161.	Sandstone, light-gray to gray, and dark-gray to black shale; alternating fine-grained, micaceous, dense silty sandstone and blocky, waxy shale; some intervals of platy micaceous siltstone. Well-developed sole marks on many sandstone beds. Possible small faults in this unit.	115
160.	Sandstone, light-gray, and dark-gray to black shale; alternating medium to fine-grained, dirty, micaceous, hard sandstone and fissile shale. Sandstone about 60 percent and shale 40 percent of interval	60
159.	Siltstone, buff-weathering, and black shale; alternating thin micaceous siltstone and thin hackly shale containing silty streaks	33
158.	Sandstone, white, fine- to medium-grained, micaceous, soft, silty	12
157.	Shale, dark-gray to gray, and gray sandstone; domin-	

	antly shale with thin interbeds of fine-grained, micaceous, dense sandstone; some sandstones have black organic bands; some weather light maroon and others olive; lower 20 to 25 feet weathered shale. Shale about 85 percent	59
156.	Sandstone, light-gray, buff-weathering, fine-grained, silty, micaceous, dense; bedding 1 to 3 feet	16
155.	Shale, gray, and sandstone; platy, silty, shale with thin sandstone beds. Top is below a small fault with slight displacement	12
154.	Sandstone, gray, fine- to medium-grained, micaceous, massive	10
153.	Sandstone, light-gray, buff-weathering, and gray shale; alternating fine-grained, dirty, micaceous sandstone with thin shale stringers; upper part has 4- to 8-foot-thick beds of gray, carbonaceous, platy soft shale	72
152.	Shale, black, fissile	10
151.	Sandstone, white, and tan to light-gray shale; mostly medium-grained, hard, massive sandstone in beds up to 7 feet thick interbedded with thin leached shales	28
150.	Shale, tan to light-gray; buff, weathered, fine-grained, friable micaceous sandstone lenses	13
149.	Sandstone, light-gray, and dark-gray shale; interbedded agrillaceous, silty sandstone beds 1 to 2 feet thick with silty shale; some sandstone becomes friable on weathering. Fossil molds in sandstone float near upper part of this unit, but source bed is weathered and difficult to locate in place	32
148.	Shale, dark-gray; with thin siltstone and fine-grained sandstone 1 to 4 inches thick. Both shale and sandstone weather to light rust-brown	42
147.	Sandstone, brown, medium-grained, dense; beds 4 to 18 inches thick. Good fossil mold bed 2 to 3 inches thick at base of unit. This may be Honess' "mold fauna"	8
	Total Atoka exposed	5,622

JOHNS VALLEY FORMATION:

146.	Shale, light-gray to gray; weathers to reddish brown; abundant exotic boulders of limestone, chert, and silty sandstone incorporated in the upper 100 feet; sideritic concretions up to 18 inches long common; a few scattered phosphatic marblelike nodules; lower part weathered and poorly exposed	810
145.	Covered; probably Johns Valley Shale	180
	Total Johns Valley	990

JACKFORK GROUP

GAME REFUGE-WESLEY FORMATIONS (undifferentiated):

144.	Shale, reddish-brown, arenaceous, weathered	15
143.	Sandstone, dark-gray, and black shale; massive, dense, quartzitic sandstone beds 1 to 6 feet thick interbedded with shale beds 4 to 8 inches thick. Sandstone about 60 percent	38
142.	Shale, black, platy; contains thin ¼- to 1-inch siltstone stringers. Shale about 95 percent	45
141.	Shale, black, platy; numerous siltstone stringers and black, dense, quartzitic beds 4 to 12 inches thick. Shale about 80 percent and sandstone 20 percent	45
140.	Shale, dark-gray to black, and dark-gray sandstone; platy shale with 1- to 4-inch siltstone and sandstone stringers. In middle of unit is 14-inch bed of dense sandstone that partly changes to sandstone stringers up the cut bank. Shale predominates in interval	17.6
139.	Sandstone, dark-gray, dense, quartzitic; good convolute bedding in upper part	5
138.	Shale, black, platy, silty; interbedded thin siltstone stringers ¼ to 1 inch thick; some small sideritic concretions	16
137.	Sandstone, dark-gray, medium- to coarse-grained, dense massive	9
136.	Sandstone, dark-gray to black, medium-grained, argillaceous, friable, structureless; may be zone of fault gouge; some rolled sandstone masses that appear to be of tectonic origin; weathers easily	35

From the lower part of the Atoka to this point the section was measured on the east side of the road. Units 135 through 105 were measured on west side of road beginning just across bridge culvert.

135.	Sandstone, dark-gray; like unit 133	75
134.	Shale, reddish-brown to gray; contorted as if gouge of local fault. This unit downward measured on west side of road	19
133.	Sandstone, dark-gray, massive, dense, quartzitic; some fossil molds; weathers to clean white sandstone; large flute casts at base	95
132.	Sandstone, gray, silty, carbonaceous, highly shattered and weathered; may be zone of movement	7
131.	Shale, reddish-brown to gray; contains well-developed siderite concretions	25
130.	Sandstone, dark-gray to black, dense, quartzitic	1.5
129.	Shale, black, platy; contains numerous thin stringers	

	of siltstone, some of which weather into iron oxide-stained rectangular blocks	6
128.	Sandstone, black, and black shale; alternating dense sandstone beds with platy shale, which contains thin stringers of siltstone and fine-grained sandstone	15
127.	Sandstone, dark-gray, argillaceous; abundant carbonaceous plant fragments; highly weathered into spheroidal masses	7.5
126.	Shale, black, and dark-gray sandstone; contorted sandstone beds 1 to 3 feet thick interbedded in platy shale with thin siltstone sringers	44
125.	Sandstone, dark-gray; several massive sandstone beds; part is faulted out at bottom of bank	10
124.	Shale, black, platy, one 6-inch sandstone bed	5
123.	Sandstone, dark-gray, single massive bed; excellent large flute casts on bottom	2
122.	Shale, black, and dark-gray sandstone; lower half mostly sandstone with thin shale interbeds; upper half mostly thin sandstone interbeds	34
121.	Sandstone, dark-gray, massive, well-developed convolute bedding	2
120.	Shale, black, platy with a profusion of thin ¼- to 1-inch siltstone stringers; one 18-inch sandstone bed in middle	14
119.	Sandstone, black, dense, thick-bedded	19
118.	Sandstone, black, and black shale; alternating silty sandstone containing thin laminae of carbonaceous material, beds 4 to 12 inches thick and platy shale	7
117.	Shale, black, platy with thin 1- to 2-inch stringers of fine-grained sandstone and siltstone	7
116.	Sandstone, black, dense, quartzitic, beds 8 to 18 inches thick alternating with thin shale beds 4 inches thick	5
115.	Shale, black, platy with numerous ¼- to 1-inch stringers of siltstone	14
114.	Sandstone, dark-gray, and black shale; sandstone beds 1 to 2 feet thick, some argillaceous and friable, alternating with platy shale containing siltstone stringers	11.5
113.	Sandstone, dark-gray, massive	6
112.	Shale, black, platy; numerous thin siltstone and fine-grained sandstone stringers ¼ to 2 inches thick; one thin claystone bed near top	4
111.	Sandstone, dark-gray, massive	10
110.	Shale, black, and dark-gray sandstone; interbedded platy shale and thin siltstone stringers ¼ to 4 inches thick; one massive sandstone bed 3.5 feet thick	8.5
109.	Sandstone, dark-gray, and black shale; sandstone with clay galls interbedded with silty, platy shale	3
108.	Shale, black, platy, silty with one 4-inch dark-gray sandstone bed	4
107.	Sandstone, dark-gray, massive; gray, arenaceous 20-	

	inch shale at base of unit	12.6
106.	Sandstone, dark-gray, and black shale; dominantly sandstone, massive 4.5-foot sandstone bed at top of unit with one-foot shale bed beneath	16
105.	Sandstone, dark-gray, and black shale; carbonaceous sandstone beds 8 to 18 inches thick with thin shale beds.	14

Units 104 through 68 measured in Big Cedar Creek.

104.	Shale, black, silty.	2
103.	Sandstone, dark-gray, massive	7
102.	Shale, black, and dark-gray sandstone; platy shale interlaminated with thin ⅛-inch siltstone stringers; one 4-inch sandstone bed near top	2
101.	Sandstone, dark-gray, and black shale; interbedded dense sandstone beds 1 to 3 feet thick and thin shale beds 1 to 2 inches thick	11.5
100.	Shale, black, platy; no siltstone stringers	3
99.	Sandstone, black, dense, massive	13
98.	Shale, black, and dark-gray sandstone; silty arenaceous shale interbedded with argillaceous sandstone beds up to 4 inches thick; sandstone contains clay galls and carbonaceous plant fragments	6
97.	Sandstone, black, and black shale; dense sandstone beds up to 3 feet thick alternating with silty, carbonaceous shale 4 to 12 inches thick	11
96.	Sandstone, black, dense. massive	17
95.	Sandstone, dark-gray, and black shale; sandstone beds 8 to 12 inches thick alternating with shale beds 4 to 12 inches thick	5
94.	Sandstone, black, dense. massive	10
93.	Shale, black, sandy; with a few 2- to 3-inch beds at top of unit	7
92.	Sandstone, black, and black shale; dense sandstone beds 8 inches to 3 feet thick alternating with shale beds 3 to 12 inches thick; one shale bed contains a mass of black carbonaceous material 2 feet in diameter	20
91.	Sandstone, black, dense, massive	13
90.	Sandstone, dark-gray to black, and black shale; dense, carbonaceous sandstone beds 8 to 18 inches thick alternating with shale beds 6 to 24 inches thick; concretions in some sandstone beds; small 3-inch sandstone dike in creek bottom	14
89.	Sandstone, dark-gray, dense, massive	3
88.	Shale, black; mostly shale but 6- to 8-inch sandstone beds near top and bottom; lenticular sideritic concretions both in sandstone and shale	7
87.	Sandstone, dark-gray to black, dense, quartzitic, massive	24
86.	Shale, black, platy; many ⅛-inch siltstone stringers; upper part has one 6-inch sandstone bed; lenticular	

	concretions in middle of unit	16
85.	Sandstone, dark-gray; with 2-inch shale stringers	2.7
84.	Shale, black with ¼-inch siltstone stringers spaced about 1 inch apart	3
83.	Sandstone, dark-gray, beds 2 to 8 inches thick with interbeds of shale stringers 1 inch thick	6
82.	Shale, black, and black sandstone; shale beds 1 to 3 feet thick with ¼- to 2-inch siltstone stringers interbedded with dense sandstone beds 7 to 14 inches thick; some sandstone beds show definite thinning up the creek bank	7
81.	Claystone, reddish-brown; single bed	0.1
80.	Sandstone, black, and black shale; mostly dense, massive sandstone beds 9 inches to 3 feet thick interbedded with thin 1- to 6-inch shale beds	7
79.	Sandstone, black, dense, massive	9
78.	Sandstone, black, and black shale; 2 sandstones beds 20 and 4 inches thick interbedded with two shale beds 2 and 6 inches thick	2.7
77.	Sandstone, black, and black shale; mostly dense, quartzitic sandstone 2 to 8 inches thick interbedded with shale one inch thick	13
76.	Shale, black, and black sandstone; dominantly platy shale with 1-inch siltstone stringers interbedded with a few sandstone beds 4 to 10 inches thick	9.6
75.	Sandstone, black, and black shale; one massive sandstone 6 feet thick with 4-inch shale at base	6.3
74.	Sandstone, black, and black shale; alternating beds of dense sandstone 1 to 3 inches thick and platy shale 1 to 2 inches thick; some thin siltstone stringers; one 12-inch sandstone at base; well-developed sole markings on sandstones	9.2
73.	Shale, black, platy; with 5 siltstone stringers 1 to 2 inches thick	1.5
72.	Shale, black, and dark-gray sandstone; platy shale with interbeds of dense, quartzitic sandstone 2 to 11 inches thick	6.5
71.	Shale, black, platy; with several fine-grained sandstone to siltstone beds 1 to 2 inches thick near base of unit	12
70.	Sandstone, black, and black shale; dense, quartzitic, sandstone beds 4 to 12 inches thick interbedded with platy shale beds 12 to 18 inches thick; argillaceous siltstone stringers ¼ to ½ inch thick throughout shale	10
69.	Sandstone, black, and black shale; mostly dense, quartzitic sandstone beds 3 to 12 inches thick with thin shale stringers less than 1 inch thick; sandstones show excellent convolute bedding and sole markings	6
68.	Sandstone, black, and black shale; poorly exposed, alternating dense quartzitic sandstone beds 2 to 12 inches thick with thin platy, hard shale beds; ¼-inch siltstone stringers in shale. Bottom of unit begins about 25 feet	

	south of bridge culvert	20
67.	Covered; probably shale like unit 83	65

Units 66 through 1 (bottom of section) measured in road cut on east side of road.

66.	Shale, olive-gray to light-brown, hackly; rounded sandstone masses in lower part of unit	100
65.	Sandstone, dark-gray, dense, quartzitic, massive	11
64.	Sandstone, dark-gray, weathered, friable, argillaceous; abundant carbonaceous plant fragments	1.5
63.	Sandstone, dark-gray, and black shale; dense, quartzitic sandstone with excellent sole marks; 6-inch platy shale at base	1.5
62.	Sandstone, dark-gray, dense, quartzitic, massive; sole marks	22
61.	Shale, black, platy; with thin cross-bedded fine-grained sandstone to siltstone stringers	5
60.	Shale, olive-gray to light-brown, hackly; lower 50 feet contains rolled sandstone masses; upper contact grades into unit 61	165
	Total Game Refuge-Wesley (undifferentiated)	1421.3

MARKHAM MILL-PRAIRIE MOUNTAIN-UPPER WILDHORSE MOUNTAIN FORMATIONS (UNDIFFERENTIATED):

59.	Sandstone, dark-gray, dense; weathers to friable sand	20
58.	Shale, black, platy; with a few thin 1- to 2-inch argillaceous sandstone beds	3
57.	Sandstone, dark-gray, dense, quartzitic, massive; shattered by blasting	20
56.	Sandstone, and sandy shale; argillaceous, weathered	2
55.	Sandstone, dark-gray, much weathered, medium- to fine-grained	3
54.	Shale, black platy	1.5
53.	Sandstone, dark-gray, dense	0.9
52.	Sandstone, and sandy shale; argillaceous, weathered	0.9
51.	Sandstone, dark-gray; weathers rust brown to gray; upper part friable due to weathering	7
50.	Sandstone, and sandy shale; argillaceous, weathered	1
49.	Sandstone, dark-gray, massive; weathers gray and friable; some clay galls up to 3 inches across	21
48.	Sandstone, gray, and black shale; alternating argillaceous, friable sandstone and platy shale, much weathered	9
47.	Sandstone, gray, medium-grained, massive; parts of unit weather into gray, friable, thin, argillaceous laminae	13
46.	Sandstone, gray, argillaceous, carbonaceous, friable	0.5

45.	Sandstone, light-brownish-gray, medium-grained; 2 foot bed at base	7.5
44.	Sandstone, reddish-brown, argillaceous, carbonaceous, friable, weathered; black shale stringers also weathered reddish brown	1.5
43.	Sandstone, dark-gray, medium-grained, dense, massive, weathered	20
42.	Shale, silty, sandy, highly weathered; weathers rust red	3
41.	Sandstone, dark-gray, dense, quartzitic; beds 2 to 12 inches thick	14
40.	Sandstone, light-brown, highly argillaceous, friable; some black shale stringers	1.5
39.	Sandstone, light- to dark-gray, dense, quartzitic; bottom has pit marks where clay galls have been weathered out; some carbonaceous clay fragments remain	11
38.	Shale, dark-gray, sandy, silty	0.7
37.	Sandstone, dark-gray, medium-grained, silty, massive; weathers light brown on surface	4
36.	Sandstone, gray, and black shale; thin, dense, cross-bedded, fine-grained sandstone to siltstone and interbedded shale; shale weathers reddish brown	7
35.	Sandstone, brown to rust-red, massive; weathers white on surface	4
34.	Shale, weathered olive-gray	0.9
33.	Sandstone, dark-gray, dense, quartzitic, massive; large flute casts on bottom	35
32.	Shale, black, platy; a few thin cross-bedded fine-grained sandstone stringers	2
31.	Sandstone, dark-gray, dense, quartzitic, massive	8
30.	Sandstone, dark-gray, and black shale; dense, quartzitic sandstone beds 10 to 16 inches thick alternating with platy, shale beds 8 to 20 inches thick; shale contains thin 1-inch siltstone stringers; sandstone beds have well-developed sole marks	7
29.	Shale, black to light-pink, and dark-gray sandstone 6-inch shale beds interbedded with dense, quartzitic sandstone beds	5
28.	Sandstone, dark-gray, dense, quartzitic; shows dark- and light-gray laminae on weathered surface	1.1
27.	Sandstone, dark-gray, and black to light-pink shale; 6-inch dense, quartzitic sandstone beds interbedded with 6-inch shale beds	3
26.	Sandstone, dark-gray, dense, quartzitic; 6-inch beds intercalated with thin 1-inch black shale stringers; well-developed sole marks on sandstones	3
25.	Sandstone, dark-gray, dense, quartzitic; bedding 6 to 24 inches; well-developed sole marks	5
24.	Siltstone, dark-gray, and black shale; alternating thin siltstone and shale stringers	3
23.	Sandstone, dark-gray, dense, quartzitic, thick-bedded, highly contorted	10

22.	Sandstone, light-gray, and black shale; fine-grained sandstone; weathers white; cross-bedded; bedding 1 to 2 inches thick with platy shale stringers	2
21.	Sandstone, dark-gray, dense, quartzitic, massive	11
20.	Sandstone, dark-gray, dense, quartzitic; bedding 1 to 6 inches thick; interlaminated black platy shale	3
19.	Sandstone, dark-gray, medium-grained, dense	2
18.	Siltstone, dark-gray, and black shale; $\frac{1}{8}$- to $\frac{1}{4}$-inch siltstone stringers interlaminated with platy shale	0.9
17.	Sandstone, dark-gray, dense; bedding 4 to 12 inches	3.7
16.	Sandstone, gray, and black shale; thin cross-bedded sandstone stringers $\frac{1}{4}$ to 1 inch thick interlaminated with platy shale stringers	4
15.	Sandstone, dark-gray, medium-grained, dense, massive	10
14.	Fault zone; highly contorted sandstone and shale. This unit and units 8 and 4 below comprise the Briery fault	7
13.	Sandstone, dark-gray, medium-grained, dense, quartzitic, with thin clay shale $\frac{1}{4}$-inch stringers in middle of unit	9
12.	Sandstone, light-gray, argillaceous, friable; weathers lavender	0.7
11.	Sandstone, gray, quartzitic, shattered; sole marks	3
10.	Shale, dark-gray, and brown sandstone; interbedded shale and sandstone; abundant carbonaceous plant fragments in sandstone	0.7
9.	Sandstone, light-gray to gray, dense, quartzitic, shattered; sole marks; middle of unit is 18-inch zone of 2-inch sandstone beds and interbedded sandy, silty shale	7
8.	Fault zone; contorted shale with incorporated sandstone masses	15
7.	Sandstone, brownish-gray, silty, massive; an 8-inch white micaceous shale near middle of unit	10
6.	Sandstone, white to pinkish-white, argillaceous, friable	0.7
5.	Sandstone, dark-gray to black, and light-gray shale; upper 1 foot is carbonaceous shale; lower 2 feet is quartzitic sandstone	3
4.	Fault zone; highly contorted sandstone and shale	20
	Total Markham Mill-Prairie Mountain-upper Wildhorse Mountain Formations (undifferentiated) exposed	372.7

STANLEY GROUP (UNDIFFERENTIATED)

3.	Shale, olive-gray, sandy, silty	15
2.	Shale, olive-gray, and dark-gray to brown sandstone; shale 1 to 3 feet thick interbedded with medium-grained, dirty, quartzitic sandstone beds 6 to 12 inches thick	9
1.	Shale, olive-gray, sandy, silty; contains large rolled sandstone boulders, up to 5 feet in diameter, incorporated in the shale during faulting. At the base of the	

unit is exposed 4 feet of dark-gray, dirty, massive sandstone, much shattered and weathered; base is covered ... 40

Total Stanley exposed ... 64

INDEX

(**Boldface** indicates main reference)