



DEPOSITIONAL FEATURES TYPICAL IN THE LARGER ROOMS OF THE DIAMOND
CAVE NEAR JASPER, NEWTON COUNTY

STATE OF ARKANSAS
Arkansas Geological Survey

GEORGE C. BRANNER

State Geologist

BULLETIN 3

Geology of the Arkansas Paleozoic Area

With Especial Reference to

Oil and Gas Possibilities

By

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LITTLE ROCK

1930

LETTER OF TRANSMITTAL

ARKANSAS GEOLOGICAL SURVEY
LITTLE ROCK, ARK., JULY 1, 1930

HON. HARVEY PARNELL,
Governor, State of Arkansas,
Little Rock, Arkansas.

Sir:

I have the honor to submit herewith the report, "The Geology of the Arkansas Paleozoic Area with Especial Reference to Oil and Gas Possibilities," by Dr. Carey Croneis, Assistant Professor of Geology of the University of Chicago.

The area covered by this report includes approximately 25,000 square miles in the central, northern, western, and northwestern parts of the State. This area is commonly known as the highland area of the State and is usually divided into three main physiographic regions, namely, the Ozark Plateaus, the Arkansas River Valley, and the Ouachita Mountains.

The report places especial emphasis on the oil and gas possibilities of the area and in this connection approximately 168 structures including 73 anticlines, 61 synclines, and 34 faults were mapped in the Arkansas River Valley. This region appears to be the most favorable portion of the highland area for the accumulation of gas or oil. Maps of these structures are included in the report as well as a detailed description of each structure and definite opinions as to the oil and gas possibilities of each structure described.

Although the structures of the Ouachita Mountains evidently have slight commercial possibilities, they have been studied in order to better understand the nature of the forces and the character of the crustal movements which have been responsible for the structural conditions in the Arkansas River Valley. Most of the structural information bearing on the Ouachita Mountain area has been gathered from field records of the State and Federal Surveys.

It is believed that the western Arkansas area, particularly the Arkansas River Valley section is one which may prove of much greater importance in the future than it has up to the present time for its production of natural gas. Its discovery and development may prove of importance to the industrial future of Arkansas. In addition, there appear to be petroleum possibilities in the Mississippian and older beds in this area. It is believed this report will assist to some degree in stimulating the necessary exploration for both gas and oil.

Respectfully submitted,

GEORGE C. BRANNER,
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ABSTRACT

LOCATION AND SUBDIVISIONS OF THE AREA

The area of outcrop of the Arkansas Paleozoic rocks occupies essentially the northwestern half of the State and covers about 25,000 square miles. Unlike the low-lying Gulf Coastal Plain, on the southeast, it is a fairly rugged highland. It is divisible into several physiographic provinces, of which the larger are the Ozark Highlands, which lie north of the Arkansas River; the Arkansas Valley, through which the river flows; and the Ouachita Mountains, which lie between the Arkansas Valley and the Gulf Coastal Plain on the south and southeast. The Ozark Highlands are made up of deeply dissected plateaus, which rise toward the south and reach a maximum height of about 2,400 feet above sea level. The Arkansas Valley is a westward-trending structural topographic trough, above whose low, undulating surface rise sharp-topped ridges and flat-crested, mesa-like mountains, which attain a maximum height of more than 2,800 feet. The Ouachita Mountains are a series of nearly westward-trending rather rugged ridges of complex structure. The highest peaks reach elevations of about 2,700 feet above sea level and rise 1,500 feet above the adjacent lowlands.

ROCKS AND STRUCTURE OF THE OZARK HIGHLANDS

The rocks of the Ozark Highlands include beds of limestone, shale, sandstone, dolomite, chert, and conglomerate, and range in age from Ordovician to Pennsylvanian. Most of these beds, particularly those of Carboniferous age, are fossiliferous. The more common and diagnostic fossils of the Carboniferous formations are named and figured in the report. Deep wells in the northern part of the Arkansas Valley or in the southern Highlands penetrate most of these formations, and their recognition and determination from well records is important.

The structure of the Ozark Highlands is simple. The beds dip gently southward near the Missouri boundary, and the regional dip gradually increases toward the Arkansas Valley. A series of anticlinal terraces near the southern edge of the province links the structure of this area with that of the more intricately folded Arkansas Valley. The Highland area is normal-faulted at several places. Most of the faults are downthrown south of their traces, where the

beds have been folded into synclines near the fault lines. The anticlines, some of which are suitable reservoirs for oil and gas, are described in detail, and their axes are indicated on a large structural map.

ROCKS AND STRUCTURE OF THE ARKANSAS VALLEY

The beds in the Arkansas Valley consist chiefly of unfossiliferous shale and sandstone, all of Carboniferous age and most of them belonging to the lower part of the Pennsylvanian series. The rocks are generally highly carbonaceous and in some places are coal bearing. They contain little or no calcareous material. The maximum thickness of the Paleozoic rocks in the Arkansas Valley is about 30,000 feet, of which at least 15,000 feet are exposed. The sedimentary beds are at a few places cut by igneous intrusive rocks of mid-Cretaceous age. These intrusive rocks, which were discovered during the field work done for this report, are described in detail.

The Arkansas Valley is a synclinorium in which the folds are more open toward the north than toward the south. The structural axes generally trend westward, but some deviate notably from that direction. Most of the anticlines in the southern part of the Valley are asymmetrical in that their north limbs are steeper than their south limbs; many near the center of the valley are nearly symmetrical; and some near its north border are slightly asymmetrical, but here most of the south limbs of the anticlines are slightly steeper than the north limbs.

Large thrust faults are common south of the Arkansas River but are not common north of it. Normal faults are found throughout the province but are more common north of the Arkansas River than south of it. In most parts of the province the topography is an expression of the structure. Broad, open synclines are expressed by high, flat-topped mountains; steeply tilted limbs of anticlines and synclines are generally expressed by sharp ridges, some of which are many miles long.

ROCKS AND STRUCTURE OF THE OUACHITA MOUNTAINS

The rocks of the Ouachita Mountains consist of shale, sandstone, novaculite, chert, conglomerate, and minor amounts of limestone and volcanic tuff. They range in age from Cambrian to Carboniferous and have an aggregate thickness of at least 25,000 feet. They are intruded at some places by alkaline igneous rocks of mid-Cretaceous age, but the total area of igneous rocks is very small. The sedimentary rocks are essentially non-fossiliferous, but the Ordovician and Silurian beds have yielded a few graptolites, and the Carboniferous formations contain macerated remains of plants.

The Ouachita Mountains constitute a complexly folded anticlinorium, in which Cambrian rocks are exposed near the crest and Carboniferous sediments on the north and south flanks. Some of the small anticlines of which the major anticlinorium is composed are themselves rather complex anticlinoria and synclinoria. Most of the structural axes trend slightly north of east, as do the ridges that express with fair accuracy the underlying structure. Close folding is general throughout the province, but in places there are open folds. Faulting is not so common as might be expected in view of the great deformation, but there are both thrust and normal faults.

GENERAL STRUCTURAL FEATURES OF THE ARKANSAS PALEOZOIC AREA

The sedimentary rocks of the Arkansas Paleozoic area were deposited in a geosynclinal basin that lay between Ozarkia on the north and Llanoria on the south. Most of the material forming them was derived from a landmass that occupied the present position of Louisiana and eastern Texas. The sediments spread at least as far north as the Arkansas-Missouri boundary, but they are best represented and thickest in the Ouachita Mountains and Arkansas Valley provinces. The sea near the northern landmass—a mass that was both smaller and lower than Llanoria—was normally clearer than it was farther south, and in it were deposited the limestones of the Ozark Highlands. At several times, however, relatively small quantities of elastic material were contributed to the basin of deposition by Ozarkia. Most of the sediments of the Arkansas Valley and the Ouachita Mountains were laid down in shallow water, and the geosyncline gradually but continually subsided during their deposition.

The Paleozoic beds of Arkansas were deformed by folding and faulting during the mid-Pennsylvanian epoch of mountain building. The pressure that crumpled the beds was applied from the south. The results of this pressure are therefore most apparent in the Ouachita Mountains, and the intensity of the folding and the amount of faulting diminish toward the north. The landmass of Ozarkia and the competent rocks formed just south of it resisted the force applied from the south but were bodily elevated by it. The rocks of this general area were thrown into gentle irregular domes and broad synclinal basins, and when the pressure was released normal faults were formed as a result of the tension following compression.

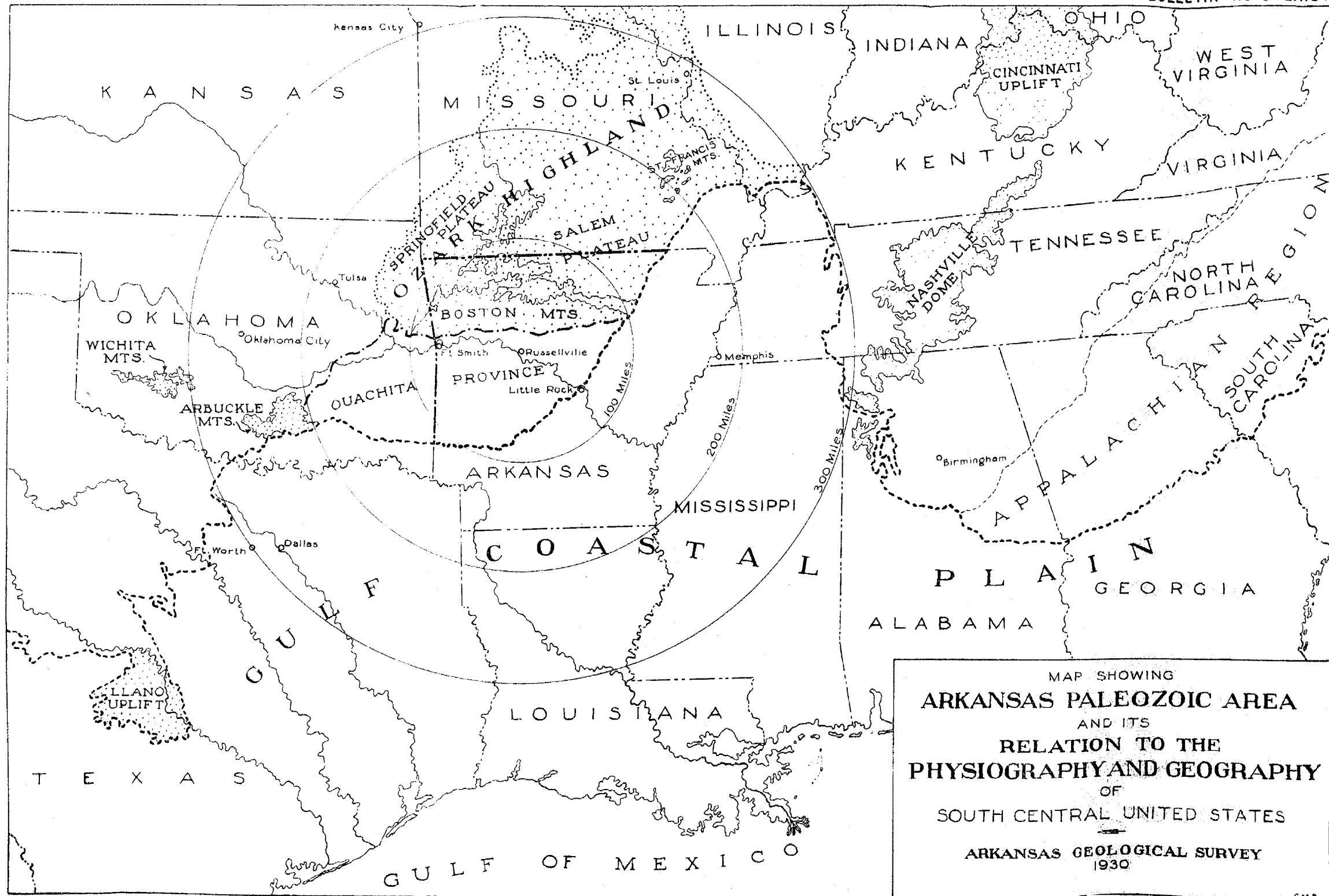
OIL AND GAS IN THE ARKANSAS PALEOZOIC AREA

Dry gas in considerable quantities has been produced from fields in the Arkansas Valley for about 25 years, and the productive territory has been and is now being rapidly extended. In the course of the field work done for this report a large number of anticlines and

synclines in the Arkansas Valley were mapped. Many of these anticlines are structurally favorable for the accumulation of gas, which may be expected at some places in the province where the anticlines have adequate closure and the sands are not impervious. The present and potential productive sands are in the Atoka formation. The beds of this formation were deposited rapidly, and they vary so greatly in lithology, both vertically and horizontally, that they cannot be divided into separate units, for subdivisions established for one area may be unrecognizable a few miles away.

The folds and faults described include a few in the Ouachita Mountains and many in the Ozark Highlands. Attempts have been made to determine the economic possibilities of all the anticlinal folds, but extensive drilling should not be started without supplementing the information contained in this report with more detailed geologic exploration. In general terms the Ouachita Mountain province is regarded as unfavorable for the production of either oil or gas, the Arkansas Valley is regarded as favorable for gas, and the southern Ozark Highland is regarded as slightly less favorable for gas but as having a slight chance for oil. The carbon ratios of Carboniferous coals are shown to have no significance in ruling out areas unsuited for the production of gas, as some of the largest fields occur where the ratios are as high as 88. It is also shown that most of the fundamental criteria for the occurrence of oil and gas are satisfied by the geologic conditions found in the southern Ozark Highlands and the Arkansas Valley, but that the degree of metamorphism of the beds as a criterion is somewhat uncertainly evaluated and the porosities of the potential productive sands are not well known.

Logs of most of the important test wells are included in the report, and the more accurate ones are interpreted.



GEOLOGY OF THE ARKANSAS PALEOZOIC AREA

By CAREY CRONEIS

INTRODUCTION

NEED OF INVESTIGATION

Gas in commercial quantities has been produced from the Carboniferous rocks of the Arkansas Valley for more than a quarter of a century, but until the last few years the productive fields have been limited to an area near Fort Smith. Although the production was reasonably large and relatively remunerative, no serious attempt was made to open new fields until late in 1925, when the initial well in the Clarksville area was completed. This seeming lack of enterprise was due chiefly to the fact that no oil had been found in association with the gas and that there was no large market for gas. In addition, since the carbon ratio theory was propounded, in 1915, the very high carbon ratios of the coals of the Arkansas Valley have deterred the larger organizations from exploring that area.

When exploration was begun in the Clarksville district, however, several of the larger oil and gas companies and many local concerns became interested in the area, new markets for gas were opened, and the idea that high carbon ratios in a region precluded the possibility of finding gas there began to be seriously questioned. Some of the drilling was done under competent scientific advice, but much of it, and indeed most of all the previous drilling in the Arkansas Paleozoic area, was so poorly directed that it not only wasted a great deal of money but its generally unfavorable results deterred strong organizations from prospecting in the area. Accordingly the Arkansas Geological Survey decided not only to point out the possibility of obtaining gas in the Arkansas Valley but to delineate its major structural features, and in June, 1927, that organization undertook a detailed reconnaissance survey of the Arkansas Valley province. In the course of the work, increased exploration for oil and gas in adjacent areas made it seem expedient to enlarge the scope of the report to include the entire Paleozoic area in Arkansas.

ACKNOWLEDGMENTS

The writer wishes to express his indebtedness to G. C. Branner, State Geologist of Arkansas, for constructive criticism and generous

assistance in the preparation of this report. Thanks are due also to H. D. Miser, Chief of the Section of Geology of Fuels of the U. S. Geological Survey, for many helpful suggestions and for access to a large amount of unpublished data, particularly concerning the Ouachita Mountain area. David White, of the same organization, has made a number of valuable suggestions in regard to the regional metamorphism of the Paleozoic area as indicated by the carbon ratios of coals. Acknowledgments are due also to W. Z. Miller of Tulsa for permission to examine his manuscript map and report on the geology of a large part of the eastern Boston Mountains and Arkansas Valley. C. L. Severy of Tulsa kindly supplied a great deal of such generalized information as could be given without jeopardizing the interests of his clients, and A. G. Williams, of Fort Smith, supplied general information concerning the gas fields in the Fort Smith district. Thanks are due to Harry and Leigh Kelley, of Fort Smith, who contributed most of the data concerning the Mansfield gas field, to the officials of the Federal Court at Fort Smith for access to the records of the Twin Cities Pipe Line rate case, to D. W. Johnston of Clarksville, and to A. B. Rowley of Tulsa, who supplied manuscript maps of several areas in the Arkansas Valley and Boston Mountains.

The writer is especially indebted to Samuel Hayes of Tulsa for placing at his disposal several analyses of coal and shale, as well as reports prepared for Mr. Hayes by consulting geologists. A number of others who assisted in the work are mentioned in the text. The list of those who have helped to facilitate the field work is too long to be given here, although their aid has been greatly appreciated.

In the course of the field work the writer was assisted by Cecil D. Robinson, Bryan Parks, and Homer L. Anderson. The maps and structure sections were drawn by E. A. Schmitz and Carl Blacklock.

Acknowledgment is also made to George McLane Wood for editing the manuscript, Margaret R. Clark for assembling and correcting the printed material, and Lucy Marion for typing the report.

METHOD OF WORK

The field party began work in the Arkansas Valley early in June, 1927, at Russellville, Arkansas, and proceeded eastward north of Arkansas River to Little Rock. From Little Rock the work was carried westward south of Arkansas River to the Oklahoma boundary, which was reached early in September. The party then moved north of the river and continued its work eastward back to Russellville. This circuit, which was completed in about $3\frac{1}{2}$ months, was made necessary by the lack of easy means of transportation across Arkansas River for most of the distance between Little Rock and Fort Smith.

Headquarters were established in towns near the areas explored

and mapping was carried over an area having a radius of 10 to 15 miles from each center. On the completion of each map the base of operations was moved to the largest town in the adjacent area. As it was desirable to complete the work as rapidly as possible, much of the mapping was facilitated by the use of automobiles, three of which were in almost constant service. Mapping by this means was found practicable, for not only the best but the most numerous exposures were on or near the roads. All the large stream courses, however, were traversed, and in areas where outcrops were rare, or where the roads were impassible, all the work was done on foot. The great rains early in 1927 made transportation through the region much more difficult than usual, for they destroyed many miles of roads, particularly of the secondary roads. On the other hand, the floods produced many more outcrops than can ordinarily be found.

The field work was completed for the area that lies between T. 2 and 13 N., the Oklahoma boundary on the west, and the Coastal Plain on the east. This area, which includes slightly less than 9,000 square miles, is nearly coincident with the Arkansas Valley, but it includes also the southern edge of the Boston Mountains and the northeastern part of the Fourche Mountain province. (See Pl. III.) After the field work in the region originally outlined for investigation had been completed and work on the report had been started the increase in drilling throughout the Paleozoic area of Arkansas made it seem desirable to make the report cover a larger area. Very little field work, however, was done in areas north and south of the region whose boundaries are given above. On the other hand, several years of independent work had made the writer rather familiar with the general geology of the Ozark plateaus and had given him some knowledge of the Ouachita Mountain province. The published and manuscript reports on these areas have therefore been summarized in the light of the writer's knowledge, and although the details may be subject to revision, the larger features are doubtless correctly outlined.

In 1888 the topographers of the United States Geological Survey made a reconnaissance topographic survey of most of the Arkansas Valley, and the results of their work were shown on topographic sheets of a number of 30-minute quadrangles, which were published on a scale of one-half inch to the mile, with a contour interval of 50 feet. Unfortunately, these maps are deficient both in topographic detail and in culture, their most notable defect being the lack of township and section lines. When the former Arkansas Geological Survey undertook to study the geology of the Arkansas Valley coal field the available maps were found inadequate, and a topographic survey was made in connection with the geologic work. The topography was sketched on the Land Office maps by a number of assist-

ants, who retraced the section lines and determined elevations by barometric readings. The result of this work was a detailed topographic map of the coal-field area on a scale of one inch to the mile, with a contour interval of 20 feet. The former State Survey, however, was discontinued before these maps were completed, and they have never been published, although the engraving of the plates by the United States Geological Survey was nearly finished. Through the courtesy of that organization a small edition of these maps was printed for use in the field work for the present report. Although they are very deficient in culture these maps were helpful in enabling the rapid determination of the major structural features of the areas for which they are available.

For areas east and north of the coal fields the topographic maps of the United States Geological Survey, after they had been sectionized, were of some assistance. County maps, road maps, and soil survey maps were used as base maps where topographic maps were not available; and a manuscript map of the unsurveyed area east of Conway, made by J. H. Means, which shows topographic features by means of hachures, was also of some service. In general, however, the lack of satisfactory base maps made the work much more difficult than it would otherwise have been, especially as the area to be covered was too great to permit plane-table traverses, so that the locations of outcrops had to be made with reference to some readily recognizable point or known land line. In many areas such points were not available; in others the farmers were unable to supply land descriptions of their farms; and still others were essentially uninhabited, and locations in them had to be made by speedometer or by pacing.

On account of these difficulties, all of which could have been overcome if more time had been available, the location of some of the structural features shown in Plate I may be slightly erroneous. As Brunton compasses were used instead of plane tables, the structural features that are most clearly defined were best located, and the chance of error in the delineation of the structure becomes greater as the folds become flatter.

A summary of the more valuable geologic and economic results of the work is given in the Abstract.

GEOGRAPHY

Location.—The Paleozoic rocks of Arkansas crop out in a triangular area of about 25,000 square miles in the northwestern part of the State. This area is bounded on the north by the State of Missouri, on the west by Oklahoma, and on the southeast by the Gulf Coastal Plain. (See Pl. II.) The northern border of the area is

about 215 miles long, the western border about 175 miles long, and the southeastern border, exclusive of minor irregularities, is about 350 miles long. The distances from Russellville, which is near the center of the area, to the larger cities of the central Southern States are indicated by the circles drawn on the index map, which have radii of 100, 200, and 300 miles.

Culture.—Much of the Arkansas Paleozoic area is agricultural land, but large parts of it, particularly in the Boston Mountains and the Ouachita Mountains, are still forested or are fit only for grazing. Most of the cities are in either the Arkansas Valley or the Springfield Plateau. There are practically no towns in the Boston Mountains and not many south of the Arkansas Valley. Most of those south of the valley are in intermontane basins. Hot Springs, the single large city in the Ouachita region, owes its size to its popularity as a place of recreation and a health resort.

The principal crops grown in the Arkansas Paleozoic area are cotton, corn, vegetables, and fruits, but cereal and forage crops, such as wheat, oats, alfalfa, and hay, are also grown. Cotton and corn are most extensively cultivated in the Arkansas Valley, and most of the fruits and vegetables are grown on the Springfield plateau. Lumbering, small farming, and stock raising are the chief occupations of those who live in the more mountainous areas. The industrial center of the Paleozoic area is the Arkansas Valley district, which supplies cheap fuel in the form of coal and natural gas to the industries, most of which are at or near Fort Smith or Little Rock.

The towns and cities of the Paleozoic area of Arkansas that had a population of over 1,000 in 1920, are listed below:

Atkins	1,529	Hot Springs	11,695
Batesville	4,299	Huntington	1,453
Bentonville	2,313	Leslie	1,472
Berryville	1,474	Little Rock	65,142
Booneville	2,199	Mena	3,441
Clarksville	2,127	Morrilton	3,010
Coal Hill	1,057	Mulberry	1,095
Conway	4,564	North Little Rock	14,048
Dardanelle	1,835	Ozark	1,262
Eureka Springs	2,429	Paris	1,740
Fayetteville	5,362	Rogers	3,318
Fort Smith	28,870	Russellville	4,505
Greenwood	1,374	Searcy	2,826
Harrison	3,477	Siloam Springs	2,569
Hartford	2,067	Springdale	2,263
Heber Springs	1,675	Van Buren	5,224

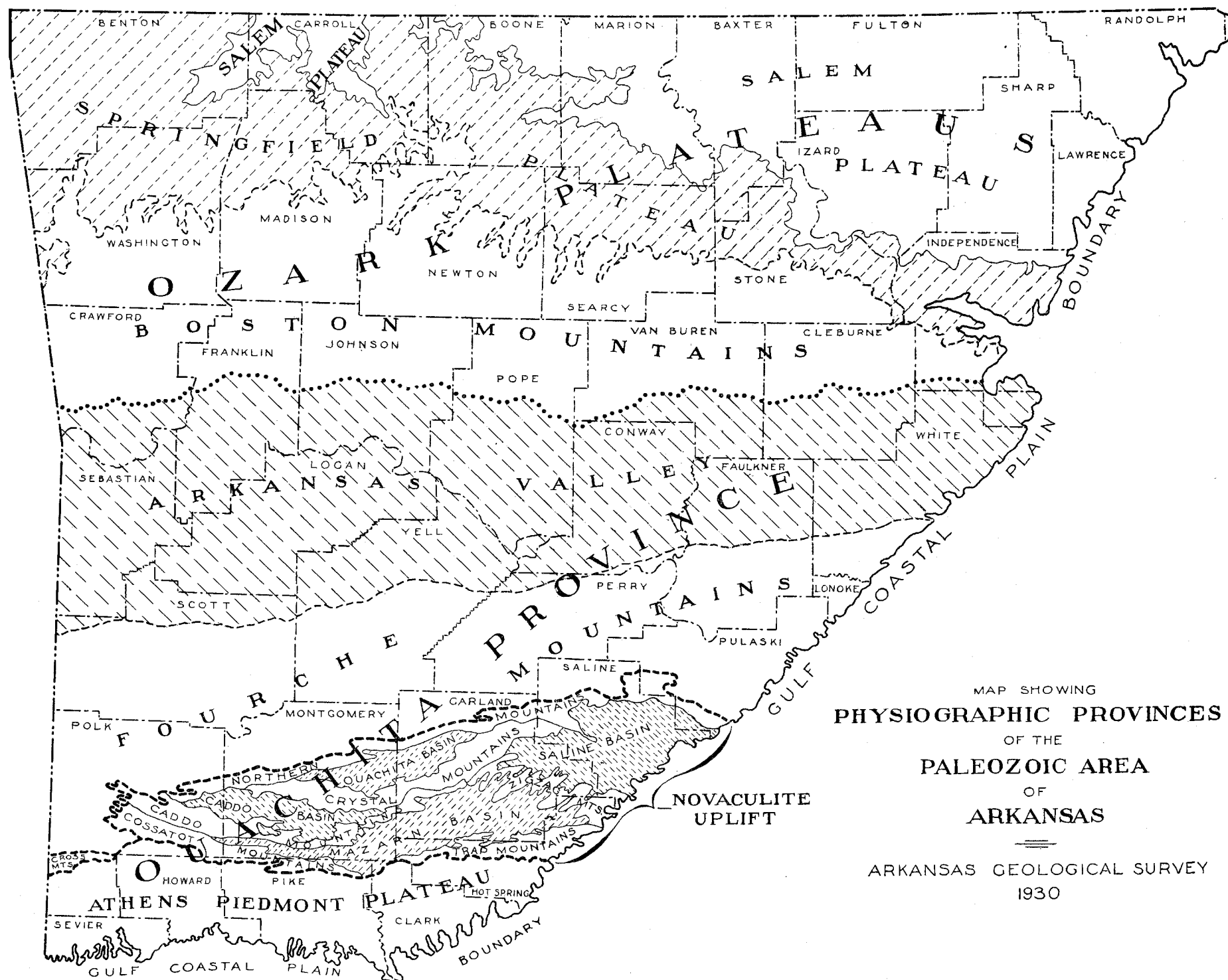
The population of these towns has greatly increased since the last census, and that of some of them has more than doubled. Little Rock, which had 65,000 inhabitants in 1920, is now a city of more than 100,000; Fayetteville, which had a population of 5,000 in 1920, now has a population of at least 11,000; and Fort Smith, which had a population of 29,000 in 1920, is now said to have a population of

40,000. A few of the coal-mining towns, however, have decreased in size; but several towns that had a population of less than 1,000 in 1920 now have considerably more than that number.

The Paleozoic area is only moderately well supplied with means of transportation, and Newton County is entirely without railroad service. The chief railroads are the St. Louis and San Francisco, the Missouri Pacific, the Chicago and Rock Island, the Kansas City Southern, and the Missouri and North Arkansas. A number of branch lines, such as the Arkansas Western, the Central Arkansas, the Little Rock, Maumelle and Western, the St. Paul and Muskogee branches of the Frisco system, and the Caddo Gap and Hot Springs branches of the Missouri Pacific, serve relative large areas. These railroads furnish satisfactory means of transportation in the western part of the Paleozoic area and in the Arkansas and White River valleys, but many places in the Boston and Ouachita Mountains and some in the Salem Plateau are still 10 to 25 miles from the nearest shipping point.

All-weather gravelled roads have now been built between most of the larger towns, and a number of paved roads have been constructed in the more densely populated areas. In addition, several highways have been built or started from north to south across the Boston and the Ouachita Mountains, so that at favorable times it is possible to visit most parts of the Paleozoic area by automobile. The secondary roads, however, are not kept in good repair, and in many of the rougher parts of the area it is impossible to travel by automobile in bad weather.

Topography.—The surface of the Paleozoic area of Arkansas presents many diverse types of topography, but in general it is moderately rough to very rugged as compared with the gently undulating surface of the Coastal Plain. The area is divisible into several provinces, whose chief characteristics are described under the heading, "Physiography of the Paleozoic Area of Arkansas," on pages 7-18.



MAP SHOWING
PHYSIOGRAPHIC PROVINCES
 OF THE
PALEOZOIC AREA
 OF
ARKANSAS

ARKANSAS GEOLOGICAL SURVEY
 1930

PHYSIOGRAPHY OF THE PALEOZOIC AREA OF ARKANSAS

SUBDIVISIONS

Arkansas lies within two great physiographic provinces, whose boundary divides the State into nearly equal parts. The Interior Highland province includes that part of Arkansas which lies northwest of a line passing from a point on the Missouri boundary near the northeast corner of Randolph County southwestward through Little Rock to a point near Arkadelphia and thence nearly due west to the Oklahoma border. The Coastal Plain province includes that part of the State which lies southeast of the line described. The following table shows the subdivisions of the major provinces that have been recognized in Arkansas.

A. COASTAL PLAIN:

I. *Mississippi Alluvia* Plain.

II. *West Gulf Coastal Plain*.

B. INTERIOR HIGHLANDS:

I. *Ozark Plateaus*:

A. Salem Plateau.

B. Springfield Plateau.

C. Boston Mountains.

II. *Ouachita Province*:

A. Arkansas Valley.

B. Ouachita Mountains.

1. Fourche Mountains.

2. Novaculite Uplif*.

a. Caddo Mountains.

b. Cossatot Mountains.

c. Cross Mountains.

d. Crystal Mountains.

e. Northern Mountains.

f. Trap Mountains.

g. Zigzag Mountains.

h. Caddo Basin.

i. Mazarn Basin.

j. Ouachita Basin.

k. Saline Basin.

3. Athens Piedmont Plateau.

As the Paleozoic area of Arkansas is coincident with its Interior Highland province, it is necessary only to mention the major features of the Coastal Plain of Arkansas in this report.

COASTAL PLAIN

The Coastal Plain of Arkansas, which occupies about 27,370 square miles, or about 52 per cent of the total area of the State, ranges in elevation from 100 to 700 feet above sea level. It is a southward-sloping plain whose western part is a rolling, slightly hilly country, most of whose surface stands at elevations of from 200 to 400 feet

above sea level. The eastern and northern parts of the Coastal Plain in Arkansas are somewhat more gently undulating than the rest of the plain and stand at heights of 100 to 300 feet. Crowley's Ridge, however, the most prominent topographic feature in northeastern Arkansas, rises above this plain. This ridge extends northward from Helena into Missouri and varies in width from 1 to 12 miles. Its crest reaches an elevation of about 400 feet near its southern end, but it rises gradually toward the north and is 500 feet above sea level in Clay County.

A narrow belt along the Mississippi River, which has the topographic features of old age, such as oxbow lakes, meandering streams, natural levees, and low relief, is called the Mississippi Alluvial Plain. The rest of the Coastal Plain of Arkansas is classed as the West Gulf Coastal Plain. Practically all the rocks of the Coastal Plain are of sedimentary origin, but a small body of igneous rocks lies near Benton, in Saline County; another crops out near Murfreesboro, in Pike County; and a third lies south of Little Rock, in Pulaski County. The sedimentary rocks of the Mississippi Alluvial Plain are all fine-grained clastic sediments of Quaternary age. Most of those of the West Gulf Coastal Plain are composed of clay, sandstone, marl, chalk, conglomerate, and lignite, and range in age from early Cretaceous to Quaternary. Most of the rocks of the Coastal Plain are poorly cemented, and none of the beds has been greatly deformed.

INTERIOR HIGHLAND

The Interior Highland province of Arkansas occupies about 25,155 square miles, or 48 per cent of the total area of the State. All the rocks exposed in this province except a few small mid-Cretaceous intrusions are of Paleozoic age, and they represent all the geologic systems from the Cambrian to the Carboniferous, inclusive. At some places these rocks have undergone great deformation; at others they still lie in essentially the attitude in which they were deposited. Some of these rocks, such as dolomite and novaculite, are very hard; others, such as shale and shaly sandstone, are readily weathered by erosion. As a consequence of these differences in structure and lithology in different parts of the Interior Highland, a number of diverse topographic features have been developed in the Paleozoic area. These various surface forms are the bases for the subdivisions of the Highland area that are shown in outline on the accompanying map (Pl. III), and briefly described in the following pages.

OZARK PLATEAUS

EXTENT AND SUBDIVISIONS

The Ozark area in northwestern and north-central Arkansas occupies a belt averaging 65 miles in width and extending from the Okla-



A. VIEW ACROSS WHITE RIVER BOTTOMS NEAR MONTE NE

The hills in the background are a part of the Eureka Springs escarpment. Their even-crested surface represents the level of the Springfield plateau. The Salem Plateau is here represented by the valley flats in the foreground.



B. THE BOAT MOUNTAIN GROUP SEEN LOOKING WEST FROM THE VICINITY OF WESTERN GROVE AT A DISTANCE OF ABOUT 6 MILES

These mountains stand as monadnocks on the undulating surface of the Springfield Plateau, seen in the foreground.

homa border eastward nearly to the valleys of the Black and White rivers. The northern boundary of this belt is the Missouri border; its southern boundary is roughly the line between Ts. 10 and 11 N. All the rocks exposed in this province are of sedimentary origin and range in age from Ordovician to Carboniferous. In general, the oldest beds are exposed at or near the northern and the youngest along the southern boundary. Much of the Ozark area stands rather high, most of it more than 1,000 feet above sea level, and relatively large parts of the Boston Mountains reach heights above 2,000 feet.

The divisions of the Ozark Highland in Arkansas, named from north to south, are the Salem Plateau, the Springfield Plateau, and the Boston Mountains.

SALEM PLATEAU

The Salem Plateau occupies chiefly the northeastern part of the Arkansas Ozarks in Stone, Marion, Baxter, Fulton, Izard, Sharp, Independence, Lawrence and Randolph counties, but a part of it extends into Carroll and Benton counties, along White River and its tributaries. (See Pl. IV, A.) This plateau, although it is lower than the Springfield plateau, has been deeply and intricately cut by numerous streams, and its topography is very rough. The tops of the hills and ridges, however, stand nearly at the same general level, although the dissected surface has been developed on several different formations, all dipping gently southward. Nearly all the surface rocks are of Ordovician age, and most of them consist of dolomite and limestone, although sandstone is in places conspicuous.

The surface elevations range from about 250 feet in Lawrence County to 1,250 feet in Carroll County.

SPRINGFIELD PLATEAU

Resistant cherts and limestones of Mississippian age form the sinuous, northward-facing Eureka Springs escarpment, which separates the Salem Plateau from the higher Springfield Plateau on the south. The scarp reaches a height of 400 feet near Eureka Springs, but it becomes progressively less well-defined toward the east and finally, north of Batesville, it is insignificant. Most of the plateau stands between 1,000 and 1,500 feet above sea level, but at several places, particularly in the Fayetteville, Eureka Springs, and Harrison quadrangles, prominent monadnocks rise above the general surface. Most of these erosional remnants stand between 1,500 and 1,750 feet above sea level, but the Boat Mountain group, south of Bellfonte, rises to an elevation of 2,220 feet. (See Pl. IV, B.)

The surface of the Springfield Plateau is rather rough, particularly near its northern border, where streams are cutting back into the Eureka Springs escarpment, and also near its southern border, where

monadnocks are most numerous. In many areas, however, the surface of the plateau is only gently undulating. Such areas, which are locally called "prairies," are most abundant in the extreme northwestern part of the State. Osage Prairie, which lies between Bentonville and Rogers, is perhaps the most typical of these flatlands, but other similar areas are seen at or near Lowell, Springdale, Farmington, Prairie Grove, Pea Ridge, Hindsville, Clifty, Bergman, and Harrison. These "prairies" range in size from about 5 to 50 square miles, and their greatest difference in relief rarely is more than 100 feet. Their combined area is not great, but they comprise the better farm land of the plateau. They have determined the location of many towns and villages.

Most of the surface rocks of the plateau belong to the Boone formation, but upper Mississippian formations are exposed near the southern border of the area, and Pennsylvanian beds cap a few of the higher monadnocks. The weathering of the Boone formation produces a mantle of insoluble chert, which is left after the limestone has been dissolved, and this characteristic surface veneer is widely distributed over the Springfield Plateau. Over large areas also, where the Boone is the surface formation, the plateau is marked by solution valleys. These valleys are strikingly uniform in width and most of them are nearly straight. Their slopes are steep but not precipitous. Their heads are somewhat cirquelike and simulate the appearance of sink holes cut in half along a vertical plane. These valleys commonly join each other at an angle of less than 90 degrees, and as they are extremely numerous, they dissect the surface of the plateau in labyrinthine fashion. Few of these solution valleys carry water at the surface near their heads. Their slopes are covered with fragments of chert, branches, and leaves for the most of the year, and only after torrential rains is there evidence of the action of running water. These valleys of solution gradually change downstream to valleys of corrasion, but the change in type becomes complete only in streams that reach the permanent water table. These valleys are so characteristic of the Springfield Plateau that they may be used as a criterion of that physiographic province.

The fragments of the Boone chert that are carried by streams form an effective abrasive agent. Where they are washed over the Kings River or the St. Peter sandstone they commonly form straight-sided symmetrical potholes. (See Pls. VIII and X.) These are minor though locally spectacular physiographic features, which are generally found in the southern part of the Salem plateau or in the northern part of the Springfield plateau.

Caves also are abundant in the Boone formation throughout the Springfield Plateau, and many of the larger ones are near its south-



CLIFF AND SMALL WATERFALL NEAR WINSLOW

Similar topographic features are common throughout the Boston Mountains. Photograph by Luther Powhatan.

ern boundary in Arkansas. The Diamond Cave, near Jasper, Newton County, is perhaps the most spectacular in showing deposition from groundwater. (See Pl. X, *B*, and frontispiece.)

Most of the beds of the Springfield Plateau lie nearly flat, but they show a slight regional dip toward the south, which is most pronounced near the southern edge of the province. At some places, however, they have been flexed into shallow basins and low domes and are displaced by normal faults.

BOSTON MOUNTAINS

The so-called Boston Mountains rise above the Springfield Plateau in a second, and more prominent northward-facing escarpment, which attains a height of 800 feet. Viewed from the Springfield Plateau this escarpment appears to be a uniform, even-topped wall. In reality it is very irregular, for many outliers of the Boston Mountains stand on the plateau, and streams have deeply serrated the scarp. Steep cliffs (see Pl. V) and deep, narrow valleys are numerous throughout the province. The southern slope of the mountains to the Arkansas Valley generally is less precipitous, but at some places, as north of Clarksville, it descends abruptly and is broken by many ravines.

The Boston Mountain escarpment is capped by the resistant basal sandstone of the Atoka (Winslow) formation, which is the surface rock over most of the mountain area. The Morrow group and the Chester beds, however, crop out below the Atoka in the escarpment, and the Morrow is exposed in a few of the deeper valleys south of the crest of the mountains. Most of the mountain tops stand at about the same level and form a greatly eroded table-land that rises 1,900 to 2,200 feet above sea level (see Pl. VI), but a few monadnocks rise several hundred feet above the deeply dissected plateau. Gorges 500 to 1,250 feet deep, which lie between steep ridges and jagged spurs, are common enough to warrant the application of the term "mountainous" to this highland region. The beds that form the Boston Mountains, however, are little folded, though a series of southward-dipping monoclinical folds on the southern slopes bring the younger beds there into view.

OUACHITA PROVINCE

LOCATION AND GENERAL FEATURES

The Ouachita province lies immediately south of the Boston Mountains. Its major topographic divisions are the Arkansas Valley on the north and the Ouachita Mountains on the south. It is very different from the Ozark plateaus both structurally and topographically. Most of the topography is of the ridge-and-valley type. Some of the ridges can be traced for miles; others are short and overlapping;

and a few are arranged in zigzag fashion. There is greater diversity in relief in the Ouachita than in the Ozark province, and the mountains rise to somewhat greater heights, but no relatively large areas stand uniformly as high as the Boston Mountains. The highest elevation in the province is Magazine Mountain, in Logan County, which stands 2,823 feet above sea level, and the lowest is at the point where the Arkansas River enters the Coastal Plain near Little Rock, where the elevation is about 250 feet.

Nearly all the rocks exposed in the Ouachita province are of sedimentary origin, but there are a few small mid-Cretaceous intrusives, the largest area of which is at Magnet Cove, Hot Spring County. The sedimentary rocks range in age from Cambrian to Carboniferous. Most of them consist of shale and sandstone, though novaculite is very conspicuous near the south-central part of the province. The younger beds are exposed both north and south of what is here called the Novaculite Uplift (commonly known as the true Ouachita system); the oldest at the structural center of that uplift. All the beds in the Ouachita province have undergone crustal deformation, and in some parts of the province they have been intensely crumpled, folded, and thrust faulted.

ARKANSAS VALLEY

The Arkansas Valley, which varies in width from 25 to 35 miles, extends from the Oklahoma boundary eastward to the Coastal Plain near Searcy. Its northern boundary coincides with the southern boundary of the Boston Mountains. At some places this boundary is marked by an escarpment; at other places the Boston Mountains merge insensibly into the Arkansas Valley, so that the boundary must be fixed arbitrarily. At such places the dividing line shown on the accompanying map follows roughly the 750-foot contour line. The southern limit of this province as here described is the southern limb of the combined Poteau-Menifee synclines, which extend, in a direction slightly north of east, completely across the Paleozoic area. By this definition the anticlinal Dutch Creek Mountain lies within the Ouachita Mountains, whereas the synclinal Petit Jean Mountain, next to it on the north, lies in the Arkansas Valley. Similarly the Cadron Ridges, east of the Arkansas River and north of Little Rock, are here described as a part of the Ouachita Mountains, whereas the synclinal hill just to the north, on which Holland is built, lies in the Arkansas Valley province. This limitation of the province is at considerable variance with former limitations, but it may be rather strongly defended on a structural basis.

The Arkansas Valley is a gently undulating plain, most of which stands between 300 and 600 feet above sea level. Many long, sharp ridges rise above this plain, however, as well as several broad-topped



A. VIEW NORTHWARD ACROSS BOSTON MOUNTAINS FROM THE TOP OF WHITEOAK MOUNTAIN, NORTHEAST OF HECTOR

Most of the summits and higher slopes are heavily wooded, and it is difficult to obtain good panoramic views.



B. MOUNT NEBO, A TYPICAL FLAT-TOPPED SYNCLINAL MOUNTAIN OF THE ARKANSAS VALLEY

Seen looking south from Ouita Ridge just above Mill Creek station. The low anticlinal ridges below Mount Nebo are Wood and Dardanelle ridges.

synclinal hills and mountains (see Pl. VI, *B*), all trending in general north of east. The most prominent mountains are Sugarloaf, Poteau, Petit Jean, Magazine, and Whiteoak. Of these, Magazine Mountain, which stands 2,823 feet above sea level and rises abruptly 2,300 feet above the adjacent country, is the highest and most prominent not only in the Arkansas Valley but in the State.

The surface rocks consist of sandstone and shale, are of Carboniferous age, and nearly all of them belong to the Pennsylvanian series. The topographic forms already mentioned owe their origin to the structure, which is that of a compound syncline—a synclinorium. The beds have been close folded and thrust faulted near the southern part of the valley, but they are open folded and normal faulted near the Boston Mountains.

OUACHITA MOUNTAINS

General features.—The Ouachita Mountains lie north of the Coastal Plain and south of the Arkansas Valley, but the beds in the mountains, unlike those in the valley, have been folded into an anticlinorium rather than a synclinorium. The Ouachita Mountains are composed of numerous ridges that trend nearly westward, several intermontane basins, and a narrow piedmont plateau, which extends along their southern border. The ridges have sharp, narrow crests and commonly occur in groups, which are either parallel, overlapping, or disposed in zigzag fashion. Near Little Rock these ridges are ill defined, and most of them stand about 500 to 700 feet above sea level. Farther west, however, they increase in height, and mountains that stand more than 2,000 feet above sea level are common in Polk and Montgomery counties. Rich Mountain, north of Mena, which attains an elevation of nearly 2,800 feet and stands more than 1,800 feet above the adjacent lowlands, is the highest elevation in the province.

The rocks exposed in the Ouachita Mountains range in age from Cambrian to Carboniferous and consist mostly of shale and sandstone, although novaculite is common. (See Pl. VII.) The Ouachita Mountains are separable into three subprovinces, the Fourche Mountains on the north flank of the anticlinorium, the Athens Piedmont Plateau on the south limb, and the Novaculite Uplift along the crest.

Fourche Mountains.—The Fourche Mountains occupy a belt about 25 miles in width, which, in Arkansas, extends slightly north of east from the Oklahoma boundary to the Coastal Plain near Little Rock. Parallel ridges are most characteristic of this province, but synclinal eminences and horseshoe ridges are common. Most of the mountains in the western part of the province are rugged and rise 1,000 feet or more above the adjacent stream valleys (see Pl. XLIV), but they decrease in height eastward until, east of the Arkansas River, they rarely stand 200 feet above the lowlands. The ridges east of the

river, however, particularly the Cadron group, are fine examples of topographic expression of structure.

The rocks of the Fourche Mountains are all of Carboniferous age and belong to the Stanley, Jackfork, and Atoka formations. They have been complexly folded and to a certain extent thrust faulted. Many of the folds have been overturned toward the north, so that southern dips are common, but some of the folds are overturned toward the south. Many of the mountains are anticlinal, and some of the larger valleys, such as that of the Fourche la Pave River, are topographic expressions of the underlying synclinal structure. In the Fourche Mountains there are a number of readily recognizable topographic basins, such as the one in which Mena stands.

Novaculite Uplift.—The term Novaculite Uplift is used here for what is commonly known as the true Ouachita system. This change in nomenclature is made in order to reduce the use of the word Ouachita, whose present repetition in the terms Ouachita province and Ouachita Mountains, which do not have the same meaning, is confusing. The Novaculite Uplift is a spindle-shaped area which extends from the vicinity of Little Rock slightly south of west to southern Polk County. The Cross Mountains, a small disconnected range, extend from the Novaculite Uplift into Oklahoma. The Novaculite Uplift is almost completely encircled by ridges of novaculite, so that it is at most places definitely set off from the adjacent physiographic subdivisions. In the vicinity of Malvern, however, the uplift merges indistinctly into the Coastal Plain, and the line between the two is arbitrarily drawn at the boundary between the Paleozoic and the Tertiary beds.

The rocks of the Novaculite Uplift range in age from Cambrian to Carboniferous. The oldest formation exposed is the Collier shale; the youngest is the Stanley shale. The rocks are complexly folded into compound anticlines and synclines, and in some places they are thrust faulted. Recumbent folds are the rule rather than the exception, and in places the beds are fan-folded. The Arkansas novaculite is the principal ridge-making formation, but near the center of the uplift beds of Ordovician sandstone determine the topographic expression. The Novaculite Uplift is divisible into several basins and ranges, which are outlined on Plate III.

The *Caddo Mountains* extend from the vicinity of Potter, in western Polk County, slightly south of east to Caddo Gap, from which point they continue northeastward to the Ouachita River, in the eastern part of T. 2 S., R. 21 W. They are bounded on the north by the Caddo Basin and the Crystal Mountains and on the south by the Cossatot Mountains and the Mazarn Basin. The mountains have a total length of about 65 miles, but in places east of Caddo Gap

they are rather poorly defined. They consist of parallel ridges 2 to 4 miles across, which have an average height of 500 to 600 feet above the adjacent stream valleys and rise into a few peaks that stand 1,000 feet above the neighboring lowlands. The highest elevation is reached in the Missouri Mountains, which rise 2,212 feet above sea level.

The Caddo Mountains lie on the south flank of the main Ouachita anticline, which, in the Caddo Mountain area, has been folded into a number of anticlinal noses and short synclines. The principal formation is the Arkansas novaculite.

The *Cossatot Mountains* form the southwestern boundary of the Novaculite Uplift. They extend from T. 3 S. slightly south of east to the Caddo River near Rosboro, a distance of about 45 miles. They vary in breadth from a single narrow ridge to a series of parallel ridges 6 miles wide. The Cossatot Mountains are the highest of the novaculite ridges in Arkansas, a number of the peaks standing more than 2,300 feet above sea level.

These mountains also lie on the south flank of the great Ouachita anticlinorium but they are somewhat lower than the Caddo Mountains, and they are themselves folded into a secondary anticlinorium. The Arkansas novaculite is the chief formation exposed, but the Stanley shale has been infolded in a number of the deeper synclines.

The *Cross Mountains* are isolated westward-trending novaculite ridges in the northern part of T. 5 S., Rs. 31 and 32 W. The mountains are about 11 miles long in Arkansas. They are separated from the Cossatot Mountains, whose nearest ridges lie about 6 miles to the northeast, by complexly folded, nonresistant Carboniferous beds. The Cross Mountains form the eastern termination of one of the major structural features of the Ouachita province of Oklahoma and are included here for convenience only. The ridges of the Cross Mountains are anticlinal in structure and stand about 400 feet above the adjacent lowlands.

The *Crystal Mountains* extend from the southern part of T. 2 S., R. 27 W. southeastward to T. 3 S., R. 24 W., where they turn northeastward and terminate just north of Goosepond Mountain, in T. 1 N., R. 18 W. The mountains are about 60 miles long and are composed of parallel ridges having a combined breadth of 3 to 4 miles. Unlike the other mountains of the Novaculite Uplift, these ridges are of sandstone rather than novaculite, and as they occupy the central part of the Ouachita anticlinorium, most of the formations in them are older than those in the other divisions of the Uplift.

The Crystal Mountains are rough, but not so steep-sided as the typical novaculite ridges. A number of the peaks stand more than 1,500 feet above sea level, and High Peak, in Sec. 19, T. 3 S., R. 24 W.,

attains an elevation of 1,834 feet. The mountains have a general compound anticlinal structure.

The *Northern Mountains*, which are less well defined than any other division of the Novaculite Uplift, lie along the northern border of that province. They extend from the Coastal Plain south of Little Rock westward to the vicinity of Board Camp, in Polk County, and have a total length of about 105 miles. Most of the ridges stand less than 300 feet above the adjacent valleys, and at some places they are so low as to be topographically negligible. The Arkansas novaculite is the chief formation exposed in them. Their structure is anticlinal, for they are produced by crenulations on the north flank of the main Ouachita anticline.

The *Trap Mountains* comprise a system of low novaculite ridges along the southeastern border of the Novaculite Uplift. They extend slightly north of east from the southern part of T. 4 S., R. 22 W., to the Coastal Plain in the vicinity of Malvern. They have a maximum length of 35 miles, and are from 1 to 5 miles in width. Most of the ridges stand less than 1,100 feet above sea level and rise about 500 feet above the adjacent valleys.

The Arkansas novaculite is the chief formation exposed in these mountains, and it has produced their topographic expression. The structure is somewhat similar to that of the Cossatot Mountains. Fan-folding is rather common; but in most respects the structure is less complex than that in the Cossatots.

The *Zigzag Mountains* lie between the Saline and Mazarn Basins and may be regarded as the continuation of the Caddo Mountains east of the Ouachita River. They extend from the vicinity of Hawes post-office southeastward to the Coastal Plain, a distance of about 25 miles. They occupy a belt 6 to 10 miles wide, its width being determined by the length of the ridges, which are disposed in zigzag fashion nearly at right angles to the trend of the system. Most of the ridges stand 500 to 600 feet above the adjacent lowlands, but West Mountain, near Hot Springs, attains an elevation of more than 1,400 feet above sea level and rises about 900 feet above the neighboring valleys.

The Zigzags form one of the most complicated parts of the south limb of the main Ouachita anticline. The Arkansas novaculite, which is exposed in parallel plunging anticlines and synclines, has caused the peculiar topographic expression of these mountains.

The *Caddo Basin* lies between the Caddo Mountains on the south, the Crystal Mountains on the northeast, and the Northern Mountains on the northwest. The beds exposed in the basin consist of sandstone, shale and chert, which are older than the Arkansas novaculite. These beds have been thrown into many small folds, which are

superimposed on the central part of the main Ouachita antiline. The surface is rougher than that in the other basins, and the streams have steeper gradients. Most of the land stands 700 to 900 feet above sea level, but a number of hills rise several hundred feet above the general surface.

The *Mazarn Basin* forms a great topographic and structural depression between the Caddo and Zigzag Mountains on the north and the Cossatot and Trap Mountains on the south. (See Fig. 26.) It is surrounded by novaculite ridges except at the small break between the Cossatot and Trap Mountains, at the Caddo River. The basin is 60 miles long and has a maximum breadth of about 10 miles. Its surface is rather rough, though the relief is not great. Low westward-trending sandstone ridges and alternate narrow valleys are rather characteristic of the province. Much of the surface stands 500 to 600 feet above sea level, but the larger streams have cut their valleys about 200 feet lower, and Pigeon Roost and Mazarn Ridge stand high above the general surface. The Stanley shale is practically the only formation exposed in the basin, which is a very complicated synclinalorium.

The *Ouachita Basin* is bounded on the north by the Northern Mountains and on the south by the Crystal Mountains. It is a spindle-shaped topographic depression, which extends from the western part of T. 2 S., R. 25 W., northeastward to the northwestern part of T. 1 S., R. 20 W., a distance of about 30 miles. The chief formations exposed are the Womble, Mazarn, and Polk Creek shales, the Blakely sandstone, and the Bigfork chert. The surface of the basin is not so rough as that of the Caddo Basin but somewhat more rugged than that of the Saline Basin. Most of the land stands 550 to 750 feet above sea level.

The *Saline Basin* lies between the Northern Mountains on the north, the Zigzags on the southwest, and the Coastal Plain on the southeast. The surface differs markedly from place to place, but in general is gently rolling, and some of the land near the larger streams is swampy. Much of the land stands 400 to 600 feet above sea level, but several flat-topped hills are 800 to 1,080 feet high, and some of the land near the Saline River stands less than 300 feet above sea level. The surface rocks are the same as those exposed in the Caddo and Ouachita basins, and the structure is similar.

Athens Piedmont Plateau.—The Athens Piedmont plateau is bounded on the north by the Novaculite Uplift and on the south and southeast by the Coastal Plain. It extends in a belt, 8 to 18 miles wide, from near the Ouachita River, in Hot Spring County, westward into Oklahoma. Its surface slopes from an elevation of about 1,100 feet near the novaculite ridges, in northern Howard and Pike

counties, to 400 feet along its southeastern border. Much of the surface is marked by eastward-trending parallel sandstone ridges, which rise 150 to 250 feet above the adjacent narrow valleys. The most common type of elevation is a table-land or flat ridge having a long, gentle southern slope and a relatively steep northern face.

Practically all the rocks of the plateau are of Carboniferous age, and most of them are sandstones and shales. All the beds have been complexly folded and faulted and at many places are inclined at high angles. The folds that produced the sandstone ridges are superimposed on the south flank of the Ouachita anticlinorium. The surface of the plateau was reduced to a peneplain in pre-Cretaceous time, and its present roughness is due to relatively recent elevation.

STRATIGRAPHY OF THE PALEOZOIC AREA OF ARKANSAS

TENTATIVE CORRELATION

The stratigraphy of the Paleozoic rocks of Arkansas is here considered under subheadings covering two areas (1) the Ozark plateaus, (2) the Ouachita Mountains and the Arkansas Valley. This division has been made not only for convenience but largely from necessity, for the rocks of the two areas of the same age are different in almost every respect. In Figure 1, however, an attempt has been made not only to correlate the formations exposed north of the Arkansas River with those exposed south of it, but to assign them all *tentatively* to the proper ages in the standard time scale. These correlations are given here for the convenience of the reader, but they should not be regarded as final. Because of a lack of paleontologic data, or because of the seeming contradictions involved in the evidence available, many of the correlations are subject to extensive revision.

Graphic representations of the lithology and thickness of each formation exposed in the Paleozoic area of Arkansas are given in the columnar sections on Plates VII and XXV.

STRATIGRAPHY OF THE OZARK PLATEAUS PRE-CARBONIFEROUS ROCKS

The pre-Carboniferous rocks of northern Arkansas include strata belonging to the Ordovician, Silurian, and Devonian systems. Of these, however, only the Ordovician formations are of considerable thickness or of large areal extent. Practically all these formations have been encountered in wells drilled in areas south of their outcrop, but these wells have found in them neither oil nor gas. Therefore, although these formations will probably be tested further, they are not considered in detail in this report, for the chances of obtaining from them either oil or gas in commercial quantities are poor.

ORDOVICIAN SYSTEM JEFFERSON CITY DOLOMITE

The Jefferson City dolomite is the oldest formation that has been recognized in Arkansas north of the Arkansas River. It is exposed in the extreme northeastern part of the area of Paleozoic rocks of the Ozark region in Arkansas, principally in Marion, Baxter, Fulton, and Randolph counties. The beds consist of gray crystalline dolomite, ordinarily with considerable chert, alternating with

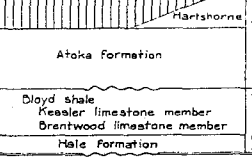
GENERALIZED TYPE SECTION FOR MISSISSIPPI VALLEY			OZARK HIGHLAND SECTION	COMBINED ARKANSAS VALLEY AND OUACHITA MOUNTAIN SECTION	
PALEOZOIC	PENNSYLVANIAN	ALLEGHENY		Savanna Formation	
		POTTSVILLE		Doris shale	
	Ft. Smith sandstone				
	Spadra shale				
	Hartshorne sandstone				
	Atoka formation				
	Atoka formation				
	Atoka formation				
	Morrow				
	MISSISSIPPIAN	CHESTER	UPPER	Pittkin limestone	Jackfork Sandstone
MIDDLE			Fayetteville Formation	Jackfork Sandstone	
LOWER			Wedington sandstone member	Jackfork Sandstone	
ST. LOUIS		SPERSEN	Datesville sandstone	Jackfork Sandstone	
		WARSAW	KEOKUK	Moorefield shale	Stanley shale
			DURLINGTON	Boone Formation	Stanley shale
FERNGLEN			St Joe limestone member	Stanley shale	
KINDERHOOK		Chattanooga shale	Hot Springs sandstone		
		Sylamore sandstone	Hot Springs sandstone		
		Sylamore sandstone	Hot Springs sandstone		
DEVONIAN	UPPER	Clifty limestone	Arkansas Novaculite		
	MIDDLE	Peters chert	Arkansas Novaculite		
	LOWER	Peters chert	Arkansas Novaculite		
SILURIAN	CAYUGAN	Lafferty limestone	Missouri Mountain slate		
	NIAGARAN	St Clair limestone	Missouri Mountain slate		
	ALEXANDRIAN	Brassfield limestone	Blaylock sandstone		
ORDOVICIAN	CINCINNATIAN	Cason shale	Polk Creek shale		
		Fernvale limestone	Polk Creek shale		
		Fernvale limestone	Polk Creek shale		
	MOHAWKIAN	Kimmswick limestone	Big Fork chert		
		CHAZYAN	Plattin limestone	Womble shale	
			Jasper limestone	Womble shale	
	Joachim limestone		Womble shale		
	BIG BUFFALO	St Peter sandstone	Womble shale		
		Everton Formation	Blakely sandstone		
		Kings River sandstone member	Blakely sandstone		
UPPER CANADIAN	Sneads limestone lentil	Blakely sandstone			
	Powell limestone	Mazam shale			
	Cotter dolomite	Mazam shale			
MIDDLE CANADIAN	Jefferson City dolomite	Mazam shale			
	LOWER CANADIAN	Limestone and sandstone encountered in wells	Crystal Mountain sandstone		
		Limestone and sandstone encountered in wells	Collier shale		
CAMBRIAN		Limestone and sandstone encountered in wells	Collier shale		
PRE-CAMBRIAN	Rhyolite, or granite, or arkose reached by deep wells	Unknown; not encountered in wells			

FIGURE 1.—Table showing correlation between the generalized type section for the Mississippi Valley, the Ozark Highland region, and the combined Arkansas Valley and Ouachita Mountain region.

Period	Formation	Columnar Section	Thickness in Feet	Character of Rocks	Distribution in Area
PENNSYLVANIAN	Atoka (Winslow)		1400±	Black and drab clay shale with thin interbedded platy sandstone. Massive, light brown to gray, cross-bedded sandstone with white quartz pebbles at base.	General south of Boston Mountain escarpment. Thicker toward south.
	Fayetteville Formation				
	Batesville Sandstone				
	MISSISSIPPIAN MORROW GROUP				
	Boyd shale		0-150	Dark brown to black clay shale.	Thickest in southwest, in Washington and Crawford counties. Thins toward northeast, where it disappears.
	Kessler limestone lentil		(0-10)	Dirty brown to brownish red limestone, in places conglomeratic.	
	Baldwin coal		(0-1)	Gray fossiliferous limestone with some shale.	
	Brentwood limestone lentil		50-275	Carbonaceous shale with sandy plates and flaggy sandstone; brown calcareous sandstone and sandy ferruginous limestone.	General in Boston Mountain area; thickest in southwestern part.
	Hale formation		0-100	Massive gray fossiliferous limestone.	General, but thinner to the north, where it is absent in places.
	Unconformity				
Pitkin limestone		10-400	Black carbonaceous fissile clay shale with clay-ironstone concretions, particularly in lower part.	Absent only in northern areas, where it has been removed by erosion.	
Unconformity					
Fayetteville formation		(0-150)	Medium to fine grained gray to brown sandstone, in part calcareous and in places cross bedded.	Sandstone member thickest in Washington and Crawford counties; probably not present east of Newton and Boone counties.	
Wedington sandstone member		(0-30)	Blue-gray, fine-grained, fossiliferous limestone (in western part only).	Thickest in the vicinity of Batesville; thins progressively toward the west.	
Basal limestone ("Mayes" formation)		0-225	Gray to brown, even-bedded sandstone; somewhat calcareous in places.	Present only in northwest; thickest in Madison and Washington counties.	
Batesville sandstone		(0-50)	Chert conglomerate, with gray oolitic limestone above.		
Hindsville limestone member		0-275	Light gray to blue-black friable shale with some limy phases.	Thickest in the eastern areas; not present west of St. Joe.	
Moorefield shale		0-50	Compact, blue-gray limestone and saccharoidal sandstone.	Exposed near Jasper, Newton County.	
Unconformity					
Joachim limestone		0-160	Drab, compact, sandy magnesian limestone, calcareous sandstone, with some friable white sandstone.	Exposed in Newton County and eastward; absent in west.	
MISSISSIPPIAN	Unconformity				
	Boone formation		200-450	Gray crystalline fossiliferous limestone, with much gray to red chert, which is also fossiliferous; several discontinuous oolitic horizons.	General north of Boston Mountain escarpment.
	St. Joe limestone member		(0-100)	Pinkish gray, coarsely crystalline, fossiliferous limestone.	Basal member ordinarily present, but locally absent.
	Unconformity				
	Chattanooga shale		0-85	Black fissile clay shale.	Thickest in west; locally absent, but ordinarily present.
	Sylamore sandstone		0-55	Light brown to white phosphatic sandstone, in part conglomeratic.	Thickest in west. Absent at many places.
	Clifty limestone		0-20?	Gray compact sandy limestone.	Exposed in southwestern Benton County.
	Unconformity				
	Penters chert		0-90	Grayish blue to dark non-fossiliferous chert.	Exposed in the east only in Independence County.
	Unconformity				
Lafferty limestone		0-75	Gray to red compact earthy, thin-bedded limestone, with few fossils.	Exposed in the east only in Izard County.	
Unconformity					
St. Clair limestone		0-100	Pink coarse-grained fossiliferous limestone.	Absent in western part of area; exposed in northeastern part.	
Unconformity					
Brassfield limestone		0-15?	Thin blue-gray limestone.	Exposed only in Searcy and Independence counties.	
Unconformity					
Cason shale		0-25	Platy gray calcareous shale.	Not present in west; small outcrops in central and eastern areas.	
Unconformity					
Fernvale limestone		0-125	Pinkish-gray to dark, massive, coarse-grained fossiliferous limestone.	Absent in west; exposed over large areas in northeast.	
Unconformity					
Kimmswick limestone		0-50	Light gray to blue-gray massive, fine-grained limestone; locally coarse-grained.	Exposed only in Izard, Stone, and Independence counties.	
Unconformity					
Platin limestone		0-250	Dove-colored, even bedded, fine-grained limestone which breaks with a conchoidal fracture; fossils are rare.	Exposed over large areas in the east; absent in the west.	
Unconformity					
Jasper limestone		0-50	Compact, blue-gray limestone and saccharoidal sandstone.	Exposed near Jasper, Newton County.	
Jefferson City dolomite		350+	Gray dolomite with locally considerable chert.	Exposed in northeastern Marion County and eastward.	
ORDOVICIAN	Cotter dolomite		550	Gray dolomite with some chert and a few beds of friable sandstone; local thin green shales.	General in the north, but thickest in the east.
	Unconformity				
	Red arkose		15?	Red to dark-brown arkosic sediment.	Reported from several wells.
	Unconformity				
	igneous complex			Rhyolite in one well; syenite or granite in others.	Reached by several wells at depths of less than 2,500 feet in northern part of area.
	St. Peter sandstone		0-150	Massive laminated and cross-bedded saccharoidal sandstone.	Thin or absent in the west; thickest toward the southeast.
	Unconformity				
	Everton limestone		0-225	Dove-colored, compact limestone; some sandstone.	Thickest in central part, from which it apparently thins in all directions.
	Kings River sandstone member		(0-35)	Heavy-bedded, white, friable sandstone.	Sandstone member usually present.
	Sneeds limestone lentil		(0-50)	Heavy-bedded, dark, sandy magnesian limestone.	Limestone lentil crops out in Marion and Newton counties only.
CAMBRO-ORDOVICIAN	Powell limestone		0-200	Gray magnesian limestone with a limestone conglomerate at the base in some places.	Absent in west and locally not present in the east.
	Unconformity				
	Jefferson City dolomite		350+	Gray dolomite with locally considerable chert.	Exposed in northeastern Marion County and eastward.
	Unconformity				
	St. Peter sandstone		0-150	Massive laminated and cross-bedded saccharoidal sandstone.	Thin or absent in the west; thickest toward the southeast.
	Unconformity				
	Everton limestone		0-225	Dove-colored, compact limestone; some sandstone.	Thickest in central part, from which it apparently thins in all directions.
	Kings River sandstone member		(0-35)	Heavy-bedded, white, friable sandstone.	Sandstone member usually present.
	Sneeds limestone lentil		(0-50)	Heavy-bedded, dark, sandy magnesian limestone.	Limestone lentil crops out in Marion and Newton counties only.
	Unconformity				
CAMBRIAN	Unconformity				
	Red arkose		15?	Red to dark-brown arkosic sediment.	Reported from several wells.
	Unconformity				
	igneous complex			Rhyolite in one well; syenite or granite in others.	Reached by several wells at depths of less than 2,500 feet in northern part of area.
	Unconformity				
	St. Peter sandstone		0-150	Massive laminated and cross-bedded saccharoidal sandstone.	Thin or absent in the west; thickest toward the southeast.
	Unconformity				
	Everton limestone		0-225	Dove-colored, compact limestone; some sandstone.	Thickest in central part, from which it apparently thins in all directions.
	Kings River sandstone member		(0-35)	Heavy-bedded, white, friable sandstone.	Sandstone member usually present.
	Sneeds limestone lentil		(0-50)	Heavy-bedded, dark, sandy magnesian limestone.	Limestone lentil crops out in Marion and Newton counties only.
PRE-CAMBRIAN	Unconformity				
	Jefferson City dolomite		350+	Gray dolomite with locally considerable chert.	Exposed in northeastern Marion County and eastward.
	Unconformity				
	St. Peter sandstone		0-150	Massive laminated and cross-bedded saccharoidal sandstone.	Thin or absent in the west; thickest toward the southeast.
	Unconformity				
	Everton limestone		0-225	Dove-colored, compact limestone; some sandstone.	Thickest in central part, from which it apparently thins in all directions.
	Kings River sandstone member		(0-35)	Heavy-bedded, white, friable sandstone.	Sandstone member usually present.
	Sneeds limestone lentil		(0-50)	Heavy-bedded, dark, sandy magnesian limestone.	Limestone lentil crops out in Marion and Newton counties only.
	Unconformity				
	Powell limestone		0-200	Gray magnesian limestone with a limestone conglomerate at the base in some places.	Absent in west and locally not present in the east.

thin-bedded, fine-grained, lighter dolomite without chert. The formation includes also thin beds of sandstone, shale, and oolite, but these beds are not widely distributed and their aggregate thickness is not great. They are in places ripple-marked and they show mud cracks, so that they were probably deposited in shallow water. Some of the more argillaceous layers are laminated and are darkened by organic material. When rock taken from these layers is freshly broken it gives off a fetid odor somewhat like that of petroleum, but hydrocarbons are not widely distributed through the formation.

Either the conditions for the preservation of organisms were unfavorable or marine life was scanty in the sea in which the Jefferson City dolomite was deposited, for the formation contains practically no fossils. From its position in reference to the overlying and underlying strata, however, it is placed in the lower half of the Canadian division of the Ordovician system. Its known thickness in Arkansas is at least 350 feet, but its base is not exposed, and it may be much thicker, particularly as it is 1,000 feet thick in southern Missouri. The Roubidoux formation, which underlies it, may outcrop in the extreme northeastern Paleozoic area, for the contact between that formation and the Jefferson City dolomite is not easily found and as determined is drawn arbitrarily.

The Jefferson City dolomite cannot be regarded either as a possible source or a potential reservoir of oil or gas. It has been penetrated by the drill at several places, with uniformly unpromising results.

COTTER DOLOMITE

The Cotter dolomite was so named by E. O. Ulrich from Cotter, in Baxter County, Arkansas, where it is typically exposed. In the reports of the older Arkansas Geological Survey it was called the "magnesian" limestone, and in Missouri it was called the "Second Magnesian Limestone." In 1904, however, the name Yellville¹ was applied to the beds now called the Cotter dolomite and Powell limestone.² "Yellville" is a synonym of Powell and is no longer used.

The Cotter dolomite, as its name implies, consists largely of dolomite rock, but it includes shale, chert, and sandstone, though in minor amounts. It is exposed over considerable areas in the northern part of the state, but the thickest outcrops are in northern Boone County and the counties east of Boone, where sections over 500 feet thick have been measured. Berryville, Carroll County, is built upon this formation.

The beds are made up of two kinds of dolomite, a massive, medium-grained, gray rock, which becomes dark on exposure, and a fine-

¹ Adams, G. I., and Ulrich, E. O.: U. S. Geol. Survey Prof. Paper 24, p. 18.

² See U. S. Geol. Survey Geol. Atlas, Eureka Springs-Harrison folio (No. 202), for an explanation of the usage of these terms.

grained, earthy, white to buff rock, known as "cotton rock". These two types are interbedded with each other and with thinner layers of sandstone and shale or, rarely, of chert. The lime and magnesia occur in almost the exact proportions of a true dolomite, as is shown by the following analysis of the rock.³

Partial analyses of Cotter dolomite

A, Leatherwood switch, south side; B, Leatherwood switch, north side; C, Eureka Springs depot.

	A	B	C
Silica and silicates.....	8.65	(a)	14.71
Iron and alumina.....	4.72	(a)	(a)
Magnesia (MgO).....	18.68	19.05	17.03
Lime (CaO).....	26.83	27.74	26.57

(a) Present, but not determined.

A rather prominent layer near the top of the formation contains hemispherical algal masses of chert showing concentric structure. These silicified, reef-building, coral-like algae are known as *Cryptozoon minnesotense*. They are of considerable stratigraphic value, for they are not found above the top of the Cotter dolomite in Arkansas, and they occur but rarely in the underlying Jefferson City formation. The other fossils are molluscs, chiefly gastropods and cephalopods, which are similar to those found in the middle and upper Beekmantown limestone of the Champlain districts of New York. About half the species are identical with those found in the Shakopee dolomite of the upper Mississippi Valley. The early Ordovician age of the Cotter dolomite is therefore well established.

The Cotter rests disconformably upon the Jefferson City, but as the two formations are lithologically similar and the contact is exposed at only a few places, it is not everywhere easy to distinguish the one formation from the other. After the Cotter formation was deposited the region must have been uplifted and slightly folded, because the overlying Powell limestone rests upon a weathered and somewhat undulating surface.

POWELL LIMESTONE

The Powell limestone, which at some places is 200 feet thick, consists of magnesian limestone, calcareous green shale, and, at many places, of a conglomerate, which occurs at its base. The formation is exposed in a large area in Benton, Carroll, Boone, Marion, Newton, Fulton, Izard and Sharp counties, but it is absent at some places in that area. It was named from Powell, Marion County, which is now an abandoned railroad station.

Most of the Powell limestone effervesces readily with cold dilute

³ Hopkins, T. C., Marbles and other limestones: Arkansas Geol. Survey Ann. Rept. for 1890, vol. 4 (1893), p. 117.

hydrochloric acid, a reaction which cannot ordinarily be obtained with rock from the underlying Cotter dolomite. The exposed layers are somewhat rounded, and the rock breaks with conchoidal fracture into many small, angular fragments. White chert in the form of concentrically banded nodules is distributed through parts of the limestone, but at no place abundantly. A single massive bed containing much drusy quartz occurs in the lower half of the formation in Boone, Newton, and Marion counties. This stratum, which is several feet thick, has yielded numerous fossils at a place near Yellville, where the fossiliferous bed lies from 50 to 70 feet below the top of the formation. The fauna is related to that of the Cotter dolomite and is similar to that of the upper Beekmantown of New York.

The Powell limestone rests disconformably upon the Cotter dolomite and is disconformably overlain at different places by the Everton limestone, the St. Peter sandstone, and the Chattanooga shale.

The deposits of early Powell time are in places conglomeratic, and some of the material at the base of the Powell formation may be a residual mantle of erosional material formed in post-Cotter time and recemented in place. As the depositional conditions were favorable to the preservation of fossils, and as only a few gastropods, cephalopods, and trilobites are found in the Powell limestone, the implication is that most of that limestone was formed as a chemical precipitate. The formation is therefore not a possible source of either oil or gas, nor does it contain any bed that may be regarded as a potential reservoir.

EVERTON LIMESTONE

The Everton limestone is widely exposed in the northeastern part of the region of Paleozoic rocks in Arkansas, but it is thickest in an area in Marion, Newton, and Boone counties. In the region north, east, and west of that area it becomes thinner. In the region farther south it is covered by younger beds, so that its features there cannot be learned, but it appears to increase in thickness toward the south. The formation was named by E. O. Ulrich from Everton, Arkansas, where it is particularly well exposed.

The Everton limestone consists of three divisions, which show considerable differences in character and are irregularly distributed. These divisions have been graphically portrayed by Purdue and Miser for the Eureka Springs and Harrison quadrangles. (See Fig. 2.)

The lower division of the formation, the Sneys limestone lentil, occurs only in Newton and Marion counties and is best exposed near Willecockson and south of Compton. It is a hard, sandy, compact

magnesian limestone, whose heavy beds form hackly ledges where they crop out. The lower beds of the lentil are somewhat conglomeratic, containing pebbles derived from the underlying Powell limestone. The lentil has a greatest known thickness of 50 feet which

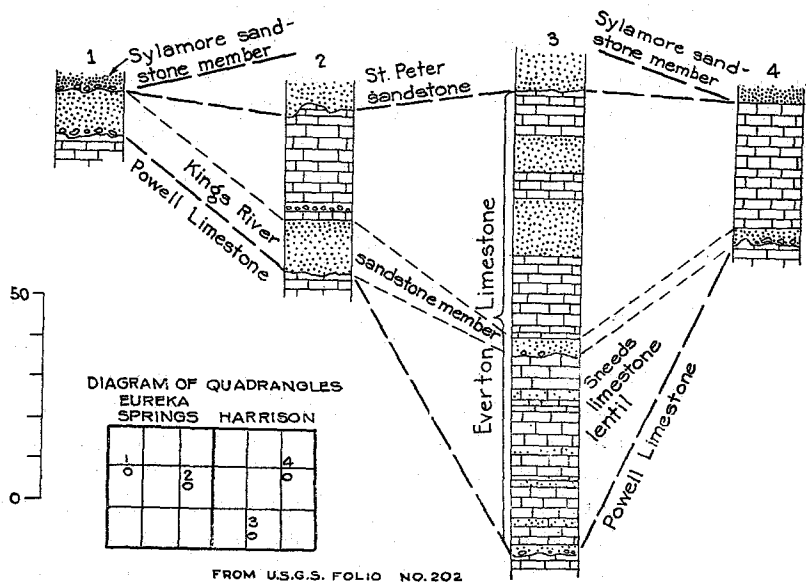


FIGURE 2.—Sections of the Everton limestone in the Eureka Springs and Harrison quadrangles, showing the variability of the formation, the unconformity within it, and the overlap of the Syamore sandstone member of the Chattanooga shale. (After Purdue and Miser.)

1, Little Clifty Creek; 2, Kings River, 1 mile above the mouth of Piney Creek; 3, Hemmed-in Hollow, 2 miles south of Compton; 4, Wolf Creek, east of Francis.

it reaches about 2 miles south of Compton, in and near Hemmed-in Hollow. Further investigation may show that the Sneed's limestone should be regarded as a distinct formation, particularly as it is limited both above and below by disconformities.

The middle part of the Everton, the Kings River sandstone, is the most widespread division of that formation, and at a number of places, particularly in the Eureka Springs quadrangle, it is the only division exposed. This sandstone, which is ordinarily massive, received its name from its exposure on the Kings River, in Carroll and Madison counties. In its typical development it is a white, friable, finely laminated sandstone composed of well-rounded, medium sized quartz grains. At its base there are pebbles of chert and limestone, which were derived from underlying formations. Its greatest thickness is about 40 feet, but at some places it is so thin that it is scarcely distinguishable from the overlying limestone. Columns or "pipes" of this sandstone, whose sides converge downward, are exposed in some bluffs. These so-called "pipes" were formed of sand



DEEP, SYMMETRICAL POTHoles CARVED IN THE KINGS RIVER SANDSTONE
NEAR THE HEADWATERS OF BIG CLIFTY CREEK

The holes were carved by a small stream using fragments of Boone chert as cutting tools.

that settled and hardened in solution cavities in the underlying limestone.

The upper part of the formation, the Everton proper, is composed of massive, compact blue-gray limestone interbedded with some friable white sandstone. The limestone is at most places magnesian, and in Marion County it is a true dolomite. These upper beds are in places over 150 feet thick, but they are generally much thinner.

The Sneeds limestone lentil at most places contains no fossils, but the matrix of the basal conglomerate in the Yellville quadrangle has yielded a few. The Kings River sandstone is unfossiliferous, but the upper limestone contains fossils, particularly in eastern Harrison and western Yellville quadrangles. Most of these fossils, however, are not those found in other formations, so that they are of little value in determining the age of the beds in which they occur. The general aspect of the fauna gives the impression that the beds are younger than the Beekmantown and older than the Chazy. These sediments were deposited, then, at a time when most of the North American continent was being eroded.

The basal part of the formation is at many places conglomeratic, and a distinct stratigraphic break between the Everton and the underlying formations may be seen in some localities. As the contact is not very irregular, however, the break can be recognized clearly only in good exposures. The Sneeds limestone lentil is disconformably overlain by the Kings River sandstone, which in some parts of its area is overlapped by the upper limestone. Where the upper limestone has been eroded the Kings River sandstone is overlain by the St. Peter or, more rarely, by the Clifty limestone, or even the Sylamore sandstone. A conglomeratic phase appears at the base of the upper limestone member of the formation in the Eureka Springs quadrangle only. Elsewhere the Kings River sandstone is conformably overlain by the upper limestone beds.

The same formations that rest disconformably upon the Kings River member where the limestone is missing appear above the limestone where it is present. The disconformity, however, is generally between the Everton upper limestone and the St. Peter sandstone. The surface of the limestone is very rough, the irregularities in it being due to stream erosion and to solution by ground water when the limestone was a surface rock. The irregular contact is particularly noticeable in bluffs along many of the tributaries of Buffalo Fork of White River. At some places the St. Peter sandstone has filled old caverns or sinks in the Everton limestone and at these places irregularity of contact between the two formations is still more marked. These two types of contact, which are illustrated by

Figures 3 and 4 are less common than a third type in which the top of the Everton is so smooth that the disconformity with the overlying St. Peter is not distinct.

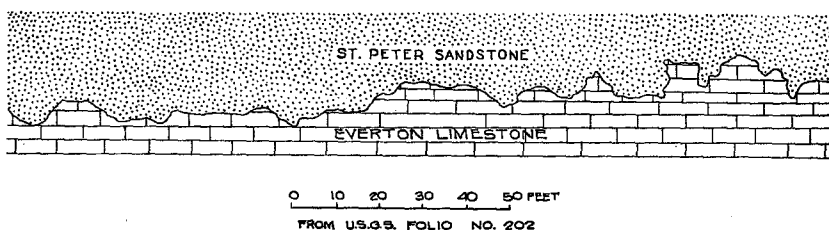


FIGURE 3.—Disconformity between the Everton limestone and the St. Peter sandstone exposed in a bluff $3\frac{1}{4}$ miles southeast of Green Forest, in Sec. 19, T. 19 N., R. 23 W.

The irregularity of these contacts is one cause of the difference in the records of wells drilled in the area of the Kings River sandstone, even of test wells drilled close together and started on the same formation. The Kings River sandstone is the oldest bed exposed in the State that might serve as a potential reservoir for oil and gas. It is a relatively porous sandstone and is of considerable areal extent, but it is not adjacent to rocks that may be sources of oil or gas, nor is it overlain by impervious beds. Therefore, although

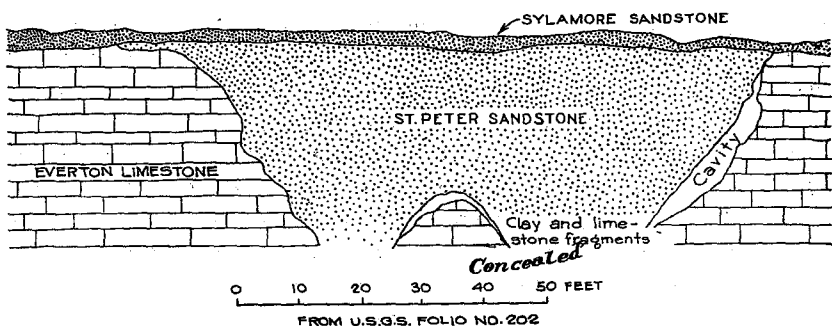


FIGURE 4.—Relations of the Sylamore sandstone to the Everton limestone and St. Peter sandstone in a bluff on Bear Creek, 1 mile northeast of Francis, in Sec. 13, T. 19 N., R. 21 W.

wildcat wells in the northern part of the State are said to have found showings of either oil or gas at a depth that may be that of the Kings River, all wells drilled in this region should be stopped short of that horizon.

ST. PETER SANDSTONE

The St. Peter sandstone, which is widely distributed over the upper Mississippi Valley, crops out as far south as the Boston Mountain area and is exposed in many of the deeper stream valleys in the northeastern Ozarks, in Arkansas. Both the St. Peter and the Kings River sandstone are described in the reports of the Arkansas

Geological Survey as "saccharoidal sandstone." The St. Peter has also been called the "Bürgen" in northeastern Oklahoma, the "Key" in the Yellville district of Arkansas, and the "First," "Pacific," "Crystal City," and "Cap-au-Gres" in Missouri. The formation consists of well-rounded, medium-sized, transparent quartz grains, which are cemented by a small amount of calcium carbonate. The rock is massive and friable and is porous, particularly where it is weathered.

The formation ranges in thickness from a feather edge to over 175 feet, becoming thicker toward the southeast. It is not found north of the middle of the Eureka Springs-Harrison quadrangles, and it is unknown in the Winslow and Fayetteville quadrangles, but still farther west, on the Illinois River north of Tahlequah, Oklahoma, a section of the formation at least 100 feet thick is exposed. The bluffs formed by the St. Peter sandstone are at many places conspicuous topographic features, and the formation has produced most of the Ozark waterfalls. (See Pl. IX.) Small streams that flow over the sandstone have formed pot-holes, such as are shown in Plate XII, A.

Fossils are very rare in the St. Peter sandstone, and none has been found at this horizon in Arkansas. Both the overlying and underlying formations, however, have yielded the same fossils that are found in the St. Peter sandstone in Minnesota. This fact, together with the evidence furnished by the records of deep wells, shows that the St. Peter sandstone of Arkansas is of the same age as the sandstone of the same name farther north.

The St. Peter is apparently conformable with the overlying Joachim limestone, but where the Joachim is missing the St. Peter is disconformably overlain by either the Sylamore sandstone or the St. Joe limestone. The St. Peter ordinarily rests disconformably upon the upper Everton limestone, but in places it overlies either the Kings River member of that formation or the Powell limestone. The Kings River and the St. Peter sandstones are so much alike that where the upper Everton limestone, which commonly separates them, is absent and but one bed of sandstone is present, the identity of that sandstone can be determined only by tracing the beds to some locality where the Everton limestone also crops out.

The St. Peter sandstone in itself would be an ideal reservoir for oil or gas, but unfortunately it is neither capped by impervious beds nor is it at any place adjacent to important source rocks. The sandstone underlies areas far south of its most southerly outcrop and has been penetrated by wells in the northern part of the Arkansas Valley. Although its horizon has been tested by several wells, it has yielded only small amounts of gas in Arkansas.

JOACHIM LIMESTONE

The Joachim limestone is a gray, fine-grained, magnesian limestone, which is sandy in places and which contains thin beds of sandstone near its base. It is exposed from Newton County on the west to Lawrence County on the east, where it attains its maximum thickness. The formation thins abruptly toward the northwest and does not crop out north or west of the southeast corner of the Harrison quadrangle. The areal extent of these beds is small; they generally crop out as a narrow band on steep slopes just above the escarpment formed by the underlying St. Peter sandstone.

A few specimens of the pelecypod *Psiloconcha senecta* were found in the lower beds of the Joachim limestone near Guion by Ulrich, but the formation as exposed in Arkansas has yielded no other definitely determinable fossil. The species found, however, is one which has been described by F. W. Sardeson from the St. Peter sandstone of Minnesota. The Joachim limestone is probably the offshore equivalent of the St. Peter sandstone as developed farther north, and the paleontologic evidence lends some support to this idea, though in itself it is admittedly inconclusive.

The Joachim limestone represents the lower part of the so-called "Izard limestone" of the older geological reports on northern Arkansas. The lower part of that formation, however, is sandy and more or less magnesian, and it rests conformably upon the St. Peter. This part of the "Izard" is overlain unconformably by fine-grained, nearly pure limestone, which is identical with the Plattin limestone, to be described later. It thus is apparent that the term "Izard" had been applied to beds of diverse characteristics and of different ages. For this reason the names Joachim and Plattin are now used in place of Izard, which has been dropped out of the literature.

The Joachim formation rests conformably upon the St. Peter sandstone and is overlain, probably disconformably, by the Jasper limestone. Where the later Ordovician formations are not present, the Sylamore sandstone or the St. Joe limestone rests disconformably upon the Joachim limestone.

The formation is not a source rock for oil or gas or a potential reservoir of those products.

JASPER LIMESTONE

The Jasper limestone was described in the older reports of the Arkansas Geological Survey as a part of the Izard limestone, but the Jasper limestone is not found at the type locality of that formation. In Izard County the Izard formation consists of the Joachim limestone and the Plattin limestone, which are separated by a disconformity. In Arkansas this stratigraphic break in the sedimen-



MARBLE FALLS, NEAR WILCOCKSON, ONE OF THE LARGER WATERFALLS IN THE ST. PETER SANDSTONE

The massive structure of the white saccharoidal sandstone is well shown in this typical exposure.

tary record is represented in part by the Jasper formation, which crops out only in Newton County. Its exposures are practically confined to the valleys of Little Buffalo and Big Buffalo Forks of White River, and most of them are in the southeastern part of the Harrison quadrangle.

The formation consists of compact blue-gray limestone interbedded with white friable sandstone. The limestone is even bedded in layers that average more than a foot in thickness. The rock is a fairly good building stone and has been used for that purpose in Jasper. The sandstone occurs in thick beds, which are most prominent in the lower part of the formation, and the basal sandstone is at places 20 feet thick. The beds of sand are similar in appearance to those of the St. Peter, but they lack the fine lamination and cross-bedding of the beds of that formation. The Jasper formation is about 50 feet thick at the type locality, near the town of that name, but ordinarily it is much thinner.

Fossils are rare in this formation, but certain beds are fossiliferous. A study of the fauna obtained from these beds has shown that the Jasper limestone is the equivalent of neither the Joachim nor the Plattin formation, but was probably deposited during a time between the desposition of those formations. The fossils support the view that the Jasper is older than the Plattin, but not that it is the equivalent of a part of the Chazy. Ulrich has suggested that the Everton, St. Peter, and Joachim formations represent the hiatus between the Beekmantown and the Chazy of the New York section, and Purdue and Miser believe that the Jasper limestone may belong in the same category.

The Jasper limestone rests disconformably upon the Joachim limestone and is overlain, probably disconformably, by the Fernvale limestone at places where that formation is present. At other places the Sylamore sandstone or the St. Joe limestone rests upon the Jasper formation.

The Jasper limestone is of little significance in the search for oil and gas, but geologists interpreting the drill records in northern Arkansas must remember that it may be included in the records and that it may complicate the lower part of the section.

PLATTIN LIMESTONE

The Plattin limestone, which ranges in thickness from a feather edge to 250 feet, is exposed over large areas in Stone, Izard, Sharp, Independence, and Searcy counties, but it is absent farther west. This formation is the same as the upper part of the Izard limestone as described in the older geologic reports on northern Arkansas. The Plattin is an even-bedded limestone, which occurs in both thin

and thick layers. Its dominant color is blue-gray, and its texture is homogeneous, so that it commonly breaks with a conchoidal fracture. Lithographic stone has been found in the Plattin formation, both in Arkansas and Missouri, but no stone of commercial value has been discovered. The limestone is suitable both for building stone and for making lime.

The surface of the Plattin limestone, in marked contrast to the surfaces of the Joachim and Kimmswick formations, is ordinarily nearly free from lichens and other plants, a fact due in part to the denseness of the rock. This smoothness, although it is not an infallible guide, may be conveniently used to identify it. At some places the formation is rather cherty, but in general it is notably free from chert. At some places also the limestone may be so coarsely crystalline that it greatly resembles the Kimmswick limestone, but this phase of the formation is not widespread.

The Plattin is essentially the same as the Platteville of the Upper Mississippi Valley, and both are apparently correlatives of the Lowville of New York. It is at no place abundantly fossiliferous, but it has yielded several species, particularly from its upper layers. A list of common species follows:

<i>Crania trentonensis</i>	<i>Liospira obtusa</i>
<i>Dinorthis deflecta</i>	<i>Orthoceras</i> sp.
<i>Pianodema subaequata</i>	<i>Bumastis milleri</i>
<i>Rafinesquina alternata</i>	<i>Illaenus americanus</i>
<i>Strophomena incurvata</i>	<i>Leperditia fabulites</i>
<i>Streptelasma corniculum</i>	

The Plattin limestone is at some places disconformably overlain by the Kimmswick limestone, and at others by either the Fernvale limestone, the Sylamore sandstone, or the St. Joe limestone. The Plattin rests disconformably upon the Joachim limestone at most places in northern Arkansas where the base of the Plattin has been observed.

The Plattin limestone is only an unimportant source of oil and gas and cannot be regarded as a potential reservoir for them. It is likely to be encountered by the drill only in the northern and eastern parts of the area of Paleozoic rocks. It probably will not be found in test wells drilled west of the western boundary of Searcy County.

KIMMSWICK LIMESTONE

The Kimmswick limestone, which in places reaches a thickness of 50 feet, is exposed only in Stone, Independence, and Izard counties. This formation is the same as the lower part of the "Polk Bayou limestone" of some of the older geologic reports on northern Arkansas and was included in the "St. Clair marble" of still other reports.

The Kimmswick limestone is an even-bedded, massive, light-gray, fine-grained to very coarse-grained limestone. In some places the upper beds are compact and blue-gray, resembling the typical Platin. The formation is fairly fossiliferous throughout, but it contains few identifiable fossils. Thin bands of chert are found in it at many places, but most of them are in the upper part of the formation. The lower beds are in some places sandy, and where the calcium carbonate has been dissolved they appear to be a porous sandstone. The weathered surface of this formation is generally conspicuously rough and knobby, though this feature is more prominent in Missouri than in Arkansas.

The fauna of the Kimmswick formation has been studied by Bradley,⁴ who believes that it is early Trenton rather than late Black River. He lists as common fossils in the Kimmswick limestone of Independence County *Iliaenus depressicapitatus*, *Goldius slocomi*, *Mcewanella raymondi*, and *Anastrophia primigenia*. The upper beds of the formation generally contain abundant specimens of the valuable horizon marker *Receptaculites oweni*, but this fossil is not so common in Arkansas as it is farther north.

The Kimmswick limestone rests disconformably upon the Platin limestone and is disconformably overlain by the Fernvale limestone. The contacts of these formations with one another, however, as seen in the field are strikingly even.

This formation may be regarded as a potential source of oil or gas, but one of no great value in northern Arkansas. It will be reached by the drill only in wells drilled in the northeastern Ozarks of Arkansas.

FERNVALE LIMESTONE

The Fernvale limestone is a widespread formation which, in Arkansas, is well exposed in Stone, Independence and Izard counties and is known from very small outcrops in Searcy and Newton counties. It reaches in places a thickness of 125 feet and is thickest in the Batesville district, where its average thickness is about 100 feet. It is probably not present west of Harrison. The Fernvale was formerly regarded as the upper part of the "Polk Bayou limestone," and still earlier it was included in the "St. Clair limestone" or "marble." Ulrich, however, discovered that these Arkansas rocks are of the same age as the Fernvale limestone of Tennessee.

The Fernvale limestone is generally a coarsely crystalline, massive, somewhat cross-bedded; medium to pinkish-gray, fossiliferous limestone, which makes a good building stone. In the Batesville district, manganese ores occur in the Fernvale and in its residual clays. At

⁴Bradley, J. H., *Stratigraphy of the Kimmswick limestone of Missouri and Illinois: Jour. Geol.*, vol 33, pp. 49-74, 1925.

some places the limestone contains lenses, nodules, and irregular masses of gray and brown chert, but over large areas it is almost wholly calcareous. In the Batesville district the Fernvale is marked by channels, pinnacles, caves, and sink holes, and its upper surface is irregular.

The formation is fossiliferous throughout, but notably so near its base and top. Its characteristic fossil is the brachiopod *Rhynchotrema capax*, but it contains other species, such as *Dinorthis subquad-rata*, *Strophomena planodorsata*, and *Plectambonites praecosis*. In Tennessee the Fernvale is the second formation of the Richmond group, the Arnheim shale being the first; but in Arkansas, Missouri, and Oklahoma the Fernvale represents the first deposit of Richmond time.

The Fernvale rests disconformably upon the Jasper limestone in Newton County, but it generally overlies disconformably the Kimmswick limestone. The stratigraphic break is inconspicuous in the field, but it nevertheless represents most of Trenton time, as is conclusively shown by the faunas of the overlying and underlying formations. The Fernvale is at some places disconformably overlain by the Cason shale, at other places it is overlain by younger beds.

The Fernvale limestone is a potential source of hydrocarbons, but it is of no importance in that respect in Arkansas. It will be encountered in wells drilled in the extreme eastern Boston Mountains.

CASON SHALE

The Cason shale, which is in places 20 feet thick, is exposed chiefly in Independence, Izard, and Stone counties, but small outcrops are known near Jasper, in Newton County, and Duff, in Searcy County. The shale received its name from its exposure at the Cason manganese mine north of Batesville, and in that neighborhood the formation and its residual clay generally contain manganese.

The Cason shale consists of calcareous shale and small amounts of sandstone, argillaceous limestone, phosphate rock, and, near Jasper, of a basal conglomerate. Phosphate is widely disseminated through the formation, but at only a few places is it found in commercial quantities. The basal conglomerate is made up of ferruginous phosphatic material, manganese oxide, some rounded quartz grains, and a few phosphatic, fossiliferous pebbles. In its exposure near Jasper the formation consists mainly of fissile bluish and greenish-yellow shale, which breaks into rough, uneven plates, but before it has weathered it is an argillaceous limestone. At several places west of Polk Bayou it includes a bed of greenish gray or yellowish brown sandstone, which contains grains of quartz, phosphatic pebbles, fragments of fossils, and grains of glauconite. This sand-

stone was at one time regarded as a possible volcanic ash, but Hayes, Larsen, and Miser have shown that the supposed igneous material is merely a phosphate.

In the Batesville district the formation contains many flattened, concretion-like masses, or "buttons," which measure about an inch in their greatest dimension. Ulrich identifies these as fossil algae belonging to the genus *Girvanella*, and as related to *G. richmondensis*, a species found in beds of the Richmond group in Indiana. The fossils found in the basal conglomerate are so fragmentary that it is difficult to identify many of them specifically. *Leptobolus occidentalis*; however, is relatively common, and as this species is the characteristic fossil of the lower Maquoketa shale in Iowa its presence suggests the correlation of the Cason shale with that division of the Richmond group. The other species found in the Cason shale do not invalidate this suggested correlation, but their evidence is not conclusive. Later investigations may show that the Cason and the Maquoketa are identical, in which case the term Cason must be dropped in favor of Maquoketa.

The Cason shale rests disconformably upon the Fernvale at most places, but at the Ball mine, in the Batesville area, it rests upon the Kimmswick limestone. The formation is overlain disconformably in some places by the St. Clair limestone, but generally all the Silurian and Devonian rocks are missing, and the St. Joe limestone rests, probably with slightly angular unconformity, upon the Cason shale.

The Cason shale is of no consequence in the search for oil and gas in Arkansas except that it may complicate the record of wells drilled east of Harrison, in the Boston Mountain area.

SILURIAN SYSTEM BRASSFIELD LIMESTONE

The Brassfield limestone is at present known only at three localities between Duff and Tomahawk, in Searcy County, and from fossils found in the residual clay of the formation at the Montgomery mine, 5 miles northeast of Cushman, in Independence County. This limestone was formerly included with the St. Clair formation, but its fossils, lithology, and stratigraphic position all point to its identity with the Brassfield of southeastern Missouri and of central southwestern Tennessee.

The Brassfield limestone of northern Arkansas is a light-gray fossiliferous limestone, which at most places is granular and contains a small quantity of glauconite. It is not more than 5 feet thick in the southern Ozarks, and consequently some of its outcrops may not yet have been discovered. In southeastern Missouri the Brassfield is speckled with crystals of pink calcite, by which it can be easily

identified, but these crystals are apparently not conspicuous or common in the exposures in Arkansas.

Manganese oxide casts of the interior of fossils have been found in the residual clay of the Brassfield at the Montgomery mine. Among these fossils Ulrich has identified *Cyclonema daytonense*, *Triplecia ortonii*, *Girvanella* sp., and several species of *Cycloceras* and *Orthoceras*. The most characteristic of these fossils is *Triplecia ortonii*, which is found also in the Brassfield of Kentucky, Ohio, Indiana, Illinois, and Oklahoma. Flint and Ball⁵ regard the Brassfield as the youngest formation of the Alexandrian series.

The Brassfield overlies the Cason shale disconformably as a residual clay in some places and the Fernvale limestone in others. It is overlain disconformably by the Lafferty limestone at one outcrop, by the Penters chert at others, or (with slightly angular unconformity) by some part of the Boone chert at still others.

The Brassfield limestone may be encountered in wells drilled in the northeastern Arkansas Ozarks, but it will be found at only a few places in that area. It is of no significance either as a reservoir or source of oil or gas.

ST. CLAIR LIMESTONE

The St. Clair limestone, as restricted at present, reaches in places a thickness of about 100 feet. It is a coarse-grained, highly fossiliferous generally light-gray to pinkish-gray limestone. It is exposed at several places in Independence, Izard, and Stone counties but is of small areal extent. The St. Clair as originally defined by Penrose,⁶ and later by Hopkins,⁷ included the Kimmswick limestone, the Fernvale limestone, the Cason shale, and the St. Clair as now defined. The St. Clair limestone, in the restricted sense, was limited by Williams⁸ to the uppermost of the four formations just mentioned.

The St. Clair limestone is similar in general appearance to the Fernvale limestone, but where typically developed it is lighter than that formation. The upper part of the St. Clair is bluish gray and is finer grained than the lower part, but the basal beds are shaly. The formation is massive, and at many places on hillslopes it crops out in rounded masses. The limestone is relatively pure, as can be seen from the following analysis, given by Hopkins:⁹

⁵ Flint, R. F., and Ball, J. R., Revision of the Silurian of southeastern Missouri: Jour. Geol., vol. 34, pp. 248-256, 1926.

⁶ Penrose, R. A. F., jr., Manganese—Its uses, ores, and deposits: Arkansas Geol. Survey, Ann. Rept. for 1890, vol. 1, pp. 124-128, 1891.

⁷ Hopkins, T. C., Marbles and other limestones: Arkansas Geol. Survey Ann. Rept. for 1890, vol. 4, pp. 212-215, 1893.

⁸ Williams, H. S., The Paleozoic faunas of northern Arkansas: Arkansas Geol. Survey Ann. Rept. for 1892, pp. 281, et seq., 1900.

⁹ Hopkins, T. C., op. cit., p. 217.

Analysis of St. Clair limestone from St. Clair Spring

[R. N. Brackett, analyst]

Lime (CaO).....	54.70
Manganese oxide (MnO ₂).....	.26
Iron oxide (Fe ₂ O ₃).....	.19
Silica (SiO ₂).....	.54
Alumina (Al ₂ O ₃).....	.18
Magnesia (MgO).....	.78
Potash (K ₂ O).....	
Soda (Na ₂ O).....	
Loss on ignition (CO ₂ , etc.).....	43.35
	100.00

The St. Clair limestone carries an abundant fauna, in which brachiopods and trilobites are dominant. The fossils have been studied by E. O. Ulrich, N. L. Thomas, and others, but very little has been published about them. Ulrich, however, is of the opinion that the St. Clair limestone is of Niagaran age and is approximately the correlative of the Rochester shale of New York or of the Laurel limestone of Tennessee, Kentucky, and Indiana.

At some places the St. Clair disconformably overlies the Brassfield limestone; at others it rests, also disconformably, upon the Cason shale, the Fernvale limestone, or the Kimmswick limestone. The St. Clair is disconformably overlain by the Lafferty limestone at the only place where that formation is found. Elsewhere it is overlain disconformably by the Penters chert or the St. Joe limestone.

The St. Clair limestone may be a potential source of both oil and gas, but it is of slight extent in the southern Ozark region. Wells drilled in the extreme eastern part of the Boston Mountain area, however, may encounter it, but it probably will not be found in wells drilled west of the longitude of Little Rock.

LAFFERTY LIMESTONE

The Lafferty limestone, which is in places 85 feet thick, is known from a single exposure north of Penters Bluff station and west of West Lafferty Creek, from which it receives its name.

The formation consists of even-bedded, earthy limestone, which becomes platy on weathering. Most of it is distinctly red, but its upper fourth is gray. The rock is essentially unfossiliferous, but the fragmentary fossils obtained from it have led Ulrich to believe that the Lafferty may be in part the correlative of the Dixon red earthy limestone of central southwestern Tennessee and of about the same age as the Laurel limestone of Tennessee, Indiana, and Kentucky.

The Lafferty limestone was first described by Miser.¹⁰ Other

¹⁰ Miser, H. D., Manganese ore in the Batesville district, Arkansas: U. S. Geol. Survey Bull. 734, pp. 31-32, 1922.

geologists who have worked in the Batesville district either did not observe this formation or included it in the St. Clair limestone.

The Lafferty limestone overlies conformably the St. Clair formation and is probably disconformably overlain by the Boone chert, although the contact has not been observed.

The Lafferty limestone is of small extent and will probably not be encountered in wells drilled in the southern Ozarks.

DEVONIAN SYSTEM

PENTERS CHERT

The Penters chert, which reaches a maximum thickness of 90 feet, is found only in two small areas in Independence County. One of these is a short distance north of Pfeiffer; the other is near Penters Bluff station, from which the formation was named. The Penters chert, which was so named by Miser,¹¹ had been observed by Penrose,¹² who, however, assigned it to the overlying Boone formation.

The Penters chert is a dense, massive, light gray to bluish gray chert, which breaks with a conchoidal fracture. The upper part of the formation is distinctly darker than the lower, and the chert is black where it is overlain by the Chattanooga shale. Near its base there are thin beds of gray, fine-grained limestone. A bed of breccia 6 to 7 feet thick occurs at the top of the formation in some places. This breccia consists of angular blocks of chert of various sizes, which have been cemented by an earthy material containing fine particles of chert and grains of quartz sand. According to Miser, this breccia represents the surficial part of the formation, which was fractured and weathered on an old land surface. The flexures in the beds are due to the settling of the chert to fill the solution cavities in the underlying St. Clair limestone. This flexure is evidently the result of pre-Chattanooga movement, for both the Chattanooga and the Boone formation rest on the upturned edges of the Penters chert.

The formation has thus far yielded no fossils, so that its age must be determined by its lithology and its stratigraphic position. Ulrich suggests that it is of the same age as the Clear Creek cherty limestone of southeastern Missouri and southern Illinois and as the Camden chert of west-central Tennessee. The lower part of the Arkansas novaculite of the Ouachita Mountain area has yielded no fossils, but it has likewise been correlated with the Camden and Clear Creek formations. If this correlation is correct the Penters chert and the lower Arkansas novaculite are also of the same age. The Penters chert may, however, be the Arkansas equivalent of the Bailey

¹¹ Miser, H. D., *op. cit.*, pp. 32-34.

¹² Penrose, R. A. F., jr., *op. cit.* pp. 131-133.

chert of St. Genevieve County, Missouri, and may be of Helderbergian rather than of Onondagan age.

The Penters chert probably rests disconformably upon the St. Clair limestone, but the contact between the two formations has not been seen. The chert is overlain unconformably by the Chattanooga shale at some places and by the Boone chert at others.

The formation is of no importance in the search for oil and gas in Arkansas.

CLIFTY LIMESTONE

The only known exposure of the Clifty limestone is on the east fork of Little Clifty Creek, in the southeastern part of Benton County. At this place the formation is nowhere as much as 4 feet thick, and generally it is about 2 feet thick. The Clifty limestone was named by Purdue and Miser,¹³ who were the first geologists to observe it.

The lower part of the formation is a gray, compact, cross-bedded, laminated limestone, which contains a large amount of quartz sand and a few fossils. The upper part is a dense, light-blue limestone having a conchoidal fracture. It also is sandy, but less so than the lower part.

The fossils found in the lower layer constitute a small but diagnostic Middle Devonian faunule. The characteristic species that have been confidently identified are *Spirifer fornacula*, *S. audaculus*, *Tropidoleptus carinatus*, and *Homalonotus dekayi*. A few others, less positively identified, and the remaining undetermined species tend to confirm the evidence afforded by the forms just named—that the beds containing them are of the age of the Hamilton shale of the New York Devonian section. More exactly determined, the Clifty is the correlative of the Sellersburg limestone of Indiana.

The Clifty limestone rests with relatively profound disconformity upon the Kings River sandstone, for, although the erosional surface is even, the interval represents middle and late Ordovician and all of Silurian and early Devonian time. The formation is disconformably overlain by the Sylamore sandstone, but there is no marked field evidence of erosional break.

The Clifty limestone may be present in other localities in the southern Ozarks, and thus it may be encountered in any test well in the area that is started in stratigraphically higher formations. Its extent is so small and its thickness is so slight that it is of no consequence in the search for oil and gas.

CARBONIFEROUS ROCKS

The Carboniferous rocks of the Ozark area in Arkansas include beds that belong to formations which represent rather completely

¹³ Purdue, A. H., and Miser, H. D., Description of the Eureka Springs and Harrison quadrangles: U. S. Geol. Survey Geol. Atlas, Eureka Springs-Harrison folio (No. 202), p. 9, 1916.

the Mississippian series but only the lower formations of the Pennsylvanian series. As the Carboniferous formations may be regarded as the most promising sources or reservoirs of oil and gas, not only in the Ozark region but in the Arkansas Valley, they will be described in greater detail than the lower, older formations.

Although much of the information here presented is new, a large part of it has been compiled from the scattered writings of many geologists, mainly those of the Arkansas and the United States Geological Surveys.

MISSISSIPPIAN SERIES

SYLAMORE SANDSTONE

Definition and distribution.—The Sylamore sandstone, so named by J. C. Branner from Sylamore Creek, in Stone County, where it is clearly exposed, is here considered a formation, although in recent reports on the geology of northern Arkansas it is regarded as the basal member of the Chattanooga shale. It is well exposed in the Fayetteville, Eureka Springs, Harrison, and Yellville quadrangles, and it occurs also in Stone County, and possibly in Independence County. The formation is found also at four places in the Tahlequah quadrangle, in Oklahoma, so that it extends from east to west for a distance of more than 200 miles. It occurs also in southern and southeastern Missouri.

Character.—The Sylamore sandstone is generally 2 to 5 feet thick, but its thickness changes greatly within short distances. In spite of this great irregularity, scattered outcrops of the formation are found in a large part of northern Arkansas, though at many places it is only a few inches thick. It becomes notably thicker toward the west, so that, though it has been only doubtfully identified near Batesville, it reaches its maximum thickness of 75 feet in a bluff on the south bank of White River just east of the mouth of Hickory Creek, near Springdale. Farther west, in Oklahoma, it is apparently thinner, for at Marble, its southernmost exposure, it is less than 30 feet thick, though this measurement is far greater than its average thickness.

The Sylamore sandstone generally consists of one or more massive beds, but at some places it is thin bedded. It is typically very porous, and it is so friable that a fragment of it struck by a hammer falls into loose sand. At some places, however, it is more tightly cemented, and at others it is somewhat bituminous. Its color is dominantly light, though in places it is darkly mottled. In its general appearance it is not unlike the St. Peter sandstone, and where it is thick and rests on Ordovician limestone it has been mistaken for that formation. The typical Sylamore however, is darker than either the Kings River or the St. Peter sandstone, it weathers to more

rounded surface forms, and is neither so cross-bedded nor so finely laminated as those sandstones.

The grains of sand are translucent and well rounded, and among them are small particles of limonite derived from pyrite. Pebbles and grains of dark-brown or black phosphatic rock are scattered through the sandstone or are cemented to its upper surface, and in places thin layers of the sandstone contain disseminated black phosphatic material. At some places it contains fragments of large fish bones, small fish teeth, and fragments of rock similar to the underlying beds, particularly in the lower layers.

In Oklahoma the basal beds of the Sylamore are calcareous, and in Missouri the formation is generally either conglomeratic or limy. In its limy phases the formation in Missouri is uniformly harder than in Arkansas.

Fossils and correlation.—Worn or fragmental teeth of *Ptcytodus calceolus* are widely scattered through the formation, and fragmentary bones of larger fish, possibly of *Dinichthys*, are common in its conglomeratic phase. A rather large imperfect fish bone that may be one of the mandibles of a giant *Dinichthys* has been found near Duff. Identifiable invertebrate remains have not been found in the Sylamore sandstone in Arkansas, but those discovered in it in Missouri by E. B. Branson appear to be of earliest Mississippian age.

Stratigraphic relations.—There is still some legitimate doubt as to the exact stratigraphic position of the Sylamore sandstone. At some places in northeastern Oklahoma the Chattanooga shale rests upon it. The surface of the formation is rough; it appears to have been worn into uneven, shallow, oval depressions. Upon this irregular surface the Chattanooga shale was deposited, but no detrital sandstone derived from the underlying beds has been incorporated in the basal beds of the shale. In the Fayetteville quadrangle the Chattanooga overlies the Sylamore with essentially the same relations, but at many of the outcrops of the Sylamore the Chattanooga is not found in the Eureka Springs-Harrison quadrangles. In the Yellville quadrangle, according to Adams,¹⁴ the Sylamore sandstone invariably overlies a dark-greenish shale whose maximum thickness is about 15 feet. This is a relationship similar to that seen in Missouri near Providence and near Wilton, where a bed of shale 3 to 4 feet thick underlies the Sylamore. Four miles north of Jefferson City a bed of shale more than 10 feet thick appears beneath the sandstone. In the Batesville district a sandstone of sporadic occurrence, which is here tentatively regarded as the Sylamore, over-

¹⁴ Adams, G. I., Zinc and lead deposits of northern Arkansas: U. S. Geol. Survey Prof. Paper 24, pp. 22-24, 1904.

lies a dark shale that Miser has called the Chattanooga but that Ulrich thinks is older than that formation.

The question therefore seems to be whether the Sylamore consists of two beds of sandstone and one bed of shale or of two beds of shale and one bed of sandstone. As the outcrops of the formation are scattered and as it contains few fossils, this question is very difficult to answer.

It appears to the writer, however, that the black shale found below the Sylamore sandstone east of the Harrison quadrangle is older than the typical Chattanooga, and the Sylamore contains only a single sandstone, which is probably the earliest Mississippian deposit in northern Arkansas.

Contacts between the Sylamore sandstone and the adjacent beds are well exposed at but few places. The sandstone, however, rests disconformably upon several formations at different places, among them the upper Devonian black shale (in the Batesville district), the Joachim, Everton, and Powell limestones, and the Cotter dolomite. At many places the Sylamore is probably conformably overlain by the Chattanooga shale, but the relations already described may indicate a short period of erosion before the shale was deposited. At other places the Boone chert succeeds the Sylamore disconformably.

Petrologic significance.—The Sylamore sandstone has been encountered in several wells, and in a few of them it yielded showings of oil and gas. A well drilled on the Carrollton dome, in Carroll County, encountered the Sylamore as a sand two feet thick at a depth of about 400 feet. A reported initial production of 1,000,000 cubic feet of wet gas was obtained from this well.

All wells drilled in the northern Ozarks of Arkansas should be carried at least as deep as the Sylamore sandstone. The formation is in places somewhat bituminous at its outcrop, and it may serve as a reservoir for hydrocarbons that have migrated from the adjacent Chattanooga shale. It is possible that oil or gas will be obtained from this sandstone in commercial quantities, but the combination of the phosphatic Sylamore sandstone and the Chattanooga shale has its greatest economic value in affording an easily recognized marker for subsurface correlation.

CHATTANOOGA SHALE

Definition and distribution.—The Chattanooga shale is exposed in Benton, Washington, Carroll, and Madison counties. It has also been reported from Searcy and Independence counties, but there is some reason to believe that the shale described as Chattanooga in the extreme eastern Ozark area is older than the Chattanooga rocks that crop out farther west. The formation is widespread in the cen-

tral Mississippi Valley. It is typically a black clay shale that breaks into thin plates and slabs, and gives off the odor of petroleum when it is struck with a hammer. It has been described in several reports on the geology of northern Arkansas as the "Eureka" or "Noel" shale.

Character.—The Chattanooga shale ranges in thickness from a few feet, or even a few inches, to a maximum of nearly 85 feet, but its average thickness is about 30 feet. The lower and greater part of the formation is a black, carbonaceous, fissile clay shale, which weathers into thin flakes. The beds are cut by prominent intersecting joints, which divide the rock into polygonal fragments. The upper part is lighter in color, slightly sandy, and contains considerable pyrite. These upper beds are less fissile than the lower beds, and they weather into well-defined prismatic blocks. Although the formation is dominantly black, it is at some places green, brown, or even bronze colored, its shade depending largely on the stage of weathering and the quantity of carbonaceous material it contains. Almost any fragment of the unweathered shale has the odor of petroleum, but the formation is more bituminous at some places than at others.

The Chattanooga shale thickens toward the west, and is thicker in northeastern Oklahoma than in Arkansas. It is apparently absent east of the central part of the Harrison quadrangle, and is less than 10 feet thick in its western part and in the eastern part of the adjoining Eureka Springs quadrangle, but it is 30 to 70 feet thick in Washington and Benton counties.

Fossils and correlation.—The Chattanooga shale contains few fossils. In some places it has yielded linguloid shells, and teeth and plates of the type known as conodonts. Macerated fragments of fossil wood belonging to the genus *Dadoxylon* have been found in it at several places. These fossils, however, do not clearly indicate the age of the beds in which they occur. The linguloid shells resemble Devonian species, but most linguloids are so much alike that they have slight diagnostic value.

The shale in the Batesville area, to which Miser has applied the name Chattanooga, has yielded fossils belonging to the species *Schizobolus truncatus*. This form was first found in the Genesee shale of New York and presumably indicates late mid-Devonian time. This shale, however, like that in the Yellville quadrangle, occurs beneath the Sylamore sandstone, and is therefore older than the shale found above that formation farther west.

If the Sylamore sandstone of Missouri and of Arkansas are of the same age, as there is reason to believe, then the Chattanooga shale,

which overlies the Sylamore in northwestern Arkansas, must be of Mississippian age.

Stratigraphic relations.—At some places the Chattanooga shale rests either conformably or with slight disconformity upon the Sylamore sandstone. At other places it rests disconformably, or perhaps with slight angular unconformity, upon either the St. Peter sandstone, the Everton or the Powell limestone, or the Cotter dolomite. At some places the shale apparently grades upward into the St. Joe limestone; at others the contact between the two formations is sharper, and there is some evidence that a short period of erosion occurred before the deposition of the St. Joe limestone.

Petrolific significance.—The pronounced bituminous odor of the freshly fractured shale has led to the belief that oil might be obtained from the Chattanooga formation, but many wells drilled into or through it have obtained neither oil nor gas directly from it. The gas obtained from the Sylamore sandstone in the Carrollton dome well, however, was probably derived from the Chattanooga shale. The shale will yield oil when it is artificially distilled, but this fact does not necessarily show that natural distillation has driven off hydrocarbons from it in sufficient quantities to make the adjacent beds a commercial source of them. The quantity of oil that may be obtained from the Chattanooga by distillation is not sufficient to make distillation profitable.

The Chattanooga shale will be encountered in most wells drilled in the northwestern part of the State, where it will serve as an easily recognizable horizon marker. In the region east of the longitude of Harrison the shale is probably absent, but the shale that lies below the Sylamore in that region marks nearly the same horizon. Along the crest of the Boston Mountains the Chattanooga will be encountered at depths ranging from 1,000 to 1,750 feet, the depth depending on the elevation of the surface and the structure. In a well drilled near Winslow the shale was reached at 1,407 feet.

In the southern part of the Boston Mountains the Chattanooga shale may be expected at depths between 2,500 and 3,250 feet. It was reached at 2,785 feet in the Wood well, drilled in the NW. $\frac{1}{4}$ of the NW. $\frac{1}{4}$ Sec. 29, T. 10 N., R. 31 W., Crawford County, and, although the Chattanooga is apparently not among the beds encountered in the Patrick well, drilled in Sec. 19, T. 11 N., R. 27 W., Franklin County, its position is indicated by the base of the Boone, the overlying formation, which was reached at a depth of a little over 3,000 feet.

In the northern part of the Arkansas Valley the Chattanooga will not be encountered above a depth of 5,000 feet, and in areas farther south it is probably beyond the reach of the drill.

BOONE FORMATION

Definition.—The Boone formation, or Boone chert, as it is commonly called, comprises beds of Kinderhook, Burlington, Keokuk, and Warsaw age, and it is therefore questionable whether the term "formation" can be properly applied to it, but these beds, which cover large areas in northeastern Oklahoma and northern Arkansas, have been described and mapped as the "Boone formation" by the United States Geological Survey, and the usage of that organization is followed in this report.

The Boone formation consists of chert and limestone, which vary in amount both horizontally and vertically, a feature that makes the subdivision of the beds very difficult. Over large areas, however, the basal member of the formation, the St. Joe limestone, which is free from chert, is well exposed, and at most places the middle part of the formation also carries less chert than the higher and lower beds.

The formation was named by J. C. Branner from its exposures in Boone County. Some of these beds of limestone and chert in Missouri have also been called Boone, but the terms Burlington, Keokuk, and Fern Glen have also been applied to parts of the Boone that are exposed there. In the Joplin district, C. E. Siebenthal¹⁵ has given the name Short Creek to an oolitic limestone near the top of the formation and applied the term Grand Falls to a heavy chert bed about 100 feet below it. These members probably occur at some places in Arkansas, but they have not been so called there.

Distribution and topography.—The Boone formation is of large areal extent, being widely exposed in southern Missouri, northeastern Oklahoma, and northern Arkansas. In Arkansas its greatest exposure is in the northwest part of the State, in Washington, Benton, Carroll, Madison, and Boone counties, but it is found as far east as the Paleozoic boundary, in Independence County. It is not found, however, in the extreme northeastern part of the area of Paleozoic rocks in Arkansas.

A large part of the area of the Boone formation of northern Arkansas is cut by many narrow, canyon-like valleys, but back from the larger streams the surface is much less dissected, and is gently rolling. The Eureka Springs escarpment, to be described under another heading, was formed on the steep slope of the outcrop of the Boone formation where it has been cut through to the underlying formations by stream erosion.

The stream valleys cut in the Boone formation are of two dissimilar types. Valleys of corrasion have been formed by the larger streams

¹⁵ Siebenthal, C. E., U. S. Geol. Survey Geol. Atlas, Joplin folio (No. 148), pp. 2-5, 1907.

of the region and their perennial tributaries, and valleys of solution have been formed by the smaller, relatively straight tributaries, which ordinarily contain no water. The valleys of solution, which cover much of the area of the outcrop of the Boone, form a topographic pattern which in itself ordinarily serves to identify the formation.

Character.—The Boone formation, except its basal limestone, is made up largely of limestone free from chert, cherty limestone, and chert itself, including at most places relatively little pure limestone. In section 13, T. 16 N., R. 22 W., however, the entire formation consists of limestone, including only a little nodular chert, and at several places there is either an upper, a middle, or a lower bed of limestone of variable, but considerable thickness. The limestone is generally gray, compact, finely to coarsely crystalline, and massive bedded. In these beds the remains of crinoids are very numerous, but other fossils are much less common.

Purdue and Miser report the occurrence of oolitic limestone close to the top of the formation near Kingston, Burlington, and Carrollton, and the writer has observed an oolitic bed in the Fayetteville quadrangle, which is well exposed north of Price Mountain, a few miles east of Springdale. This bed, which is probably the equivalent of the Short Creek oolite of southwestern Missouri, occurs also in northeastern Oklahoma. It is apparently a single massive layer, 10 to 15 feet thick, of compact, light-colored limestone made up of small rounded oolitic grains. At most exposures the surface of this layer exfoliates in thin sheets so as to form a concave face. This oolitic layer has not been observed east of the Harrison quadrangle.

All the limestones of the Boone above the lower limestone member are nearly pure calcium carbonate and are therefore very soluble, so that the ground water has formed in them a network of underground drainage channels. Sink holes, caves, and fissures are of common occurrence, and are generally partly filled with boulders of chert, red clay, and stalactitic and stalagmitic material. Many of these pure limestones are suitable for the manufacture of lime, but they have been utilized for this purpose at very few places. The beds, however, have been quarried at a number of localities, and they yield building stone of high quality, especially at Carthage, Missouri, and Pfeiffer, Arkansas.

Chert is found at nearly all horizons of the Boone formation above the St. Joe limestone, although it does not commonly occur at certain horizons. At some places the chert occurs as widely separated nodules; at others as connected nodules; and at still others it occurs in layers interbedded with limestone or, more rarely, the beds consist entirely of chert. Much of the unweathered chert is dense, hard,



4. SYMMETRICAL POTHOLES CARVED IN KINGS RIVER SANDSTONE ON BIG CLIFTY CREEK

Pothole was carved by stream using fragments of Boone chert as a cutting tool. View upstream from pothole shown in Plate VIII.



B. ONE OF THE MANY DEEP POOLS OF CRYSTAL CLEAR WATER IN THE FLOOR OF DIAMOND CAVE

The water is so saturated with calcium carbonate that the salt crystalizes out of solution and forms a crust over the pools strong enough in many places to bear the weight of a man. Photograph used by courtesy of Diamond Cave management.

compact, and brittle and has a conchoidal fracture. In color the rock is variable but white, gray, mottled gray, and black varieties are most common, and various shades of brown, blue, green and red are also seen. The chert of the lower part of the formation is in the main lighter in color and more dense than that nearer the top, which is likely to be more porous and to be dominantly yellowish or brownish.

Great quantities of chert are left behind as the semi-insoluble surface residue after the limestone has been dissolved by ground water. The chert itself has lost by solution whatever calcium carbonate it originally contained, as well as some of its silica, so that much of it is of fairly light weight and very porous. At places this surface mantle of chert is very fossiliferous, the fossils occurring as casts or molds, many of which are perfectly preserved. Diurnal and seasonal changes of temperature break the chert into small, shelly fragments, which collect in great quantities, particularly at breaks in slope, and have been satisfactorily utilized as road metal. On account of the mantle of chert, good exposures of the Boone formation are found only where the relief is relatively great, though at no place has the formation been very deeply buried by surface material.

Thickness.—Most of the exposures of the top of the Boone formation are far away from the exposures of the base, so that all figures showing the thickness of the formation are likely to be calculated rather than measured. In northeastern Oklahoma the formation, exclusive of the St. Joe limestone member, at its base, ranges in thickness from about 350 feet in the northern part of that region to about 100 feet in the southern part, but the diminution of thickness southward is not regular. In northern Arkansas the formation is generally between 300 and 350 feet thick, but near Ponca, in the southern part of the Harrison quadrangle, it is 400 feet thick. This measurement and the fact that a well near Winslow encountered 355 feet of the Boone, seem to cast doubt on the supposition that the formation decreases in thickness southward in Arkansas. Other wells, however, drilled south of the crest of the Boston Mountains, indicate that the Boone is 300 feet thick or less in that area, so that it probably decreases slightly in thickness toward the south. The Boone shows practically no variation in thickness from east to west, being as thick in Independence as in Washington County.

St. Joe limestone member.—Below the chert and cherty limestone of the Boone formation over a large area in the northern part of Arkansas lies the St. Joe member, a well-marked bed of gray to pink crystalline limestone, easily recognized by its freedom from chert, its color, its texture, and its general contrast with the underlying and overlying beds. The St. Joe ranges in thickness from a feather edge

to about 100 feet and is exposed in practically continuous outcrop, of dendritic pattern, from near Mountain View, in Stone County, to the Arkansas-Missouri boundary near Seligman, Missouri. This member may probably be found in Independence County also, but its outcrops are of very sporadic occurrence in the extreme eastern part of the Paleozoic area.

In northern Arkansas the St. Joe is thickest near Willcockson, where it attains a thickness of about 100 feet, but over wide areas its average thickness is not more than 25 or 30 feet. In northeastern Oklahoma the St. Joe is in places absent in the Tahlequah quadrangle and is nowhere exposed in the Muskogee quadrangle, where, however, in a well drilled near Fort Gibson, it has been reported as 20 feet of light-gray limestone. In the Tahlequah quadrangle it is less than 15 feet thick, but to the north and west it is much thicker, and it is found wherever its horizon is exposed. Along Illinois River, in the Siloam Springs quadrangle, the St. Joe is about 30 feet thick and consists of heavy-bedded crinoidal limestone. Along Cabin Creek, in the Vinita quadrangle, at its northwesternmost exposure, the St. Joe consists of about 100 feet of limestone, part of which is dense and non-crinoidal.

A study of the above figures shows that the St. Joe becomes thinner toward the east and the southwest and is thickest in the central and northwestern parts of its area of exposure.

The St. Joe limestone generally stands out on the lower part of the Eureka Springs escarpment as a low bluff, which was formed by the undermining of the Chattanooga shale and the rapid weathering of the lower part of the St. Joe itself. The upper limit of the St. Joe is commonly marked by the cherty overlying beds of the Boone formation, but not by an abrupt change in the texture or color of the limestone. In its northernmost exposures in Arkansas the St. Joe consists of three divisions. Its upper 10 to 15 feet is massive, even-bedded, gray, coarsely crystalline crinoidal limestone. Its middle part is made up of about 5 feet of red, gray, or brown thin-bedded limestone, which weathers like a shale. Its lower part is another gray, crystalline limestone containing some lenses of brown chert. These divisions cannot be clearly distinguished farther south, but the coarsely crystalline crinoidal limestone is conspicuous at most exposures.

The St. Joe limestone is described in the reports of the old Arkansas Survey as a marble, and it will take a good polish. It is available for quarrying at many places, but the beds are too thin to permit its extensive use as an ornamental stone. The Arkansas stone in the Washington monument was taken from a ledge of St. Joe limestone,

about 4 feet thick, exposed in the east half of Sec. 30, T. 17 N., R. 20 W. An analysis of a sample of this rock, as given by Hopkins,¹⁶ follows:

Analysis of limestone from St. Joe member near Willcocks

[R. N. Brackett, analyst]

		Per cent
Alumina (Al ₂ O ₃).....		0.009
Ferric oxide (Fe ₂ O ₃).....		.051
Magnesia (MgO).....		.190
Lime (CaO).....		55.390
Soda (Na ₂ O)	}	.054
Potash (K ₂ O)		
Titanic oxide (TiO ₂).....		Trace
Loss on ignition (CO ₂ , etc.).....		43.740
Phosphoric acid (P ₂ O ₅).....		.023
Manganese oxide (Mn O ₂).....		.015
Zinc oxide (ZnO) present but not determined.		
Insoluble residue (silica, etc.).....		.800
		100.272
Calcium carbonate.....		98.710

A number of apparent unconformities in the St. Joe member, such as may be seen near Yardelle or northwest of War Eagle post office, are, according to C. E. Siebenthal, the result of submarine erosion or of irregular deposition due to action of ocean currents. They evidently do not represent a long period of time, for the faunas found above the breaks are essentially identical with those found below them.

Fossils and correlation.—The fauna of the St. Joe is the equivalent of that of the Fern Glen formation of Missouri. Some of the characteristic fossils that establish this equivalency, as determined by G. H. Girty from collections made by A. H. Purdue and H. D. Miser, are the following:

	Platyceras paralum
Cyathaxonia minor	Spirifer grimesi
Cystodictya lineata	Brachythyris fernglenensis
Evactinopora sexradiata	Delthyris novamexicana
Leptaena analoga	Spiriferina subtexta
Chonetes logani	Cliothyridina prouti
Productus sampsoni	Hustedia circularis
Camarophoria bisinuata	Ptychospira sexplicata

Fossils and age of the Boone formation.—The fossils in some beds of the Boone formation that overlie the typical St. Joe member are also of Fern Glen age. The greater part of the Boone formation above its basal member, however, is the equivalent of the Burlington and Keokuk limestones. Purdue and Miser think that the part of the formation which lies above the Short Creek oolite is of Warsaw age, but the evidence for this correlation is not conclusive.

¹⁶ Hopkins, T. C., Marbles and other limestones: Arkansas Geol. Survey Ann. Rept. for 1890, vol. 4, p. 208, 1893.

PLATE XI

CHARACTERISTIC FOSSILS OF THE BOONE FORMATION

Most of the specimens shown on this and the other paleontologic plates were collected in Arkansas. The figures are copied from published reports prepared by Girty, Mather, and Weller.

FIGURES 1-3. *Rhipidomella dubia*. Brachial and lateral views of a complete specimen and an internal view of a pedicle valve.

4-6. *Cliothyridinia prouti*. Pedicle, brachial, and anterior views of a characteristic specimen.

7. *Leptaena analoga*. Pedicle view of a nearly complete specimen.

8-9. *Spirifer keokuk*. Pedicle and brachial views of a nearly complete specimen.

10-12. *Delthyris similis*. Pedicle, brachial, and posterior views of a nearly perfect internal cast.

13. *Chonetes illinoisensis*. Pedicle view of a large specimen.

14. *Brachymetopus ? elegans*. A pygidium, $\times 2$.

15-17. *Pseudosyrinx keokuk*. Brachial, posterior, and anterior views of internal casts.

18. *Cypricardinia rugosa*. Left valve, $\times 3$.

19-20. *Brachythyris fernglenensis*. Brachial and lateral views of a characteristic specimen.

21-23. *Delthyris novamexicana*. Pedicle, anterior, and posterior views of an incomplete specimen.

24. *Avonia millespinosa*. Pedicle view of a typical specimen.

25-26. *Productus sampsoni*. Brachial and lateral views of a nearly complete specimen.

27-29. *Camarophoria bisinuata*. Pedicle, brachial, and lateral views of a nearly perfect specimen.

30-31. *Chonetes logani*. Pedicle and brachial views of an average specimen.

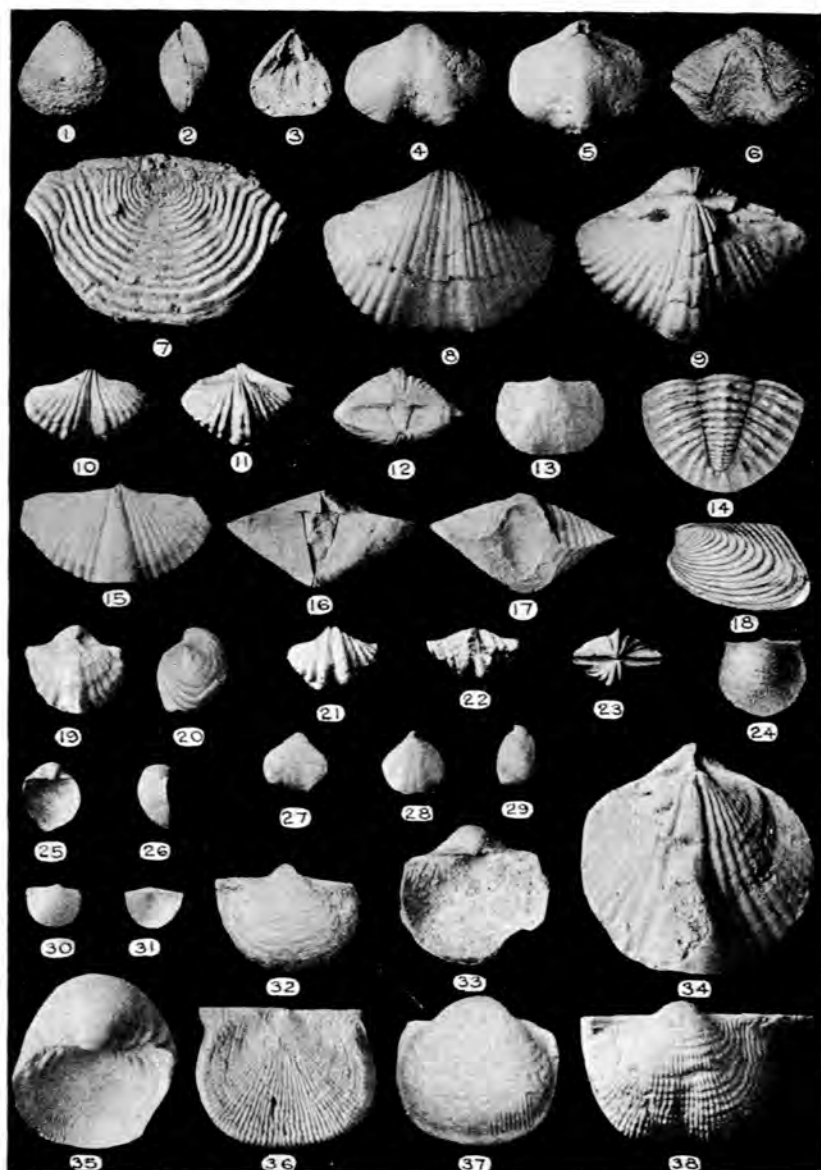
32-33. *Productus altonensis*. Posterior and brachial views of a typical specimen.

34. *Brachythyris suborbicularis*. Brachial view of an internal cast.

35. *Productus ovatus*. Brachial view of a typical specimen.

36-37. *Productus wortheni*. Brachial and pedicle valves of a typical specimen.

38. *Productus burlingtonensis*. Posterior view of a pedicle valve.



CHARACTERISTIC FOSSILS OF THE BOONE FORMATION

The Boone is particularly hard to subdivide because its faunas do not change abruptly and its upper and lower parts have many species in common. Furthermore, many of the most typical Burlington and Keokuk forms are not found in Arkansas, their places being taken by species not known from the standard sections. On the other hand, the Boone does contain many of the common Burlington and Keokuk species. Most of those in the lower part of the formation are Burlington forms, but most of those in the upper part are typical of the Keokuk. The most common forms in the lower part of the Boone formation are listed by Girty as follows:

<i>Cyathaxonia arcuata</i>	<i>Girtyella booniana</i>
<i>Cyathaxonia minor</i>	<i>Camartoechia</i> aff. <i>c. cooperensis</i>
<i>Cladochonus americanus</i>	<i>Pseudosyrinx keokuk</i>
<i>Orthotetes keokuk</i>	<i>Spirifer grimesi</i>
<i>Rhipidomella dubia</i>	<i>Spiriferella plena</i>
<i>Schizophoria swallowi</i>	<i>Brachythyris suborbicularis</i>
<i>Chonetes illinoisensis</i>	<i>Delthyris similis</i>
<i>Chonetes logani</i>	<i>Cliothyridina incrassata</i>
<i>Avonia millespinosa</i>	<i>Cyrtina burlingtonensis</i> (?)
<i>Productus burlingtonensis</i>	<i>Platyceras paraliun</i>
<i>Productus levicosta</i>	

The species named below, according to Girty, occur in the upper part of the Boone formation.

<i>Trilophyllum carinatum</i>	<i>Chonetes illinoisensis</i>
<i>Amplexus fragilis</i>	<i>Productus altonensis</i> (?)
<i>Cladochonus beecheri</i>	<i>Productus ovatus</i>
<i>Worthenopora spinosa</i>	<i>Productus semireticulatus</i>
<i>Dichotrypa</i> sp.	<i>Productus wortheni</i>
<i>Glyptopora</i> aff. <i>G. plumosa</i>	<i>Pustula punctata</i>
<i>Derbya keokuk</i>	<i>Rhynchopora beecheri</i>
<i>Reticularia pseudolineata</i>	<i>Brachythyris suborbicularis</i>
<i>Camarophoria simulans</i>	<i>Delthyris similis</i>
<i>Pseudosyrinx keokuk</i>	<i>Cyrtina neogenes</i>
<i>Cranaena</i> (?) <i>booniana</i>	<i>Eumetria marcyi</i>
<i>Spirifer keokuk</i>	<i>Myalina keokuk</i>
<i>Spirifer logani</i>	<i>Bembexia</i> aff. <i>B. nodimarginata</i>
<i>Spirifer rostellatus</i>	<i>Platyceras paraliun</i>
<i>Rhipidomella dubia</i>	<i>Brachymetopus elegans</i>

Unusual features of the Boone fauna may be seen in the occurrence of two Fern Glen species of *Cyathaxonia* at the Burlington horizon, the presence of the genus *Delthyris* throughout the formation, and the occurrence of *Hustedia circularis* and *Ptychospira sexplicata* at the Burlington or the Keokuk horizon in the Boone. Some of the abundant and characteristic species of the fauna as a whole are *Cranaena booniana*, *Girtyella booniana*, *Pseudosyrinx keokuk*, *Cyrtina neogenes*, and *Rhynchopora beecheri*. Other forms that are abundant but that are not listed above are the pygidia of a species of *Phillipsia*

near *P. portlocki* and the plates and spines of several species of echinoids.

The upper part of the Boone formation at certain places contains species that suggest the Warsaw age of its higher beds. This statement applies especially to southwestern Missouri and northeastern Oklahoma, but it is questionable whether these higher beds occur in Arkansas. A fauna found above the oolite near Carrollton contains the following species, as determined by G. H. Girty:

Zaphrentis sp.	Brachythyris suborbicularis
Chonetes illinoisensis	Pseudosyrinx keokuk
Productus semireticulatus	Camarophoria aff. C. simulans
Productus wortheni (?)	Pustula punctata
Productus aff. P. mesialis	Avonia millespinosa
Rhynchopora beecheri	Eumetria marcyi
Dielasma aff. D. utah	Phillipsia sp.

This fauna, however, is somewhat like that of the Keokuk rather than that of the Warsaw and is essentially identical with the fauna found below the oolite. It may be seen from the above discussion, therefore, that the problems presented by the Boone fauna are many and intricate, and further study is needed for their complete solution.

Stratigraphic relations.—At many places in northern Arkansas the St. Joe limestone member of the Boone formation rests conformably upon the Chattanooga shale, but at other places the relations indicate a slight disconformity. Where the Chattanooga is missing the St. Joe rests on either the Sylamore, Cason, Fernvale, Joachim, Jasper, or St. Peter formations, its position depending on the amount of local erosion preceding its disposition. At a few places where the St. Joe is not found, as near Tahlequah, Oklahoma, the cherty beds of the Boone rest disconformably upon the older formations. Essentially similar relations are found also in Independence County, Arkansas, but there the Boone chert overlies the subjacent strata with slightly angular unconformity. The St. Joe is found, however, at practically all places between Batesville and the Oklahoma-Arkansas border.

The Boone is disconformable with either the overlying Moorefield shale, Batesville sandstone, or Fayetteville formation. The basal member of the Batesville sandstone contains a conglomerate of chert pebbles derived from the Boone, and the surface of the Boone at the contact is irregular. At some places the limestone in the Boone had been removed by ground-water solution before the deposition of the overlying sediments. At such places the contact with the next younger formation may appear to be angular owing to the slumping of the chert after the removal of the interbedded calcareous material. In northeastern Oklahoma, particularly near Pryor, many inliers of the Boone formation rise as chert hills through the overlying Chester formations.



A. TYPICAL SURFACE FORMS PRODUCED BY A SMALL STREAM IN THE MASSIVE ST. PETER (KINGS RIVER?) SANDSTONE 8 MILES SOUTHWEST OF EUREKA SPRINGS



B. TYPICAL EXPOSURE OF THE BLACK, FISSILE PART OF THE MOOREFIELD SHALE NEAR MARSHALL

The resemblance to the lower black Fayetteville shale is striking, but that formation is commonly darker and concretionary.

Petrologic significance.—The Boone formation is generally very fossiliferous and may be considered a potential source of hydrocarbons. At a few places the limestone, when freshly broken, gives off the distinctive odor of crude oil, but this fact does not necessarily indicate that it will there yield oil upon drilling. Neither can the Boone be regarded favorably as a potential reservoir of oil or gas, for its beds are ordinarily too broken to retain either and are generally overlain by pervious beds. The formation, however, has yielded some gas in several wells, notably in the Banks No. 1 of the Independent Oil and Gas Company, in Sec. 6, T. 16 N., R. 27 W., and probably it is worth further testing.

The Boone is also of value to the petroleum geologist as a horizon marker. The porcellaneous chert cuttings are so distinctive that they are at once recognized by the driller and the geologist alike, and this horizon can usually be ascertained in all wells, no matter how incomplete or contradictory the rest of the record may be.

Many clearly defined minor structural features may be seen near the surface of the Boone in the area of its outcrop, but most of these were formed by the slumping of chert beds due to the removal of the unequally distributed calcareous material interbedded with them. All such features in the Boone should therefore be carefully examined before they are set down as a reflection of deeper folding. Wells started on the Boone formation in Arkansas do not have a good chance of reaching commercial supplies of oil or gas.

MOOREFIELD SHALE

Definition.—The Moorefield formation is a light-gray to blue-black friable shale, which is in places arenaceous. A thin fossiliferous limy bed at the base of the shale has been called the "Spring Creek limestone." The shale is well exposed near the village of Moorefield, in Independence County, from which it was named. As this shale is overlain by a sandstone in its type area, and as the lithologically similar Fayetteville shale near Fayetteville is also overlain by a similar sandstone, the geologists of the old Arkansas Survey regarded the sections in Washington and Independence counties as essentially the same and assigned the beds now called Moorefield to the Fayetteville shale. When later studies of the geology of the intervening area showed that the shale near Batesville, which had been called Fayetteville, was older than that formation in its type area, Adams proposed the name Moorefield for the beds thus left without a name.

Distribution and thickness.—The Moorefield shale is best exposed in an area in Independence County near Batesville and Moorefield. In this area it ranges in thickness from about 75 to 275 feet, but it becomes progressively thinner westward, through Stone and Searcy

counties, until at Marshall it is less than 30 feet thick. The westernmost exposure of the Moorefield appears to be that at St. Joe, where the formation has diminished to a thickness of about 2 feet; and it apparently does not extend as far west as Newton County. In the southern half of the Yellville quadrangle the Moorefield is found at but few places, and it nowhere exceeds 10 feet in thickness. The shale also becomes thinner toward the north and is finally overlapped by the Batesville sandstone. It evidently increases in thickness rather rapidly to the east and southeast.

Character.—The Moorefield formation is variable in character, but at many places it consists of a dark, fissile shale very similar to the typical Fayetteville black shale, for which it has been mistaken by some geologists. At some places the shale is sandy; at others it includes thin layers of sandstone. At still other places it contains thin layers of limestone or limy concretions, but it is dominantly a shale. Plate XII, *B* shows a typical exposure of the Moorefield shale. The lower black shale of the Fayetteville formation, although it greatly resembles the shale shown in the figure, is usually darker, somewhat more fissile, and more generally contains concretions.

A section of the Moorefield exposed in a small gully just northeast of Marshall shows both the underlying and the overlying formations. The section there, slightly modified from that given by Girty, is as follows:

Batesville sandstone.	
Moorefield shale:	Feet.
Dirty brown arenaceous shale.....	3
Brown sandstone.....	1
Black fissile shale.....	15
Drab arenaceous shale.....	2
Black fissile shale.....	4
Drab arenaceous shale.....	3
Fossiliferous concretionary zone.....	1
Drab arenaceous shale.....	2
Thin-bedded limestone.....	1
	—
Boone chert:	32
White chert.....	2
Dark-gray crystalline limestone.....	2

Although the formation varies greatly from place to place its general lithology is like that shown in the above section. Near Marshall and St. Joe the lower limestone is somewhat oolitic.

Fossils and correlations.—The shale of the Moorefield formation is generally barren of organic remains, but at a few places it is sparingly fossiliferous. The basal limestone, however, and the calcareous phases of the formation in general, carry an interesting and varied fauna, which has been studied by a number of writers, among whom

Williams¹⁷ and Girty¹⁸ have done the most detailed work. A faunal list representing the species found in the formation, as determined by G. H. Girty, follows:

Distribution of species in the Moorefield shale in the Batesville and Marshall quadrangles.

Species.	Spring Creek.	Moorefield.	Howard's Wells.	Marshall.
Menophyllum sp.....	+			
Enchostoma bicarinatum.....	+			
Batostomella dubia.....	+			
Batostomella parvula.....	+			
Stenopora sp.....	+			
Fenestella aff. rudis (?).....	+			
Fenestella aff. multispinosa (?).....	+			
Lingula batesvillæ.....	+			
Lingula albapinensis.....	+			
Lingulidiscina newberryi var. moorefieldana.....	+			?
Lingulidiscina newberryi var. marshallensis.....	?			+
Lingulidiscina newberryi var. ovata.....	+			
Lingulidiscina newberryi var. caneyana.....	+	+		
Chonetes sericeus.....				+
Chonetes sp.....	+			
Productella hirsutiformis.....	+	+		
Productella hirsutiformis var. batesvillensis.....	+			
Productus inflatus var. coloradensis (?).....	+			
Productus arkansanus var. multiliratus.....	+			
Productus pileiformis.....	+			+
Productus biseriatus.....	+			
Productus subsulcatus.....	+			
Productus subsulcatus var. janus.....	+			
Productus moorefieldanus.....	+			
Productus moorefieldanus var. pusillus.....	+			
Diaphragmus elegans.....	+			
Rhipidomella arkansana.....	+			
Liorhynchus carboniferum.....	+	+		+
Liorhynchus carboniferum var. polypleurum.....	+	+		+
Camarotæchia purduci.....	+			
Camarotæchia purduci var. agrestis.....	+			
Camarotæchia purduci var. laxa.....				+
Moorefieldella eurekaensis.....	+			
Moorefieldella eurekaensis var. subcuboides.....	+			
Harttina brevilobata.....	+			
Harttina brevilobata var. marginalis.....	+			

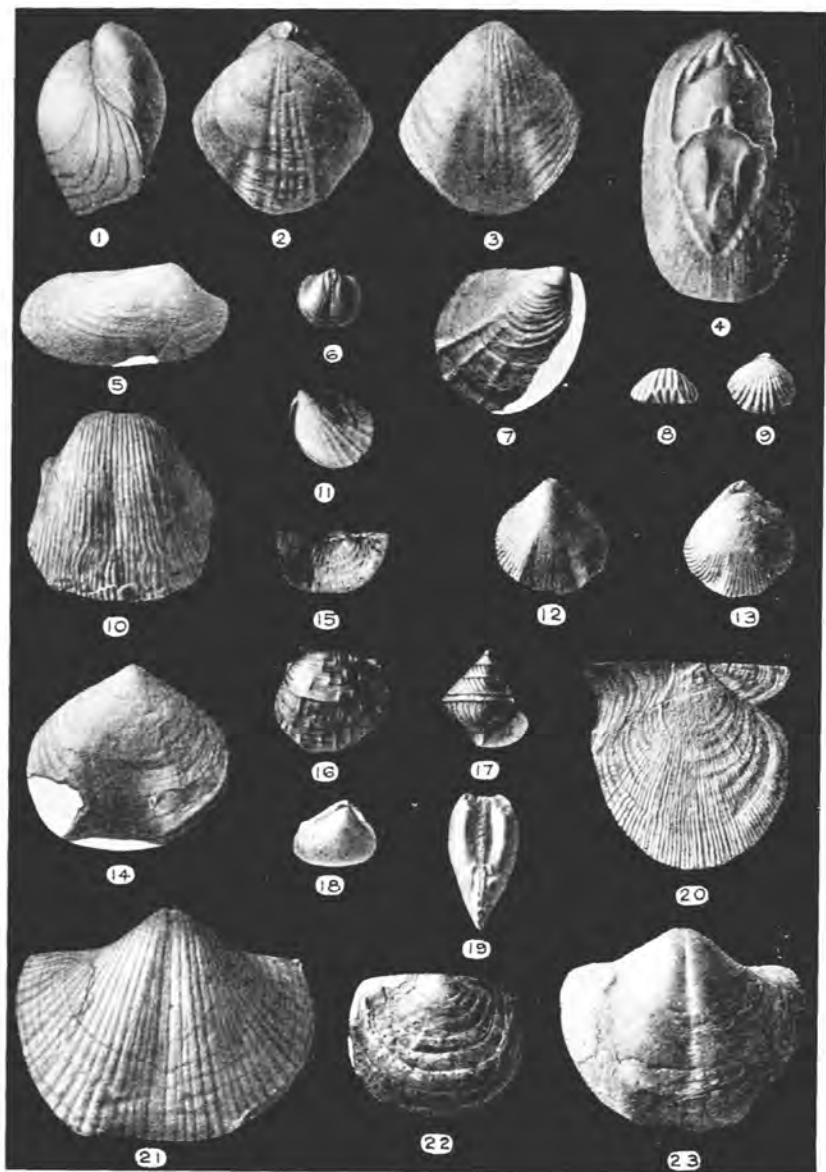
¹⁷Williams, H. S., Arkansas Geol. Survey Ann. Rept. for 1892, vol. 5, pp. 341-354, 1900.

¹⁸Girty, G. H., Fauna of the Moorefield shale of Arkansas: U. S. Geol. Survey Bull. 439, 1911.

PLATE XIII
CHARACTERISTIC FOSSILS OF THE MOOREFIELD SHALE

FIGURES 1-3. *Liorhynchus carboniferum*. Lateral, brachial, and pedicle views of a characteristic specimen.

4. *Lingula batesvillae*. Internal cast of a brachial valve, $\times 3$.
5. *Sphenotus* ? *meslerianus* ? A right valve doubtfully referred to this species.
6. *Ambocoelia levicula* ? Internal cast of a pedicle valve, $\times 2$.
- 7, 11. *Caneyella percostata*. An imperfect right valve, $\times 2$. A nearly complete left valve.
- 8-9. *Camaratoechia purduei*. Anterior and brachial views of a characteristic specimen. This species is also common in the Fayetteville formation.
10. *Diaphragmus elegans*. Pedicle view of the type found in the Moorefield shale. The species is common in the Chester formations of northern Arkansas.
- 12-13. *Moorefieldella eurekaensis*. Pedicle and brachial views of a typical specimen. This species is one of the most characteristic of the Moorefield fauna.
14. *Composita subquadrata* var. *lateralis*. An imperfect pedicle valve.
- 15-16. *Productus moorefieldanus*. Posterior and pedicle views of a typical specimen.
17. *Bembexia nodomarginata*. A complete specimen.
- 18-19. *Nucula rectangula*. A nearly complete specimen preserved as an internal cast; view of the cardinal margin of a small specimen, $\times 3$.
20. *Deltopecten batesvillensis*. A right valve. This species is also common in the Wedington and Batesville sandstones.
21. *Spirifer arkansanus*. A medium-sized pedicle valve.
22. *Productus subsulcatus*. A cast of the exterior of a brachial valve.
23. *Martinia glabra*. A somewhat flattened pedicle valve.



CHARACTERISTIC FOSSILS OF THE MOOREFIELD SHALE

Distribution of species in the Moorefield shale in the Batesville and Marshall quadrangles.—Continued.

Species.	Spring Creek.	Moorefield.	Howard's Wells.	Marshall.
<i>Spirifer arkansanus</i>	+			
<i>Spirifer moorefieldanus</i>	+			
<i>Spirifer increbescens</i>	+			
<i>Reticularia setigera</i>	+			
<i>Martinia glabra</i> (?)	+			
<i>Martinia</i> sp.	+	+		
<i>Ambocœlia lævicula</i> (?)	+			
<i>Spiriferina subelliptica</i> var. <i>fayettevillensis</i>	+			
<i>Composita subquadrata</i> var. <i>lateralis</i>	+			
<i>Composita madisonensis</i> var. <i>pusilla</i>	+			
<i>Composita</i> aff. <i>humilis</i>	+			
<i>Eumetria marcyi</i>	+			
<i>Solenomya</i> (?) sp.	+			
<i>Sphenotus</i> (?) <i>meslerianus</i> (?)	+			
<i>Sphenotus</i> (?) sp.	+			
<i>Solenopsis nitida</i> (?)	+			+
<i>Edmondia crassa</i>	+			
<i>Nucula rectangula</i>	+			+
<i>Leda vaseyana</i>	?	?		
<i>Leda nasuta</i> (?)	+			
<i>Parallelodon multiliratus</i>	+			
<i>Cypricardinia</i> (?) <i>moorefieldana</i>	+			
<i>Caneyella vaughani</i>		+		
<i>Caneyella wapanuckensis</i> (?)				+
<i>Caneyella percostata</i>	+			
<i>Caneyella nasuta</i>	+			
<i>Schizodus batesvillensis</i>	+			?
<i>Deltopecten batesvillensis</i>	+	+	+	
<i>Deltopecten</i> (?) sp.	+			
<i>Allerisma walkeri</i> var. <i>abbreviatum</i>	+			
<i>Bembexia nodimarginata</i>	+			
<i>Pleurotomaria</i> (?) sp.		+		+
<i>Bucanopsis cancellata</i> (?)	+			
<i>Bellerophon</i> sp.	+			
<i>Strophostylus</i> aff. <i>carleyanus</i>	+	?		
<i>Orthoceras</i> aff. <i>crebriliratum</i>	+			
<i>Orthoceras</i> sp. a.		+		
<i>Orthoceras</i> sp. b.	+	+		
<i>Endolobus ornatus</i>		+		
<i>Bactrites</i> (?) <i>carbonarius</i>		+		
<i>Bactrites?</i> <i>smithianus?</i>	+			
<i>Goniates choctawensis</i>	?	+	+	
<i>Goniates crenistria</i>		+		

Distribution of species in the Moorefield shale in the Batesville and Marshall quadrangles.—Continued.

Species.	Spring Creek.	Moorefield.	Howard's Wells.	Marshall.
<i>Goniatites subcircularis</i>	+			
<i>Goniatites newsomi</i>	?			
<i>Gastrioceras richardsonianum</i> (?).....		?		
<i>Gastrioceras caneyanum</i>	+		+	
<i>Eumorphoceras bisulcatum</i>			+	
<i>Adelphoceras meslerianum</i> (?).....			+	
<i>Griffithides</i> (?) sp.....	+			
<i>Paraparchites nicklesi</i>	+			
<i>Primitia moorefieldana</i>	+			
<i>Bairdia attenuata</i>	+			

The stratigraphic position of the Moorefield, which lies immediately above the Boone, suggests its correlation with the St. Louis, but few species are common to the faunas of the two formations, and it is extremely difficult to correlate the beds in Arkansas with those of the standard section in the Mississippi Valley. Both Girty and Williams, however, point out that the fauna of the Moorefield shale is related to that of the Caney shale of Oklahoma and to the faunas of the Carboniferous beds in Nevada.

Of the 89 species of invertebrates recorded from the Moorefield in the Batesville area, only 22 are found in the overlying Batesville sandstone, according to Girty. Furthermore, the present writer has found that of the 78 *specifically identified* forms found in the Moorefield, 47 have been found in the Fayetteville, and that 14 of the 16 species found in the lower black shale of the Fayetteville are found also in the Moorefield. These figures serve only to show the necessity of correlating the intimately related upper Mississippian formations in Arkansas by a consideration of faunal facies. This necessity is made more evident by the fact that two of the most abundant and characteristic Moorefield fossils, *Liorhynchus carboniferum* and *Moorefieldella eurekaensis*, although unknown from the overlying Batesville sandstone, are found in the younger but lithologically similar lower shales of the Fayetteville formation.

Stratigraphic position.—The Moorefield shale apparently rests disconformably upon the Boone chert, but the contact between the two formations is only slightly irregular. (See Pl. XXXIV.) The Moorefield shale is conformably overlain by the Batesville sandstone, for, despite the rather different faunas of the two formations there was apparently no break between them in deposition. (See Pl. XIV.)



CONTACT OF THE MOOREFIELD SHALE (BELOW) WITH THE BATESVILLE SANDSTONE (ABOVE) IN A RAILROAD CUT NEAR MARSHALL

The hammer handle rests on the basal bed of the Batesville formation (see p. 61), which at this place contains considerable shale.

Petrolific significance.—The Moorefield shale may be a potential source of oil and gas. Like the Fayetteville and the Chattanooga shale, it gives off an odor of petroleum when freshly fractured, but it is probably not so rich in kerogen as either of those formations. The shale has been reached or penetrated by a number of wells but has not yielded oil or gas in commercial quantities.

The formation may be reached by wells drilled in the Boston Mountain area east of the longitude of St. Joe. In the extreme eastern part of that area it is at least 200 feet thick, and at some places it may be thicker, although this supposition is not supported by well records.

BATESVILLE SANDSTONE

Definition.—The Batesville formation is a coarse-grained, cream-colored to brown sandstone, which is particularly well exposed near Batesville, from which it was named by J. C. Branner. The term Batesville, however, was first used as a formation name by F. W. Simonds¹⁹ and R. A. F. Penrose²⁰ in two reports published in 1891, on widely separated areas in Arkansas. Simonds applied the name Wyman to what is now known as the Batesville and used the name Batesville for the sandstone now known as the Wedington, supposing that the Moorefield shale of the Batesville district was the same the lithologically similar Fayetteville shale of the Fayetteville area. The changes that have taken place in the nomenclature of certain formations in Arkansas are shown in the table on page 58.

All recent writers have employed the terminology used by Purdue and Miser in 1917, which differs from that of Adams, Purdue, and Ulrich only by the addition of the Hindsville member to the Batesville formation. This basal limestone of the Batesville was probably regarded by previous writers as a part of the Boone chert, but it is separated from that formation by a marked disconformity and contains a distinctly younger fauna.

Distribution and thickness.—The Batesville sandstone is found along the base of the slopes of the isolated hills and mountains north of the Boston Mountain escarpment in Independence, Stone, Searcy, Newton, Boone, Carroll, Madison, Washington, and Benton counties. Over much of the eastern part of this area the formation is everywhere present, but in the two counties last named it is thin or absent. It is doubtful whether the formation occurs in Oklahoma, although it may be represented in the Tahlequah quadrangle by a very thin bed of sandstone that directly overlies the Boone in a few places. The westernmost exposure of the typical Batesville, however, is in

¹⁹ Simonds, F. W., The geology of Washington County: Arkansas Geol. Survey Ann. Rept. for 1888, vol. 4, pp. 49-53, 1891.

²⁰ Penrose, R. A. F., Manganese: Its uses, ores, and deposits: Arkansas Geol. Survey Ann. Rept. for 1890, vol. 1, pp. 139-140, 1891.

Changes in names of certain Mississippian formations of Arkansas

[The dates given at the tops of columns are dates of publication.]

F. W. Simonds, 1891 ²¹	R. A. F. Pen- rose, 1891 ²²	H. S. Williams, 1895 ²³	Stuart Weller, 1897 ²⁴	H. S. Williams, 1900 ²⁵	Stuart Weller, 1900 ²⁶	G. I. Adams, A. H. Purdue, and E. O. Ulrich, 1904 ²⁷	A. H. Purdue and H. D. Miser, 1913 ²⁸
						Fayetteville Region	
Archimedes lime- stone.....					Archimedes lime- stone (shaly sandstone).....		
Marshall shale. Batesville sand- stone.....	Marshall shale. Batesville sand- stone.....	Batesville sand- stone.....	Batesville sand- stone.....	Batesville sand- stone.....	Marshall shale. Batesville sand- stone.....		
Fayetteville shale Wyman sand- stone.....	Fayetteville shale to the west.....	Spring Creek lime- stone.....	Spring Creek lime- stone and shale Fayetteville shale of Arkansas ge- ologists.....	Spring Creek black shale and limestone, Fay- etteville shale of Penrose's re- port.....	Fayetteville shale. Wyman sandstone		Pitkin limestone..... Fayetteville shale..... Wedington sand- stone member..... Fayetteville shale.....
						Fayetteville formation sandstone member..... Fayetteville formation sandstone.....	{ Batesville sandstone..... Hindsville limestone member.....
						Batesville sand- stone.....	
						Moorefield shale. Spring Creek lime- stone member.....	
Boone chert and limestone.....	Boone chert.....	Boone chert.....	Boone chert.....	Boone chert.....	Boone chert.....	Boone formation.....	Boone limestone.....

²¹ Ann. Rept. Arkansas Geol. Survey for 1888, vol. 4, p. xiii; Washington County (Fayetteville region).

²² Ann. Rept. Arkansas Geol. Survey for 1890, vol. 1, p. 113; Batesville region.

²³ Am. Jour. Sci., 2d ser., vol. 49, pp. 94-96; Batesville region.

²⁴ Trans. New York Acad. Sci., vol. 16, pp. 278-282; Batesville region.

²⁵ Ann. Rept. Arkansas Geol. Survey for 1892, vol. 5, p. 277; northern Arkansas.

²⁶ Ann. Rept. Arkansas Geol. Survey for 1892, vol. 5, p. 274.

²⁷ Prof. Paper U. S. Geol. Survey No. 24.

²⁸ U. S. Geol. Survey Geol. Atlas, Eureka Springs and Harrison folio (No. 202).

the Wedington Mountains, in the western part of Washington County, where, although it has not before been recognized, the formation is about 3 feet thick.

The Hindsville limestone member is best represented near Hindsville, in Madison County. Its westernmost exposure known to the writer is near Prairie Grove, and it extends eastward to a point within 2 miles of Harrison, but it is not found east of that city. It extends northward into southwestern Missouri for an undetermined distance. In northeastern Oklahoma also some thin conglomeratic beds that overlie the Boone at a few places may represent the Hindsville. This member thickens distinctly toward the north, and apparently toward the northeast. The outcrop of the Hindsville member is everywhere a very narrow band, which usually appears beneath the Batesville formation, but at some places, as in the southwestern part of the Eureka Springs quadrangle, it is the only representative of the Batesville.

The thickness of the Hindsville member is extremely variable, ranging from about 2 feet near Goshen to nearly 50 feet near Garfield. Its average thickness, however, over most of the area of its exposure, is only slightly more than 10 feet.

The Batesville sandstone, exclusive of its basal member, ranges in thickness from a feather edge in the western part of the area of its exposure to about 225 feet near Batesville. Its thickness increases toward the north as well as toward the east, for it is thicker in the isolated knobs north of the Boston Mountain escarpment than in the escarpment itself. In the southwestern part of the Eureka Springs quadrangle and in the Fayetteville quadrangle it is at most places less than 5 feet thick. In the vicinity of Burlington it is nearly 100 feet thick, but its average thickness in the Eureka Springs and Harrison quadrangle is less than 25 feet. In Marion County, however, its average thickness increases to 75 feet, and the beds become thicker toward the Paleozoic-Tertiary boundary, in Independence County.

In the extreme eastern part of the area of Paleozoic rocks the outcrop of the Batesville sandstone is relatively large, but in its western part, near the base of the Boston Mountain escarpment, it ordinarily forms only a narrow band. An exception may be seen in the relatively wide surface distribution of the sandstone in the Harrison quadrangle, particularly near Green Forest, Burlington, Gaither, and Batavia.

Hindsville limestone member.—The Hindsville limestone, first recognized as distinct from the Boone chert by Purdue and Miser, is coextensive with the Batesville sandstone over much of the Eureka Springs and Harrison quadrangles, and is also found at places in the Fayette-

ville quadrangle. At some places, however, the Hindsville is the only part of the Batesville that is seen, but at still other places it is overlapped by the sandstone of the Batesville.

The Hindsville consists mainly of limestone, with which is interbedded at some places thin beds of sandstone. The limestone is dark gray but weathers lighter. In general it is heavy bedded and coarsely crystalline, and at most places it is fossiliferous. The limestone is cross-bedded at a number of its exposures, as is shown by the configuration of the sandy streaks left after the solution of the calcium carbonate. The rock contains hydrocarbons and gives off a strong odor of petroleum when freshly fractured.

At the base of the Hindsville at most places there is a conglomeratic bed several feet thick, which is particularly well displayed in the southern part of the Eureka Springs quadrangle. The matrix of this bed is a dark-gray limestone, which contains both waterworn and angular fragments of chert. These fragments are extremely variable in size; some of those seen at the exposure north of Prairie Grove, where the conglomerate is most spectacularly displayed, are at least 10 inches in diameter, but in the Eureka Springs quadrangle most of them are less than 4 inches in maximum diameter. These fragments may make up the greater part of the conglomerate, but at some places the limestone matrix greatly predominates and the fragments are sparsely distributed through it. These fragments of chert were derived from the underlying Boone formation, but it is not known whether they were washed in from an adjacent area or were derived from the surface of the Boone directly beneath the Hindsville.

The sandstone in the basal member is soft, fine-grained, yellow or brown, and porous. Before it has weathered it is distinctly calcareous, and in general it strongly resembles the sand of the Batesville.

Character of the Batesville sandstone.—The Batesville sandstone is a light yellow or buff rock, which, at many places grades into a brown rock. It is generally medium-grained, but at some places it is coarse-grained and at others it is fine-grained. In fresh exposures the formation appears to be massively bedded, but its flaggy nature becomes apparent by weathering, and beds more than two feet thick are rare. Lenticular masses of shale are found in the sandstone at a few places but are more common in the eastern than in the western area of its exposure. Thin layers of green and black shale, however, occur in the Harrison quadrangle, both near the top of the sandstone and at its base.

The Batesville has been rather extensively quarried, particularly near Batesville, and at many places in fresh exposures it is so cal-

careous that it is regarded as a compact limestone. In the same quarry, however, the rock may vary from porous sandstone to compact limestone, which may be only slightly arenaceous. This variation and the fact that the rock is highly calcareous where it is unweathered have led to the inference that much of the Batesville was originally calcareous. Although the sandstone is commonly flaggy on exposed surfaces, it is at some places prominently laminated and cross bedded. The formation is generally softer and thinner bedded in its lower part and harder and massive above. At several places the Batesville contains thin beds of siliceous oolitic limestone, but these beds form only a small part of it.

The flaggy basal part of the Batesville is well shown in Plate XIV.

Fossils and correlation.—Fossils are rather common in the lower limestone member of the Batesville formation, and the fauna is particularly rich in pelecypods and gastropods, many of which are dwarfs such as are found in the Spergen limestone of Indiana. Furthermore, a number of the Hindsville species are conspecific with those of the Spergen formation. According to Girty,²⁹ however, the Hindsville fauna is more closely related to that of the St. Genevieve limestone. It appears to be of Chester rather than Meramec age, for it contains *Diaphragmus elegans*, *Spiriferina transversa*, and other more or less diagnostic Chester types.

The Hindsville fauna is large and varied, but many of the most typical species have not yet been described. The life assemblage, however, not only differs markedly from that of the underlying Boone but is different from that of the related overlying Chester formations, including the Batesville. Further study may show that it should be considered a distinct formation, rather than a member of the Batesville sandstone. A list of the more common fossils, as given by Girty, follows:

<i>Agassizocrinus conicus</i>	<i>Productus adairensis</i> (?)
<i>Fistulipora excellens</i>	<i>Productus arkansanus</i>
<i>Fenestella</i> several sp.	<i>Productus punctatus</i>
<i>Septopora cestriensis</i> (?)	<i>Diaphragmus elegans</i>
<i>Archimedes intermedius</i>	<i>Camarotoechia purduei</i> var. <i>agrestis</i>
<i>Stenopora</i> several sp.	<i>Girtyella turgida</i> var. <i>elongata</i>
<i>Batostomella parvula</i>	<i>Spirifer batesvillae</i>
<i>Glyptopora</i> aff. <i>G. michelinia</i>	<i>Reticularia setigera</i>
<i>Streblotrypa nicklesi</i>	<i>Spiriferina transversa</i>
<i>Rhipidomella dubia</i>	<i>Composita subquadrata</i>
<i>Productus ovatus</i>	<i>Cliothyridina sublamellosa</i>
<i>Cliothyridina elegans</i>	<i>Levidentalium venustum</i>
<i>Eumetria verneuilliana</i>	<i>Bellerophon sublevis</i>
<i>Ariculipecten talboti</i>	<i>Bucanopsis textilis</i>

²⁹ Girty, G. H., Identification of Carboniferous invertebrates in the Eureka Springs-Harrison folio: U. S. Geol. Survey Atlas, Eureka Springs-Harrison folio (No. 202), p. 12, 1917.

PLATE XV

CHARACTERISTIC FOSSILS OF THE BATESVILLE SANDSTONE

FIGURES 1-2. *Productus inflatus* var. *coloradoensis*. Pedicle and posterior views of an incomplete specimen.

3. *Caneyella hopkinsi*. A left valve with traces of costae.

4. *Myalina wellesiana*. A small left valve.

5. *Girtyella turgida* var. *elongata*. Brachial view of a characteristic specimen.

6, 7, 14. *Diaphragmus fasciculatus*. Pedicle and lateral views of a large specimen with fasciculate costae; cast of a brachial valve.

8. *Glyptopleura rhomboidalis*. A left valve, $\times 30$.

9-10. *Spirifer increbescens*. Internal cast of an average sized brachial valve and internal cast of a small pedicle valve. This species occurs also in the Fayetteville formation.

11. *Paraparchites nicklesi*. A bivalved specimen, $\times 10$.

12. *Allerisma neglectum*. A characteristic right valve.

13. *Dellopecten batesvillensis*. A nearly complete left valve. Common in the Batesville and Wedington sandstones.

15. *Leptodesma carboniferum*. A large left valve.

16, 19, 20. *Eumetria marcyi*. Brachial view of a large, rounded specimen; pedicle and brachial views of a more characteristic specimen. This species occurs also in the Fayetteville formation.

17. *Sphenotus vulgaris*. A characteristic right valve.

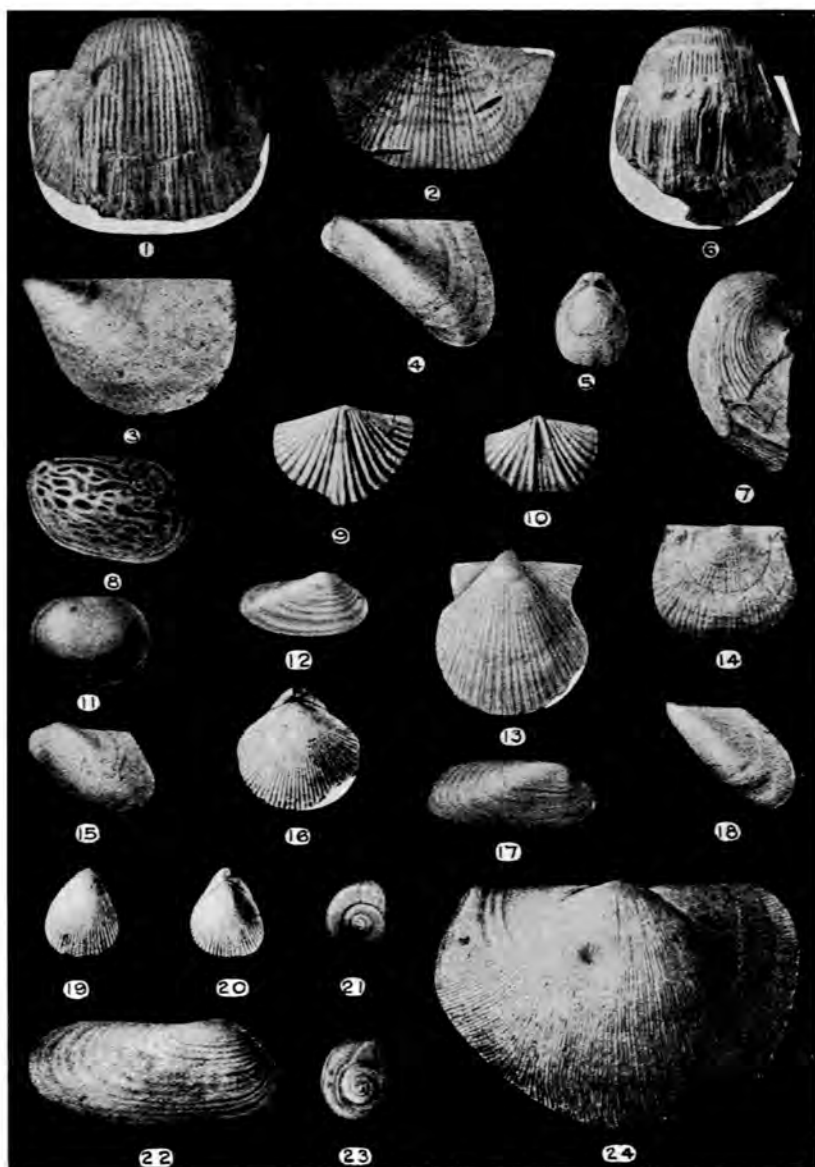
18. *Myalina elongata*. A nearly complete left valve.

21. *Pleurotomaria* aff. *perhumerosa*. Apical view of a nearly complete specimen, which is an internal cast, $\times 2$.

22. *Allerisma walkeri*. An average-sized right valve.

23. *Euomphalus similis*. Apical view of a typical specimen, $\times 2$.

24. *Orthotetes subglobosus* var. *batesvillensis*. Internal cast of a large brachial valve.



CHARACTERISTIC FOSSILS OF THE BATESVILLE SANDSTONE

<i>Leptodesma</i> n. sp.	<i>Euphemus</i> n. sp.
<i>Myalina</i> <i>welleriana</i>	<i>Pleurotomaria</i> sev. sp.
<i>Myalina</i> <i>monroensis</i>	<i>Euomphalus</i> <i>similis</i> var. <i>planus</i>
<i>Nucula</i> <i>illinoisensis</i>	<i>Naticopsis</i> several sp.
<i>Cypricardina</i> <i>indianensis</i>	<i>Zygopleura</i> several sp.
<i>Parallelodon</i> <i>miconema</i>	<i>Cyclonema</i> sp.
<i>Cypricardella</i> aff. <i>C. oblonga</i>	<i>Griffithides</i> <i>mucronatus</i>
<i>Cypricardella</i> <i>subalata</i>	<i>Paraparchites</i> <i>nicklesi</i>

The sandstone of the Batesville formation is only sparingly fossiliferous in the western part of its exposure, but the following fossils, collected by Purdue and Miser and identified by Girty, occur in the Eureka Springs-Harrison quadrangles:

<i>Batostomella</i> sp.	<i>Myalina</i> <i>illinoisensis</i> (?)
<i>Fenestella</i> sp.	<i>Leptodesma</i> <i>carboniferum</i>
<i>Archimedes</i> <i>confertus</i> (?)	<i>Leptodesma</i> <i>spargenense</i> (?)
<i>Glyptopora</i> <i>melinina</i>	<i>Aviculopecten</i> <i>multilineatus</i>
<i>Orthotetes</i> <i>subglobosus</i> (?)	<i>Dellopecten</i> <i>batesvillensis</i> (?)
<i>Diaphragmus</i> <i>elegans</i>	<i>Nucula</i> <i>illinoisensis</i>
<i>Girtyella</i> <i>turgida</i> var. <i>elongata</i>	<i>Bellerophon</i> <i>sublevis</i>
<i>Dielasma</i> <i>gracile</i>	<i>Pleurotomaria</i> aff. <i>P. meekana</i>
<i>Spirifer</i> <i>batesvillae</i>	<i>Holopea</i> <i>proutana</i> (?)
<i>Composita</i> <i>subquadrata</i>	<i>Naticopsis</i> n. sp.
<i>Cliothyridina</i> <i>sublamellosa</i>	<i>Aclisina</i> sp.
<i>Eumetria</i> <i>marcyi</i>	<i>Cyclonema</i> n. sp.
<i>Myalina</i> <i>monroensis</i>	

A comparison of this fauna with that of the Hindsville indicates only a general relation between the two formations, but the faunal differences may be explained in part by differences in sedimentation. The Batesville formation is either more fossiliferous or has been more carefully studied in the eastern part of the area of its exposure, which has yielded 128 species that have been described by Girty. Of the forms collected, 109 were found near Batesville and 69 near Marshall, 19 of the forms found near Marshall not being recorded from the area near Batesville. The relation of the western Batesville fauna above listed to the fauna of Batesville farther east is not very close, for 14 of the 25 western species do not occur in the Batesville-Marshall list. The diagnostic species, however, are the same, and the differences are perhaps no greater than should be expected in view of the distance separating the two areas. The fauna of the Batesville formation in the eastern area of its exposure as given by Girty³⁰ is as follows:

<i>Trochammina</i> (?) sp.	<i>Sulcatipinna</i> <i>arkansana</i>
<i>Endothyra</i> <i>discoidea</i>	<i>Leptodesma</i> <i>carboniferum</i>
<i>Zaphrentis</i> aff. <i>spinulosa</i>	<i>Leptodesma</i> <i>spargenense</i> var. <i>robustum</i>
<i>Spirorbis</i> sp.	

³⁰ G. H. Girty, Fauna of the Batesville sandstone: U. S. Geol. Survey Bull. 593, p. 12, 1915.

- Batostomella parvula*
Lioclema (?) sp.
Tabulipora miseri
Tabulipora aff. gracilis
Cystodictya sp.
Glyptopora aff. punctipora
Glyptopora aff. sagenella
Glyptopora aff. plumosa
Fenestella tenax
Fenestella aff. serratula
Fenestella sp. *a*
Fenestella sp. *b*
Fenestella sp. *c*
Polypora sp.
Archimedes proutanus var.
Rhopalonaria (?) sp.
Lingulidiscina batesvillensis
Crania (?) sp.
Schuchertella williamsi
Orthotetes subglobosus (?)
Orthotetes subglobosus var. *batesvillensis*
Orthotetes subglobosus var. *protenus* (?)
Productella hirsutiformis
Productus arkansanus
Productus inflatus var. *coloradoensis* (?)
Productus pileiformis
Productus adairensis
Diaphragmus fasciculatus
Diaphragmus elegans
Camarotoechia purduei
Camarotoechia purduei var. *inflata*
Dielasma formosum var. *whitfieldi* (?)
Girtyella turgida var. *elongata*
Spirifer increbescens
Reticularia setigera (?)
Spiriferina spinosa
Spiriferina transversa
Cliothyridina sublamellosa
Cliothyridina elegans
Composita subquadrata
Composita acinus
Eumetria mareyi
Sphenotus washingtonensis
Sphenotus vulgaris
Sphenotus aff. branneri
Sphenotus cultellus
Sphenotus constrictus
Sphenotus aff. meslerianus
Sphenotus sp.
Edmondia equilateralis
- Conocardium cuneatum* (?)
Caneyella hopkinsi
Myalina illinoisensis
Myalina illinoisensis var.
Myalina monroensis
Myalina elongata
Schizodus batesvillensis
Schizodus depressus (?)
Schizodus depressus var. *abruptus*
Schizodus depressus var. *circulus*
Schizodus brannerianus
Schizodus arkansanus
Deltopecten batesvillensis
Deltopecten batesvillensis var.
Deltopecten sp. *a*
Deltopecten sp. *b*
Deltopecten sp. *c*
Myoconcha (?) *duba*
Lithophagus (?) *batesvillensis*
Allerisma maxvillense
Allerisma walkeri
Allerisma walkeri var.
Allerisma neglectum
Cypricardella oblonga
Levidentalium venustum
Lepetopsis levettei (?)
Pleurotomaria arkansana
Pleurotomaria aff. perhumerosa
Pleurotomaria sp.
Pleurotomaria (?) sp.
Euconospira disjuncta
Euconospira sp.
Bembexia (?) sp.
Bellerophon sublevis (?)
Belleraphon sp.
Patellostium branneri
Bucanopsis cancellata (?)
Euphemus sp.
Euomphalus similis
Naticopsis genevievensis (?)
Platyceras acutirostre (?)
Platyceras sp.
Strophostylus aff. carleyanus
Strophostylus splendens
Loxonema (?) sp.
Orthoceras indianum
Orthoceras caneyanum
Orthoceras aff. eurekaense
Orthoceras sp.
Protochiloceras sp.
Solenocheilus (?) sp.
Goniatites choctawensis
Gastrioceras caneyanum

Edmondia crassa	Adelphoceras meslerianum (?)
Edmondia crassa var. symmetrica	Aptychus solidum
Edmondia sp.	Griffithides mucronatus
Nucula rectangula	Paraparchites nicklesi
Nucula shumardiana	Primitia fayettevillensis
Leda pandoriformis (?)	Primitia seminolis
Leda nuculiformis (?)	Glyptopleura rhomboïdalis
Yoldia levistriata (?)	Cytherella glandella

The correlation of the fauna above listed has been a subject of some controversy, but it is evidently of early Chester age. Some geologists have suggested that the Batesville should be correlated with the Cypress sandstone of the Illinoian section, but this correlation is not based on paleontologic evidence.

Stratigraphic relations.—In the eastern part of the area of Paleozoic rocks in Arkansas the Batesville rests conformably upon the Moorefield shale. (See Pl. XIV.) West of St. Joe, however, it rests disconformably upon the Boone limestone, for the Moorefield is not found in the western part of the State. The Batesville is overlain conformably by the Fayetteville shale, and in the western area, where the Fayetteville in places rests directly on the Boone, the Batesville apparently was never deposited.

Petrolific significance.—The Hindsville limestone member of the Batesville is a potential source of oil and gas. It is ordinarily very fossiliferous, and at most places it gives off a strong odor of petroleum when struck with a hammer. The Batesville, on the other hand, although it is in places calcareous and contains fossils, is not a probable source of hydrocarbons. The sandstone, however, is very porous and may serve as an excellent reservoir for either oil or gas. These products might migrate to the sand either from the underlying Moorefield or Hindsville, or from the overlying Fayetteville shale. Many wells have been drilled into the Batesville, but most of them have yielded only water. A few wells, however, notably that of the War Eagle Oil and Gas Company near Witter, found a show of oil at the horizon of the Batesville.

The Batesville was not encountered in the Gruber well near Winslow, was only a foot thick in a well drilled near Prairie Grove, and was rather doubtfully identified as a bed of sandy shale 25 feet thick in the Wood well, drilled 6 miles north by east of Van Buren. Thus it appears that the Batesville sandstone will not be struck by wells drilled at all places in the western part of the State. Farther east, where the formation is thicker and may perhaps be found at all places, it has not been properly tested. Positive statements as to its distribution and thickness south of the crest of the Boston Mountains cannot be made, for few drill records in that area are available.

FAYETTEVILLE SHALE

Definition.—The Fayetteville formation of Arkansas and Oklahoma is generally a black, fissile, carbonaceous shale having near its top a prominent sandstone known as the Wedington sandstone. The formation was named from Fayetteville, in whose environs it is extensively exposed, and the Wedington member was named from the Wedington Mountains, where it is well displayed. The Wedington is the same as the Batesville sandstone of Simonds' report on the geology of Washington County, and the upper Fayetteville shale corresponds to that writer's "Marshall shale." These differences in correlation and the consequent differences in nomenclature have been considered in the text on the Moorefield shale, where a tabular presentation of the changes made and references to publications showing these changes are given.

Distribution and thickness.—The Fayetteville has been observed as far north as Fairland, Oklahoma, in Sec. 15, T. 26 N., R. 29 E. Its southernmost exposure is 4 miles northeast of Gore, Oklahoma, in Sec. 20, T. 13 N., R. 21 E. Its easternmost exposure known to the writer is in Sec. 35, T. 12 N., R. 5 W., which is a few miles southeast of Batesville, Arkansas. Its exposures extend westward to Sec. 2, T. 17 N., R. 19 E., on the east bank of the Neosho River, in Oklahoma. Thus the formation crops out over an area measuring broadly about 80 miles from north to south and 225 miles from east to west. Its outcrop from north to south, however, is at most places confined to a belt that coincides roughly with the lower slopes of the northern face of the Boston Mountains.

In the area above defined the Fayetteville is at no place missing, and the shale of the formation is generally uniform in character. Its beds, however, are somewhat more calcareous both in the extreme eastern and in the extreme western outcrops.

The Fayetteville shale is highly variable in thickness. In Arkansas alone the measured extremes are 10 and 400 feet. At a number of places extremes of thickness occur close together. One of the most notable of these occurrences is 4 miles south of Carrollton, on the structure known as the Carrollton dome, where the formations below the Fayetteville are abruptly domed. At the top of the dome the Fayetteville shale is only 40 feet thick; yet a mile and a half to the east it is 400 feet thick. In spite of these notable variations, the formation becomes generally thicker toward the south, for its thickest exposed sections are all near the Boston Mountain escarpment. It evidently becomes thinner to the north, northwest, and west, for in the remnants of it near the Missouri boundary and in northeastern Oklahoma it is not more than 10 feet thick. It does not decrease in



A. SEPTARIAN ZONE IN THE LOWER BLACK SHALE OF THE FAYETTEVILLE FORMATION AS EXPOSED IN A RAVINE ONE MILE NORTH OF WYMAN

The heavy blocks of sandstone at the left are boulders of Wedington sandstone, which have been carried down from above.



B. CONTACT OF THE WEDINGTON SANDSTONE WITH THE UPPER FAYETTEVILLE SHALE NEAR GOSHEN

The flaggy upper Wedington beds are slightly calcareous and contain marine fossils.

thickness toward the east, however, for at the eastern boundary of the Paleozoic area it is 275 feet thick. It is therefore, on the average, at least as thick in the Batesville quadrangle as it is in the Eureka Springs quadrangle, 100 miles farther west.

The Fayetteville is the surface rock over moderately large areas, but it is most commonly exposed on rather steep slopes. Most of the areas of its exposure are forested, for after land where it is the surface rock has been cleared the soil formed by its disintegration has been found to be not very fertile. The shale itself is generally concealed by surface material or soil, and its exposures are limited to steep hillsides and the valleys of actively eroding streams.

Character.—The Fayetteville formation consists chiefly of black shale, but it includes, near its top, a member known as the Wedington sandstone. This member has been mapped throughout a relatively large area in the central and western parts of the outcrop of the Fayetteville. Below the Wedington sandstone lies the thickest and most characteristic division of the formation, known as the lower black shale. A bed of shale that is found at many places above the Wedington sandstone is thinner and of lighter color than this lower bed.

The lower shale is a thick black, fissile, carbonaceous bed, which weathers to sticky red and yellow clays. Near its base it contains numerous concretions of clay ironstone, or siderite, most of which are cut by veins of calcite and show the structure of septaria. (See Pl. XVI, A.) These concretions are in places so numerous that they make up almost continuous septarian layers. Although they are not confined to the base of the lower shale they are so much more numerous there than at any other horizon that they may be used as stratigraphic markers. A thin bed of limestone at the base of the formation is particularly rich in fossils. This bed, which is rather widespread in the Fayetteville area, is thin or absent farther east, although it is found as far east as Batavia. The limestone becomes more and more prominent toward the west, and in Mayes County, Oklahoma, it attains a thickness of 50 to 100 feet. Snider³¹ has called its beds in that region the Mayes formation.

In the southwest corner of the Eureka Springs quadrangle the shale above the Wedington member reaches a thickness of 70 feet. From this area it decreases in thickness toward the east and north, and possibly toward the west. In the Harrison quadrangle its average thickness is about 15 feet, but at some places it is absent. In the Tahlequah (Oklahoma) quadrangle, the upper shale is generally about 25 feet thick. Farther west, however, the Wedington sandstone

³¹ Snider, L. C., *Geology of northeastern Oklahoma*: Okla. Geol. Survey Bull. 24, p. 27, 1915.

is absent and the thickness of the upper shale, if it is present, cannot be ascertained.

Thin layers of fossiliferous limestone are in places interbedded with the upper shale. The lower shale is also calcareous at certain places, particularly in the eastern part of the area of its exposure. This limy phase is well developed near Mountain View, as is shown in Plate XVII, A.) The formation is perhaps even more calcareous in Oklahoma, in the Pryor and Vinita quadrangles, where the limestone is a dense, fine-grained, dark-colored rock, which weathers light and breaks into small subcubical fragments.

Wedington sandstone member.—The Wedington member is a dense, hard, grey to brown sandstone, commonly fine-grained and at many places calcareous. It is ordinarily thin to medium bedded, and its upper layers are generally flaggy, but at some places, notably near West Fork and in the Wedington Mountains, it is relatively massive. Much of it was laid down in shallow water, for at many places it bears ripple marks of short wave length and oscillation ripples. The cross-bedding, which is characteristic, indicates that the sediments came from the south, southwest, or possibly from the southeast, but at no place do the beds suggest a northern source of their material.

The sandstone ordinarily forms a narrow bench above a low, steep escarpment, and, where it has been undermined by the erosion of the shale, great blocks of it accumulate in the stream valleys. Where the rock is not calcareous it is very hard, and the blocks commonly have sharp edges. In some areas the sandstone is coextensive with the upper shale, but at a few places it is of larger areal extent and is directly overlain by the Pitkin limestone. At such places it forms the base of the escarpment made by that formation.

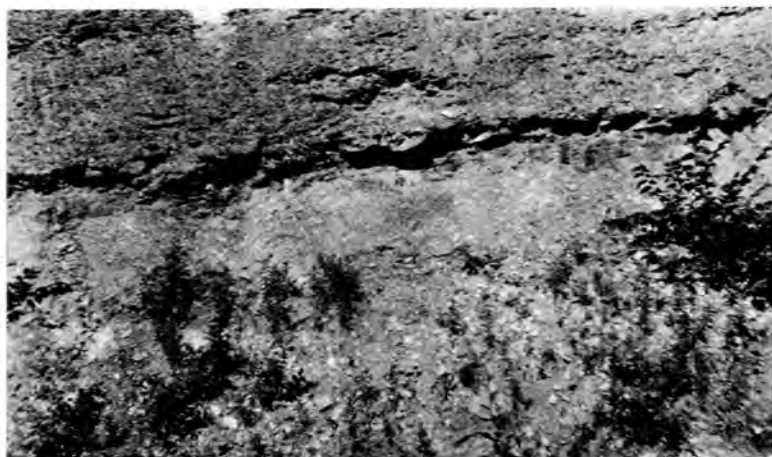
In the Wedington Mountains, northwest of Prairie Grove, the sandstone is over 150 feet thick, but its thickness decreases rapidly to the east, north, and west. It is only 4 feet thick at St. Joe, and is very thin or absent east of that place. It has not been found west of the Tahlequah (Oklahoma) quadrangle, and has been identified only doubtfully as far north as Garfield, Arkansas. Near the outer margins of its exposure the sandstone is somewhat calcareous.

Fossils and correlation.—The basal limestone of the Fayetteville formation carries an abundant and diverse fauna. The Wedington sandstone is likewise very fossiliferous at many places, particularly near Fayetteville and St. Joe. Ordinarily, however, the sandstone member, where it is typically developed, is nearly barren of fossils. Wherever the shale is calcareous fossils are numerous, and the concretions already described may also be fossiliferous. The black shale itself, however, is scantily fossiliferous, and was once considered bar-



A. THE FAYETTEVILLE FORMATION AS EXPOSED IN A ROAD-CUT SOUTH OF MOUNTAIN VIEW

Shows the type of bedding and the calcareous nature of the shale in the eastern part of its area of exposure.



B. DISCONFORMITY BETWEEN THE UPPER FAYETTEVILLE SHALE AND THE HALE FORMATION OF THE MORROW GROUP AT FAYETTEVILLE

ren; but diligent search in it will usually reveal crushed and fragmentary shells of pelecypods. At several places a rather well preserved fauna has been found at the horizon of the black shale.

The paleontologic studies of the Fayetteville formation made by the writer³² have shown that its fauna consists of at least 250 species, many of which are new to science. The formation is undoubtedly of Chester age, but its faunal assemblage is different from that of the typical Chester formations. Therefore, although these Arkansan beds may be correlated with parts of the Chester series of Illinois, they are paleontologically more closely related to such southern formations as the Caney shale of Oklahoma and the upper Gasper, Golconda, and Bangor formations of Alabama. The detailed results of the study of the fauna of the Fayetteville formation will be published later, but faunas shown by the abridged lists given here are typical of the parts of the formation specified.

The lower limestone has yielded the following species:

<i>Palaeacis cuneata</i>	<i>Rhynchopora miseri</i> n. sp.
<i>Palaeacis carinata</i>	<i>Moorefieldella eurekensis</i>
<i>Michelinia meekana</i>	<i>Dielasma whitfieldi</i>
<i>Zaphrentis spinulosa</i> (?)	<i>Dielasma branneri</i> n. sp.
<i>Pentremites patei</i>	<i>Dielasma arkansanum</i>
<i>Pentremites pulchellus</i>	<i>Dielasma subspatulatum</i>
<i>Agassizocrinus dactyliiformis</i>	<i>Girtyella brevilibata</i>
<i>Cystodictya nitida</i>	<i>Spiriferina spinosa</i>
<i>Streblotrypa nicklesi</i>	<i>Spiriferina transversa</i>
<i>Fenestella serratula</i>	<i>Delthyris ozarkana</i> n. sp.
<i>Archimedes confertus</i> (?)	<i>Spirifer leidyi</i>
<i>Archimedes distans</i>	<i>Spirifer humulis</i> n. sp.
<i>Archimedes communis</i>	<i>Spirifer arkansanus</i>
<i>Batostomella parvula</i>	<i>Spirifer rheana</i> n. sp.
<i>Lingula batesvillae</i>	<i>Brachythyris ozarkensis</i>
<i>Orthotetes subglobosus</i>	<i>Reticularia setigera</i>
<i>Orthotetes protensus</i>	<i>Eumetria marcyi</i>
<i>Orthotetes kaskaskiensis</i>	<i>Eumetria welleri</i> n. sp.
<i>Chonetes sericeus</i>	<i>Cliothyridinia elegans</i>
<i>Chonetes oklahomensis</i>	<i>Composita acinus</i>
<i>Productella hirsutiformis</i>	<i>Composita hootsi</i> n. sp.
<i>Productus ovatus</i>	<i>Sphenotus washingtonensis</i>
<i>Productus inflatus</i>	<i>Edmondia equalateralis</i>
<i>Productus adairensis</i>	<i>Leda vaseyana</i>
<i>Productus arkansanus</i>	<i>Sulcatipinna arkansana</i>
<i>Diaphragmus elegans</i>	<i>Caneyella nasuta</i>
<i>Camarophoria cestriensis</i>	<i>Myalina elongata</i>
<i>Camarotoechia purduei</i>	<i>Aviculopecten inspeciosus</i>
<i>Camarotoechia moorei</i> n. sp.	<i>Allerisma arkansana</i>
<i>Camarotoechia transversa</i> n. sp.	<i>Pleurotomaria snideri</i> n. sp.
<i>Liorhynchus carboniferum</i>	<i>Bembexia nodomarginata</i>

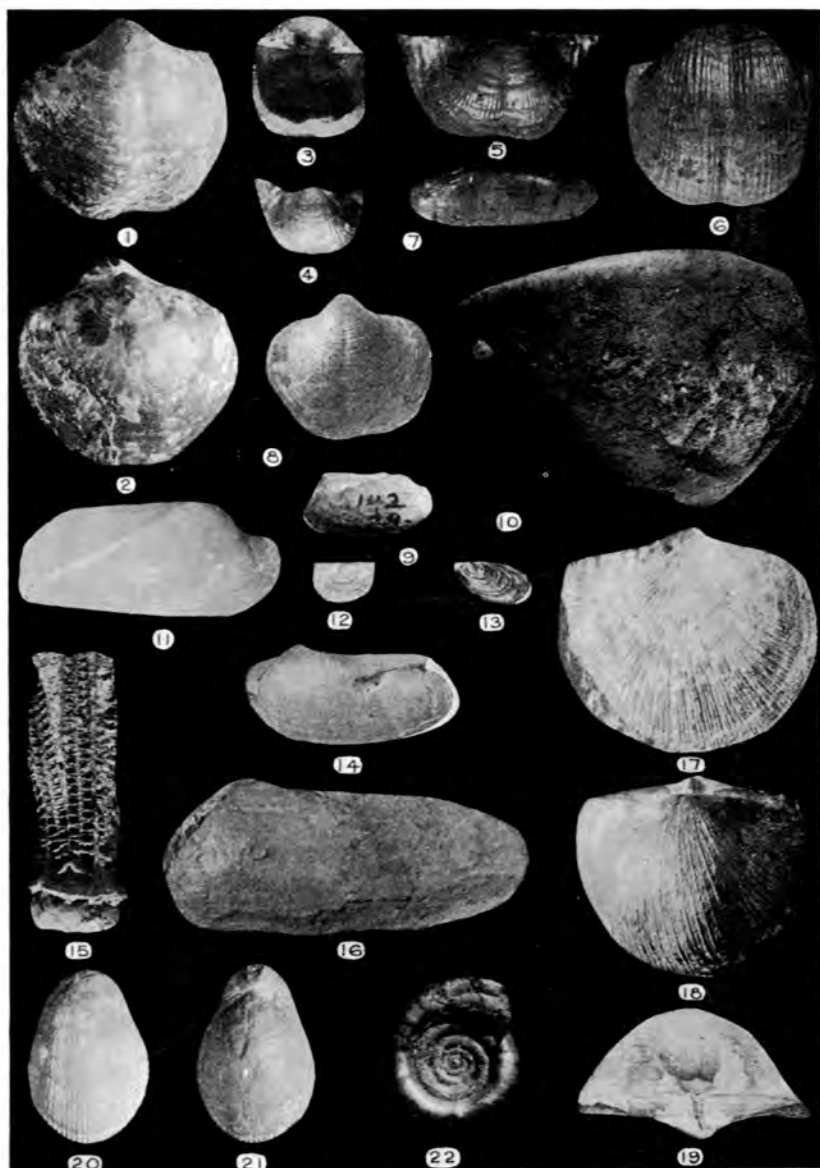
³² Croneis, Carey, The Fayetteville formation, its fauna and stratigraphy: Doctor's thesis, unpublished, Harvard College library, 1927.

PLATE XVIII

CHARACTERISTIC FOSSILS OF THE FAYETTEVILLE FORMATION

(The species that are illustrated here for the first time will be described in another publication.)

- FIGURES 1-2. *Martinia glabra* ? Pedicle and brachial views of the typical Fayetteville form referred to this species.
- 3-4. *Productus adairensis*. Brachial and posterior views of a nearly perfect specimen. This is one of the most characteristic species of the lower Fayetteville formation.
- 5-6. *Productus inflatus*. Posterior and pedicle views of a complete specimen.
7. *Solenopsis nitida* ? Left valve preserved as an internal cast.
8. *Reticularia setigera*. Pedicle view of a somewhat distorted specimen.
9. *Cypricardinia fayettevillensis* ? Lateral view of a complete bivalved specimen.
10. *Myalina fissuratu* n. sp. Lateral view of a complete bivalved specimen. Common in the Wedington sandstone.
11. *Sphenons acutiliratus* n. sp. Right valve preserved as an internal cast. Common in Wedington sandstone.
12. *Chonetes sericeus*. Pedicle view of a typical specimen.
13. *Caneyella nasuta*. Left valve of an imperfect specimen. This species is common at certain localities in the lower black shale of the Fayetteville formation.
14. *Sphenotus aff. meslerianus*. Left valve of an incomplete specimen. Common in the Wedington sandstone.
15. *Delocrinus milleri* n. sp. Lateral view of a specimen preserved in sandstone.
16. *Sphenotus hendricksi* n. sp. Lateral view of a somewhat distorted bivalved specimen preserved as an internal cast.
- 17-19. *Orthotetes subglobosus*. Pedicle, brachial, and posterior views of a nearly perfect specimen.
- 20-21. *Eumetria welleri* n. sp. Pedicle and brachial views of the holotype.
22. *Gastrioceras richardsonianum*. Side view of a mature specimen, $\times 4$. Abundant locally in the lower black shale of the Fayetteville formation.



CHARACTERISTIC FOSSILS OF THE FAYETTEVILLE FORMATION

Bellerophon sublevis
Euphemus randolphensis
Sphaerodoma subcorpulenta
Bulimorpha bulimiformis
Paleocapulus lodiensis
Endolobus ornatus
Paraparchites nicklesi
Primitia fayettevillensis
Griffithides mucronatus
Cladodus corrugatus
Caneyella vaughani
Caneyella nasuta
Caneyella wapannuckensis

Caneyella girtyi n. sp.
Phanerotrema grayvillense (?)
Euomphalus similis
Rayonnoceras solidiforme
Rayonnoceras fayettevillensis
Rayonnoceras cadyi
Goniaticites choctawensis
Goniaticites crenistria
Goniaticites subcircularis
Goniaticites newsomi
Gastrioceras caneyanum
Gastrioceras richardsonianum
Adelphoceras meslerianum

The Wedington sandstone has yielded the following typical species:

Pentremites wedingtonensis n. sp.
Hydreionocrinus cadyi n. sp.
Delocrinus milleri n. sp.
Fenestella serratula
Archimedes proutanus
Archimedes compactus
Archimedes swallowanus
Archimedes terebriformis
Archimedes meekanus
Batostomella parvula
Lingulidiscina raymondi n. sp.
Orthotetes subglobosus
Orthotetes kaskaskiensis
Productus ovatus
Productus arkansanus
Diaphragmus elegans
Camarotoecchia purduei
Dielasma arkansanum
Dielasma platynotum n. sp.
Schizodus circulus
Dielasma platynotum n. sp.
Bellerophon sublevis
Bellerophon chesterensis
Euphemus randolphensis
Euomphalus wedingtonensis n. sp.
Sphaerodoma subcorpulenta
Platyceras subrotundum
Platyceras brevicurvatum n. sp.

Spiriferina spinosa
Spirifer increbescens
Reticularia setigera
Eumetria marcyi
Composita trinuclea
Sphenotus vulgaris
Sphenotus acutiliratus
Nucula rectangula
Sulcatipinna arkansana
Leptodesma robustum
Leptodesma carboniferum
Myalina angulata
Myalina elongata
Myalina curvata n. sp.
Myalina magna n. sp.
Schizodus depressus
Aviculopecten morrowensis
Aviculopecten inspeciosus
Dellopecten batesvillensis
Allerisma arkansana
Euconospira disjuncta
Orthoceras henbesti n. sp.
Cycloceras (?) *ovatum* n. sp.
Cycloceras parksi n. sp.
Endolobus ornatus (?)
Gastrioceras nolinense
Griffithides mucronatus
Griffithides pustulosus

Collections from the upper Fayetteville shale contain the following characteristic species:

Pentremites platybasis (?)
Fenestella compressa
Fenestella serratula
Fenestella cestriensis
Archimedes proutanus
Archimedes owenanus

Eumetria marcyi
Cliothyridinia sublamellosa
Composita trinuclea
Composita corbetti n. sp.
Sphenotus vulgaris
Nucula rectangula

Archimedes swallowanus	Leda vaseyana
Lingulidiscina raymondi n. sp.	Yoldia fayettevillensis n. sp.
Lingulidiscina altirostris n. sp.	Myalina angulata
Chonetes oklahomensis	Myalina elongata
Chonetes subquadratus n. sp.	Schizodus depressus
Productus ovatus	Schizodus batesvillensis
Productus arkansanus	Schizodus abruptus
Productus dunbari n. sp.	Aviculopecten morrowensis
Pugnoides alatus n. sp.	Allerisma arkansana
Dielasma subspatulatum	Bellerophon sublevis
Dielasma arkansanum	Bucanopsis cancellata
Spiriferina spinosa	Cyclloceras alternatus n. sp.
Delthyris ozarkana n. sp.	Brevioceras arkansanum n. sp.
Spirifer increbescens	Gastrioceras nolinense
Spirifer matheri n. sp.	Griffithides mucronatus
Reticularia setigera	Deltodus wortheni

Stratigraphic relations.—The Fayetteville shale is at most places overlain by the Pitkin limestone, which rests upon different beds of the Fayetteville in different parts of its area of exposure in such a way as to suggest a stratigraphic break between the two formations. The contact between the two in the northern part of the State is probably disconformable, but farther south sedimentation may have been uninterrupted at the end of Fayetteville time. In some areas the Pitkin was entirely removed by pre-Pennsylvanian erosion, and in such areas the Fayetteville is overlain disconformably by some division of the Morrow group. (See Pl. XVII, B.) In northern Oklahoma the Morrow is also missing and there the Fayetteville is succeeded above by still younger Pennsylvanian beds, which should probably be correlated with the Atoka (Winslow).

The Fayetteville rests conformably upon the Batesville sandstone at most places except in the western part of its area of outcrop, where it disconformably overlies the Boone formation. At a few places where the sandstone of the Batesville is not present the shale rests directly upon the Hindsville member of the Batesville.

Petrolific significance.—The Fayetteville black shale is an ideal source of oil and gas. It is widespread, thick, and fairly uniform in character. The writer has identified the base of the shale at a depth of 4,826 feet in a well near Mulberry, and the Fayetteville no doubt underlies the entire Boston Mountain area. At almost all its exposures the fresh shale gives off a strong odor of petroleum, and some of the septarian concretions yield liquid hydrocarbons when broken, particularly the concretions found near Kingston and Jasper.

The Wedington sandstone must be regarded as a potential reservoir of gas or oil, not only because it has the physical properties of a reservoir rock, but because it lies adjacent to a bed that is a possible source of those products. Oil has no doubt migrated into the We-

dington sandstone, for oil seeps occur in it and showings of both oil and gas have been found in it in several wells. The Gruber test well, drilled near Winslow, encountered the Wedington at a depth of 820 feet and obtained a good showing of oil and considerable gas at a depth of 885 feet, the base of the sandstone. The Wedington was reached at less than 200 feet in the War Eagle Oil and Gas Company's well near Witter, which, it is said, obtained from it a good showing of oil and gas and some salt water.

Although the Wedington may be encountered in wells drilled in the area east of Newton County it is likely to be thin or absent in that part of the Boston Mountains.

PITKIN LIMESTONE

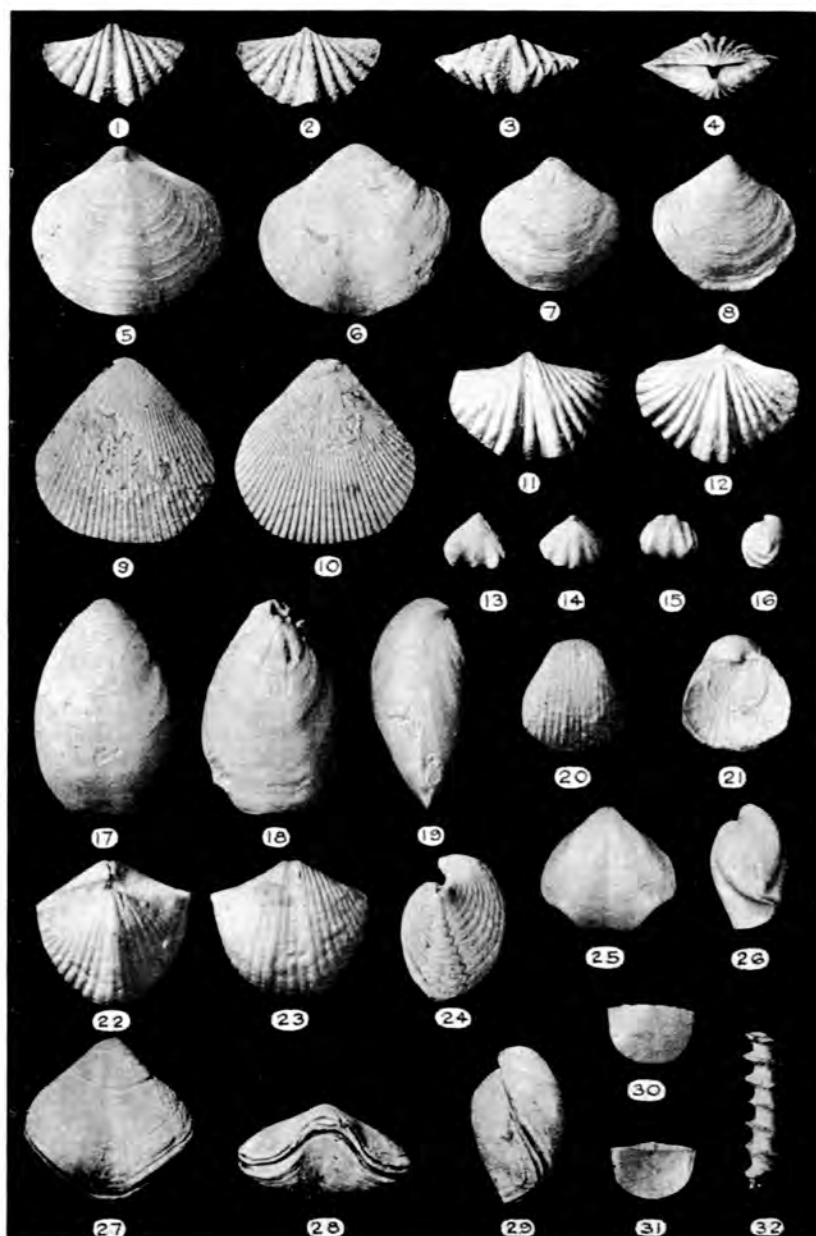
Definition.—The Pitkin limestone is the upper formation of the Mississippian system in northern Arkansas. In the reports of the old Arkansas Geological Survey this formation was called the "Archimedes" limestone, because the screwlike central supports of the bryozoan *Archimedes* are scattered thickly over its weathered surface. The present name was taken from the post office of Pitkin, Washington County, where the formation is well exposed.

Distribution and thickness.—The Pitkin formation crops out from the Batesville (Arkansas) district on the east to the Muskogee (Oklahoma) district on the west, but it is not found at all places in the intervening area. In the Muskogee district the formation averages about 50 feet in thickness; in the Tahlequah district it ranges from a thin shaly layer to massive beds 70 feet thick. In the Fayetteville district its thickness ranges from 2 to 40 feet, and in some places in that district it is absent. Its stratigraphic position, however, may be marked by a conglomeratic layer at the base of the Hale sandstone, which contains transported Pitkin fossils. At the south end of Boat Mountain, south of Bellefonte, the Pitkin is 100 feet thick, but over much of the Eureka Springs and Harrison quadrangles it is less than half that thick, and it is not found at some places in those quadrangles, particularly toward the north. Farther east its thickness is generally between 10 and 40 feet, but in Pilot Mountain, northeast of St. Joe, it is 90 feet thick. The formation is thus likely to be found at practically all points in the Boston Mountain escarpment; and its presence beneath the higher beds in those mountains is indicated not only by the records of wells drilled south of the crest of the Boston Mountains but by small outcrops of it, particularly in Franklin, Johnson, and Newton counties.

Character.—In its typical phase the Pitkin formation consists of massive layers of compact, bluish-gray limestone, which is at many places ferruginous and porous. Where the rock is rather sandy in-

PLATE XIX
CHARACTERISTIC FOSSILS OF THE PITKIN LIMESTONE

- FIGURES 1-4. *Spiriferina spinosa*. Pedicle, brachial, anterior, and posterior views of a typical specimen. This species is found also in the Fayetteville formation and is occasionally found in the Batesville sandstone.
- 5-6. *Reticularia setigera*. Brachial and pedicle views of a typical specimen. This species is found also in the Fayetteville formation; it is rare in the Batesville and Moorefield formations.
- 7-8. *Cliothyridina sublamellosa*. Brachial and pedicle views of a perfect specimen. This species is found also in the Batesville and Fayetteville formations.
- 9-10. *Eumetria vera*. Pedicle and brachial views of a large specimen. This species is found, but less abundantly, in the other Chester formations of Arkansas.
- 11-12. *Spirifer leidyi*. Pedicle and brachial views of an average-sized specimen. This species is found also in the Fayetteville formation.
- 13-16. *Camarophoria explanata*. Pedicle, brachial, anterior, and lateral views of an average specimen. This species is common in both the Pitkin and Fayetteville formations.
- 17-19. *Dielasma arkansanum*. Pedicle, brachial, and lateral views of a large specimen. This species is common in the Pitkin and Fayetteville formations. It is rare in the Morrow group.
- 20-21. *Diaphragmus elegans*. Pedicle and brachial views of a small specimen. This species is common in all the Chester formations of northern Arkansas.
- 22-24. *Spirifer pellaensis*. Brachial, pedicle, and lateral views of a small specimen. Found also in the Fayetteville formation.
- 25-26. *Composita trinuclea*. Pedicle and lateral views of an average sized specimen. Common in the Chester formations of northern Arkansas.
- 27-29. *Composita subquadrata*. Pedicle, anterior, and lateral views of an average specimen. Common in the Chester formations of northern Arkansas.
- 30-31. *Chonetes chesterensis*. Pedicle and brachial views of an average specimen.
32. *Archimedes swallovanus*. The central support of this common Pitkin bryozoan.



CHARACTERISTIC FOSSILS OF THE PITKIN LIMESTONE

distinct cross-bedding is apparent on its weathered surfaces. The Pitkin does not weather to rounded surfaces like those presented by pure limestone but breaks down into angular blocks and thin plates having sharp edges. Owing to the weathering of the non-resistant subjacent Fayetteville shale, the Pitkin stands out at many places as a steep cliff, whose height is ordinarily the thickness of the formation.

At its northernmost exposures the Pitkin is thin and is commonly represented by dark-red or brownish conglomeratic layers, which belong, in part at least, to the overlying Hale formation. In the eastern part of its exposure the formation is ordinarily rather sandy, but in the western part, particularly in Oklahoma, it is more shaly and in general more variable.

Fossils and correlation.—Fossils are common in the Pitkin limestone, but the fauna has not yet been studied in detail. Bryozoans, particularly those belonging to the genus *Archimedes*, are very common, as are also corals, crinoids, and brachiopods. Both the fauna and the stratigraphic position of the Pitkin indicate that it is of late Chester age.

Some of the characteristic elements of the fauna, as determined by Girty from collections made in the Eureka Springs and Harrison quadrangles, are as follows:

<i>Archimedes invaginat</i> (?)	<i>Camarophoria explanata</i>
<i>Archimedes swallowianus</i>	<i>Dielasma formosum</i> ?
<i>Glyptopora michelinia</i>	<i>Spirifer pellaensis</i> (?)
<i>Chonetes sericeus</i>	<i>Reticularia setigera</i>
<i>Productus ovatus</i>	<i>Composita subquadrata</i>
<i>Productus arkansanus</i>	<i>Eumetria marcyi</i>
<i>Diaphragmus elegans</i>	<i>Aviculopecten multilineatus</i>
<i>Tetracamera</i> n. sp.	<i>Griffithides mucronatus</i>

A somewhat larger fauna is listed by Snider³³ for the Pitkin formation of northeastern Oklahoma, as follows:

<i>Zaphrentis spinulosa</i>	<i>Edmondia crassa</i> var. <i>suborbiculata</i>
<i>Pentremites</i> sp.	<i>Edmondia pitkinense</i>
<i>Archimedes</i> several sp.	<i>Nucula illinoiensis</i>
<i>Lingulidiscina newberryi</i> var. <i>moore-</i>	<i>Leda vaseyana</i>
<i>fieldana</i> (?)	<i>Conocardium peculiare</i>
<i>Lingulidiscina newberryi</i> var. <i>ovata</i>	<i>Leioptera</i> (?) sp.
<i>Orthotetes kaskaskiensis</i>	<i>Myalina compressa</i>
<i>Chonetes oklahomensis</i>	<i>Myalina longicardinales</i>
<i>Chonetes sericeus</i> (?)	<i>Schizodus depressus</i>
<i>Productus ovatus</i>	<i>Schizodus chesterensis</i>
<i>Productus arkansanus</i>	<i>Schizodus insignis</i>
<i>Pustula alternata</i>	<i>Schizodus</i> sp.
<i>Diaphragmus elegans</i>	<i>Dellopecten batesvillensis</i>

³³ Snider, L. C., *Geology of northeastern Oklahoma*; Oklahoma Geol. Survey Bull. 24, pp. 41-43, 1915.

<i>Camarophoria cestriensis</i>	<i>Aviculopecten eurekensis</i>
<i>Dielasma shumardana</i>	<i>Aviculopecten keoughensis</i>
<i>Spirifer pellaensis</i>	<i>Aviculopecten pitkinensis</i>
<i>Spirifer leidy</i>	<i>Allerisma walkeri</i>
<i>Reticularia setigera</i>	<i>Allerisma arkansana</i>
<i>Spiriferina spinosa</i>	<i>Bellerophon</i> sp.
<i>Hustedia multicostata</i>	<i>Bellerophon pitkinensis</i>
<i>Eumetria vera</i>	<i>Straparollus planidorsatus</i>
<i>Eumetria costata</i>	<i>Holopea newtonensis</i>
<i>Eumetria pitkinensis</i>	<i>Platyceras subrotundum</i>
<i>Athyris cestriensis</i>	<i>Sphaerodoma subcorpulenta</i>
<i>Composita trinuclea</i>	<i>Strophostylus</i> sp.
<i>Composita</i> sp.	<i>Orthoceras eurekensis</i>
<i>Solenomya</i> (?) sp.	<i>Cycloceras randolphensis</i>
<i>Sphenotus cherokeeense</i>	<i>Cycloceras sequoyahensis</i>
<i>Sphenotus quadriplicatum</i>	<i>Leuroceras</i> (?) sp.
<i>Sphenotus gibsonense</i>	<i>Griffithides pustulosus</i>
<i>Edmondia crassa</i>	<i>Griffithides</i> sp.

Stratigraphic relations.—As has already been stated, the Pitkin probably rests upon the Fayetteville shale, conformably at some places and disconformably at others. Disconformity is suggested by the fact that the Pitkin rests at different places upon the upper shale of the Fayetteville formation, upon the Wedington sandstone, and upon the lower black shale of the Fayetteville. The Pitkin is overlain disconformably by the Hale formation, as shown by the basal conglomerate of the Hale and the irregular upper surface of the Pitkin. In the southern part of the area of the Pitkin outcrop, however, the contact between the two formations is apparently conformable.

Petrolific significance.—The Pitkin may be a potential source of oil and gas, but it is not a reservoir for them. It is of some use as a horizon marker, for it is easily identified, and it will be reached by moderately shallow wells drilled in the Boston Mountains. On the northern border of the Arkansas Valley the Pitkin should be reached at a depth of about 2,750 feet, but it is nearly 2,000 feet lower at Mulberry, and wells drilled much farther south will probably not reach it.

Solid hydrocarbons have been found in the Pitkin limestone, especially in the shells of fossil brachiopods, and concretionary masses in the formation contain oil of fairly high gravity, especially near Fayetteville. These facts, however, do not show that oil in commercial quantities may be obtained from the formation. On the other hand, they do suggest that hydrocarbons have been generated from the organic matter in the Pitkin, and that, under suitable structural conditions, they may have migrated to reservoirs, such as the overlying Hale sandstone.

PENNSYLVANIAN SERIES

MORROW GROUP

The beds of sandstone, shale, and limestone that form the Morrow group are of little topographic importance, but the area of their outcrop in northern Arkansas and northeastern Oklahoma is fairly large. They are variable in lithology, thickness, and arrangement, and ordinarily they form the middle part of the Boston Mountain escarpment. They are overlain by the "Millstone grit," a heavy sandstone of the Atoka (Winslow) formation, and rest upon either the Pitkin limestone or the Fayetteville shale. In the type area of the Morrow, which is near Morrow, Washington County, Arkansas, the group is divisible into two formations, the Hale below and the Bloyd above. In Oklahoma the beds forming the group are more calcareous than in Arkansas, and have been called the Morrow formation.

HALE FORMATION

Definition.—The Hale formation was named by Taff from Hale Mountain, in the western part of the Winslow quadrangle, where it is exposed in typical form. In the reports of the old Arkansas Geological Survey the beds of the Hale are called the Washington sandstone and shale. The formation consists mainly of sandstone and shale but includes some beds of limestone and conglomerate, all of which are extremely variable in lithology, distribution, and thickness.

Distribution and thickness.—The Hale sandstone crops out almost as far west as Manard postoffice, in the eastern part of the Muskogee (Oklahoma) quadrangle, where it is only a few feet thick. Near Jamestown, at the easternmost exposure of the Morrow group, the beds are at least 200 feet thick, but it is not known whether all the beds exposed at that place belong to the Hale or whether some of them belong to the overlying Bloyd formation. Most of these beds in the Batesville district, however, belong to the Hale formation. In the intervening area the Hale ranges in thickness from a few feet to more than 275 feet, a thickness it attains in Diera Mountain, in the Eureka Springs quadrangle. The sandstone ranges in thickness from 110 feet at the northeast corner of the Tahlequah (Oklahoma) quadrangle to a feather edge at the eastern border of the Muskogee quadrangle. In western Arkansas its average thickness is probably more than 150 feet, but at some places, as near Compton, in the Harrison quadrangle, it is only half that thick.

Character.—In places where the Hale rests on the eroded edges of the Pitkin limestone, or where the Pitkin has been removed, there is at the base of the Hale a conglomeratic layer made up of well rounded, small limestone pebbles cemented in a ferruginous limestone matrix.

These pebbles were obviously derived from the Pitkin formation, and the matrix of the conglomerate contains also waterworn Pitkin fossils. At the base of the formation, but above the conglomerate, there is ordinarily a black clay shale containing thin beds of ripple-marked sandstone. Above this part of the formation the beds are made up of sandstone, shale, and limestone. The shale is generally intercalated between two beds of sandstone. The upper bed is more massive and more calcareous than the lower and is generally thicker. This upper sandstone constitutes most of the Hale formation in Oklahoma, where it is at some places calcareous enough to be called a siliceous limestone. To the east the calcareous beds of the formation are not so extensive.

The shale between the two sandy beds ranges in thickness from 20 to 200 feet and is generally a conspicuous part of the formation. This division of the Hale, though predominantly shaly, includes considerable sandstone, which is either hard, gray, and ripple-marked, or soft, brown, calcareous, and cross-bedded.

The divisions of the Hale formation indicated are not at all constant, for at many places, even in the Winslow, Fayetteville, Eureka Springs, and Harrison quadrangles, where their relations are best understood, the divisions of the formation cannot be identified. Elsewhere the divisions are different lithologically as well as in their relations.

Fossils and correlation.—The fauna of the Morrow group has attracted considerable attention because it contains both Mississippian and Pennsylvanian elements. This fact is well illustrated by faunal lists prepared by Mather,³⁴ who has made a detailed paleontologic study of the Morrow group. The following species include the most typical of the Mississippian residual faunal element:

Residual Mississippian element of the Morrow fauna

<i>Amplexus corrugatus</i>	<i>Glyptopora crassistoma</i>
<i>Pentremites angustus</i>	<i>Dielasma arkansanum</i>
<i>Pentremites rusticus</i>	<i>Brachythyris laticosta</i>
<i>Cromyocrinus grandis</i>	<i>Spiriferina transversa</i>
<i>Stenopora tuberculata</i>	<i>Eumetria vera</i>
<i>Anisotrypa</i> sp.	<i>Sphenotus halensis</i>
<i>Fenestella serratula</i>	<i>Aviculopecten talboti</i> (?)
<i>Archimedes juvenis</i>	<i>Lepetopsis chesterensis</i> (?)
<i>Rhombopora attenuata</i>	<i>Bellerophon</i> cf. <i>sublevis</i>
<i>Rhombopora tabulata</i>	<i>Straparollus</i> cf. <i>spergenensis</i>

In contrast to the above residual species are the following proemial Pennsylvanian forms:

³⁴ Mather, K. F., Fauna of the Morrow group: Denison Univ. Sci. Lab. Bull., vol. 18, p. 78, 1915.

Proemial Pennsylvanian element of the Morrow fauna

<i>Zaphrentis gibsoni</i>	<i>Platyceras parvum</i>
<i>Lophophyllum profundum</i>	<i>Squamularia perplexa</i>
<i>Campophyllum torquium</i>	<i>Squamularia transversa</i>
<i>Michelinea eugeneae</i>	<i>Spiriferina campestris</i>
<i>Michelinea eugeneae</i>	<i>Hustedia brentwoodensis</i>
<i>Chaetetes milleporaceus</i>	<i>Hustedia miseri</i>
<i>Eupachyrinus cf. magister</i>	<i>Edmondia subtruncata</i>
<i>Delocrinus dubius</i>	<i>Nucula parva</i>
<i>Delocrinus pentanodus</i>	<i>Leda bellistriata</i> (?)
<i>Delocrinus sp.</i>	<i>Parallelodon sangamonensis</i>
<i>Polypora elliptica</i>	<i>Myalina cuneiformis</i> (?)
<i>Acanthocladia sp.</i>	<i>Myalina recurvirostris</i>
<i>Rhombopora lepidodendroides</i>	<i>Aviculopecten hertzeri</i>
<i>Orticuloidea missouriensis</i> (?)	<i>Aviculopecten</i> (?) <i>cf. interlineatus</i>
<i>Rhipidomella pecosi</i>	<i>Deltopecten occidentalis</i>
<i>Schizophoria resupinoides</i>	<i>Monopteria</i> (?) <i>sp.</i>
<i>Orthotetes robusta</i>	<i>Pseudomonotis precursor</i>
<i>Meekella striatocostata</i>	<i>Pseudomonotis inflata</i>
<i>Chonetes laevis</i>	<i>Pleurophorus tropidophorus</i>
<i>Productus nanus</i>	<i>Bellerophon crassus</i> <i>var. wewokanus</i>
<i>Pustula nebraskensis</i>	<i>Euphemus carbonarius</i>
<i>Pustula pertenuis</i> (?)	<i>Worthenia tabulata</i>
<i>Pustula punctata</i>	<i>Euomphalus catilloides</i>
<i>Spirifer opimus</i>	<i>Strophostylus subovatus</i> (?)
<i>Spirifer rockymontanus</i>	<i>Meekospira</i> (?) <i>sp.</i>

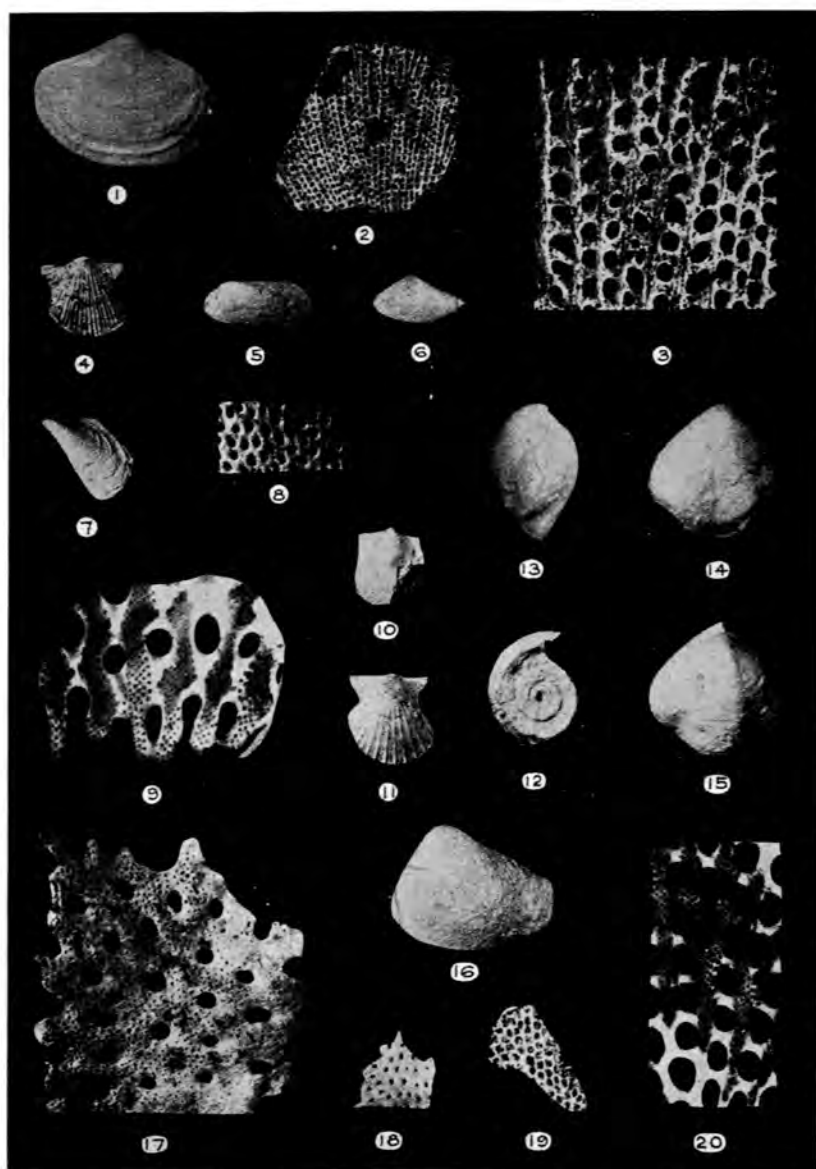
A study of the faunal lists given by Mather shows that 22 of the 49 Pennsylvanian index fossils listed above appear in the Hale formation. Six of the 20 species that form the residual Mississippian element of the Morrow fauna, however, are found in the Hale. Nine per cent of the 69 species recorded from the Hale are forms that are usually regarded as indicating Mississippian time, and 32 per cent are diagnostic Pennsylvanian types. The remaining forms, or nearly 60 per cent of those known from the Hale, are not of established value as definite horizon markers.

The faunal list for the Hale formation follows:

<i>Penetremites angustus</i>	<i>Squamularia perplexa</i>
<i>Fistulipora sp.</i>	<i>Squamularia transversa</i>
<i>Fenestella morrowensis</i>	<i>Spiriferina campestris</i>
<i>Fenestella venusta</i>	<i>Spiriferina transversa</i>
<i>Polypora anastomosa</i>	<i>Hustedia brentwoodensis</i>
<i>Polypora anastomosa var. spinicarnata</i>	<i>Hustedia miseri</i>
<i>Polypora constricta</i>	<i>Composita gibbosa</i>
<i>Polypora halensis</i>	<i>Composita ovata</i>
<i>Polypora magna</i>	<i>Composita ozarkana</i>
<i>Polypora purduei</i>	<i>Composita transversa</i>
<i>Polypora reversispina</i>	<i>Composita wasachensis</i>
<i>Polypora washingtonensis</i>	<i>Sphenotus halensis</i>
<i>Polypora triseriata</i>	<i>Nucula parva</i>

PLATE XX
CHARACTERISTIC FOSSILS OF THE HALE SANDSTONE

- FIGURES 1. *Squamularia transversa*. Brachial view of one of Mather's cotypes.
- 2-3. *Septipora crebripora*. The type zoarium and a part of it, $\times 4$.
4. *Aviculopecten halensis*. An external cast of a left valve, $\times 2$.
5. *Sphenotus halensis*. A left valve, $\times 2$.
6. *Leda bellistriata*. An incomplete left valve.
7. *Myalina orthonota*. The type specimen, a nearly complete left valve.
- 8-9. *Polypora anastomosa*. Reverse face of the type zoarium and the same specimen, $\times 4$.
10. *Aviculopecten aurisculptis*. An incomplete left valve.
11. *Aviculopecten arkansanus*. An external cast of a left valve, $\times 2$.
12. *Euomphalus catilloides*. A typical specimen. Found also in the Brentwood.
- 13-15. *Composita ozarkana*. Lateral, pedicle, and brachial views of a typical specimen. This species is common throughout the Morrow group.
16. *Schizodus morrowensis*. An incomplete left valve.
- 17-18. *Phylopora perforata*. Obverse face of the holotype, $\times 4$, and the same, natural size.
- 19-20. *Polypora halensis*. The type zoarium, and the same, $\times 4$.



CHARACTERISTIC FOSSILS OF THE HALE SANDSTONE

Phyllopora perforata	Leda bellistriata
Septopora crebripora	Monopteria (?) sp.
Dictyoeladia triseriata	Myalina orthonota
Cystodictya brentwoodensis	Myalina recurvirostris
Cystodictya sinuomarginata	Schizodus morrowensis
Orbiculoidea minuta	Aviculopecten arkansanus
Rhipidomella altirostris	Aviculopecten aurisculptis
Schizophoria resupinoides	Aviculopecten halense
Orthotetes robusta	Aviculopecten talboti
Chonetes laevis	Deltopecten occidentalis
Productus cora	Pleurophorus tropidophorus
Productus fayettevillensis	Leptopsis chesterensis
Productus gallatinensis	Bellerophon cf. sublevis
Productus nanus	Euphemus carbonarius
Productus morrowensis	Euomphalus catilloides
Productus welleri	Strophostylus subovatus
Pustula pertenuis	Flatyceras parvum
Pustula punctata	Aclisina (?) sp.
Pugnoides triangularis	Gastrioceras branneri
Dielasma subspatulatum	Griffithides morrowensis
Spirifer goreii	Petalodus sp.
Spirifer rockymontanus	

The fauna of the Hale is closely related to that of the Bloyd formation, which contains a Pottsville flora; and thus, despite the Mississippian aspect of some of the fossils, the Pennsylvanian forms predominate, and the early Pennsylvanian age of the formation is fairly well established.

Stratigraphic relations.—In the area immediately south of the northernmost outcrop of the Pitkin formation the Hale sandstone rests disconformably upon that formation, but still farther south the contact is apparently conformable. At places where the Pitkin has been removed the Hale lies disconformably upon either the upper Fayetteville, the Wedington sandstone, or the lower Fayetteville shale, its position depending on the amount of erosion that preceded the deposition of the Hale at that place. (See Pl. XVII, B.)

The Bloyd shale rests conformably upon the Hale, but where the Bloyd is absent the Atoka (Winslow) lies either disconformably or with slight angular unconformity upon the Hale.

Petrolific significance.—The Hale sandstone is one of the most widespread Carboniferous formations in the southern part of the Ozark region. It is not a considerable source of hydrocarbons, but it is an excellent potential reservoir for them. Some oil that has migrated into this formation escapes from oil seeps in it at several places, notably near Huntsville and near Deer. In the northern part of the Boston Mountains the cover over the formation is at most places so thin that hydrocarbons entrapped in it have probably escaped. In the area south of the crest of the mountains, however, the impervious

cover of the Hale is ample. In that area the formation should be reached by wells sunk to a depth of 500 to 1,000 feet near the crest of the mountains, and at 1,500 to 2,500 feet in the area farther south, the figures naturally varying considerably with variations in the topography and structure. The formation may be reached in the northern part of the Arkansas Valley at a depth of 3,000 to 4,000 feet.

BLOYD SHALE

Definition.—The Bloyd shale was named by A. H. Purdue from Bloyd Mountain, Washington County, Arkansas, where it is well exposed and where it consists of dark, carbonaceous shales, with which are interstratified two members or lentils of limestone. The lower member is now called the Brentwood limestone, but it was formerly called the “Pentremital” limestone, because of the large number of blastoids of the genus *Pentremites* found in it. The upper limestone was called the Kessler by Simonds because it is typically exposed on Kessler Mountain, southwest of Fayetteville.

Between the Brentwood and the Kessler limestone is a shale containing at some places a thin seam of coal, here called the Baldwin coal. In the publications of the former Arkansas Geological Survey and in other geological reports these beds were called the “coal-bearing shale.”

Distribution and thickness.—The Bloyd shale has a smaller areal extent than the Hale formation, but it is well exposed in the Fayetteville, Winslow, and Eureka Springs quadrangles. It has also been identified at a few places in the Harrison quadrangle, but it has not been found east of that area. If the Bloyd does crop out in the eastern part of the State its character there is very different from its typical character in the areas mentioned above.

The Bloyd formation attains a maximum exposed thickness of nearly 200 feet in northern Crawford County, but it becomes thinner toward the north and east; and in Oklahoma it becomes not only thinner but much more calcareous. Near the head of War Eagle Creek, in the southern part of the Eureka Springs quadrangle, the formation is 176 feet thick, but from this place it appears to become thinner in all directions except toward the south. Near Ponca, in the Harrison quadrangle, the Bloyd is 70 feet thick, but its average thickness in that area is much less. In the Fayetteville quadrangle the formation is everywhere found at its proper horizon and its average thickness is more than 100 feet.

Character.—The Bloyd shale, as already stated, consists of shale and two lentils of limestone. The Brentwood, or lower limestone, is generally separated from the Hale formation by 5 to 20 feet of black fissile clay shale, but at some places the shale is either covered or ab-

sent. This lower shale is thickest in the southern part of its outcrop. The Kessler is separated from the Brentwood by beds about 20 feet thick, consisting mostly of black, carbonaceous shale but including some lower sandy beds. The coal seam is in this part of the formation and ordinarily lies nearer to the Kessler than to the Brentwood lentil. At the abandoned Chambers mine, in Sec. 1, T. 13 N., R. 32 W., the Kessler is less than 5 feet above the top of the coal. The shale overlying the Kessler is variable in thickness and is absent at many places in the Eureka Springs and Harrison quadrangles, but it attains a thickness of over 125 feet at places farther south. This shale, where it is typically exposed, resembles very much the lower Fayetteville shale, for it is black, fissile, and carbonaceous, and like the Fayetteville it weathers to plastic yellow and red clays. It also contains at some places many siderite concretions such as are found in the Fayetteville, but the Bloyd is somewhat more arenaceous than the Fayetteville.

Brentwood limestone member.—The Brentwood member consists of one, two, or three layers of limestone, each from 3 to 15 feet thick, interstratified with beds of shale. Its thickness, including the shale, is in places as much as 60 feet, but its average thickness is less than half that much. The limestone is generally irregularly bedded, fine-grained, impure, very fossiliferous, and very hackly on fresh surfaces. At some places, however, the limestone weathers to fairly rounded surfaces and is in part crystalline. In general the Brentwood member contains purer limestone and is more massive in its northernmost exposures, although its thickness decreases toward the north.

Kessler limestone member.—The Kessler limestone is less widely distributed than the Brentwood, and is at all places thinner. The beds generally lie within 60 feet of the top of the Bloyd, but the overlying shale is irregular in thickness. The Kessler lentil is a compact, gray to brown, fossiliferous limestone, which is conglomeratic at some of its exposures. It is 30 feet thick in a few places, but its ordinary thickness is less than 10 feet, and its outcrops are inconspicuous. This limestone resembles the Brentwood but is of darker color and, unlike the Brentwood, it weathers into thin, shaly plates.

Fossils and correlation.—The fauna of the Brentwood limestone is described by Mather,³⁵ who points out that, although it includes characteristic Mississippian genera such as *Pentremites* and *Archimedes*, it is essentially early Pennsylvanian. A list of species given by Mather follows:

Zaphrentis gibsoni
Amplexus corrugatus
Campophyllum torquium

Orbiculoidea missouriensis
Orbiculoidea minuta
Ehipidomella pocosi

³⁵ Mather, K. F., op. cit.

PLATE XXI

CHARACTERISTIC FOSSILS OF THE BRENTWOOD LIMESTONE

FIGURES 1-3. *Zaphrentis gibsoni*. Two views of a nearly complete specimen showing the primary and alar septa; a cross-section of the apical portion of another specimen, $\times 2$. Brentwood only.

4-5. *Amplexus corrugatus*. A transverse section through a typical specimen; a nearly complete specimen of a mature individual. Brentwood only.

6-7. *Pachypora carbonaria*. A longitudinal section; a small corallum. Brentwood only.

8-10. *Rhynchopora magnicosta*. Pedicle, brachial, and anterior views of Mather's type. Chiefly Brentwood.

11-13. *Spirifer opimus*. Pedicle, brachial, and lateral views of a typical specimen. Chiefly Brentwood.

14-16. *Dielasma bilobatum*. Pedicle, anterior, and brachial views of a characteristic specimen. Brentwood only.

17-18. *Eumetria vera*. Pedicle and brachial views of the Brentwood type referred to this species.

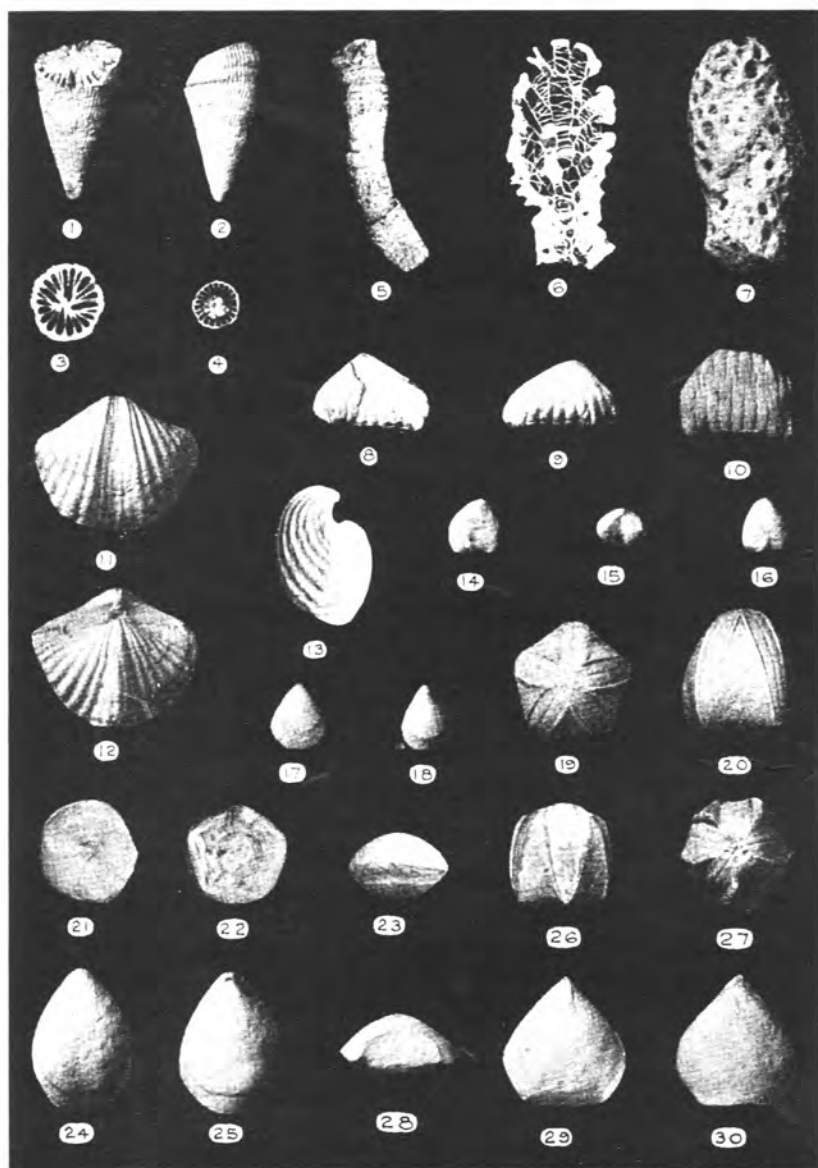
19-20. *Pentremites angustus*. Ventral and lateral views of a typical specimen. Found also in the Hale formation but is chiefly and typically Brentwood.

21-22. *Delocrinus dubius*. Dorsal and ventral views of Mather's type. Brentwood only.

23-25. *Dielasma arkansanum*. Anterior, pedicle, and brachial views of the Brentwood type of this species, which is found also in the Chester formations of northern Arkansas.

26-27. *Pentremites rusticus*. Lateral and ventral views of a typical specimen. Brentwood only.

28-30. *Composita deflecta*. Anterior, pedicle, and brachial views of Mather's type. Brentwood only.



CHARACTERISTIC FOSSILS OF THE BRENTWOOD LIMESTONE

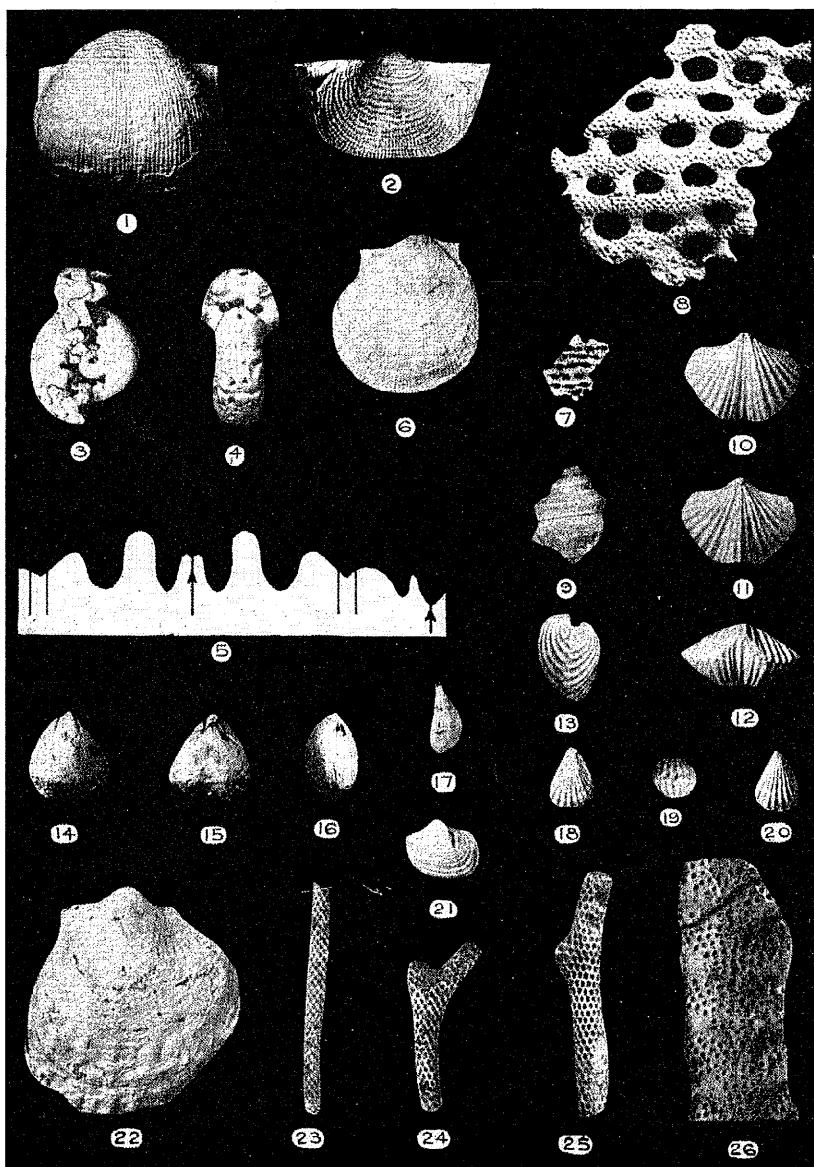
<i>Pachypora carbonaria</i>	<i>Schizophoria resupinoides</i>
<i>Michelinia eugeneae</i>	<i>Orthotetes robusta</i>
<i>Michelinia exilimura</i>	<i>Orthotetes</i> sp.
<i>Michelinia eugeneae</i>	<i>Chonetes arkansanus</i>
<i>Pentremites angustus</i>	<i>Productus cora</i>
<i>Pentremites rusticus</i>	<i>Productus fayettevillensis</i>
<i>Hydreionocrinus</i> sp.	<i>Productus gallatinensis</i>
<i>Cromyocrinus grandis</i>	<i>Productus morrowensis</i>
<i>Eupachyrcinus</i> cf. <i>magister</i>	<i>Productus welleri</i>
<i>Delocrinus dubius</i>	<i>Fustula bullata</i>
<i>Archeocidaris</i> sp.	<i>Fustula globosa</i>
<i>Fistulipora</i> sp.	<i>Fustula nebraskensis</i>
<i>Stenopora tuberculata</i>	<i>Fustula pertenuis</i>
<i>Stenopora</i> sp.	<i>Fustula punctata</i>
<i>Anisotrypa</i> sp.	<i>Pugnoides triangularis</i>
<i>Fenestella morrowensis</i>	<i>Rhynchopora magnicosta</i>
<i>Fenestella venusta</i>	<i>Dielasma arkansanum</i>
<i>Fenestella serrata</i>	<i>Dielasma bilobatum</i>
<i>Archimedes juvenis</i>	<i>Dielasma subspatulatum</i>
<i>Polypora anistomosa</i>	<i>Spirifer opimus</i>
<i>Polypora constricta</i>	<i>Spirifer rockymontanus</i>
<i>Polypora elliptica</i>	<i>Squamularia perplexa</i>
<i>Polypora magna</i>	<i>Spiriferina campestris</i>
<i>Polypora purduei</i>	<i>Spiriferina transversa</i>
<i>Polypora washingtonensis</i>	<i>Hustedia brentwoodensis</i>
<i>Polypora triseriata</i>	<i>Hustedia miseri</i>
<i>Septopora implexa</i>	<i>Eumetria vera</i>
<i>Septopora reversispina</i>	<i>Cosmoposita deflecta</i>
<i>Dictyoeladia triseriata</i>	<i>Composita gibbosa</i>
<i>Cystodictya brentwoodensis</i>	<i>Composita ovata</i>
<i>Cystodictya sinuomarginata</i>	<i>Composita ozarkana</i>
<i>Coscinium fayettevillensis</i>	<i>Composita transversa</i>
<i>Coscinium gracile</i>	<i>Composita wasatchensis</i>
<i>Glyptopora crassistoma</i>	<i>Parallelodon cancellosus</i>
<i>Parallelodon pergibbosus</i>	<i>Euomphalus catilloides</i>
<i>Cypriocardinia laevicula</i>	<i>Platyceras parvum</i>
<i>Pseudomonotis precursor</i>	<i>Aclisina</i> (?) sp.
<i>Aviculopecten</i> cf. <i>interlineatus</i>	<i>Meekospira</i> (?) sp.
<i>Bellerophon crassus</i> var. <i>wewokanus</i>	<i>Sphaerodoma</i> sp.
<i>Bellerophon</i> cf. <i>sublevis</i>	<i>Orthoceras</i> sp.
<i>Euphemus carbonarius</i>	<i>Gastrioceras pygmaeum</i>
<i>Euconospira arkansana</i>	<i>Griffithides morrowensis</i>
<i>Straparollus</i> cf. <i>spergenensis</i>	<i>Griffithides</i> sp.

A comparison of the above list with a list of the residual Mississippian and proemial Pennsylvanian forms found in the Morrow fauna as a whole shows that 51 per cent of the 49 Pennsylvanian species have been recorded from the Brentwood. On the other hand, 70 per cent of the Mississippian species have also been found in the Brentwood. Expressed in other terms, 27 per cent of the Brentwood species have a definite Pennsylvanian aspect, 15 per cent of them are Mississippian types, and 58 per cent of them have no definite

PLATE XXII

CHARACTERISTIC FOSSILS OF THE KESSLER LIMESTONE

- FIGURES** 1-2 *Productus morrowensis*. Pedicle and posterior views of a typical specimen. This species is found throughout the Morrow group.
- 3-5. *Gastrioceras kesslerense*. Two views of Mather's type and the suture of the same. Kessler only.
6. *Aviculopecten hertzeri*. A left valve of this rare species. Kessler only.
- 7-8. *Polypora kesslerensis*. The obverse face of the type zoarium, and the same enlarged 4 diameters. Kessler only.
9. *Worthenia tabulata*. An incomplete cast of the exterior.
- 10-13. *Spirifer rockymontanus*. Pedicle, brachial, anterior, and lateral views of a typical specimen. Common throughout the Morrow group.
- 14-16. *Girtyella emarginata*. Pedicle, brachial, and lateral views of a specimen preserved as an internal cast.
17. *Myalina cuneiformis*. An internal cast of a left valve.
- 18-20. *Rustedia miseri*. Brachial, anterior, and pedicle views of a typical specimen.
21. *Edmondia maccoyii*. Internal cast of a left valve. Kessler only.
22. *Pseudomonotis inflata*. Internal cast of a left valve. Mather's type. Kessler only.
23. *Rhombopora attenuata*. A typical zoarium, $\times 4$.
- 24-25. *Rhombopora lepidodendroides*. Two fragmentary zoaria, $\times 4$.
26. *Prismopora concava*. Part of Mather's type, $\times 4$.



CHARACTERISTIC FOSSILS OF THE KESSLER LIMESTONE

stratigraphic significance. These figures disclose an interesting anomaly, which may be explained in part by facies control, namely, that the underlying Hale formation has a more definitely Pennsylvanian fauna and a less marked Mississippian aspect than the Brentwood.

The flora associated with the Baldwin coal has been studied by David White,³⁶ who found that it is in large part identical with that of the Sewanee group, or Pottsville, of Tennessee.

The fauna of the Kessler member is more definitely Pennsylvanian than that of the other divisions of the Morrow. For this reason, and because of the rather pronounced Mississippian aspect of the Brentwood fauna, some writers incline to the view that the top of the Mississippian should be extended to the top of the Brentwood. Such an extension would still leave the Pennsylvanian flora in its proper system, but it would not only divide the Morrow group, which is a stratigraphic and paleontologic unit, but would place in the Mississippian system rocks whose fauna, although transitional, is more dominantly Pennsylvanian than Mississippian.

The Kessler fauna, listed below, is made up of 52 species, of which 42 per cent are typical Pennsylvanian forms and only 4 per cent have Mississippian affinities.

<i>Zaphrentis gibsoni</i> (?)	<i>Schizophoria resupinoides</i>
<i>Michelinia eugeneae</i>	<i>Orthotetes robusta</i>
<i>Fenestella venusta</i>	<i>Meekella striatocostata</i>
<i>Polypora kesslerensis</i>	<i>Productus cora</i>
<i>Rhombopora attenuata</i>	<i>Productus fayettevillensis</i>
<i>Rhombopora lepidodendroides</i>	<i>Productus gallatinensis</i>
<i>Coscinium fayettevillensis</i>	<i>Productus morrowensis</i>
<i>Prismopora concava</i>	<i>Productus welleri</i>
<i>Productus</i> sp.	<i>Edmondia subtruncata</i>
<i>Pustula nebraskensis</i>	<i>Nucula kessleriana</i>
<i>Pustula pertenuis</i>	<i>Nucula</i> sp.
<i>Pustula punctata</i>	<i>Parallelodon sangamonsis</i>
<i>Dielasma subspatulatum</i>	<i>Pseudomonotis inflata</i>
<i>Girtyella</i> (?) <i>emarginata</i>	<i>Myalina cuneiformis</i>
<i>Spirifer goreii</i>	<i>Myalina orthonota</i>
<i>Spirifer opimus</i> (?)	<i>Aviculopecten arkansanus</i>
<i>Spirifer rockymontanus</i>	<i>Aviculopecten hertzeri</i>
<i>Squamularia perpixa</i>	<i>Aviculopecten</i> sp.
<i>Spiriferina campestris</i>	<i>Dellopecten occidentalis</i>
<i>Spiriferina transversa</i>	<i>Palaeolima inequicostata</i>
<i>Hustedia miseri</i>	<i>Lepetopsis</i> sp.
<i>Composita ovata</i>	<i>Worthenia tabulata</i>
<i>Composita ozarkana</i>	<i>Platyceras parvum</i>
<i>Composita wasatchensis</i>	<i>Aclisina</i> (?) sp.
<i>Solenomya</i> sp.	<i>Gastrioceras kesslerense</i>
<i>Edmondia maceyii</i>	<i>Griffithides morrowensis</i>

³⁶ White, David, Bull. Geol. Soc. Am., vol. 6, p. 316, 1895.

Stratigraphic relations.—The Bloyd shale rests conformably upon the Hale formation and is overlain, ordinarily with a slight angular unconformity, by the Atoka (Winslow) formation. (See Pl. XXIII, A.) As the Bloyd becomes thinner toward the north and northeast, the Atoka rests at some places upon the upper shale, at others on the Kessler member or the Brentwood, or, where the Brentwood also is absent, upon the Hale formation.

Petrolific significance.—The Bloyd shale is a possible source of oil and gas. Both the Kessler and the Brentwood limestones are very fossiliferous, and at many places the interiors of some of the fossils found in them are filled with solid or, rarely, liquid hydrocarbons. Some of these products may have migrated from the Bloyd either into the Hale sandstone below or into the Atoka above.

A shale that crops out above the Pitkin in Sec. 18-19, T. 14 N., R. 11 W., and that occupies the stratigraphic position of the Bloyd, though it may be a part of the Hale formation, has been analyzed to determine its content of oil. The analysis, made by the Kansas City Testing Laboratory, is given here through the courtesy of Samuel Hayes, of Tulsa, Oklahoma.

Yield of oil per ton of shale.

	Pounds		Per cent
Oil.....	162.6	21.6 gal.	8.13
Water.....	54.6	6.5 gal.	2.73
Gas.....		642.0 cu. ft.	3.55
Ammonium sulphate.....	2.2		0.11
Carbon (not separable).....	180.4		9.02
Mineral matter.....	1509.2		75.46

The quantities stated were obtained by laboratory distillation, and the samples used were obtained from an outcrop some weeks before the analysis was made. Fresh samples of the shale taken somewhat back from the outcrop would therefore probably yield at least as much oil as that shown by this analysis.

ATOKA FORMATION³⁷

Definition.—The Atoka formation consists of a rather unvarying series of alternating beds of sandstone and shale, and, although some of the beds are or have been somewhat calcareous, no limestone has been found among them in the Boston Mountains. The Atoka, which rests unconformably upon the rocks of the Morrow group, is the youngest formation that crops out in the Boston Mountains.

The Atoka formation was named by Taff and Adams,³⁸ presumably from Atoka, Oklahoma, at and near which it is exposed. The term Atoka is here applied to beds that have been called the Winslow for-

³⁷ The Atoka formation is considered also on pages 116-139.

³⁸ Taff, J. A., and Adams, G. I., U. S. Geol. Survey, 21st Ann. Rept., 1900, pt. 2, p. 273.



**A. SLIGHTLY ANGULAR UNCONFORMITY BETWEEN THE BLOYD SHALE (BELOW)
AND THE HEAVY BASAL LAYERS OF THE ATOKA FORMATION NEAR FORT
DOUGLAS**



**B. IRREGULARLY BEDDED SANDSTONE AND SHALE OF THE UPPER PART OF
THE ATOKA FORMATION EAST OF RUSSELLVILLE**
The dark layers are very carbonaceous sandstones.

mation. The reasons for this change in nomenclature are given under the heading "Fossils and correlation" (p. 90).

Distribution and thickness.—The Atoka formation has a larger areal extent than any other Paleozoic formation exposed in Arkansas. It is the surface rock at the crest of the Boston Mountains, it occurs on the tops of outlying ranges north of those mountains, and it is the only formation that crops out over large areas on their southern slopes, though older formations are exposed at a few places in the deeper ravines. In the Boston Mountains its largest areas of outcrop are in Washington, Crawford, Madison, Franklin, Newton, Johnson, Pope, Searcy, Stone, Van Buren, Cleburne, Conway, White, and Independence counties, but it is also widely exposed in the Arkansas Valley and the Ouachita Mountains.

The formation increases in thickness from a feather edge on the outliers of the Boston Mountains, in the northern part of the State, to 1,750 to 2,250 feet in the area between those mountains and the Arkansas Valley.

Character.—The Atoka formation consists of alternating beds of sandstone and shale and a few beds of calcareous sandstone of small areal extent. The sandstone beds range in thickness from less than 1 foot to more than 125 feet. Near or at the base of the formation there are one or two thick beds of conglomeratic sandstone that contain small waterworn quartz pebbles. These beds, which form prominent bluffs, have been described as the "Millstone grit" in some of the earlier geologic reports on northern Arkansas. The sandstone, despite its prominence, probably does not make up more than 25 per cent of the formation in the northwestern part of the State. Farther east the Atoka becomes more arenaceous, and in an exposed section of 500 feet in the southwestern part of the Marshall quadrangle practically all the rock is arenaceous, and more than 50 per cent of it is medium-bedded to thick-bedded sandstone.

The sandstones of the Atoka exposed in the Boston Mountains are very variable in character, but most of them are medium-grained and are light to dark brown in color. Most of the thin beds are ripple-marked, and many of the thick beds show cross-bedding. Some of the sandstones are micaceous; others are subsaccharoidal. All the thicker beds of sandstone grade upward from sandy shale to massive beds of sandstone and are so similar that no single bed can be traced over even a relatively small area.

The shales are ordinarily black and carbonaceous, and although they are less fissile than those of the Fayetteville and Bloyd formations they closely resemble those beds. Many of the shaly layers, however, form soft brown or drab clays; others are micaceous or aren-

aceous and are associated with thin beds of dense, ripple-marked sandstone, which are streaked with carbonaceous material.

Thin beds of coal occur in the shaly parts of the formation, but all such beds found in the Boston Mountains are less than 2 feet thick and are not mined.

Fossils and correlation.—The Atoka formation is essentially non-fossiliferous, but a few poorly preserved fossils have been found in its more calcareous parts and in the basal beds of sandstone. The fauna has not been studied in detail, but all that is known of it indicates that the Atoka is of Pottsville age.

The "Winslow" formation, according to Purdue,³⁹ who so named it, "is named from the town of Winslow, at the summit of the Boston Mountains It rests upon the Bloyd shale, and the rocks belonging to it are the only ones that outcrop along the summit of the Boston Mountains and on the southern slopes, except in the deepest ravines, where older ones have been exposed." Accordingly, all the rocks that crop out in the southern part of the Winslow quadrangle were mapped by Purdue as belonging to the "Winslow" formation. Later work by Collier,⁴⁰ however, showed that the Hartshorne sandstone and the Spadra shale (=lower McAlester) crop out over a small area in the southern part of the Winslow quadrangle.

Several years prior to the work of either Purdue or Collier, Taff and Adams,⁴¹ in describing the geology of the eastern Choctaw coal field, proposed the names Atoka, Hartshorne, and McAlester for strata that extend uninterruptedly northward and northeastward from this small area into the area studied by Purdue. The "Winslow" formation as defined by Purdue in 1907 is essentially the same as the Atoka formation of Taff, but its uppermost part includes also strata that Taff, in 1900, assigned to the Hartshorne and McAlester formations.

In its type area the Atoka formation is underlain by the Wapanucka limestone (which carries a Morrow fauna) and is overlain by the Hartshorne sandstone. In the Boston Mountains the "Winslow" formation of Purdue rests on rocks of the Morrow group and is overlain farther south by the Hartshorne sandstone. Further proof of the equivalence of the "Winslow" (restricted) and the Atoka, besides their lithologic identity, is furnished by the fact that the Atoka of the Arkansas Valley and the "Winslow" of the Boston Mountains are absolutely continuous with one another. As it is impossible to determine where the "Winslow" ends areally and the Atoka begins, it is necessary to use a single name for the beds that lie between

³⁹ Purdue, A. H., U. S. Geol. Survey Atlas, Winslow folio (No. 154), p. 3, 1907.

⁴⁰ Collier, A. J., The Arkansas coal field: U. S. Geol. Survey Bull. 326, p. 13 et seq., 1907.

⁴¹ Taff, J. A., and Adams, G. I., *op. cit.*



**BLOCK OF THE MASSIVE LOWER BED OF SANDSTONE OF
THE ATOKA FORMATION SOUTH OF FORT DOUGLAS**
The rock has moved a considerable distance down the slope
from its outcrop.

those having a Morrow fauna and the overlying Hartshorne sandstone, and as Atoka has priority over "Winslow," it is used in this report.

Petrolific significance.—The Atoka formation yields natural gas in Arkansas Valley but has not yielded either oil or gas in commercial quantities in the Boston Mountains. In large areas in the northern part of those mountains the cover over the possible producing beds is very thin, but near the Arkansas Valley the cover is sufficiently thick and impervious to hold oil and gas in the underlying beds.

The shales of the Atoka are potential sources of oil and gas and its thicker beds of sandstone are suitable reservoirs for both. A more detailed description of the Atoka is given in the text on that formation as it occurs in the Arkansas Valley, where it has been more carefully studied and more extensively tested.

STRATIGRAPHY OF THE OUACHITA MOUNTAIN AND ARKANSAS VALLEY PHYSIOGRAPHIC PROVINCES

The details of the stratigraphy of the Ouachita Mountains and the Arkansas Valley, except of the area of active coal mining, are not so well known as those of the Ozark province. This deficiency of knowledge can never be completely remedied, because the Ouachitas are mainly without valuable mineral resources, such as would warrant intensive geological study, and because their structure is at many places too complex to be interpreted without the aid of fossils, which are practically absent. Nevertheless, additions to our meager knowledge of these geologic provinces have been made from time to time, and all that is known of their geology is summarized in the following pages. A generalized columnar section is given in Plate XXV.

PRE-CARBONIFEROUS ROCKS

The rocks of the pre-Carboniferous formations of the Ouachita Mountains crop out along the axis of the anticlinorium that extends southwestward from near Little Rock through Saline, Garland, Montgomery, and Polk counties and are found also in smaller areas in Pulaski and Hot Spring counties. All the early Paleozoic periods are represented by these rocks, but exact correlations of the formations with those in other areas are practically impossible because of the almost total lack of fossils in these formations in Arkansas. None of these pre-Carboniferous formations crops out in the Arkansas Valley province.

Although it is very unlikely that any of these formations will produce either oil or gas, owing to the great regional metamorphism they

have suffered, a synopsis of the characteristics of each formation is given here in order to complete the stratigraphic descriptions.

CAMBRIAN SYSTEM

COLLIER SHALE

The Collier shale is the oldest formation exposed in the Ouachita Mountains in Oklahoma and Arkansas. In Arkansas this shale is exposed only in Montgomery County, in a westward-trending valley lying between Mount Ida and Womble. The exposure, which is about 15 miles long and from 1 to 3 miles wide, covers about 25 square miles. The thickness of the Collier is unknown, as its base is concealed, but exposed sections of it in Arkansas measure fully 500 feet.

In Oklahoma the Collier has been positively identified in the neighborhood of Glover post office. Other rocks that are exposed extensively along Lukfata, Yashoo, and East Cedar creeks, in central southern McCurtain County, also may belong to this formation. In Oklahoma, as in Arkansas, the base of the formation has not been seen, so that its total thickness is not known, but Honess⁴² has estimated its exposed thickness near Glover at not less than 200 feet.

The formation is made up mainly of soft, dark, graphitic clay shale, which is intensively crumpled, but it contains a few thin layers of dark chert and some dark, siliceous, thin-bedded limestone, particularly near its top. Most of the beds of limestone are found just below the characteristic basal conglomerate of the Crystal Mountain sandstone, and their total thickness is not more than 35 feet. All the upper 100 feet of the formation, however, contains some limestone, which occurs as thin, dark, crystalline lenses about an inch thick, sparsely distributed through the shale.

The limestone is in part conglomeratic, both in Oklahoma and in Arkansas. The beds of conglomerate are thin and are probably local, but they all lie at about the same horizon, which is high in the formation. The rock is made up of cobbles of limestone, rounded grains of quartz of the size of peas or smaller, and masses of black chert measuring 6 to 8 inches in their greatest dimension, all set in a matrix of siliceous limestone.

The shale, which constitutes the bulk of the formation, is dark, soft, graphitic, and extremely contorted. At widely separated horizons thin beds of dense, black, fractured chert occur. The shale has been subjected to stresses so severe that they have at many places obliterated all traces of bedding and formed incipient slaty cleavage. Smooth, slickensided surfaces are common, and small quartz veins in places occupy the shear zones. Furthermore, Honess has shown that

⁴² Honess, C. W., *Geology of the southern Ouachita mountains of Oklahoma*: Oklahoma Geol. Survey Bull. 32, Part I, p. 36, 1923.

not only the beds of shale have been greatly twisted and crushed, as is revealed by microscopic study, but that the beds of limestone and conglomerate likewise give both megascopic and microscopic evidence of severe regional metamorphism.

Although the Collier is exposed only in the areas already mentioned, it is reasonable to suppose that the formation extends continuously under much of the Ouachita Mountain province. Particularly good evidence for this supposition may be seen in the fact that the rocks comprising the exposures in Montgomery County, Arkansas, and those near Glover, Oklahoma, although many miles apart, are nevertheless almost identical in lithology, arrangement of strata, type of bedding, and degree of metamorphism.

Honess⁴³ has found a few fossils in the Collier limestone, but they are so poorly preserved that not even a phyletic determination of them can be made, though they probably include remains of sponges and algae. The assignment of the Collier to the Cambrian system is therefore not beyond question, since paleontologic evidence for it is lacking, and the stratigraphic position of the formation, although suggestive, is still not conclusive proof of its Cambrian age. The formation, however, lies disconformably below the Crystal Mountain sandstone, and that formation in turn underlies the Mazarn shale. The age of the Mazarn shale, as determined from its graptolite fauna, is early Ordovician, and hence the underlying, older formations can only be very oldest Ordovician or pre-Ordovician. As the Collier is separated from the Crystal Mountain sandstone by a stratigraphic break, it has been logically, if somewhat arbitrarily, placed in the Cambrian system.

The Collier shale may once have been a source of hydrocarbons, but if so they have been driven off by the regional metamorphism that the beds have undergone. It is therefore almost impossible that these strata will yield either oil or gas in the Ouachita Mountains in Arkansas, and the formation is beyond the reach of the drill in the Arkansas Valley, where the beds presumably are less deformed.

ORDOVICIAN SYSTEM

CRYSTAL MOUNTAIN SANDSTONE

The Crystal Mountain sandstone was named by Purdue⁴⁴ from the Crystal Mountains, a group of ridges in Montgomery County south of Mount Ida, where it is typically exposed. As originally defined the formation consisted typically of two divisions, a lower massive sandstone and an upper part made up of heavy layers of sandstone interbedded with dark shale, but the upper division included the sandstone now called the Blakely. The maximum observed thickness

⁴³ Honess, C. W., op. cit., p. 44.

⁴⁴ Purdue, A. H., *Slates of Arkansas*: Arkansas Geol. Survey, p. 32, 1909.

of the formation in its exposures in Arkansas is 850 feet, and the upper division is generally somewhat thicker than the lower. In McCurtain County, Oklahoma, the sandstone is more uniform in character throughout than in Arkansas, and the formation is slightly thinner, though its thickness probably averages more than 500 feet.

At the base of the formation at most points of exposure, particularly near Glover, Oklahoma, there is a prominent conglomerate. This rock contains pebbles of quartz, coarse and fine sandstone, limestone, chert, shale, slate, and some quartzite. Some of the larger fragments of limestone and chert are 10 inches in their greatest diameter, but most of them are less than 2 inches in diameter. The angular fragments are as common as the rounded ones, and cherty material is perhaps more abundant than other types.

The matrix is a fine-grained, dense, siliceous limestone or a calcareous sandstone, its quartz content being extremely variable. The fragments are more numerous near the base of the conglomerate, hence the matrix increases in quantity toward the top. Fragments and matrix alike are cut by numerous quartz veins, and the rock shows many slight displacements. The conglomerate weathers into large blocks, from which the calcareous parts of the rock are leached, their solution causing the chert and other insoluble fragments to stand out in jagged relief. Exfoliation also is an active process, operating alike on the bedded rock and the talus and cutting straight through fragments and matrix to form slabs several inches thick.

The lower sandstone is the most resistant part of the formation, and the Crystal Mountains owe their existence to this massive stratum. The sandstone is composed of coarse, well-rounded grains, which are firmly cemented, either by silica, which has been added to the original grains in crystallographic continuity, or by fine grained material resembling chert.⁴⁵ The sandstone is in part calcareous, and according to Honess, some of it probably represents quartzite that has been in part replaced by carbonate. The rock is nearly white when freshly fractured, but it commonly weathers to the color of brown sugar. In most places it is thickly set with a network of quartz veins, which range in thickness from a thirty-second of an inch to about 6 inches. At some places in Arkansas there are fissures ranging in width from several inches to several feet, the walls of which are lined with quartz crystals. The common occurrence of these clusters of crystals gave the name to the mountains in which they are found, and thus in turn to the formation. In Oklahoma the quartz crystals are smaller and not so common.

The upper part of the formation has been largely removed by

⁴⁵ Honess, C. W., *op. cit.*, p. 52.

erosion and has not been thoroughly studied, and the best known part of it is now referred to the Blakely. The beds of sandstone of the upper division of the Crystal Mountain, however, are finer grained and thinner bedded than those of the lower division. Interbedded with the beds of sandstone are beds of gray to black shale, which are in every way similar to those of the overlying Mazarn formation. In some places these shales have been altered to ribboned slate. In Oklahoma, however, this argillaceous phase of the formation is not well developed.

No fossils have been obtained from the Crystal Mountain sandstone, and, indeed, there is some evidence for believing that much of the sandstone without visible bedding and with large rounded grains possibly may be of eolian origin. The sandstone has been assigned to the Ordovician, however, because it passes gradually upward into the shales of the Mazarn formation, whose early Ordovician age has been definitely determined from paleontologic evidence. Furthermore, the marked similarity of the shales of the upper Crystal Mountain formation and those of the Mazarn may be taken as additional evidence that the two should be placed in the same system.

MAZARN SHALE

The Mazarn shale received its name from its typical exposure at the headwaters of Mazarn Creek, in the northeastern part of the Caddo Gap quadrangle. It includes the lower part of the "Ouachita" shale of Purdue. More precisely placed it lies between the Crystal Mountain sandstone below and the Blakely sandstone above.

The Mazarn outcrops in Montgomery, Saline, Pulaski, and Garland counties, Arkansas, and in McCurtain County, Oklahoma. The exposures are everywhere limited to valleys, and the shale is generally very inconspicuous topographically. For this reason, and because the beds are intricately contorted, it has been impossible to determine accurately the thickness of the formation. Its thickness, both in Oklahoma and Arkansas, however, has been estimated as more than 1,000 feet.

The formation consists predominantly of shale but includes also sandstone, limestone, and chert. The shale is mainly black, clayey, and fissile, but green shale, in thin layers alternating with the darker variety, is relatively common. At many places slaty cleavage has been developed and at a few others almost all traces of the original bedding has been obscured. At such places the differently colored layers form ribboned shale or slate. The clay formed by the weathering of the shale is plastic, and is either red or light yellow. Quartz veins, which are numerous in certain areas, cut the formation in all

directions, and at some places the residual quartz from the veins makes a surface veneer.

The limestone makes up only a small part of the formation. It occurs somewhere near the middle of the shale and is dense, thin-bedded, fine-grained, and blue-gray. Like the shale it is cut by a network of veins of white quartz. It probably does not exceed 10 feet in thickness and it is apparently not present at all localities.

The sandstone occurs at many places and presumably at several horizons. It is a dense, quartzitic, laminated, gray rock and ordinarily occurs in thin layers, but at some places it attains a thickness of several feet. At a few places high in the formation, dense, black flint has been found.

In McCurtain County, Oklahoma, the Mazarn is apparently somewhat more highly metamorphosed than in Arkansas, and limestone and chert have not been found in it. It contains scattered pebbles of sandstone, however, and in general it is very similar to the shale exposed in Arkansas.

The Mazarn shale has yielded a few graptolites from two localities near Womble and from another 12 miles west of Little Rock. According to Ulrich, these fossils indicate that the Mazarn is the age equivalent of the lower part of the Beekmantown limestone of the Appalachian area.

The Mazarn shale rests conformably upon the Crystal Mountain sandstone and is overlain, perhaps with a slight stratigraphic break, by the Blakely sandstone.

The formation has no petrolific significance in the Ouachita Mountain area, and its character away from its outcrop has not been determined.

BLAKELY SANDSTONE

The Blakely sandstone was named from Blakely Mountain, in Garland County, Arkansas, where it is typically exposed in a series of ridges that extend northeastward from Womble, Montgomery County, across Garland, into Saline County. The formation has not been found north of Womble, and is probably absent at most places west of that town, although it has been somewhat doubtfully identified as far west as McCurtain County, Oklahoma.

The Blakely formation varies in thickness from a feather edge to about 500 feet. It consists of interbedded shale and sandstone, the shale constituting three-fourths of the thickness of an average section. In spite of this preponderance of the shale, the sandstone is the conspicuous part of the formation, for it stands out in short rugged ridges, many of which are prominent topographic features. The sandstone is ordinarily medium bedded, but a few beds are very thick, and one on Little Glazypeau Creek, in the Hot Springs district,

attains a thickness of 80 feet. The sand is generally medium-grained and is firmly cemented either by silica or by calcium carbonate. The sandstone with the silica cement is quartzitic, light gray to blue in color, extensively jointed, and resistant to weathering. As a result the crests of ridges are strewn with angular boulders, which are in places so numerous as to suggest their derivation from very massive beds of sandstone. Most of the beds, however, are rather thin and are separated by thick layers of shale.

The calcareous sandstone is darker than the quartzitic variety and it weathers more rapidly, the resulting weathered material being very friable. Both varieties of sandstone are extensively cut by thin quartz veins, and clear and limpid quartz crystals commonly line the fissures along bedding and joint planes.

The shale is a black and green argillaceous sediment, which in some places is ribboned, so that it resembles the ordinary Mazarn and Womble shales.

Several beds of conglomerate have been observed in the formation. One of these, which is a thin bed of small, rounded chert fragments in a sandy matrix, occurs sporadically near the base of the Blakely sandstone. Another bed of conglomerate, several feet thick, occurring near the middle of the formation, consists of small rounded pebbles of chert and limestone set in a matrix of dark calcareous sandstone. Still a third conglomeratic horizon is found near the top of the formation in the Hot Springs district. This conglomerate is made up of small pebbles of sandstone in a matrix of black shale containing numerous rounded cavities, which were probably occupied by limestone pebbles, now dissolved.

The early Ordovician age of the Blakely sandstone is suggested by graptolites found in shale of the formation in Blakely Mountain. These fossils, which came from the NE. $\frac{1}{4}$ Sec. 29, T. 1 S., R. 20 W., occur about in the middle of the formation, and, according to Ruedemann and Ulrich, they indicate that the lower Blakely sandstone and the upper Levis shale of Quebec were deposited contemporaneously.

The conglomerate which occurs locally at the base of the Blakely sandstone suggests that there may have been a short period of erosion between the deposition of the Mazarn and the Blakely formation. The contact of the Blakely with the overlying Womble shale, however, is perfectly conformable and, in general, the contact of the Blakely with the subjacent and overlying formations is arbitrarily established.

The Blakely sandstone is of no importance as a potential source of oil or gas in the Ouachita Mountains, for in that area it has been greatly metamorphosed. If present in the Arkansas Valley area it has presumably suffered less regional alteration there, and the chances

that the formation may serve either as a source or a reservoir for hydrocarbons in that physiographic province are better, though certainly they are not good. It is doubtful, however, whether the formation will be encountered in the Arkansas Valley, even in the deeper wells.

WOMBLE SHALE

The Womble shale, which is named from the town of Womble, is exposed in valleys that extend eastward from Big Fork, in Polk County, through Montgomery, Garland, and Saline counties into Pulaski County. The formation has also been identified in McCurtain County, Oklahoma, but its character there is somewhat different from that in Arkansas.

The Womble shale, in its exposures in Arkansas, ranges in thickness from about 250 to 1,000 feet, and in Oklahoma it may be even thicker, although in that State it has been impossible to make accurate measurements of any complete section of it. In Arkansas the rocks are dominantly black graphitic shales, with thin beds of sandstone near the base of the formation and limestone near the top, but in Oklahoma sandstone predominates. The shale of the Womble formation resembles that of the Mazarn, but it is generally darker and the green layers are less numerous. Slaty cleavage is seen at many places and is particularly characteristic of the lower beds. At the top of the Womble shale there are some thin layers of black chert like those in the overlying Big Fork chert. Veins of white quartz cut the shale in all directions, and the quartz remains after the shale has weathered, forming an insoluble residue, which at some places makes a rather conspicuous surface mantle.

The limestone occurs only locally, but at some places it is as much as 25 feet thick, and at Cedar Glades, Garland County, and Black Springs, Montgomery County, it has been used to some extent for making lime. The rock is a dense, blue limestone, which occurs in layers ranging from half an inch to a foot in thickness, and is intersected by numerous quartz veins. The sandstone is a very subordinate part of the formation in Arkansas, but as it occurs in widely separated beds, sandstone float covers relatively large areas. The rock is generally dark gray to dark blue in color, compact and fine-grained, and occurs in beds ranging from 3 inches to 3 feet in thickness. In McCurtain County, Oklahoma, rocks identified by Honess⁴⁶ as beds of the Womble formation are described by him as green, schistose, micaceous sandstones invariably weathering red. The sediments in Oklahoma may therefore be regarded as the near-shore equivalents of the shales in Arkansas.

⁴⁶ Honess, C. W., *Geology of the southern Ouachita mountains of Oklahoma*. Oklahoma Geol. Survey Bull. 32, Part I, pp. 62-70, 1923.

Graptolites of two different faunas have been collected from the Womble shale in the Hot Springs quadrangle. The older fauna indicates that the Womble shale is of the same age as the upper Beekmantown of New York or the Upper Levis shale of Quebec. The younger fauna is that of the Normanskill shale—the *Nemagraptus gracilis* fauna—which indicates that the upper Womble shale is of early middle Ordovician age, whereas the older fauna suggests a late early Ordovician age for the part of the formation in which it occurs.

The Womble shale rests conformably upon the underlying Blakely sandstone and is conformably overlain by the Bigfork chert.

The Womble shale, like the older formations of the Ouachita province, is of no petrolific significance at or near its area of outcrop. In areas farther north, where the rocks are deeply buried, its characteristics have not been ascertained.

BIGFORK CHERT

The Bigfork chert, so called because of its typical exposure near Bigfork post office, crops out in Arkansas in areas between Shady post office, in Polk County, and Pulaski County, and is exposed also in the Ouachitas of southern Oklahoma. The areas of its outcrop are characterized by shallow valleys and low, steep-sided, but rounded knobs. The formation has been intensely crumpled, so that all attempts to measure its thickness accurately have been very difficult. It is at least 700 feet thick in Arkansas, and possibly slightly thicker in Oklahoma.

The formation consists of thin-bedded gray to black, shattered chert interbedded with varying amounts of coal-black shale and some sandstone and cherty limestone. The cherty limestone is rare in Arkansas but is rather common in Oklahoma.

The chert generally occurs in thin, even-bedded layers whose ordinary thickness is between 3 and 6 inches but which in a few places are as thin as 1 inch or as thick as 3 feet. It is extremely brittle and can be easily broken with a hammer into numerous fragments, which show uneven to conchoidal fracture. The layers are completely jointed, and the stone breaks along the joints so readily that it is difficult to find an unweathered specimen of it. Most of the joints are filled with thin quartz veins containing some calcite. As a result of the complex jointing the formation breaks down rather rapidly on weathering, and large quantities of the chert fragments collect at breaks in the slopes. This material is used satisfactorily as road metal at several places.

The shale, which is interbedded with the chert, occurs in layers that range in thickness from a fraction of an inch to several feet and is found at all horizons in the formation. Near the base, however,

the shale is not only more prominent but more siliceous, and on weathering it alters to a peculiar light-gray rock, which disintegrates into splintery, needle-like fragments. The sandstone makes up only a minor part of the formation and is limited to the upper beds. It is exposed at several places in the Zigzag Mountains, and it reaches its maximum thickness on the northwest slope of Glazypeau Mountain, in the Hot Springs district, where it is about 50 feet thick. Beds of limestone containing large amounts of chert are common throughout the formation in McCurtain County, Oklahoma, but, although such beds are found in Arkansas at a few places high in the formation, they are, in general, scarce in that State.

Determinable fossils are rare in the Bigfork chert, but fragmental remains of brachiopods, crinoids, and sponges are fairly common, particularly in the cherty limestones of McCurtain County, Oklahoma; and they testify to the marine origin of the rock. Fragments of shells collected near the top of the formation on Blaylock Creek, in the DeQueen quadrangle, in Arkansas, were examined by Ulrich, who, because of their poor preservation, was able to recognize only a single genus, *Hindia*, out of a possible dozen species represented. This evidence, although very meager, together with that afforded by the graptolites from the shale of the formation, indicates that the Bigfork is of middle Ordovician age, and that, placed more exactly, it belongs somewhere between the lower Trenton and the Upper Utica of the New York Ordovician section.

The Bigfork chert rests conformably upon the subjacent Womble shale and is succeeded without evidence of a break in sedimentation by the Polk Creek shale.

This formation has no petrolific significance at or near the areas of its exposure, and its character farther north is obscured by the overlying sediments.

POLK CREEK SHALE

The Polk Creek shale was named from Polk Creek, in the Caddo Gap quadrangle, along whose headwaters it is typically exposed. It is seen on steep slopes and in narrow valleys in close association with the Bigfork chert. It crops out in Polk, Montgomery, Garland, Saline, and Pulaski counties, Arkansas, as well as in the southern Ouachita Mountains, in Oklahoma. The thickness of the formation has not been accurately determined, but it apparently ranges from a feather edge to about 200 feet.

The Polk Creek shale is black, fissile, graphitic, and either very soft or hard and slaty. The softer beds are clayey, and are graphitic enough to soil the fingers. The harder beds, which are most common near the base of the formation, have been altered to a slate whose cleavage is either at an angle with the bedding or parallel to

it. On weathering the shale forms a light bluish-gray float, which indicates its presence; the rock itself crops out at but few places. Thin beds of dense, black chert and layers of quartzitic sandstone are relatively common in the formation but they make up only a minor part of it.

All divisions of the Polk Creek are contorted, jointed, and crumpled, and hence slickensided. Quartz veins occur along the joints and bedding planes, and small crystals of pyrite may be found in most fresh exposures. The lower part of the formation has been prospected for slate near Big Fork, in Polk County, and near Washita, in Montgomery County.

Fossil graptolites are common in the lower part of the formation and may be found at most outcrops. In fact, the Polk Creek is so noticeably fossiliferous in comparison with the other formations of the Ouachita area that this feature alone will usually serve to identify it. The graptolites, according to Ulrich, are related to those of the Hartfell shale of Scotland, which is late Ordovician in age.

The Polk Creek shale rests conformably upon the Bigfork chert, and is conformably overlain, at least at most places, by the Blaylock sandstone. In the Zigzag Mountains, however, where the Blaylock is missing, the Polk Creek is disconformably overlain by the Missouri Mountain formation.

The Polk Creek formation as originally deposited was a black mud, at some places more sandy than at others, but with a uniformly high organic content throughout. In the area of its exposure the rock is so intensely metamorphosed and contorted that it cannot now be regarded as a potential source of oil and gas. In areas farther north, where the formation, if present, has not suffered so much regional metamorphism, it lies deep below the surface and has not been encountered by the drill. There is some evidence, however, even in the area of its outcrop, that the Polk Creek becomes thinner toward the north. If it does, it may be thin or absent in the Arkansas Valley.

BLAYLOCK SANDSTONE

The Blaylock sandstone was named from Blaylock Mountain, in the southwest corner of Montgomery County, Arkansas, where it is typically exposed. It crops out in a small area near Bog Springs, Polk County, and in other small and generally isolated areas extending as far east as the vicinity of Malvern, in Hot Spring County. The formation is also found in McCurtain County, Oklahoma, where its area of outcrop is probably greater than in Arkansas. Along its most southern outcrops in Arkansas it has an estimated thickness of 1,500 feet, but it thins so rapidly northward that it may not be present a few miles north of places where it attains its maximum

thickness. The formation also thins toward the east, as it is only 550 feet thick at the southwest corner of the Hot Springs quadrangle, and it has further diminished to 300 feet at the southeastern edge of that area. The total thickness of the sandstone, as measured by Honess,⁴⁷ in a section near Hochatown, Oklahoma, is 804 feet. Although it is not certainly known that the formation deviates markedly from that thickness in its other exposures in Oklahoma there is nevertheless some evidence that it also thins toward the north in Oklahoma, though less rapidly than in Arkansas.

The formation consists of fine-grained, light-gray to dark-gray or green compact sandstone and interbedded argillaceous sandstone and dark shale. In Oklahoma the formation is dominantly red in its weathered exposures, but in Arkansas this feature is less noticeable, and some of the weathered materials retain their original gray tone. The sandstone occurs in even-bedded layers, which are ordinarily 1 to 6 inches in thickness, but which at a few places, attain a thickness of several feet. Most of the sandstone is hard, homogeneous, and quartzitic, but some of it is laminated and relatively soft. The rock consists essentially of fine grains of quartz, but it contains small quantities of plagioclase, zircon, tourmaline, garnet, and leucoxene, and in a few places flakes of mica. The cementing agent is either quartz or chlorite, the chlorite producing the green color commonly seen in the sandstone. Joints are numerous, and many of them are filled with thin veins of quartz, which is dominantly smoky in Oklahoma but milky in Arkansas.

The interbedded shale, which in places makes up a large part of the formation, is micaceous, dark-gray or black, and generally fissile. The beds of shale are thicker in the eastern than in the western exposures, and this fact and others indicate a southwestern source of the sediments.

The Blaylock sandstone has yielded only a few specifically identifiable fossils. These are graptolites from the interbedded shale exposed at the southern base of Blaylock Mountain, in the Caddo Gap quadrangle. According to Ulrich⁴⁸ the graptolites are more closely related to those of the Birkhill shales of Scotland than to any found in North America. As the Birkhill shales are regarded as basal Silurian, Ulrich regards the Blaylock also as of early Silurian age.

A few indeterminable remains of graptolites belonging to the family Diplograptidae have also been found at several places in the sandstone itself. In addition, some markings of obscure origin, which are ordinarily interpreted as worm trails, are very common at cer-

⁴⁷ Honess, C. W., op. cit., p. 95.

⁴⁸ Purdue, A. H., and Miser, H. D., U. S. Geol. Survey Geol. Atlas, Hot Springs folio (No. 215), p. 4, 1923.

tain horizons in the formation. Some of these markings, however, are more likely to be trails made by arthropods rather than by worms, and still others are probably impressions of plants.

At most of its exposures the Blaylock sandstone rests conformably upon the subjacent Polk Creek shale, but in the De Queen quadrangle a local conglomerate suggests a slight stratigraphic break at this horizon. A conglomerate is found also at the base of the Missouri Mountain slate, the overlying formation, in the Zigzag Mountains, but in that area the Blaylock sandstone is missing. Farther south, however, the Missouri Mountain formation overlies the Blaylock with apparent conformity. Nevertheless, the sudden appearance of the Blaylock and its rapid thickening southward suggests a disconformity at its top.

The Blaylock formation is of no value either as a source or a reservoir of oil or gas. It has suffered regional metamorphism in the area of its outcrop, and from its rapid thinning northward it apparently does not extend many miles in that direction.

MISSOURI MOUNTAIN FORMATION

The Missouri Mountain formation was named from the Missouri Mountains, in Polk and Montgomery counties, Arkansas, where it is typically exposed. It crops out in high ridges from Polk County eastward to Pulaski County, but it is absent at a few places near Mount Ida. It is exposed also in the southern Ouachita Mountains of Oklahoma. The formation is familiarly known as a slate, but it is little different in character from the metamorphosed Collier, Mazarn, and Polk Creek shales. Nevertheless, it has been prospected extensively for commercial slate near Hawes and Baer, in Garland County, and at many places in Polk and Montgomery counties. At Slatington it has been quarried for use in switchboards.

The formation is 60 to 100 feet thick in McCurtain County, Oklahoma, and ranges in thickness from a feather edge to 300 feet in Arkansas. Its thickness decreases toward the northeast in the Hot Springs district, but in other areas it appears to become thinner toward the south.

The formation consists of shale, slate, conglomerate, and sandstone. The shale is soft and argillaceous, and on fresh surfaces is gray, green, black, or red. In weathered exposures its ordinary colors are buff, green, yellow, or reddish brown, and many of the darker shales on weathering change, first to green and finally to buff. Small crystals of iron pyrite are scattered through the rock, which is intricately cut by a network of joints. Slaty cleavage is well developed at many places, but the rock does not contain enough quartz and sericite and is too rich in chlorite to form a tough, sonorous,

slate. It thus fails to meet the requirements of a first-class commercial slate, not because it has been subjected to insufficient pressure, but because of deficiencies in its composition.⁴⁹

The conglomerate at the base of the formation is best exposed on Glazypeau Creek, in the western part of the Hot Springs area, where it is about 4 feet thick. The rock is composed of limestone pebbles and cobbles and chert pebbles, embedded in a matrix of black arenaceous shale. The conglomerate is also found at a few places in the Zigzag Mountains. The layers of sandstone and quartzite average 3 to 5 inches in thickness and are more common near the top and the bottom of the formation than at the middle. Thin beds of limestone occur high in the formation in Oklahoma and carry fragments of fossils and of volcanic ash. Unfortunately, the fossils are too poorly preserved to be of any stratigraphic significance, and no others have yet been discovered. The position of the formation, however—between the Blaylock sandstone, of early Silurian age, and the Arkansas novaculite, the lower part of which is probably of early Devonian age—suggests that the Missouri Mountain formation may also be Silurian. Until further paleontologic evidence is available, these rocks are therefore tentatively regarded as either Niagaran or Cayugan (middle or late Silurian).

At some places the Missouri Mountain formation overlies the Blaylock sandstone with apparent conformity. In its northerly exposures it overlaps that sandstone and rests disconformably upon the Polk Creek shale. At most of its exposures, the Arkansas novaculite rests conformably upon the Missouri Mountain formation, but in several places the novaculite is separated from the shale by several feet of conglomerate, which Purdue and Miser,⁵⁰ however, do not regard as basal.

The Missouri Mountain formation is of no petrolifc significance in the Ouachita Mountain area, and its characteristics farther north have not yet been ascertained. If present in the Arkansas Valley district, it is deeply buried, and, so far as is known, it has not yet been encountered in wells drilled there.

DEVONIAN SYSTEM

ARKANSAS NOVACULITE

The Arkansas novaculite consists mainly of an unusual type of rock, to which Schoolcraft, as early as 1819, gave the name "novaculite," a term now in general use. Although this kind of rock is uncommon in most areas, it is widely distributed in the Ouachita Mountains; in fact, it makes up the largest part of what may be regarded as the principal formation of that region. The novaculite crops out

⁴⁹ Honess, C. W., *op. cit.*, p. 104.

⁵⁰ Purdue, A. H., and Miser, H. D., *op. cit.*, p. 4.

almost unbrokenly from Pulaski County, Arkansas, westward to McCurtain County, Oklahoma, a distance of about 200 miles. Its greatest extent from north to south is in the eastern Ouachitas, where the distance between the northernmost and the southernmost outcrop is more than 30 miles. The formation is exposed in narrow, nearly parallel disconnected belts extending from east to west, whose narrowness is due to the high inclination of the beds at most of the outcrops. Because of the great hardness of the novaculite, these belts stand out as steep, narrow ridges, both the younger and the older beds forming the adjacent valleys.

The novaculite is thickest in its southern outcrops, where its average thickness is perhaps 900 feet, but it thins toward the north rather rapidly, and is apparently absent at a few places as in the vicinity of Mount Ida. It is 800 feet thick at the southern border of the Hot Springs quadrangle, but it is 300 feet thinner at the city of Hot Springs, and only 100 feet thick at Hawes. Part of the thinning toward the north is thought to be due to a disconformity at the top of the formation and to several local disconformities within it. In Oklahoma the formation is thinner than in Arkansas, where its greatest thickness is not more than 600 feet, and in Oklahoma it becomes thinner toward the west as well as toward the north.

At practically all its outcrops the Arkansas novaculite consists of three well-defined divisions. The lower division is made up almost entirely of massive white novaculite; the middle division is composed of thin beds of black novaculite interbedded with shale; and the upper division is essentially massive, calcareous novaculite. These divisions vary greatly from place to place, both in thickness and in lithology, but at most localities they can easily be identified.

The lower division has an average thickness of about 225 feet, but, like the entire formation, it becomes thicker toward the south. At Caddo Gap its thickness is 410 feet, but in the northeast corner of the De Queen quadrangle it is only 25 feet thick. In the southern part of the Hot Springs district it is 425 feet thick, but only 10 miles to the north it is in places absent. The beds of this division are generally from 2 to 10 feet thick and are even bedded. The white color and massiveness of these beds make this division the most conspicuous one of the formation and it is generally the one that caps the ridges. Thin layers of fine, laminated sandstone are interbedded with the lower beds of novaculite at a few places in the Hot Springs quadrangle. Locally a conglomerate consisting of partly rounded sandstone and novaculite pebbles in a matrix of dense novaculite is found at the base of this division. The conglomerate is generally separated from the massive novaculite by several feet of red clay shale similar to that of the Missouri Mountain formation.

The novaculite itself is dense, homogeneous, highly siliceous, and translucent on thin edges, and is commonly bluish white. Although white is its dominant color, it is at some places red, green, brown, yellow, or even black. These various shades are produced by carbonaceous matter or by iron and manganese oxides. The rock has an uneven to conchoidal fracture and a waxy luster very similar to that of chalcedony. The novaculite is complexly jointed, the major set of joints being normal to the bedding.

The middle division of the formation ranges in thickness from about 10 to about 350 feet and becomes thinner not only toward the north, but in some degree toward the west. It is made up of interbedded shale and novaculite. The novaculite is similar to that of the lower division but is darker and is consistently thin-bedded, the layers being generally 1 to 6 inches thick. The beds of shale range in thickness from several inches to 100 feet and make up the bulk of this division. The shale is commonly black and fissile, and much of it weathers buff or reddish brown, but near Hawes, in the Hot Springs quadrangle, the division contains about 100 feet of red slate. At several other places farther west the shale has also been altered to a poor grade of slate, and much of it resembles either the Missouri Mountain shale or the shale of the lower Stanley formation. A conglomerate occurs at the base of the middle division at a number of places. It consists of small rounded to subangular pebbles of novaculite and sandstone embedded in a matrix of novaculite or of dense sandstone. This conglomerate, although it is present at many places, is probably most conspicuous in an area northwest of Hot Springs, where it rests either upon the massive lower novaculite or, where that division is missing, upon the Missouri Mountain formation. Other similar thin conglomeratic layers occur elsewhere in the division, locally replacing beds of novaculite.

The upper division of the Arkansas novaculite ranges in thickness from about 10 to about 180 feet, being thickest in its southern exposures and thinning rapidly toward the north. This division also gradually diminishes in thickness from the east toward the west, its maximum thickness in the western part of Arkansas being 50 to 75 feet less than in Garland and Hot Spring counties. This division, like the lower novaculite, is resistant and forms many low ridges. It is made up chiefly of massive calcareous, light-gray, blue, or bluish-black novaculite, but it contains also a few thin beds of the chalcedonic novaculite that is found in the lower divisions. When weathered the rock loses its calcium and manganese carbonate and becomes white and porous.

According to Honess⁵¹ the formation is remarkably similar throughout its outcrop, the descriptions of its exposures in Arkansas being applicable also to those in Oklahoma. In Arkansas, however, according to Miser,⁵² the novaculite contains calcite, which Honess was unable to identify positively in specimens from Oklahoma, in which the carbonate is dominantly rhodocrosite, or manganese carbonate.

The novaculite of the lower division is quarried near Hot Springs for oilstones or whetstones, and the common trade names of the rocks most suitable for the oilstones are "Arkansas" stone and "Ouachita" stone. These stones, obtained principally from quarries on North and Indian Mountains, in Garland County, are used extensively in the United States and are also exported to foreign countries. For many years this industry has placed Arkansas ahead of other States in the production of abrasives of this kind. The novaculite was also quarried by the Indians for use in making their stone implements.

A more detailed account of the Arkansas novaculite is given in the excellent monograph by Griswold,⁵³ or in the later works of Purdue and Miser,⁵⁴ and of Honess.⁵⁵ These writers and many others, have attempted to determine the origin of novaculite, but the question is still open. Griswold regards the rock as a siliceous mud or a very fine grained silt; Honess considers it a precipitated colloidal silica, the precipitation having been due to physical-chemical agencies rather than to organisms; and Purdue and Miser consider it a chert. Others have regarded it as a siliceous replacement of limestone or dolomite or as a product of the metamorphism of ordinary chert. Honess has found a volcanic agglomerate at the top of the lower division at a few places, and has therefore suggested that the novaculite might be a silicified volcanic ash, though he himself has pointed out that its uniformly high content of silica is hard to explain if it had this origin.

The following analyses indicate the chemical composition of the various types of novaculite:⁵⁶

⁵¹ Honess, C. W., op. cit., p. 114.

⁵² Miser, H. D., Manganese deposits of the Caddo Gap and De Queen Quadrangles, Arkansas: U. S. Geol. Survey Bull. 660-C, 1917.

⁵³ Griswold, L. S., Novaculites of Arkansas: Ark. Geol. Survey Ann. Rept., Vol. III, 1890.

⁵⁴ Purdue, A. H., and Miser, H. D., U. S. Geol. Survey Geol. Atlas, Hot Springs folio (No. 215), 1923.

⁵⁵ Honess, C. W., op. cit., pp. 109-39.

⁵⁶ Purdue, A. H., and Miser, H. D., op. cit., p. 5.

Analyses of Arkansas novaculite.

	1	2	3	4	5	6
Silica.....	99.45	99.47	99.49	99.06	99.12	^a 99.635
Alumina.....	.26	.17	.13	.30	.48	.113
Iron.....		.12	.06	.06	.02	Trace
Lime.....	.12	.09	.04	.09	.12	Trace
Magnesia.....	^b Trace	.05	.08	.13	.06	.087
Potash.....	.19	.07	.16	.13	.14	Trace
Soda.....	.54	.15	.10	.13	.24	.165
Loss on ignition.....	.06	.12	.14	.08	.22	Trace
	100.62	100.24	100.20	99.98	100.40	100.000

^a By difference. ^b Very slight.

1. "White novaculite," Hot Springs, Ark.
2. "Gray Arkansas stone," Rockport, 2 miles northwest of Malvern, Ark.
3. "Fine Ouachita," Sutton's quarry No. 6, on Indian Mountain.
4. "Ouachita," Barnes's big quarry on Indian Mountain.
5. "White Ouachita stone," Ten Mile quarry, 8 to 10 miles east of Hot Springs.
6. "White Novaculite," Hot Springs.
- 1-5. R. N. Brackett, analyst, Arkansas Geol. Survey Ann. Rept. for 1890, vol. 3, p. 161, 1892.
6. C. E. Wait, analyst, Am. Jour. Sci., 3d ser., vol. 7, p. 520, 1874.

Unfortunately, the material used for the above analyses was weathered, and hence its carbonate content does not appear in the tables.

All the Arkansas novaculite is tentatively placed in the Devonian system, but only the lower division is definitely known to be of that age. For many years the lower division has been correlated with the Camden chert of Tennessee on purely lithologic grounds. The Camden chert, formerly regarded as of Oriskany or early Devonian age, has been subdivided by Dunbar,⁵⁷ who states that the typical Camden chert is of Onondaga and not of Oriskany age. The lower part of the section, however, formerly included in the Camden, he divided into the Decaturville, Quall, and Harriman formations, which are early Devonian. Thus the Arkansas novaculite, if it is the equivalent of the undivided Camden chert, may include beds of either early or middle Devonian age, or both. Honess found a single recognizable brachiopod in the upper part of the lower division, which Schuchert identified as *Leptocoelia flabellites*, a characteristic Devonian species, but unfortunately one that may be of either Oriskany or Onondaga age. Whether the Arkansas novaculite is entirely Oriskany or contains strata belonging to both Oriskany and Onondaga cannot yet be stated with certainty.

A single collection of conodonts, small linguloids, and sporangites has been obtained from an inconspicuous novaculite conglomerate and an associated shale in the middle division of the formation at Caddo Gap, Arkansas. These fossils, according to Ulrich, indicate that the middle division of the novaculite, and perhaps the upper division also, is of the same age as the Woodford chert and the Chattanooga shale. If Ulrich is correct the upper divisions of the Arkansas novaculite should be referred to the Mississippian system. The United States

⁵⁷ Dunbar, C. O., Stratigraphy and correlation of the Devonian of western Tennessee: Tenn. Geol. Survey Bull. 21, p. 82, 1919.

Geological Survey, however, regarding the novaculite as a unit, places the upper divisions tentatively in the Devonian system. The correlation made by that organization is adopted in this report.

The Arkansas novaculite rests conformably upon the Missouri Mountain shale at most places, but a conglomerate that appears here and there at the base of the formation suggests either a slight stratigraphic break or the presence of adjacent land at the beginning of the deposition of the novaculite. The formation is disconformably overlain by the Stanley shale in the eastern part of the area of the outcrop of novaculite, but in Oklahoma the contact between the two formations is apparently conformable. In the Zigzag Mountains of the Hot Springs area the novaculite is disconformably overlain by the Hot Springs sandstone, a formation having a small areal extent in the eastern part of the Ouachita region.

The Arkansas novaculite is of no value either as a source or a reservoir of oil or gas. The formation has not been encountered by wells drilled in the Arkansas Valley, and as it becomes thinner toward the north it may not be present in that region.

CARBONIFEROUS ROCKS

The Carboniferous rocks of the Ouachita Mountains and the Arkansas Valley, like those of the Ozark province, are much more important as potential sources of oil or gas than those belonging to the older systems. Many of them contain large bodies of carbonaceous shale and beds of relatively porous sandstone, which are potential reservoir rocks. Organic material in the form of invertebrate remains is rare in these rocks but vegetable matter is abundant, and the younger Carboniferous formations are coal-bearing. Finally, the rocks of the Atoka formation have yielded gas in considerable quantities over rather large area, and the extension of that area now seems not only possible, but probable and imminent.

MISSISSIPPIAN SERIES

HOT SPRINGS SANDSTONE

The Hot Springs sandstone was so called because of its exposures near Hot Springs, Arkansas. The formation crops out along the slopes or on the crests of the Zigzag Mountains but is not found in the Trap Mountains, only a few miles to the south. As its beds are thin and stand at a high inclination, most of their outcrops form narrow bands. The formation is lenticular and is known only in the Hot Springs district.

The Hot Springs sandstone is 137 feet thick at Hot Springs, but elsewhere its thickness varies from 85 to 200 feet within relatively short distances. It consists principally of sandstone but includes

some shale and conglomerate. Shale is common only near the top of the formation and the principal bed of conglomerate occurs at its base. The sandstone is composed of fine to medium grains of quartz firmly cemented to form dense, gray, quartzitic rock. Many of the beds are 5 or 6 feet thick, but the average bed is about 6 inches thick. The sandstone is finely laminated parallel to the bedding, and fresh surfaces of it display grains of a clayey material, which Purdue and Miser⁵⁸ suggest may be the residue of feldspar or other minerals.

The rock is extensively cut by joints, most of which are nearly normal to the bedding. Quartz veins, many of them having a fibrous structure, occur in most of the joints. On account of its complex jointing the sandstone readily breaks into resistant angular fragments, which collect in great quantities in certain areas, particularly at the heads of steep-walled ravines. The sandstone gradually diminishes in quantity toward the top of the formation and the beds of black shale become thicker.

The basal conglomerate is apparently a continuous bed, which makes up a conspicuous part of the formation. Its average thickness is perhaps 12 feet, but at several places it is as much as 25 or 30 feet thick. The fragments are of all shapes and are of sizes up to about 6 inches in the major dimension. Many are rounded, but others are subangular. Most of them are novaculite, but a few are sandstone. The matrix is a fine, argillaceous sandstone, which at some outcrops is so dense that it resembles novaculite. One or two thin beds of similar conglomerate occur at many places higher in the sandstone.

The Hot Springs sandstone overlies disconformably the Arkansas novaculite, the stratigraphic break being indicated not only by the conglomerate described above, but by the eroded upper surface of the novaculite. The formation is overlain conformably by the Stanley shale, the transition from the sandstone to the shale being very gradual.

The Hot Springs sandstone is of no value either as a potential source or reservoir of hydrocarbons.

STANLEY SHALE

Definition.—The stanley shale was named by Taff⁵⁹ from the village of Stanley, in the Kiamichi Valley, Oklahoma, where it is extensively exposed. It was originally regarded as Ordovician but is now known to be Carboniferous. Whether it should be assigned to the Mississippian or the Pennsylvanian series was also until recently a

⁵⁸ Purdue, A. H., and Miser, H. D., *op. cit.*, p. 5.

⁵⁹ Taff, J. A., U. S. Geol. Survey Geol. Atlas, Atoka folio (No. 79), 1902.

debatable question, but the consensus of present opinion is that it is Mississippian.

Distribution and thickness.—The Stanley formation crops out in Arkansas in Pike, Sevier, Polk, Howard, Montgomery, Clark, Hot Spring, and Garland counties, and in small areas in the western part of Pulaski County, in the southern part of Yell County, and in the northern part of Saline County. It is exposed also over relatively large areas in McCurtain, Pushmataha, Le Flore, Latimer, Pittsburg, and Atoka counties, Oklahoma. Thus, although the formation is non-resistant, it is the surface rock over a large part of the Ouachita Mountain region. The larger areas of outcrop are intermontane basins, such as the one in which Mena is situated and the Mazarn basin, south of Hot Springs. In addition, the Stanley is widely distributed in the Athens plateau, south of the Ouachita Mountains proper.

The beds of the formation are at most places so intricately folded and are so similar one to another that it has been very difficult to ascertain their thickness either by direct measurement or calculation. Near Glenwood, in Pike County, Arkansas, it is about 6,000 feet thick, but at many places it is probably several thousand feet thicker. Honess has recorded a calculated thickness of 9,085 feet in an incomplete section near Pickens, Oklahoma. On the other hand, in the Hot Springs district it attains a thickness of probably only about 3,500 feet, but in that area the upper beds are missing. It is therefore not certain that the formation becomes progressively thinner toward the east, although it may do so.

Character.—The formation is composed of dark, fissile clay shale interbedded with fine-grained greenish-gray or bluish-gray sandstone. At most fresh outcrops the shale is blue-black or jet-black, but where the rock has weathered its predominant colors are green, yellow, and brown. Fresh surfaces of the shale near the base of the formation are at places sufficiently graphitic to soil the fingers. At some places the basal shale has been altered to a slate, formerly called the "Fork Mountain" formation.⁶⁰ This part of the Stanley has been prospected for commercial slate in Polk, Montgomery, and Garland counties. The shale usually breaks into thin, brittle plates having smooth, glossy surfaces, which bear flakes of mica. Except where the sandstone may be used to mark a geologic horizon the structure of the formation cannot be determined, because the bedding of the shale has been obscured by intense crumpling.

The sandstone, which is a prominent though subordinate part of the formation, occurs in beds from 2 inches to 3 feet in thickness. These beds, however, are invariably separated by thicker beds of

⁶⁰ Purdue, A. H., *Slates of Arkansas*: Arkansas Geol. Survey, p. 40, 1909.

shale. As the sandstone weathers rapidly it forms no ridges in Arkansas, where the formation crops out only in valleys. In Oklahoma the beds of sandstone are somewhat more resistant, and in places in that State they form low bluffs and ridges.

The unweathered sandstone is fine grained, hard, compact, and quartzitic and is greenish-gray or bluish-gray in color, but the weathered rock is soft, argillaceous, and porous, and ranges in color from green to dark brown. At some places the sandstone is conspicuously micaceous, and at practically all its exposures it contains flakes of mica. The entire formation is cut by a complex joint system, and the joints are filled with veins of white quartz from half an inch to 6 inches in thickness. Near Gillham, in Sevier County, these veins carry minerals containing lead, zinc, and antimony.

Beds of tuff occur near the base of the formation in Polk County, Arkansas, and in McCurtain County, Oklahoma. These beds have a total thickness of about 100 feet, though Honess reports a thickness of 228 feet in one section, in which, possibly, there has been some duplication of bedding. According to Miser⁶¹ there are three or possibly four or five beds of tuff, which range in thickness from 6 to 85 feet, but Honess⁶² believes that, in Oklahoma at least, there is but a single thick bed of tuff. This bed may have been reworked, however, in such a way as to obtain what appears to be 2 or more layers from a single original fall of ash. The tuff is the only recognizable stratum in the lower part of the formation, and it affords a key to the structure in the area in which it occurs.

A bed of black chert seen at about the middle of the formation lies at another horizon that is serviceable in the work of determining the structure of the intensely folded area. The beds of black chert, which are interbedded with dark shale, are carbonaceous, argillaceous, and chalcedonic and are cut by quartz veins. Some of these beds are as much as 25 feet thick, but their average thickness is somewhat less than that. These beds of chert are widely exposed in southeastern Oklahoma. They are seen at few places in western Arkansas and are not known in the eastern part of the Ouachitas.

Near the base of the Stanley shale at a number of places, both in Oklahoma and in Arkansas, there are thin layers of novaculite conglomerate, rarely over a foot thick. The conglomerate is composed of rounded, subangular or angular fragments of novaculite set in a siliceous, fine-grained, cherty matrix, which also resembles novaculite. The angularity of the fragments is more noticeable in the western than in the eastern exposures. Most of the novaculite pebbles

⁶¹ Miser, H. D., *Llanoria, the Paleozoic land area in Louisiana and eastern Texas*: *Am. Jour. Sci.*, vol. 2, p. 71, 1921.

⁶² Honess, C. W., *op. cit.*, p. 150.

were derived from the upper divisions of the Arkansas novaculite and are dark in color, but a few, which apparently came from the lower, massive part of that formation, are light gray to white.

Cone-in-cone concretions are common in the black shales of the middle Stanley in Oklahoma and have been found also in Arkansas. They consist of lenticular masses several feet across and 3 to 6 inches thick. Most of them occur in beds of black shale, and at some places they are so numerous that they touch one another. The concretions have a central core, which is horizontally schistose and is made up of dark blue, siliceous granular material, out of which grow numerous cone-in-cone concretions normal to the curvature of the surface. These concretionary masses break readily under the hammer, but they are resistant to weathering, and at many places they project from outcropping ledges of shale.

Nearly all of the sandstone and much of the shale of the formation is ripple-marked and rill-marked and cross-bedded and contains scattered fragments of organic matter. These features of the Stanley shale, as well as others, indicate that it was probably formed in a subsiding basin into which one or more large, northward-flowing streams discharged their loads. The fact that the streams were large is indicated not only by the great bulk of the sediment deposited, but by the fineness of its grain. The almost universal occurrence of ripple marks and other shallow-water phenomena suggest that the delta included mud flats. The fragments of wood in the formation were carried into the basin by the streams, which must have flowed through well-wooded areas, judging from the large quantity of woody material they laid down. In such an area of deposition, where the water is less saline than normal, marine organisms are not common, and their absence in the Stanley is natural. During storms, however, marine animals may have been carried into the delta, just as they are today washed from the sea into the fresher water near the mouths of streams. The presence of a few fragmentary invertebrate fossils in the Stanley formation may be thus explained.

Fossils and correlation.—Despite the large number of fragments of plants found in the Stanley, all are so macerated that none can be specifically identified. A few invertebrate fossils also have been found in the formation, but they are as poorly preserved as the plants. Thus the exact age of the Stanley formation is still undetermined. David White has examined most of the fossil plants and is of the opinion that they are late Mississippian or early Pennsylvanian. Schuchert and Ulrich have studied a collection of invertebrate fossils made by Honess⁶³ from the Stanley on Little River, in McCur-

⁶³ Honess, C. W., *op. cit.*, pp. 176-178.

tain County, Oklahoma, and believe that the formation is Pennsylvanian rather than Mississippian. Girty, Miser, and others, however, believe that the formation belongs to the Mississippian system, and is so regarded in this report. The thick *overlying* Jackfork formation underlies beds that carry a Morrow or very *early* Pennsylvanian fauna, and it therefore seems improbable that the Stanley also should belong to the Pennsylvanian system.

Stratigraphic relations.—The Stanley shale rests disconformably upon the Arkansas novaculite in eastern Arkansas, but the two formations are apparently conformable in Oklahoma, and perhaps in western Arkansas. In the Hot Springs district the Stanley rests conformably upon the Hot Springs formation.

The Jackfork sandstone rests conformably upon the Stanley shale, the transition between the two being so gradual that the contact is usually established arbitrarily.

Petrolific significance.—The Stanley shale is too intricately folded to be of any petrolific importance in the Ouachita Mountains. The Stanley sandstone may contain gas at some places in the Arkansas Valley area where the structural conditions are favorable to its accumulation, but at most places in that region it is too deeply buried to be reached by any but the very deepest test wells.

JACKFORK SANDSTONE

Definition.—The Jackfork sandstone was named by Taff⁶⁴ from Jackfork Mountain, in southeastern Pittsburg County, Oklahoma, where it is typically exposed. It is a resistant ridge-forming rock, which makes many of the mountains of the Ouachita area, and with the possible exception of the Arkansas novaculite it is the most prominent formation in that area.

Thickness and distribution.—The Jackfork sandstone, which is generally between 3,500 and 6,500 feet thick, forms low, westward-trending ridges on the Athens plateau south of the Ouachita range. It also forms many of the highest ridges of the Ouachita Mountains themselves, capping, among many others, Rich Mountain, Oklahoma, the highest peak between the Rocky and the Appalachian ranges.

In Arkansas it crops out uninterruptedly from the Oklahoma border, in northern Polk and southern Scott counties, to Pulaski County, and it is also found in a few scattered outcrops on the southern border of the Arkansas Valley. One of the areas of outcrop in the Arkansas Valley is a narrow belt extending northeastward between Washburn and Chismville, in eastern Sebastian and western Logan counties, and another similar narrow outcrop, extending eastward, is in northwestern Yell County, south of Waveland

⁶⁴ Taff, J. A., U. S. Geol. Survey Geol. Atlas, Atoka folio (No. 79), 1902.

and north of Petit Jean Creek. In the southern Ouachita province the Jackfork is best exposed in Clark, Pike, Howard, Sevier, and Polk counties, but it occurs also in small areas, in Hot Spring, Garland, and Montgomery counties.

Description.—In its southern exposures the Jackfork formation consists of massive, compact, fine-grained to coarse-grained, light-gray sandstone, which carries some grit near its base and includes a subordinate amount of green, black, or blue shale. Farther north the sediments become finer grained and the shales compose more and more of the section.

The beds of sandstone range in thickness from a few inches to 50 feet, and even where the shale makes up a prominent part of the formation it is inconspicuous, for the sandstone weathers in such a way as to conceal the softer beds. The brown, ferruginous beds of sandstone are firmly cemented and resistant, but the beds of lighter color are softer, and in places they are essentially saccharoidal. At some places the sandstones are quartzitic and form prominent knobs, ledges, and cliffs. As a result of the weathering of the sandstone great piles of case-hardened boulders collect on the surface, particularly on the tops of ridges and at breaks in the slopes.

The shales are commonly arenaceous, but at some places they are coal black and carbonaceous. At other places they are argillaceous and green, blue, or gray. They are generally soft and therefore they crop out at but few places.

Fossils and correlation.—A few poorly preserved invertebrate fossils have been found in the lower sandstones of the Jackfork, but their age has been determined no more definitely than that they are Carboniferous. Some of the sandy beds of shale contain the remains of plants, which, however, are invariably so macerated that they are of little diagnostic value. Nevertheless, the paleobotanic evidence indicates that these beds are of late Mississippian or early Pennsylvanian age.

The fauna found by Honess in the Carboniferous rocks of northwestern McCurtain County, Oklahoma, and assigned by him to the Jackfork sandstone, is now regarded as belonging to the basal Atoka formation, and it is considered in this report, in the text on that formation.

Stratigraphic relations.—The Jackfork sandstone rests conformably upon the Stanley shale and is overlain in Arkansas without stratigraphic break by the Atoka formation. At some places in Oklahoma it is overlain by the Wapanucka limestone; at other places it is apparently overlain by the Caney shale, though it probably inter-fingers with that formation. In Arkansas, where a Morrow fauna

has not yet been discovered at the base of the Atoka, the Jackfork can be separated from the Atoka in an arbitrary fashion. The transition from the shaly beds of the Stanley to the more sandy beds of the Jackfork is also gradual, so that the top and bottom of the Jackfork cannot be fixed definitely.

Petrolific significance.—The Jackfork formation contains some beds that may be a potential source of hydrocarbons and others that could serve as reservoirs for them, but the formation has not yet yielded either oil or gas. In the Ouachita Mountain area it either has been removed by erosion or it occurs in folded and faulted areas where the chances for obtaining oil or gas are very poor. In the Arkansas Valley, on the other hand, where the structural conditions are favorable, it generally lies too deep to be encountered in an ordinary well, but at a few places the deeper test wells may reach it, and where the structural conditions are favorable there appears to be no reason why it should not be productive.

PENNSYLVANIAN SERIES

ATOKA FORMATION

Definition.—The Atoka formation was named by Taff and Adams⁶⁵ from the town of Atoka, Oklahoma, where it is well exposed. It lies below the Jackfork sandstone and above the Hartshorne sandstone, and it is composed of alternating beds of sandstone and shale, which are variable in thickness and in general character:

Thickness and distribution.—The Atoka formation is not only widely exposed in the Boston Mountains, where it is commonly known as the Winslow, but is exposed at most places in the Arkansas Valley and in the southern part of the Ouachita Mountains. It has a greater areal extent in Arkansas than any other Paleozoic formation.

In Oklahoma it occurs in Atoka, Coal, Pittsburg, Le Flore, Latimer, McCurtain, and Pushmataha counties, where its exposures are continuous with those in Arkansas.

The formation is about 3,000 feet thick in the Atoka and Coalgate quadrangles, in Oklahoma, but in the Stonewall area, on the north and west, it is only 800 feet thick. Near the Arkansas line, however, its thickness increases to between 6,000 and 7,000 feet, and in Pike and Clark counties, Arkansas, it is equally thick. Miser⁶⁶ estimates its thickness in Yell County, as 7,800 feet and it is more than 9,400 feet thick in Perry County. North of the Arkansas Valley its thickness decreases rapidly, and only in the southern Boston Mountains does it attain greater thicknesses than 1,500 feet.

Description.—The Atoka formation comprises a series of beds of

⁶⁵ Taff, J. A., and Adams, G. I., U. S. Geol. Survey, 21st Ann. Rept., pt. 2, p. 273, 1900.

⁶⁶ Miser, H. D., Am. Jour. Sci., vol. 2, No. 8, p. 64, 1921.

sandstone and shale that underlie the coal-bearing rocks of Oklahoma and Arkansas. It has commonly been referred to as the "Lower or Barren Measures," although it does contain here and there a few thin coal seams. The ratio of sandstone to shale in the formation varies from place to place, but at most localities there is more shale than sandstone.

At a few places in Arkansas the sandstones are slightly calcareous, but no limestone occurs. In the Stonewall quadrangle, Oklahoma, there are a few thin beds of impure limestone near the base of the formation. In addition, a bed of chert, known as the Chickachoe cherty sandstone lentil, occurs in the Coalgate and Atoka quadrangles, Oklahoma. The lentil is composed of massive beds of calcareous and cherty sandstone, which shows little variation in general character. At a few places, however, a bed of pure flint and siliceous limestone occurs in exposures of unweathered rock. This bed, which is about 75 feet thick, has not been identified in Arkansas. The Chickachoe lentil occurs in the lower part of the Atoka, and where it is exposed it is a valuable horizon marker.

The shales of the Atoka are ordinarily poorly exposed. They usually crop out in valleys and on the lower slopes of ridges and hills, where they weather to a product that ranges in color from yellow to blue. In new road cuts and similar protected places the unweathered shale is blue to black where clayey and yellow to brown where sandy.

At some places, particularly in the eastern part of the exposure at Atoka, the arenaceous shales are micaceous, containing both muscovite and phlogopite mica in abundance. Such shales are commonly also carbonaceous and carry macerated and fragmentary remains of plants. These statements apply also to some of the beds of argillaceous sandstone and to a few of the thin beds of sandstone, but the massive beds of sandstone do not carry fossil plants and are not so conspicuously micaceous as the thinner beds.

Although the ratio of sandstone to shale in the formation is variable, it is possible to make a few generalizations concerning it. The sandstone becomes more abundant toward the north, and even more strikingly so toward the east. At many places in the southern part of its exposure, as near Huntington, Arkansas, and in the southwestern part, as in eastern Oklahoma, the formation consists essentially of shale. Some idea of the variability in the lithology of the formation may be gained from the graphic sections given below.

It is rather difficult to measure a detailed section of the Atoka formation, because it is generally covered with surface material and because its structure is complex. A new road cut across the ridge between Perry and Perryville, in Perry County, however, reveals an unusually complete section of the formation, which is well exposed as compared with other sections in Arkansas, and as the dip and strike are maintained throughout the section it is probably not complicated by faulting. A detailed description of this section is given

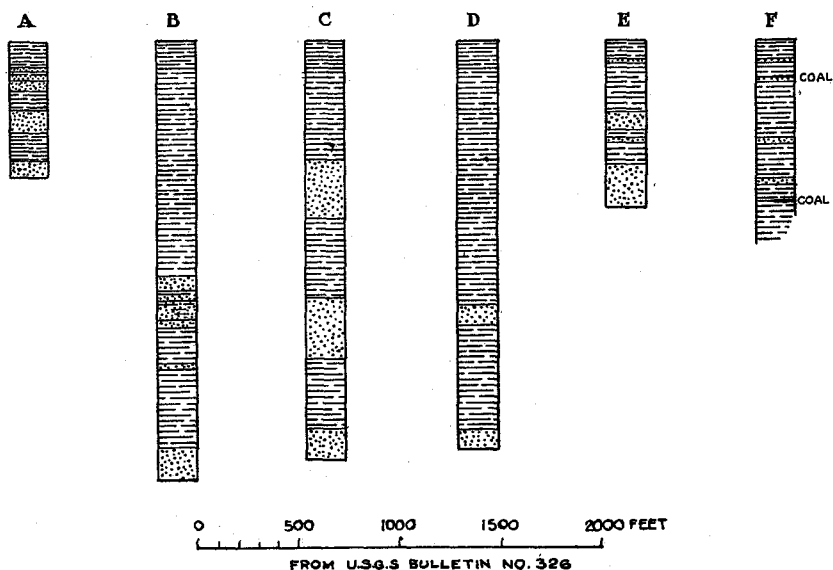


FIGURE 5.—Graphic sections of the upper part of the Atoka formation. A, north of Van Buren; B, Massard Prairie; C, Jenny Lind; D, South of Huntington; E, Denning; F, Dardanelle.

here, not only because it is the thickest and most complete one that has been measured in the formation but also because it will give operators a clear picture of the type of sediments which must be encountered in drilling in the eastern part of the Arkansas Valley.

The dip throughout the section averages 40° in a direction S. 25° E., and varies only slightly. The great thickness of the formation here, 9,400 feet, suggests the repetition of beds by faulting. At all places where the formation is covered, therefore, a careful examination for all the criteria of faulting was made, and at most of these places definite evidence that the beds were undisturbed was obtained. At a few places no certain evidence for or against the existence of faults could be obtained, but at such places the essential identity of the angle and the direction of dip above and below the covering affords a strong presumption against faulting. One badly covered interval about 3,675 feet below the top of the section is made up of

somewhat contorted beds, which may represent a possible fault zone, but as the beds above and below this stretch have the same dip and strike, and as they are not at all similar in lithology, this possible fault zone is by no means a probable one. The section follows:

Section in the Atoka formation along the State Highway between Perry and Perryville, Perry County; top and bottom not exposed.

	Ft.	In.
Coarse-grained gray sandstone in beds averaging 2 feet in thickness and dipping 42°, S. 22° E.....	26	
Gray to brown or reddish-brown arenaceous shale, with a few thin beds of sandstone. Section partly covered and rocks slightly contorted. No evidence of faulting.....	602	3
Gray to brown coarse-grained, massive sandstone, the beds averaging at least 3 feet in thickness. Dip, 42°, S. 20° E....	15	
Brown to reddish-brown sandy shale with a few thin, discontinuous lenses of sandstone. Section slightly covered, but no evidence of faulting.....	252	11
Single layer of brown sandstone, well jointed into rectangular blocks		4
Brown, sandy shale, with one layer of sandstone 2 inches thick..	1	6
Argillaceous sandstone, in single bed where fresh but weathering to numerous thin, platy layers. Dip, 40°, S. 20° E.....	1	10
Brown, arenaceous shale with a few thin layers of sandstone....	4	6
Grayish-brown sandstone.....	1	
Thinly laminated blue to brown clay shale, with a few lenses of sandstone in a partly covered section. The beds are slightly contorted, but there is no good evidence of faulting..	108	
Even-bedded, medium-grained, moderately massive, white to gray sandstone, which weathers buff and is somewhat saccharoidal. Dip, 37°, S. 20° E.....	28	
Blue to brown shale, in places somewhat arenaceous but generally fissile and slightly concretionary. Very uniform in character in general, but includes a few thin lenses of sandstone. Rock weathers to a brownish-red clay. Section partly covered, but there is practically no contortion of beds and no evidence of faulting. The average dip is 35°, S. 23° E.....	457	9
Even-bedded, well-jointed, fine-grained sandstone, which is reddish-brown where weathered and buff on fresh surfaces..	1	
Blue to brown shale and a very few thin lenses of sandstone, none over 3 inches thick.....	51	9
Fine-grained sandstone; gray with brown streaks on fresh surfaces, but weathering reddish gray. Waffle-iron surfaces are common, and the bedding is uneven.....		10
Blue to brown clay shale.....	19	3
Blue to brown shale like the above, but more arenaceous. Includes 14 layers of fine-grained sandstone ranging in thickness from ½ to 3½ inches. Dip, 40°, S. 23° E.....	22	8
Sandstone interbedded with thin shaly partings, the sandstone gray, with brown streaks. Dip, 38°, S. 20° E.....		6
Single layer of gray sandstone with brown streaks.....	1	

	Ft.	In.
Sandstone similar to the above layer.....		2
Reddish-brown shale.....		2
Dense, brownish gray sandstone.....		2
Brown to blue or grayish-blue sandy shale with few if any layers of sandstone in the upper two-thirds of the section. In the lower part of the section the sandstone becomes more and more prominent, but the thickest layer is less than 10 inches thick. The beds in this section, though somewhat covered, are not contorted and show no evidence of faulting.....	667	8
Heavy-bedded sandstone, with layers up to 2½ feet thick. The rock is dense, medium-grained and somewhat saccharoidal. It weathers a light brown, but on fresh surfaces is white to gray and has red and brown streaks.....	30	
Sandy shale and shaly sandstone, which are less sandy near the middle of the section and more sandy near the top and bottom. Section rather poorly exposed, but the beds are not contorted and there is no evidence of faulting.....	502	4
Light-colored, medium-grained, rather heavy-bedded sandstone, which weathers brown to buff.....	51	
Blue to brown shale with thin lenses of sandstone ranging in thickness from 1 to 3 inches.....	66	
Light gray to bluish-white, medium bedded sandstone.....	4	4
Brownish-red to blue shale, becoming more arenaceous lower in the section. One sandstone layer a foot thick was seen. This section is badly covered, but the beds are not contorted and there is no evidence of faulting.....	210	8
Medium-bedded and medium-grained sandstone, dirty and impure on fresh surfaces and weathering buff to brown. Partly covered. Dip, 34°, S. 30° E.....	24	3
Beds covered by debris produced by the rapid weathering of sandy shales and shaly sandstone. Beds not contorted.....	411	8
Medium to fine grained, medium-bedded, dense, bluish-gray sandstone, which weathers buff to brown. Beds are somewhat disturbed and section is badly covered. This is a possible but not probable fault zone.....	17	4
Sandy shale and shaly sandstone covered with a thick veneer of partly recemented hillside wash. The shale weathers to a light-blue clay. Near the bottom of the section (higher on the hill) the beds become more sandy, and bauxitic material is a common surface material. The strata appears to be undisturbed. Dip, 36°, S. 20° E.....	362	
Partly covered interval represented by heavy but unevenly bedded sandstone. Some of the thinner bedded dense, fine-grained material is similar to bentonite. Brecciated material, apparently of igneous origin, occurs in several beds (?), which are at least 2 feet thick. All this material is badly weathered, and it may be the source of the bauxitic material mentioned above. The weathered matrix of the breccia fuses in a forge flame in a way similar to that of the Opello volcanic breccia, described later. The fragments in the breccia are relatively well rounded pieces of dense, quartzitic sandstone and sandy shale and some subangular fragments of		

	Ft.	In.
slate. No inclusions of igneous rock were found. Dip of sandstone, 37°, S. 20° E.....	27	1
Light grayish-blue, saccharoidal sandstone, which is medium-grained and medium-bedded.....	22	4
Sandstone similar to the above, but interbedded with bluish-gray, slightly arenaceous shale, which makes up two-thirds of the section.....	27	1
Partly covered interval in which shale like that of the above unit predominate but which contains also some saccharoidal sandstone. Dip, 40°, S. 30° E.....	60	7
Medium bedded relatively coarse-grained, somewhat saccharoidal sandstone, which is light on fresh surfaces but weathers buff. Near the base of the section there are a few thin, layers of sandy shale.....	43	4
Blue clay shale, arenaceous in places, and a few layers of sandstone, the thickest 5 inches thick.....	16	9
Medium grained, medium bedded, light grayish-blue sandstone, which weathers buff. Thickest bed is 15 inches thick. Dip, 38°, S. 30° E.....	10	5
Light gray sandy shale, which weathers a dull rusty brown. Thickest layer is ¼-inch thick.....	10	
Dense brown sandstone layer.....		8
Brown shale.....		1
Dense brown sandstone.....		4
Light gray sandy shale in very thin layers. Weathers a dull brown	1	8
Thin layers of sandstone and interbedded thin layers of shale; dominantly grayish-brown.....	1	10
Two layers of dense brown sandstone.....		9
Light bluish-gray, medium-grained sandstone, which weathers buff and bears a few iron stains. At some places a few flakes of muscovite mica are seen, and at others there are clay inclusions. The beds average about 10 inches in thickness, but the thickest seen measured 30 inches and the thinnest 3 inches. There is very little shale in the section, although some beds are more argillaceous than others. The sandstone, which is somewhat saccharoidal, is remarkably uniform in character throughout the section. The rock is not very hard. Dip, 37°, S. 30° E.....	396	7
Massive, rather soft, coarse-grained, saccharoidal, light-gray to white sandstone, irregularly shot with thin veins of iron oxide, which weathers out.....	15	8
Sandstone similar to that above, equally massive, but less saccharoidal and somewhat more argillaceous.....	19	6
Blue to brown sandy shale, in part fissile, in part concretionary, containing a few layers of concretionary sandstone, the thickest measuring 3 inches.....	10	
Medium-grained, dense, grayish-brown sandstone in a single layer	1	10
Sandy shale and thin shaly sandstone, irregularly bedded and brown to blue in color. Dip, 43°, S. 30° E.....	22	

	Ft.	In.
Dense, brownish-gray sandstone with a layer 11 inches thick at the top, which is underlain by thinner, irregularly bedded layers of sandstone.....	2	9
Brown to blue clay shale and arenaceous shale, irregularly bedded, containing concretionary masses of sandstone up to 8 inches thick. No continuous layers of sandstone seen.....	53	3
Dense, heavy-bedded, brownish-gray, medium-grained sandstone, whose thickest bed is about 1½ feet thick. Dip, 40°, S. 30° E.....	18	8
Blue sandy shale, which weathers brownish-red.....	8	4
Medium-bedded brown sandstone and minor amounts of shales, but rocks becoming more argillaceous downward. A partly covered interval. Dip, 40°, S. 30° E.....	145	4
Medium-bedded, medium grained, badly fractured sandstone, which is light-gray on fresh surfaces but weathers buff.....	4	6
Blue clay shale, somewhat arenaceous in places and containing a few thin lenses of sandstone, none of them more than 5 inches thick.....	57	10
Fine-grained, thin to medium-bedded, brown sandstone.....	4	
Blue clay shale and some arenaceous shale and many layers of sandstone averaging 4 inches in thickness. Slightly covered. Dip, 40°, S. 25° E.....	149	10
Medium-grained to fine-grained brown sandstone in beds ranging in thickness from 7 to 12 inches.....	7	9
Brown arenaceous shale containing one layer of sandstone 3 inches thick.....	1	10
Medium-bedded to heavy-bedded fine-grained sandstone containing a little carbonaceous matter and a few flakes of muscovite. The thickest bed measures 15 inches.....	13	
Blue clay shale.....	1	3
Sandstone like those above the blue shale.....	5	
Blue clay shale and brown arenaceous shale, including 5 layers of sandstone from 1 to 4 inches thick.....	3	8
Medium-bedded, grayish-brown sandstone in layers averaging 7 inches in thickness.....	4	2
Blue clay shale and arenaceous shale.....	1	10
Single layer of brown sandstone.....		8
Blue shale and several thin layers of brown sandstone.....	5	
Irregularly bedded, brownish-gray, slightly micaceous sandstone, which weathers to a lighter color than that seen on fresh fractures.....	7	
Blue clay shale and reddish-brown sandy shale containing a few thin layers of sandstone.....	5	
Dense, fine-grained sandstone, brownish-gray on fresh fracture.....		9
Blue clay shale.....		7
Dense, brownish-gray sandstone.....	5	
Coarse-grained, medium-bedded, slightly saccharoidal sandstone.....	6	
Blue clay shale, weathering to brown and red clay in a partly covered interval.....	6	

	Ft.	In.
Irregularly-bedded coarse-grained sandstone, which is light gray on fresh surfaces but weathers buff to brown. Relatively uniform in character but becoming more micaceous and slightly more argillaceous downward.....	38	6
Thin beds of sandstone interbedded with layers of blue clay shale and brownish-red arenaceous shale.....	7	6
Dark-gray, fine-grained sandstone and some sandy shale.....	9	3
Coarse-grained, light-gray, medium-bedded, somewhat saccharoidal sandstone containing a few flakes of mica.....	9	
Blue clay shale.....	2	8
Dense, dark-gray sandstone.....	1	1
Sandy shale with flakes containing mica.....		8
Sandy shale containing flakes of mica.....		8
Coarse-grained brownish-gray sandstone.....		11
Arenaceous shale that weathers reddish brown.....		5
Medium-bedded to heavy-bedded coarse-grained somewhat saccharoidal sandstone containing some flakes of mica.....	10	4
Sandstone interbedded with very arenaceous shale; sandstone is darker, denser, and more micaceous than those above.....	4	6
Light grayish-blue sandy shale.....	1	9
Dense, dark-brown, micaceous sandstone.....	1	2
Coarse-grained, somewhat saccharoidal, slightly micaceous sandstone containing a few veinlets of limonite (?). In fresh exposures this rock is a single massive bed.....	10	4
Sandstone like the above but thinner bedded and slightly more argillaceous	1	10
Sandstone like the massive layer above but somewhat thinner bedded, the layers ranging in thickness from 3 to 28 inches	45	
Blue clay shale and sandy shale containing a few lenses of coarse sandstone, which are shaly and thin bedded. Some carbonaceous material and poorly preserved plant remains..	3	4
Massive layer of sandstone, fine-grained to rather coarse-grained and somewhat micaceous. Dip, 41°, S. 25° E.....	4	4
Sandstone and interbedded sandy blue clay shale. The sandstone is micaceous, containing both muscovite and phlogopite. Contains also carbonaceous material and macerated plant remains.....	2	10
Dark gray micaceous sandstone.....	1	10
Poorly cemented, relatively coarse-grained sandstone containing a few flakes of muscovite and macerated fragments of plants		6
Medium-bedded to heavy-bedded, somewhat saccharoidal, coarse-grained, and slightly micaceous sandstone, which is white to gray on fresh surfaces.....	10	9
Interbedded thin sandstone and shale. The beds of sandstone are dark-gray and average 5 inches in thickness. They contain some carbonaceous material.....	3	9
Brown to red shaly sandstone and arenaceous shale.....	2	6
Dense, dark-gray sandstone.....		10
Blue carbonaceous shale containing some muscovite mica and many macerated fragments of plants.....		6
Dense, gray, medium-grained sandstone.....	2	7

	Ft.	In.
Light-gray, medium grained to coarse-grained, medium-bedded to heavy-bedded micaceous sandstone, which is thinner-bedded and more ferruginous near its base.....	8	10
Blue clay to arenaceous shale.....		10
Light-gray, coarse-grained, micaceous sandstone.....		10
Blue clay shale, sandy in some places.....		7
Light gray, coarse-grained sandstone.....		11
Light-blue clay shale.....	3	6
Brown to buff coarse-grained poorly cemented sandstone.....	4	4
Blue clay shale and arenaceous shale.....	3	
Brown sandstone with a layer 11 inches thick at the top and becoming thinly laminated near the base.....	1	8
Coarse-grained, light gray, heavy-bedded to irregularly-bedded iron-stained sandstone.....	10	
Thinly laminated, dark gray, coarse-grained, micaceous sandstone containing considerable carbonaceous material.....		11
Dense, dark-gray to brown, micaceous sandstone.....	2	8
Blue carbonaceous shale containing a few thinly laminated layers of sandstone.....	2	11
Irregularly bedded, ferruginous, medium-grained buff sandstone.....	1	2
Blue carbonaceous fissile shale.....	2	2
Relatively dense, dark-gray micaceous sandstone.....	2	1
Light to dark blue, slightly micaceous shale containing a few thin lenses of sandstone.....		10
Dense, dark-gray, micaceous sandstone.....	2	
Blue clay shale and thinly laminated gray, micaceous sandstone containing carbonaceous material.....	2	7
Dense, dark gray, thin-bedded sandstone.....	2	1
Blue to brown shale, fissile above and having a more hackly fracture below. The shale becomes more arenaceous downward. Weathers to brown and red clay.....	42	
Shaly thin-bedded sandstone and lenticular sandstone. Darker and coarser sandstone lower in the section and considerable carbonaceous material. Partly covered interval.....	24	1
Dense, somewhat quartzitic sandstone. Dip, 40°, S. 30° E.....	2	3
Blue fissile clay shale.....	1	6
Dense quartzitic sandstone.....	1	2
Blue fissile shale and a few layers of sandstone an inch thick....	8	
Fine-grained micaceous sandstone.....	1	2
Thin bedded and irregularly bedded sandstone with interbedded coarse-grained and dense layers. Some blue fissile shale.....	1	3
Blue, fissile, carbonaceous shale containing a few very thin layers of sandstone.....	2	10
Fine-grained dark-gray sandstone.....		7
Blue shale containing lenses of argillaceous, carbonaceous, and slightly micaceous sandstone and macerated remains of plants.....	1	3
Fine-grained, dark-gray, micaceous sandstone.....	1	5

	Ft.	In.
Blue shale and some sandy concretionary layers, fissile in some places and relatively arenaceous in others, but becoming more sandy downward. Beds are not contorted and there is no evidence of faulting.....	45	6
Buff to dark gray, thin-bedded, alternating dense and coarse-grained sandstone.....	2	10
Medium-bedded, medium-grained, light brown, slightly micaceous sandstone.....	9	4
Thinly laminated blue shale and very thin layers of micaceous sandstone, which contain macerated remains of plants. Shale fairly resistant.....	7	6
Light gray to buff, medium-grained, slightly micaceous sandstone	4	1
Thin-bedded fine-grained to coarse-grained micaceous and carbonaceous sandstone containing macerated remains of plants. Micaceous gray to buff sandstone, with shaly partings and a few inclusions of fissile shale. Blue sandy shale and lenses and layers of finely laminated sandstone.....	3	
Buff to gray, dense, medium-grained sandstone.....	3	1
Thin-bedded, rather coarse-grained carbonaceous and micaceous sandstone containing remains of plants.....	6	7
Thinly laminated blue shale, weathering brownish-buff.....		5
Buff to brown fine-grained, micaceous sandstone.....	1	9
Thinly laminated, slightly fissile, blue shale and thin layers of fine-grained buff sandstone.....	4	10
Relatively coarse-grained, buff, somewhat saccharoidal sandstone	8	6
Sandstone similar to the above, interbedded with beds of blue shale and of thin arenaceous shale. Somewhat covered. Sandstone beds slightly concretionary near the top, but becoming more regularly bedded below, where they contain macerated remains of plants. Average thickness of sandstone beds, 2½ inches. Dip, 41°, S. 25° E.....	42	1
Dense buff sandstone.....	2	8
Intimately and irregularly interbedded buff, medium-grained sandstone and blue, fissile to arenaceous shale.....	16	6
Medium-bedded, poorly cemented, light brown to buff, somewhat concretionary sandstone, containing flakes of muscovite and phlogopite.....	12	9
Irregularly bedded blue to brown carbonaceous shales and a few thin beds of buff sandstone, which carry macerated remains of plants.....	2	
Buff medium-grained sandstone.....	2	7
Thin bedded to thinly laminated buff micaceous sandstone containing macerated remains of plants.....	2	7
Dense, buff, non-micaceous sandstone.....	2	5
Blue clay shale and sandy shale interbedded with thin beds of fine-grained micaceous sandstone.....	3	5
Medium-bedded to heavy-bedded, fine-grained sandstone, only moderately well cemented and carrying some flakes of muscovite. Thickest bed about 5 feet thick. Beds relatively		

	Ft.	In.
uniform in character but becoming more micaceous and saccharoidal downward. No shale seen in section.....	62	10
Blue carbonaceous shale in a partly covered interval, in which the beds are undisturbed.....	9	3
Medium-bedded, buff, slightly saccharoidal sandstone.....	14	7
Medium-bedded, dense brown sandstone, becoming thinner bedded and more argillaceous downward.....	5	8
Medium-bedded, slightly quartzitic, relatively clean sandstone showing stains of iron oxide and some flakes of mica. Dip, 40°, S. 30° E.....	11	5
Sandstone like the last but thinner bedded, and associated with a small amount of blue, carbonaceous shale.....	21	2
Medium-bedded to irregularly bedded brown sandstone and some black shale and thinly laminated sandstone.....	3	1
Fissile blue shale.....		1½
Dense buff sandstone.....	1	
Fissile blue shale.....		4½
Medium-grained, massive, buff sandstone containing very little mica.....	3	5
Light bluish gray clay shale containing considerable muscovite and some sand.....		7
Massive buff sandstone similar to one next above.....	3	1
Thinly laminated, blue to gray clay shale.....		7
Sandstone, thin-bedded above and having a massive layer below. A little blue shale in the upper part.....	4	8
Irregularly bedded argillaceous, micaceous sandstone.....		11
Massive, fine-grained, micaceous buff sandstone.....	3	
Fissile blue clay shale.....		3½
Thinly laminated, micaceous, buff sandstone.....	1	4
Blue carbonaceous shale; at some places fissile, at others arenaceous, thinly laminated and fairly resistant. Beds not contorted. Sand content becomes greater lower in section, where the rock is more micaceous.....	20	2
Fine-grained, non-micaceous, buff sandstone.....	1	7
Thinly laminated blue shale and lighter arenaceous shale.....		10
Medium-grained, medium-bedded, micaceous buff sandstone, with irregularly bedded sandstone and a little blue shale at its base.....	5	10
Buff sandstone, thinly laminated at the top, grading downward into a single layer.....	2	
Fissile blue shale.....		2½
Blue shale and thinly laminated sandy shale, containing interbedded layers of sandstone, the larger 6 inches thick.....	8	8
Fine-grained, heavy-bedded brown sandstone, with thin parting of blue shale near the top, and irregularly bedded sandstone near the base.....	7	7
Blue carbonaceous shale with thin layers of sandstone.....		10
Dull gray, medium-bedded, fine-grained, micaceous sandstone....	2	1
Thin-bedded to medium-bedded sandstone interbedded with thinly laminated blue shale. Lower part of section consists predominantly of arenaceous shale.....	13	4

	Ft.	In.
Massive, fine-grained, micaceous, buff sandstone, containing some carbonaceous matter.....	3	8
Arenaceous and blue clay shales.....	1	8
Medium-bedded, medium-grained, buff micaceous sandstone, which becomes more argillaceous downward.....	2	
Blue clay shale.....		4
Grayish-blue, medium-bedded, fine-grained, slightly micaceous sandstone	2	8
Grayish-brown, arenaceous clay shale containing abundant macerated remains of plants.....		9
Blue carbonaceous and somewhat arenaceous shale, and thin interbedded buff, fine-grained sandstone, the shale predominating	19	
Medium-bedded sandstone with interbedded, thinly laminated argillaceous sandstone, which is micaceous and carries macerated remains of plants.....	14	
Blue carbonaceous shale and thinly laminated interbedded sandy shales. The basal argillaceous sandstone is micaceous and carries some carbonaceous matter.....	2	4
Medium-bedded, fine-grained, buff sandstone and a few thin partings of blue shale and several layers of thinly laminated, micaceous, plant-bearing sandstone.....	16	6
Thinly laminated sandstone and blue carbonaceous shale, with an 8-inch bed of irregularly bedded sandstone in the middle	3	5
Fine-grained, medium-bedded buff sandstone; thinner bedded to laminated below.....	8	3
Interbedded blue clay shale becoming arenaceous downward and thin, regularly bedded sandstone, which is micaceous. Partly covered interval, but beds are undisturbed.....	25	6
Section like that above, but sandstone is in heavier beds and predominates. The shale is arenaceous, and the thinner beds of sandstone are micaceous and carry remains of plants.....	22	10
Medium-bedded, fine-grained, buff, micaceous sandstone containing in its thinner beds some carbonaceous material.....	9	
Thin-bedded sandy shale and argillaceous sandstone becoming more arenaceous and less regularly bedded downward.....	5	8
Medium-grained, medium-bedded to heavy-bedded buff micaceous sandstone, which becomes heavier bedded and more saccharoidal downward. Dip, 38°, S. 24° E.....	16	6
Interbedded thin sandstone and blue arenaceous shale.....	2	7
Medium-bedded, fine-grained, buff micaceous sandstone.....	2	5
Shaly sandstone and interbedded fine-grained, buff micaceous sandstone, in lenses.....	1	4
Medium-grained, heavy-bedded, buff micaceous sandstone.....	5	10
Blue fissile carbonaceous shale, irregularly bedded arenaceous shale, and a few discontinuous thin lenses of sandstone.....	3	4
Massive, fine-grained buff sandstone.....	5	2
Shaly sandstone and brown to blue arenaceous shale containing flakes of mica and macerated remains of plants.....		10

	Ft.	In.
Medium-bedded to massive-bedded, medium-grained, somewhat saccharoidal sandstone containing both muscovite and phlogopite mica.....	6	4
Thinly laminated sandy shale, blue clay shale, and a few thin layers of sandstone.....	2	8
Medium-bedded, fine-grained, micaceous buff sandstone.....	4	3
Fissile blue carbonaceous shale underlain by thinly laminated shaly sandstone, which is micaceous and somewhat carbonaceous	6	2
Massive-bedded, medium-grained, micaceous buff sandstone, in places poorly cemented, which becomes somewhat saccharoidal near its base.....	30	8
Blue carbonaceous shale; in places slightly arenaceous, in others fissile.....	2	5
Thin-bedded, fine-grained, non-micaceous, buff sandstone.....	2	2
Irregularly-bedded sandy blue shale.....	2	1
Medium-bedded, somewhat saccharoidal buff sandstone, which is dirty and carbonaceous in places and rather dense in its upper part	3	7
Medium-bedded, poorly cemented, slightly micaceous buff sandstone	2	7
Thin layer of blue shale and a thin layer of clay sandstone above.....		8
Medium-bedded to massive-bedded sandstone like that next above the overlying shale.....	4	10
Thinly-laminated interbedded buff sandstone and blue shale....	4	3
Fissile black carbonaceous shale.....		9
Irregularly-bedded, fine-grained, non-micaceous buff sandstone	2	9
Blue carbonaceous shale.....	1	7
Fine-grained buff sandstone; irregularly-bedded above, massive below, containing relatively little mica.....	3	6
Thin buff sandstone and interbedded blue fissile shale.....	4	5
Fine-grained buff sandstone.....	1	3
Blue carbonaceous, thinly laminated shale, predominating over thinly laminated sandstone.....	12	3
Irregularly bedded fine-grained buff sandstone.....	2	
Blue carbonaceous shale.....		4
Sandstone like that above shale.....		5
Blue carbonaceous shale.....		3
Medium-bedded, medium-grained, iron-stained, buff sandstone..	5	
Thinly-laminated, medium-grained, dirty carbonaceous shaly sandstone	2	1
Medium-bedded, fine-grained buff sandstone.....	5	1
Blue shale and dirty shaly sandstone; thinly laminated near the base.....	6	6
Medium-bedded, fine-grained, buff sandstone containing but little mica.....	7	8
Light-blue, slightly sandy shale, carrying mica and macerated remains of plants.....		2½
Sandstone like that above the overlying shale.....	1	

	Ft.	In.
Interbedded blue to black carbonaceous fissile clay shale, in places arenaceous, and thinly-laminated sandstone, which predominate in the lower part of the section. Several thin layers of dirty carbonaceous sandstone carry considerable mica and macerated remains of plants. Dip, 39°, S. 30° E.	31	2
Partly covered interval represented by blue carbonaceous, fissile shale above and a few interbedded layers of shaly sandstone, which carry macerated remains of plants. Becomes more arenaceous downward, where the fracture is hackly rather than fissile. Thin layers of sandstone appear near the base. Beds slightly contorted but not faulted.	74	
Medium-grained, poorly cemented, slightly micaceous buff sandstone	8	4
Reddish-brown, rather soft, relatively fine-grained but poorly cemented shaly sandstone.	18	6
Irregularly bedded, medium-grained buff sandstone.	1	2
Blue carbonaceous shale, fissile below and sandy above.	6	11
Thin layers of sandstone, coarse-grained and micaceous, and some layers of sandy shale. Dip, 41°, S. 28° E.	2	4
Thin-bedded to medium-bedded buff micaceous sandstone.	3	5
Blue carbonaceous shales and thin-bedded dirty argillaceous sandstone, above which is micaceous sandstone carrying macerated remains of plants.	3	10
Medium-bedded, medium-grained, buff sandstone.	11	
Blue fissile carbonaceous shale and a few thin, irregularly layers of sandstone. Shale becomes more arenaceous toward the base.	10	
Irregularly bedded, slightly micaceous, medium-grained buff sandstone	3	2
Fissile blue carbonaceous shale, slightly arenaceous at top of section but relatively uniform in character throughout. Beds very little contorted and not faulted.	47	3
Thin-bedded, dense buff sandstone containing conspicuously phlogopite mica.	1	6
Black carbonaceous shale and a few thin beds of sandstone.	4	5
Medium-bedded, dark-gray, somewhat quartzitic sandstone containing but little mica.	2	5
Black carbonaceous shale and a very little sandstone.		9
Irregularly-bedded, fine-grained, micaceous buff sandstone and, in the upper part, some carbonaceous, arenaceous shale.	3	3
Black carbonaceous, fissile shale and poorly cemented shaly sandstone, which weathers rapidly. Some concretionary sandstone. Beds not contorted; no faulting.	33	9
Massive layer of semi-quartzitic blue-gray, dense sandstone. Weathered surface lighter than that seen on fresh fracture.	1	11
Black carbonaceous, fissile shale, without sandstone. Beds not contorted; no faulting.	29	4
Black carbonaceous shale like the above, but with a few layers of sandstone, from 2 to 6 inches thick.	7	4
Medium-bedded, medium-grained, somewhat micaceous and carbonaceous buff sandstone interbedded with blue clay		

	Ft.	In.
shale and sandy shale. Sandstone predominates.....	18	6
Medium-bedded sandstone like that above, but coarser grained, interbedded with very little black carbonaceous shale.....	13	8
Black carbonaceous shale with thinly laminated dirty, micaceous, plant-bearing shaly sandstone at the base.....	3	5
Medium-bedded semi-saccharoidal buff sandstone, becoming heavier bedded and coarser grained downward.....	34	4
Fissile blue carbonaceous shale.....		10
Light bluish-gray, medium-grained, micaceous, slightly carbonaceous sandstone, which is massive in the middle of section and irregularly-bedded and not so well cemented near the base.....	23	2
Blue carbonaceous clay shale.....	1	4
Buff sandstone, dense above, semi-saccharoidal below, and heavy, better cemented layer at the base. Dip, 39°, S. 30° E.....	18	10
Blue fissile carbonaceous shale in a partly covered interval. No layers of sandstone seen in the upper two-thirds of section and only a few irregular layers in the lower third. A few clay ironstone concretions. Beds not contorted or faulted.....	164	9
Medium-bedded, fine-grained, buff to brown sandstone.....	7	8
Blue fissile shale and poorly cemented clay sandstone. Dip, 44°, S. 27° E.....	3	5
Medium-bedded, fine-grained, slightly micaceous light-gray sandstone and some interbedded shaly sandstone.....	4	10
Blue clay shale and some argillaceous micaceous sandstone, which carries macerated remains of plants.....	5	7
Blue clay shale, with a layer of poorly cemented thin, fine-grained buff sandstone in the middle and two thin layers of sandstone near the base.....	7	7
Fine-grained, slightly micaceous buff sandstone.....	1	
Blue clay shale, grading into impure, dirty, micaceous plant-bearing sandstone near the base.....	1	2
Medium-bedded, fine-grained buff sandstone containing very little mica.....	4	6
Light-blue clay shale, somewhat sandy and micaceous in places and carrying macerated remains of plants.....		10
Sandstone like that above the shale.....	1	4
Blue clay shale.....		3½
Medium-bedded, fine-grained buff sandstone. Dip 46°, S. 27° E.....		6
Blue, fissile shale and, near the top, a few thin, micaceous plant-bearing layers of sandstone. Section rather uniform in character, but varying in sand content from place to place. Near the base of the section there are thin layers of irregular-bedded, concretionary, argillaceous sandstone. Beds only slightly contorted; not faulted.....	46	3
Fine-grained, medium-bedded to irregularly bedded, micaceous buff sandstone, argillaceous above and poorly cemented below.....	5	10

	Ft.	In.
Poorly cemented sandstone and blue-gray clay shale, alternating in a partly covered interval. Most of the shale is arenaceous and the sandstone is fine-grained, micaceous, and buff to brown in color. Beds undisturbed and not faulted. Dip, 45°, S. 26° E.	18	
Badly covered interval in which blue shale predominates. Arenaceous near both top and bottom and argillaceous in the middle. One layer of sandstone 15 inches thick 40 feet from top of section. Beds appear to be undisturbed and not faulted.	130	5
Medium-bedded, medium-grained, poorly cemented buff sandstone in a partly covered interval. Some clay shale near the base.	28	9
Medium-bedded, medium-grained, non-micaceous buff sandstone.	2	9
Partly covered interval in which the beds are undisturbed, represented by alternating sandy shale and shaly sandstone. Shale predominates in lower half. Some of the sandstones are dirty and carbonaceous and contain macerated remains of plants.	60	1
Medium-bedded, medium-grained, somewhat saccharoidal buff sandstone in a partly covered interval, in which shale is inconspicuous.	37	7
Sandstone similar to that above, interbedded with shaly sandstone and blue shale. Some layers of sandstone as thick as 12 inches, but shale predominates.	57	7
Medium-bedded, medium-grained buff sandstone containing but little mica. Some blue shale in the middle of the section.	5	3
Blue clay shale.	2	7
Sandstone like that above the overlying shale.	2	1
Partly covered interval in which the beds are undisturbed. Sandy shale and considerable medium-bedded, medium-grained, micaceous rather soft buff sandstone. Dip, 42°, S. 27° E.	502	6
Massive, medium-grained, micaceous, buff sandstone, which is interbedded with some shaly sandstone and a little blue clay shale. The sandstone greatly predominates, and many of its beds are 2 to 3 feet thick. A partly covered interval in which accurate measurement of individual beds is impossible. No evidence of faulting. Dip, 45°, S. 27° E.	240	6
Medium-bedded to massive, medium-grained, light to buff sandstone, most resistant near top and bottom, more argillaceous near middle. Basal layer about 7 feet thick.	33	6
Partly covered interval in which beds of sandy shale and shaly sandstone predominate over thin beds of sandstone. Dip, 45°, S. 22° E.	50	4
A badly covered interval, which becomes totally masked by recent deposits near the base. Medium-bedded to heavy-bedded, cream-colored to buff sandstone of medium grain, and sandy shales near the top. Last dip obtainable, 45°, S. 20° E. Rest of section without exposures, but continues northward to its intersection with the projected strike of		

Ft. In.

the rocks in the ridges west of Perry, where the dip is essentially the same, 46°, S. 20° E. Base of Atoka not exposed.

Calculated thickness.....1,378

*Grand total for incomplete section.....*9479 10

The top and the bottom of the formation are unexposed, and it is impossible even to guess how much the section would be increased by the addition of the missing beds. The Hartshorne formation, at any rate, is not known to be preserved anywhere along the axis of the Perryville syncline, and the highest beds now preserved there are by calculation several hundred feet above the uppermost beds included in the section. The lowest beds of the Atoka are effectually concealed under the marshes north of Perry. It is conceivable, however, that a westward-trending strip of the Jackfork may be exposed near Perry and that beds of that formation make up the lower part of the section. Such an explanation of the great thickness of the sediments here assigned to the Atoka formation is, perhaps, natural, but the facts do not seem to fit the explanation. For instance, the Atoka, which is very thick farther west, becomes coarser grained toward the east, and naturally should thicken in that direction, and the sediments are of the same general character throughout and admit of no separation except a purely arbitrary one.

At several places the Atoka formation is cut by sandstone dikes, the most spectacular of which is shown in Plate XXVI. This dike is 5 or 6 miles north of Steve, on the road between that post office and the town of Plainview. The dike itself is composed of fine-grained, light-gray to dark-gray, irregularly-bedded sandstone enclosed in shaly sandstone, which is somewhat concretionary and is contorted for 3 to 4 feet on both sides of the dike. The Atoka in this vicinity contains other masses of concretionary, irregularly bedded sandstone, but none of them is dike-like. The Atoka shale apparently dips 62°, N. 10° W. at this point, and the dike dips 71°, N. 80° W.

Dikes composed of very fine, dark-brown sandstone cutting coarse red sandstone of the Atoka have been observed in Sec. 18, T. 8 N., R. 12 W., where at one place two dikes intersect, one striking N. 44° E. and the other N. 90° E. These dikes have a maximum thickness of about 6 inches, but their average thickness is less than 2 inches. They have no bearing on the problem of finding oil or gas.

The Atoka formation contains sporadic coal beds at several places, particularly in the eastern part of the Arkansas Valley. These beds of coal, which are perhaps thickest south and west of Danville, are practically all less than 18 inches thick, and the coal is ordinarily mixed with dirty, highly carbonaceous shale. In fact, there are practically all variations from coal to carbonaceous shale, and the



SANDSTONE DIKE IN THE ATOKA FORMATION 5 MILES
NORTH OF STEVE, IN YELL COUNTY

shale is at a few places essentially graphitic. Shale of this type, however, is rare or absent in the Arkansas Valley, and is most conspicuous in the Ouachita Mountains. A bed of such shale, 6 inches thick, occurs in the SE. $\frac{1}{4}$ of the SE. $\frac{1}{4}$ of Sec. 35, T. 4 N., R. 26 W.

The several variations from coal to carbonaceous shale are well shown in a section on the south side of the road between Chickalah and Sulphur Springs, in Sec. 14, T. 6 N., R. 22 W. Another similar section occurs high in the Atoka formation along the road up to the top of Carrion Crow Mountain, in Sec. 5, T. 7 N., R. 19 W., where the micaceous shaly sandstone is so carbonaceous that it is black and resembles asphaltic sand. The general aspect of this phase of the Atoka is shown in Plate XXIII, B. (p. 88). This view shows also the irregularity of bedding that is a common feature of the formation at certain horizons.

As the outcrop of the Atoka formation is of great areal extent, a rather determined effort was made during the field season of 1927 to find a practicable basis for subdividing it, but the effort was unsuccessful. The formation varies so greatly in character from place to place that a section determined at one locality may be invalidated within a mile. Indeed, in some good exposures the rocks vary considerably within less than a hundred feet, the sandstone grading laterally into shale and vice versa within short distances.

Of course, this great variation is not perfectly typical, for in some places certain lithologic units are identifiable over rather large areas. Any attempt to map such divisions over large areas, however, is doomed to failure. Undoubtedly a part of the irregularity is due to the rapidity with which the sediments accumulated, the conditions of sedimentation differing greatly in different parts of the basin at the same time. These facts and the nearly absolute lack of fossils make long-range correlation within the formation practically impossible.

In spite of the difficulties mentioned above, geologists will have no great trouble in mapping local structure by using certain locally distinctive beds in the Atoka.

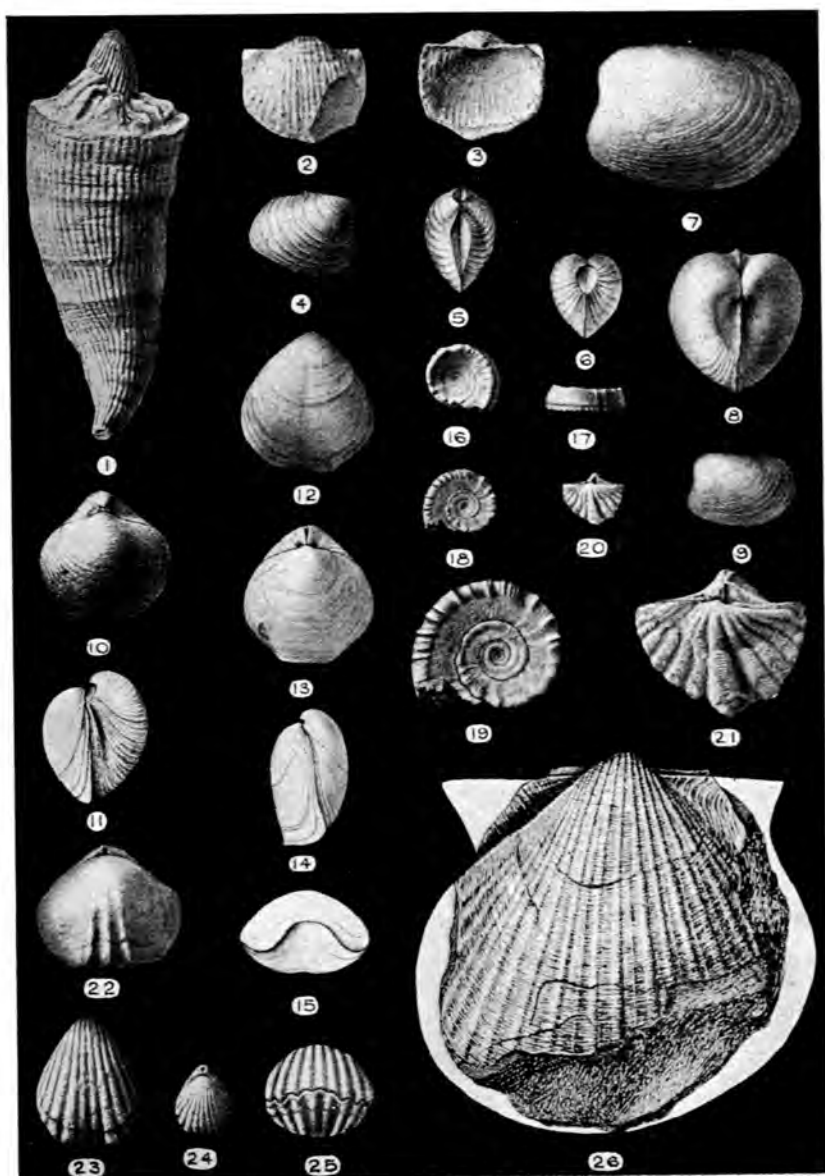
Fossils and correlation.—Fossil plants are common in the Atoka formation, but most of them are too poorly preserved to be identified specifically. Fairly well preserved plant remains, however, have been found in Sec. 14, T. 6 N., R. 22 W., in a fine, sandy clay that underlies coaly material and carbonaceous shale, which have already been described. Similar fossils were collected from an abandoned mine dump in Sec. 36, T. 6 N., R. 23 W. All these plants have a Pottsville aspect, but they have not been carefully studied.

In the course of the field work an interesting assemblage of fossil plants, preserved as sandstone casts, was found in a road-cut in the

PLATE XXVII
CHARACTERISTIC FOSSILS OF THE ATOKA FORMATION

Few of the fossils found in the Atoka formation are as well preserved as those illustrated in this plate.

- FIGURES 1. *Lophophyllum profundum*. Alar view of a specimen showing the pseudocolumella, $\times 1\frac{1}{2}$. This species is also found in the Morrow group but is very rare there.
- 2-3. *Marginifera muricata*. Pedicle and brachial views of an imperfect specimen.
- 4-6. *Astartella varica*. Lateral, cardinal, and anterior views of a perfect specimen.
- 7-9. *Nuculopsis ventricosa*. Lateral and anterior views, $\times 2$; and lateral view, natural size, of a typical specimen.
- 10-11. *Squamularia perplexa*. Brachial and lateral views of a characteristic specimen.
- 12-15. *Composita subtilita*. Pedicle, brachial, lateral, and anterior views of a characteristic specimen.
- 16-19. *Schizostoma catilloides*. Under, lateral, and upper views of a characteristic specimen, natural size; and an upper or apical view of the same, $\times 2$.
- 20-21. *Spiriferina kentuckyensis*. Brachial view of a distorted specimen, and the same, $\times 3$.
22. *Pugnax rockymontana*. Brachial view of a typical specimen.
- 23-25. *Hustedia mormoni*. Pedicle view of a large specimen, $\times 2$; brachial view of the same, natural size; and an anterior view, $\times 2$.
26. *Deltopecten texanus*. Left valve of a large, incomplete specimen.



CHARACTERISTIC FOSSILS OF THE ATOKA FORMATION

NW. $\frac{1}{4}$ of Sec. 24, T. 5 N., R. 19 W. Most of the fossils were fragments of the trunks, branches, foliage, and roots of lycopods, chiefly of the genera *Lepidodendron* and *Sigillaria*. Some of the specimens were large, several being 6 feet long and a few as much as a foot in diameter. A number of specimens have been uncovered in grading the road. Some of these were lying among the boulders at the filled side of the roadway; others were exposed in the cut at the other side. At this place, where the fossil plants constitute a small "petrified forest," they are much more numerous than usual, but isolated fragments of lycopods have been found at many places in the Atoka formation. (See Pl. XXVIII.)

Most of the invertebrate remains found in the Atoka formation are poorly preserved and difficult to identify. They have been found at several places and apparently at many horizons, but they are nowhere numerous, and many of them are fragmentary or macerated. A number of specimens collected by Collier from the upper part of the Atoka near Van Buren were identified by Girty⁶⁷ as follows:

*Invertebrate fossils from the southwest corner NW. $\frac{1}{4}$ NE. $\frac{1}{4}$ Sec. 15,
T. 9 N., R. 32 W.*

<i>Lophophyllum profundum</i>	<i>Myalina perniformis</i>
<i>Derbya</i> sp. (not <i>crassa</i>)	<i>Astartella vera</i>
<i>Productus</i> sp.	<i>Nucula ventricosa</i>
<i>Squamularia perplexa</i>	<i>Edmondia</i> aff. <i>E. nebraskensis</i>
<i>Spirifer rockymontanus</i>	<i>Pleurophorus angulatus</i>
<i>Composita subtilita</i>	<i>Macrodon obsoletus</i>
<i>Hustedia mormoni</i>	<i>Patellostium</i> (?) sp.
<i>Aviculopecten</i> sp.	<i>Orthoceras</i> sp.

From NW. $\frac{1}{4}$ Sec. 15, T. 9 N., R. 32 W., 3 miles northwest of Van Buren.

Crinoidal fragments	<i>Pleurophorus angulatus</i>
<i>Lophophyllum profundum</i>	<i>Soleniscus klippiarti</i>
<i>Composita subtilita</i>	<i>Pleurotomaria</i> sp.

From road 50 paces south of railroad, in Sec. 9, T. 9 N., R. 31 W.

Crinoidal sp.	<i>Hustedia mormoni</i>
<i>Prismopora</i> sp.	<i>Macrodon obsoletus</i>
<i>Rhombopora</i> sp.	<i>Dellopecten occidentalis</i>
<i>Derbya</i> sp. (not <i>crassa</i>)	<i>Schizodus</i> sp.
<i>Marginifera muricata</i>	<i>Pleurophorus immaturus</i> (?)
<i>Composita subtilita</i>	<i>Naticopsis</i> sp.
<i>Dielasma</i> (?) sp.	<i>Pleurotomaria</i> sp.
<i>Spirifer rockymontanus</i>	

Similar groups of fossils were collected at several other places, most of them from dirty, rusty, ferruginous sandstone, in which the specimens are preserved as casts. The faunal lists in all such collections are very similar to the above and to one another. The most

⁶⁷ Girty, G. H., U. S. Geol. Survey Bull. 326, p. 32, 1907.

common species are *Lophophyllum profundum*, *Composita subtilita*, *Hustedia mormoni*, *Spiriferina rockymontanus*, *Dellopecten occidentalis*, and *Pharkidonotus percarinatus*. All these forms are relatively long-ranged, but the general aspect of the fauna is Pottsvilleian. In the western part of the Coalgate quadrangle, in Oklahoma, similar faunal assemblages have been noted in the Atoka. A collection from Sec. 26, T. 1 N., R. 8 E., contains the following species:⁶⁸

Rhombopora sp.	Spirifer cf. cameratus
Derbya crassa (?)	Dielasma subspatulatum
Composita subtilita	Schizodus sp.
Spiriferina kentuckyensis	Bellerophon sp.
Squamularia (?) transversa	Phillipsia (?) sp.
Hustedia mormoni	

From sandstone in central Sec. 20, T. 1 N., R. 8 E. the following were obtained:

Fish tooth	Pharkidonotus percarinatus
Schizodus cf. meekaus	Gastropod trails
Allerisma terminale	

None of the faunas found above the base of the Atoka is particularly diagnostic, but a very distinctive fauna is found in a friable ferruginous sandstone that marks the base of the formation in northwestern McCurtain County, Oklahoma.⁶⁹ This fauna, which is found in Sec. 17, T. 1 S., R. 24 E., Sec. 30, T. 1 S., R. 22 E., and Sec. 6, T. 1 S., R. 23 E., has been listed by Honess as follows:

*Zaphrentis gibsoni	*Spiriferina transversa
Aulopora angularis	Spiriferina spinosa
Aulopora magna	*Spirifer rockymontanus
Aulopora gracilis	*Reticularia cf. setigera
Polypora sp.	*Brachythyris laticosta
Rhombopora sp.	*Hustedia brentwoodensis
Many underterminable bryozoa	*Hustedia miseri
*Chonetes arkansanus	Composita subtilita
Chonetes sp.	*Composita wasatchensis
*Productus cf. gallatinensis	*Composita cf. gibbosa
Productus sp. (1)	Edmondia sp.
Productus sp. (2)	Nucula anadontoides
Productus sp. (3)	*Nucula parva
*Pustula punctata	Nucula sp.
Pustula moorei	*Leda bellistriata
Avonia sp.	Leda rugosa
Marginifera splendens	Parallelodon obsoletus
*Squamularia transversa	Parallelodon tenuistriatus
*Rhipidomella pecos	Leiopteria jackforkensis
Rhipidomella sp.	Leiopteria sp.
*Schizophoria resupinoides (?)	Conocardium parrishi
*Girtyella cf. emarginata	*Myalina orthonota

⁶⁸ Morgan, Geo. D., Oklahoma Bureau of Geol. Bull. 2, pp. 64-65, 1924.

⁶⁹ Honess, C. W., Oklahoma Bureau of Geology Circular 3, pp. 14-18, 1924.



STIGMARIA. A GIANT TREE-LIKE LYCOPOD (ROOT) FOUND
IN THE ATOKA FORMATION EAST OF CHICKALA

<i>Schizodus wheeleri</i>	<i>Platyceras parvum</i>
* <i>Aviculopecten</i> cf. <i>herterzi</i>	<i>Zygopleura rugosa</i>
* <i>Aviculopecten halensis</i>	<i>Meekospira peracuta</i> var. <i>choctawensis</i>
<i>Aviculopecten</i> sp. (1)	<i>Meekospira</i> sp.
<i>Aviculopecten</i> sp. (2)	<i>Sphaerodoma intercalaris</i>
<i>Allerisma</i> cf. <i>geinitzi</i>	<i>Sphaerodoma primigenia</i>
<i>Pleurophorus oblongus</i>	<i>Orestes nodosus</i>
<i>Cypricardella oblonga</i>	<i>Conularia crustula</i>
<i>Cypricardella</i> n. sp.	<i>Orthoceras</i> sp.
<i>Astartella</i> n. sp. (1)	<i>Metacoceras cornutum</i>
<i>Astartella</i> n. sp. (2)	<i>Gastrioceras excelsum</i>
<i>Plagioglypta annulistriata</i>	<i>Gastrioceras</i> sp.
<i>Pharkidonotus percarinatus</i>	<i>Griffithides</i> sp.
<i>Euphemus carbonarius</i>	* <i>Eupachyrcinus</i> cf. <i>magister</i>
<i>Phanerotrema grayvillense</i>	<i>Eupachyrcinus</i> sp.
* <i>Worthenia</i> (?) <i>tabulata</i>	<i>Crinoid stems and plates of doubtful genus</i>
<i>Worthenia</i> sp.	<i>Fragments of wood</i>
<i>Euconospira arkansana</i>	<i>Shark spine</i>
<i>Trepsira depressa</i>	
<i>Euomphalus catilloides</i>	
<i>Strophostylus</i> cf. <i>subovatus</i>	

The species marked with asterisks occur also in the Morrow fauna, and their large number indicates a close relation between the two. The greater abundance of gastropods and pelecypods in the Atoka is perhaps due in part to the fact that the Atoka is more sandy, but since many of the species found in the Morrow do not appear in the Atoka, and vice versa, the Atoka of McCurtain County is probably somewhat younger than the Morrow, a probability that is supported by other paleontologic evidence, such as the absence in the Atoka collections of the genera *Pentremites* and *Archimedes*, as well as other forms representing the Mississippian residual element in the Morrow fauna. On the other hand, the large number of species that are common to both formations indicates their essential contemporaneity, and the deposition of the upper part of the Morrow may have been simultaneous with the deposition of the lower part of the Atoka of McCurtain County, Oklahoma.

The fauna of the Atoka considered above was formerly assigned to the Jackfork by Honess,⁷⁰ but both Honess and Miser are now of the opinion that it is a fauna of the lower part of the Atoka. A similar Atoka fauna was discovered near Clarita, Oklahoma, in lithologically similar lower Atoka beds by L. C. Snider in 1916, and the species found were listed by K. F. Mather as follows:⁷¹

<i>Camophyllum torquium</i> (Owen)	<i>Chonetes laevis</i> Keyes
<i>Rhombopora</i> sp.	<i>Productus layettevillensis</i> Mather
<i>Prismopora concava</i> Mather	<i>Productus gallatinensis</i> Girty (?)
<i>Chonetes choteauensis</i> Mather	<i>Spirifer rockymontanus</i> Marcou

⁷⁰ Honess, C. W., op. cit.

⁷¹ Mather, K. F., Am. Jour. Sci., vol. 43, pp. 133-139, 1917.

<i>Squamularia perplexa</i> (McChesney)	<i>Astartella</i> n. sp.
<i>Composita wasatchensis</i> (White)	<i>Euphemus carbonarius</i> (Cox)
<i>Nucula parva</i> McChesney	<i>Worthenia tabulata</i> (Conrad)
<i>Yoldia glabra</i> Beebe and Rogers (?)	<i>Orestes</i> sp.
<i>Caneyella</i> (?) n. sp.	<i>Euconospira turbiniformis</i> (Meek and Worthen)
<i>Pseudomontis precursor</i> Mather	<i>Strophostylus remex</i> (White)
<i>Myalina cuneiformis</i> Gurley (?)	<i>Platyceras parvum</i> (Swallow)
<i>Myalina orthonota</i> Mather	<i>Aclisina</i> ? sp.
<i>Schizodus affinis</i> Herrick	<i>Orthoceras</i> sp.
<i>Schizodus wheeleri</i> (Swallow) (?)	<i>Metacoceras</i> sp.
<i>Schizodus telliniformis</i> Girty	<i>Pronorites cyclolobus</i> var. <i>arkansasensis</i> Smith
<i>Deletopecten occidentalis</i> (Shumard)	<i>Gastrioceras listeri</i> (Martin)
<i>Aviculopecten arkansanus</i> Mather	<i>Gastrioceras hyattianum</i> Girty
<i>Plagiostoma</i> (?) <i>acosta</i> Cox	<i>Gastrioceras angulatum</i> Girty
<i>Pleurophorus subcostatus</i> Meek and Worthen (?)	<i>Gastrioceras carbonarium</i> von Buch
<i>Pleurophorus</i> n. sp.	<i>Gastrioceras kesslerense</i> Mather
<i>Pleurophorus</i> sp.	

The fauna listed above, although not so diversified as that from McCurtain County, is nevertheless very similar to it, and the two may be regarded as essentially equivalent. The fauna from Clarita comprises 42 species, of which 33 occur elsewhere. Of these 33 species 20 are found in the Morrow, but the Clarita fauna, like that of McCurtain County, does not contain the Mississippian residual element of the Morrow fauna.

It therefore cannot be doubted that the Atoka formation is of early Pottsville age, but whether basal Atoka (south of the Arkansas River) and upper Morrow sediments were deposited contemporaneously is a debatable question. The Wapanucka limestone, with its *Pentremites*, is probably the equivalent of the Brentwood limestone of the Morrow group, but its fauna appears to be older than that of either the Clarita or the McCurtain County Atoka beds. The basal Atoka fauna has not been discovered in Arkansas.

Stratigraphic relations.—The Atoka formation in general rests conformably upon the Jackfork sandstone and is overlain conformably by the Hartshorne sandstone. In northern Arkansas the Atoka (Winslow) rests upon the Morrow group, perhaps with slight unconformity. In Oklahoma the Atoka rests at some places on the Wapanucka limestone and at others on the Caney shale.

Petrolific significance.—The Atoka formation includes beds that lie at all the known gas-producing horizons in the Arkansas Valley. It is therefore an interesting formation to the geologist, and it is of equal interest to the operator, for, as it is the surface rock over large areas, most of the drilling is confined to it.

The location and the history of the oil and gas fields that have been developed by production from the Atoka formation, the origin



POTHOLE IN HARTSHORNE SANDSTONE ON CREST OF THE
EASTERN SPUR OF PETIT JEAN MOUNTAIN, SOUTHWEST
OF MORRILTON

of the gas, the history of drilling, the well records, the present known area of potential production, the future extension of that area, and the general structural conditions are all discussed fully elsewhere in this report.

HARTSHORNE SANDSTONE

Definition.—The Hartshorne sandstone was named by Taff from the town of Hartshorne, in Pittsburg County, Oklahoma, where it is typically exposed. The formation lies at the base of the productive coal measures of Arkansas and is the most widespread sandstone stratum in the Arkansas Valley province.

Thickness and distribution.—Over much of the area of its outcrop the Hartshorne is more than 100 feet thick, but it ranges in thickness from about 20 feet to as much as 300 feet. Its easternmost exposure, probably, is in Faulkner County, Arkansas, where it is thought to cap Round Mountain, 3 miles southeast of Preston. It extends westward into Pontotoc County, Oklahoma, so that the area of its exposure, measured from east to west, is about 240 miles long, although its outcrops are not continuous throughout that distance.

In Arkansas the formation crops out in Sebastian, Scott, Crawford, Franklin, Johnson, Logan, Yell, Pope, Perry, Conway, and Faulkner counties. In Oklahoma it occurs in Pontotoc, Atoka, Coal, Pittsburg, Latimer, Le Flore, Haskell, and Sequoyah counties. In both States the actual extent of the formation is much greater than that indicated by its areas of exposures, for it commonly is found in narrow bands around synclinal areas, in which it is covered by younger sediments.

Description.—The formation is essentially sandstone, but it is not markedly different from many of the heavier beds of sandstone of the Atoka or the Jackfork formation, except that it is more widespread and less variable in character. At most exposures it consists of very irregularly bedded, massive strata, which make a prominent ridge wherever the dip is moderately high. At some places, however, the formation consists of two thin beds of sandstone and an intervening bed of arenaceous shale, and at other places it consists of a single thin bed of sandstone. At a few places, as at Russellville, on the north side of the Shinn basin, the Hartshorne is made up entirely of beds of soft sandy shale, which do not appear in the topography despite their rather high dip. On the south side of the Shinn basin, less than a mile away, the formation consists of 75 feet of sandstone, thinner bedded and less irregular than usual, which makes a prominent ridge. Near Fort Smith the formation is less than 20 feet thick and the sandstone is subordinate in amount to the shale.

Although these variations are striking, they are unusual rather than typical, for over large areas the sandstone maintains a relatively uniform character. Even where the formation is least typical it may be identified by means of the Hartshorne coal, which is generally found immediately above the sandstone. These beds of coal occur in the overlying Spadra shale, and the base of the lower coal bed is arbitrarily taken as the lower limit of that formation. It is not known whether this lower coal bed extends continuously over the Arkansas coal field and the Oklahoman area or whether there are several beds at about the same horizon, one of which is generally seen. In the McAlester district of Oklahoma and near Montreal and Burma, in Arkansas, there are two definite coal horizons, the upper Hartshorne coal ordinarily being about 50 to 100 feet above the top of the Hartshorne sandstone. Over much of the Arkansan coal district, however, there is but a single well-defined Hartshorne coal horizon, which is the lower one.

At many places the Hartshorne sandstone is so intricately cross-bedded in that it is very difficult to take exact readings of the dip of the beds of this formation. At other places, particularly on the tops of ridges, the sandstone occurs in very massive layers that show rounded and exfoliated surfaces (see Pl. XXX). In such positions the sandstone is also characterized by peculiar "waffle-iron" surface markings, such as are shown in Plate XXXI. Furthermore, along the very crests of some of the highest ridges the Hartshorne sandstone is marked by fairly large potholes. All these features are of considerable interest, but their explanation does not lie within the scope of this report.

The sandstone is generally brown or yellowish-brown, but at a few places it is nearly white. It is medium-grained and ordinarily well cemented, but locally it is saccharoidal and very porous. No coal has been found in the formation in Arkansas, but a workable seam occurs near the top of the sandstone in the vicinity of Hartshorne, Oklahoma.

Fossils and correlation.—A few fragments of *Stigmara* have been found in the Hartshorne formation, but it is otherwise totally barren of organic remains. At many places, however, lumps of mud that had been included in the sandstone have weathered out and left cavities resembling casts of invertebrate fossils, for which they often have been mistaken. The age of the formation must therefore be determined otherwise than by direct paleontologic evidence. David White,⁷² however, has examined the flora of the roof shales of the overlying Hartshorne coal and has referred the coal bed to a position

⁷² White, David, U. S. Geol. Survey 19th Ann. Rept., Pt. 3, p. 468, 1899.



EXFOLIATION IN MASSIVE HARTSHORNE SANDSTONE NEAR
MILL CREEK, ON OUTA RIDGE

thick. This measurement does not necessarily indicate a diminution of thickness southward; it rather suggests that the shale has been sheared and squeezed into the present abnormally thin section in that part of its exposure.

In Arkansas the Spadra is best exposed in Sebastian and Johnson counties, but it also occurs in Scott, Crawford, Franklin, Logan, Pope, and Yell counties.

Description.—The Spadra formation consists mainly of fine-grained, blue-black or gray clay shale, but in places it contains thick lenses of sandstone. One such bed of sandstone occurs near Burma, in Sebastian County, and forms the parting between the upper and lower Hartshorne coals. This particular bed attains a thickness of 60 feet, but it thins out and disappears within a few miles from its point of maximum thickness. At many other places similar, though usually thinner beds of sandstone are found. All these are irregularly cross-bedded (see Pl. XXXII, A) and resemble the Hartshorne sandstone in their general lithologic features, but no one of them is of more than local areal extent.

The residual soil produced by the weathering of the Spadra shale is poor and thin and supports only a scant vegetation. Many hillsides in its area of outcrop are therefore so poorly covered by both plants and soil that the black shale appears widely at the surface and lends a drab tone to the landscape.

Fossils and correlation.—A number of fossil plants and a few invertebrate fossils have been found in the Spadra shale, particularly in the shale just above the Hartshorne coal. The Spadra flora is only slightly typical, and so many of the species found in it are found also in higher formations that the floras are of little value for use in systematic correlation. The floras do, however, indicate that the sediments of the Arkansas coal field accumulated more rapidly than those of the Appalachian area, and that all of the McAlester group is probably of Allegheny age. The evidence of the invertebrates collected in Arkansas supports that of the plants, but it is no more definite.

From a study of fossils found in the Stonewall quadrangle, Oklahoma, Morgan⁷⁶ has reached the conclusion that the lower part of the McAlester (=Spadra) is the equivalent of the upper Millsaps formation of Texas, and hence is older than the Cherokee formation of Kansas and Missouri. As the Spadra flora is clearly of early Allegheny age, however, the sediments in which it occurs are probably somewhat younger than Morgan supposed. In fact, it seems

⁷⁶ Morgan, G. D., Okla. Bureau of Geol. Bull. 2, p. 71, 1924.



TYPICAL WAFFLE-IRON OR TRELLIS SURFACE OF HARTSHORNE SANDSTONE ON OUITA RIDGE NORTHWEST OF RUSSELLVILLE

that the Spadra may be younger than basal Cherokee, which is of Pottsville age.

Stratigraphic relations.—The Spadra shale rests conformably upon the Hartshorne sandstone and is overlain without stratigraphic break by the Fort Smith formation.

Petrolific significance.—The Spadra shale has yielded neither oil nor gas from any of the many test borings that have penetrated it in prospecting for coal. Furthermore, there is no reason to suspect that it will produce either at any place in Arkansas.

FORT SMITH FORMATION

Definition.—The Fort Smith formation comprises the middle or sandy division of the McAlester formation as described by Taff. In Arkansas these beds are easily distinguished from the overlying and underlying beds of shale, and were assigned by Collier to a separate formation. The rocks are well exposed in the vicinity of Fort Smith, which is the type area of the formation.

Thickness and distribution.—The Fort Smith formation is widely exposed in the western part of the Arkansas Valley of Arkansas. It crops out in Sebastian, Crawford, Scott, Franklin, Logan, Johnson, Pope, and Yell counties, but its exposures in the two counties last named are small and represent only the lower beds.

The formation ranges in thickness from about 375 to about 525 feet and is somewhat thicker in Oklahoma than in Arkansas.

Description.—The Fort Smith formation in Oklahoma consists of three or four thick beds of sandstone and intervening thick beds of shale. The entire section is about 500 feet thick. The sandstone is somewhat more variable in Arkansas, and the shale is more arenaceous.

The beds of sandstone are ordinarily ripple marked, but the irregular cross bedding that is so common in the Hartshorne sandstone is relatively rare in the Fort Smith formation. The shale is arenaceous at practically all its outcrops, and the soil it forms is sandy and is yellow to red in color. This soil is so different from that formed by the disintegration of the enclosing formations that it indicates in a general way the areal extent of the formation. At some places, as at Fort Smith and Cabin Creek, flaggy sandstone has been quarried for use as flagstones and building material.

Coal is found at several horizons in the formation, but it is ordinarily of small extent, and it is too thin to be mined. Near the top of the formation, however, there is an 18-inch coal bed that was formerly stripped near Fort Smith.

The formation is well exposed near Greenwood, and the lower bed of sandstone, which is the same that is exposed at Fort Smith, makes

the ridge forming the rim of the synclinal basin in which the town of Bloomer is situated. The lower sandstone is exposed also in Tennessee Ridge near Jenny Lind, but Grand and Coal ridges and Wolf Hill are capped by higher beds of sandstone. In the eastern part of the Arkansas Valley coal field the upper part of the Fort Smith formation has been eroded, but the bed of sandstone exposed near Spadra and in Big Danger Hill, near Clarksville, is probably higher in the formation than that exposed in Tennessee Ridge or at Fort Smith.

Fossils and correlation.—A few fossil plants have been found in some of the coal beds. White⁷⁷ has referred them to the Coal Hill flora, which in his judgment is not younger than the middle Kittanning coal of the Allegheny series. The Fort Smith flora is also somewhat like that of the Hartshorne sandstone, but it is obviously younger.

Stratigraphic relations.—The Fort Smith sandstone rests conformably upon the Spadra shale and is overlain without stratigraphic break by the Paris shale.

Petrolific significance.—The Fort Smith formation has not yielded either oil or gas in Arkansas, and although some gas may be obtained from it in a few areas where the structure is favorable, neither will be obtained from it in commercial quantities in Arkansas.

PARIS SHALE

Definition.—The Paris shale was named by Collier from Paris, Arkansas, near which it is typically exposed. It is composed of clay shale, arenaceous shale, and minor amounts of sandstone, and it contains at least one workable coal bed. It is the upper division of the McAlester group as defined by Taff.

Thickness and distribution.—The Paris shale is exposed chiefly in two broad synclinal areas, one south of Charleston and the other forming the Paris basin. It occurs also in smaller exposures on the slopes of Sugarloaf, Poteau, and Magazine mountains, where it is overlain by younger beds. Although its largest areal extent is in Logan County, it is well exposed in Franklin County and, to a less extent, in Sebastian and Scott counties.

The formation is of relatively uniform thickness over large areas, being between 600 to 700 feet thick near Paris, Arkansas, and 700 feet thick at McAlester, Oklahoma.

Description.—The Paris shale is in many respects similar to the Spadra formation but is generally lighter in color and more arenaceous. The shale is gray, brown, yellow, or black and is somewhat more resistant than the Spadra shale. The sandstone is ordinarily

⁷⁷ White, David, U. S. Geol. Survey Bull. 326, pp. 20, 27-28. 1907.



A. CROSS BEDDING IN ONE OF THE RARE SANDY PHASES OF THE SPADRA FORMATION EXPOSED NEAR THE CONFLUENCE OF SPADRA CREEK WITH THE ARKANSAS RIVER



B. CROSS BEDDING IN THE HARTSHORNE SANDSTONE EXPOSED IN A WASHED-OUT ROADWAY A FEW MILES NORTHEAST OF CLARKSVILLE

shaly and has no pronounced topographic expression. The Paris coal occurs about 250 feet above the base of the formation, and one or two other seams are found at many places above the Paris coal, but they are of little economic value. The McAlester coal of Oklahoma occurs in the Paris shale but is nearer the base of the formation than the Paris coal.

Fossils and correlation.—A number of fossil plants and a few invertebrate remains have been found in the sandy shale roof of the Paris coal. The flora is similar to that found in Oklahoma in the shale just above the McAlester coal. According to White⁷⁸ the flora is not younger than that of the upper Kittanning coal of the Allegheny series. The great thickness of Allegheny sediments in Arkansas as compared with their thickness in the Appalachian region is notable and indicates rapid deposition in Arkansas. This rapidity of deposition is one of the reasons for the variability of the coals in the area and for the difficulties of correlation.

The invertebrate fossils found in Arkansas belong to two species only, *Aviculopecten whitei* and *Pleurophorus subcostatus*, and although these forms are not particularly diagnostic, they do not controvert the paleobotanical evidence. In addition, Girty⁷⁹ has collected a number of invertebrate fossils in Oklahoma from a ferruginous shale about 50 feet below the McAlester coal, some from the roof of that coal, and others from the roof of the Lehigh coal, which is still higher in the formation. All these collections confirm the Allegheny age of the Paris shale and substantiate the evidence afforded by the plants as to the rapidity of sedimentation, for the faunas are essentially identical, no matter what their position in the formation.

Stratigraphic relations.—The Paris shale rests conformably upon the Fort Smith sandstone and is apparently overlain conformably by the Savanna formation at most places, but a conglomerate at the base of that formation on Magazine Mountain may indicate a short period of local erosion before its deposition.

Petrolific significance.—The Paris shale has produced neither oil nor gas in Arkansas, and as it is essentially a surface formation it is of no importance in the search for those products.

SAVANNA FORMATION

Definition.—The Savanna formation was named by Taff,⁸⁰ who failed to give a type locality; but undoubtedly the name was derived from the village of Savanna, Pittsburg County, Oklahoma, near which it is well exposed. The formation is composed of massive beds

⁷⁸ White, David, U. S. Geol. Survey 19th Ann. Rept. Pt. 3, p. 464, 1899.

⁷⁹ Girty, G. H., U. S. Geol. Survey 19th Ann. Rept., Pt. 3, pp. 541-542, 1899.

⁸⁰ Taff, J. A., U. S. Geol. Survey 19th Ann. Rept., Pt. 3, p. 437, 1899.

of brown sandstone and thick beds of shale. There are at least five beds of sandstone and an equal number of beds of shale in Oklahoma, but only the lower part of the formation is found in Arkansas.

Thickness and distribution.—The Savanna formation is exposed in Pontotoc, Pittsburg, Coal, Atoka, Latimer, Le Flore, Haskell, Muskogee and McIntosh counties, Oklahoma, where its average thickness is about 1,000 feet, but it thins toward the north and disappears near Warner. In Arkansas it caps isolated synclinal mountains in the western part of the Arkansas Valley, in Scott, Sebastian, Logan and Franklin counties. Prominent among these mountains are Short and Little Short, Magazine, Poteau, and Sugar Loaf.

The thickness of the formation in Arkansas is at least 200 feet and may be as much as 500 feet.

Description.—The Savanna formation as it appears on the Short Mountains near Paris is a massive bed of sandstone about 100 feet thick, and similar beds of sandstone appear at or near the base of the formation on Sugar Loaf and Poteau mountains. The sandstone capping Magazine Mountain is somewhat different, but it probably belongs to the same general horizon. It is about 300 feet thick and contains some conglomeratic beds, which carry chert and quartz pebbles of the size of peas. On Sugar Loaf and Poteau mountains the beds are so much obscured by talus that their contact with the Paris shale cannot be ascertained accurately, but the Savanna is at least as thick there as on Magazine Mountain.

The western exposures of the formation in the Stonewall quadrangle, Oklahoma, contain prominent beds of conglomerate, but other than those described above, similar beds have not been seen in Arkansas. Furthermore, the bed of limestone seen near Franks, Oklahoma, near the base of the formation, does not outcrop, so far as is known, east of that area.

The sandstone of the Savanna formation is generally fine grained and compact and is brown or grayish brown in color. The lowest and the highest bed of sandstone are thicker than the intermediate beds, and in general the sandstone becomes more and more resistant toward the east.

Fossils and correlation.—No collections of fossils have been made from the Savanna formation in Arkansas, but a number of specimens have been obtained at two horizons at the west end of Poteau Mountain, about $2\frac{1}{2}$ miles northwest of Coaldale, Arkansas. These fossils have been examined by Girty,⁸¹ who believes that both horizons are somewhat higher than those of other Arkansas coal beds from which fossils were collected by Collier. This finding, of course, accords

⁸¹ Girty, G. H., U. S. Geol. Survey Bull. 362, p. 34, 1907.

with the stratigraphic evidence, as well as with the paleontologic evidence obtained by Morgan⁸² in the Stonewall quadrangle, farther west. Morgan believes, however, that the Savanna is the equivalent of the lower part of the Mineral Wells formation of Texas and of the greater part of the Cherokee formation of Kansas. Girty thinks that the higher Poteau Mountain fauna is related to that of the Flint Ridge of Ohio. The faunal lists follow:

Fossils from west end of Poteau Mountain, Indian Territory, 2½ miles northwest of Coaldale, Ark.

Lophophyllum profundum	Leda bellistriata
Crinoidal fragments	Myalina aff. M. perniformis
Stenopora (??) sp.	Solenomya sp.
Fistulipora sp.	Schizodus affinis (?)
Rhombopora lepidodendroides	Allerisma terminale (?)
Lingulidiscina aff. L. convexa	Parallelodon tenuistriatus
Septopora biserialis	Cypricardinia carbonaria
Derbya crassa	Astartella concentrica (?)
Productus cora.	Astartella varica
Pustula cf. P. nebraskensis	Edmondia mortonana (?)
Marginifera ingrata	Pleurophorus immaturus (?)
Spirifer rockymontanus	Pleurophorus tropidophorus
Spirifer cameratus	Euconospira n. sp.
Spiriferina kentuckyensis	Pleurotomaria aff. P. tenuicincta
Composita subtilita	Pleurotomaria aff. P. subconstricta
Hustedia mormoni	Pleurotomaria aff. P. giffordi
Pugnax osagensis	Patellostium marcouanum
Dielasma bovidens (?)	Bellerophon harrodi (?)
Aviculopecten aff. A. coxanus	Aclisina stevensana
Aviculopecten germanus	Sphaerodoma sp.
Limaretifera (?)	Orthoceras cribrosum (?)
Pteria ohioensis (?)	Nautilus sp.
Pseudomonotis (?) sp.	Phillipsia cliftonensis (?)

Fossils from west end of Poteau Mountain, Indian Territory, 2½ miles northwest of Coaldale, Ark., at point 150 feet higher than above locality.

Deltopecten occidentalis (?)	Allerisma terminale
Myalina perattenuata	Schizodus compressus
Myalina aviculoides	Pleurophorus sp.
Aviculopinna americana	

Stratigraphic relations.—The Savanna formation includes the youngest Paleozoic beds known in Arkansas. It rests at most places with apparent conformity on the Paris shale, although the contact between the two is at no place well exposed, and a minor or local stratigraphic break may be indicated by the slightly conglomeratic nature of the formation on Magazine Mountain.

Petrolific significance.—The Savanna formation is of no importance in the search for oil and gas in Arkansas.

⁸² Morgan, G. D., Oklahoma Bureau of Geol. Bull. 2, p. 76, 1924.

SURFICIAL DEPOSITS

The surficial deposits that rest on the Paleozoic rocks are of two general types, the recent deposits, which are best developed in the flood plains of the larger streams, and the Tertiary deposits, which are made up of sand and gravel and some fairly large chert pebbles.

The recent deposits consist of fine silt and sand and contain little or no coarse material. The surfaces of those that lie along the larger stream valleys are marked by the ordinary features of flood-plains, such as marshes and ox-bow lakes.

The Tertiary deposits are widely distributed over the general low-land, which stands above the level of the present flood-plain. The material is invariably coarser than that of the more recent deposits and includes some rounded chert pebbles more than 3 inches in their largest diameter. At some places the gravel is well bedded and is more than 20 feet thick, but such deposits are rare. The ordinary Tertiary deposit is a scattered veneer of pebbles, which generally occurs at elevations from 75 to 200 feet above the level of the present streams. These deposits are found in many parts of the Paleozoic area of Arkansas and are perhaps most noticeable in the Arkansas Valley province, particularly near Webb City and south of Morrilton, but they are seen also in the vicinity of Judsonia and Bald Knob.

These surficial deposits have been only casually studied, and nothing is certainly known as to the source of their material or of the time of its deposition. Several species of *Fusulina* have been found in some of the fragments of chert, and that genus is not known to occur in any of the Carboniferous rocks of Arkansas, nor, for that matter, are any of the Pennsylvanian formations in Arkansas known to be cherty. These facts are mentioned simply to give some idea of the problems involved in the study of the surficial deposits.

None of these deposits, however, is of any direct value as a source or reservoir of oil and gas; hence they are not further considered here. On the other hand, at many places the gravel, alluvium, and soil mask the bed-rock geology so effectually that they make the determination of the structure difficult or impossible.

IGNEOUS ROCKS IN CENTRAL ARKANSAS⁸³

BY CAREY CRONEIS AND MARLAND BILLINGS

LOCATION OF THE ROCKS AND EARLIER STUDIES OF THEM

During the field season of 1927 the attention of Mr. Croneis was called to the designation, on a rough manuscript map prepared about in 1888 by Arthur Winslow and E. C. Buchanan, of an outcrop of igneous rock on the south bank of the Arkansas River near Morrilton. This general area was visited and four sills were found, one of which is probably the mass of rock discovered earlier. As such intrusive masses may affect the possibility of obtaining gas in the area, a search was made for other igneous bodies. Two volcanic necks and an additional sill were discovered, and the location of several other igneous masses was inferred, although they were not found.

What has been called the Oppello volcanic neck was first seen by Mr. W. J. Sadler of Oppello, who sent a sample of the rock to the State Geologist, Mr. G. C. Branner, who considered it a possible igneous breccia. Mr. Sadler was kind enough to take Mr. Croneis to the outcrop. (See Fig. 7.) As the time available was too short to permit a detailed search to be made for the outcrops of other igneous bodies, some samples of the Oppello breccia were shown to many of the farmers in the neighborhood. Mr. J. R. Myers of Perryville recognized in the samples a rock similar to that in an outcrop on his farm, and thus a neck on Brazil Branch was discovered. Another outcrop of igneous rock, which we have called the Perryville sill, was encountered in measuring a section of the Atoka formation between Perryville and Perry. As these intrusive masses were found in a merely casual way, not by systematic search, other igneous bodies may be discovered in the same general area. The specimens collected were studied by Mr. Billings, and the problem of their origin was considered jointly by Mr. Billings and Mr. Croneis.

The principal areas of igneous rock in Arkansas are shown in Figure 6. The rock at Murfreesboro, according to Miser and Ross,⁸⁴ is a complex volcanic neck. Four other areas of interest—Potash Sulphur Springs, Magnet Cove, Saline County, and Fourche Moun-

⁸³ In part from New areas of alkaline igneous rocks in central Arkansas: *Jour. Geology*, vol. 37, pp. 542-61, 1929.

⁸⁴ Miser, H. D., New areas of diamond-bearing peridotite in Arkansas: *U. S. Geol. Survey Bull.* 540, 1912, pp. 534-546. Miser H. D., and Ross, C. S., Diamond-bearing peridotite in Pike County, Arkansas: *Smithsonian Report for 1923*, pp. 261-272. Miser, H. D., and Ross, C. S., Diamond-bearing peridotite in Pike County, Arkansas: *U. S. Geol. Survey Bull.* 735, pp. 279-322, 1922.

tain—which have been described by Williams⁸⁵ and Washington,⁸⁶ represent deeper-seated intrusions. Several hundred small dikes and sills, which are genetically related to the larger masses, occur in the southeastern part of the Ouachita Mountains. The location of the larger masses is indicated in Figure 6 by the numbers 5 to 9. These rocks have been comprehensively studied by Williams.⁸⁷ Miser

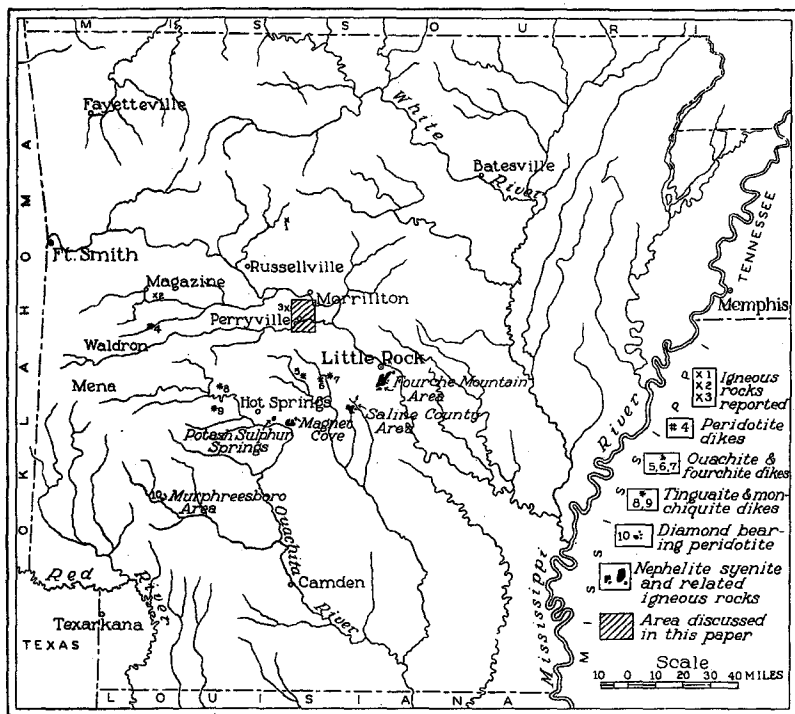


FIGURE 6.—Map showing the previously known areas of igneous rocks in Arkansas and those considered in this report.

and Ross⁸⁸ have described peridotite dikes or sills in Scott County, which lie at considerable distances from the main intrusive area. The location of these sills is shown on Figure 6 by No. 4.

The principal intrusive rocks here described lie almost in the geographic center of Arkansas, within the hachured rectangle shown in Figure 6. If the range of hills between Perry and Perryville (see geologic section accompanying Fig. 7) is taken as the boundary between the Arkansas Valley physiographic province on the north and the Ouachita Mountain province on the south, the Brazil

⁸⁵ Williams, J. F., *Igneous rocks of Arkansas*: Arkansas Geol. Survey Ann. Rept. for 1890, vol. 2, 1891.

⁸⁶ Washington, H. S., *The foyelite-ijolite series of Magnet Cove: A chemical study of differentiation*: Jour. Geology, vol. 9, pp. 607-622, 645, 670, 1901.

⁸⁷ Williams, J. F., *op. cit.*

⁸⁸ Miser, H. D., and Ross, C. S., *Peridotite dikes in Scott County, Arkansas*: U. S. Geol. Survey Bull. 735-H, pp. 271-278, 1922.

Branch breccia is in the Ouachita Mountain area, the Arkansas River sills and the Oppello breccia are in the Arkansas Valley, and the Perryville sill is about on the boundary between these areas.

The numbers 1, 2, and 3 on Figure 6 indicate other localities in Arkansas at which igneous rocks have been found. At locality No. 1, in the SW. $\frac{1}{4}$ of the SW. $\frac{1}{4}$ of Sec. 10, T. 10 N., R. 18 W., there is possibly an outcrop of "blue granite" (syenite?), which is indicated

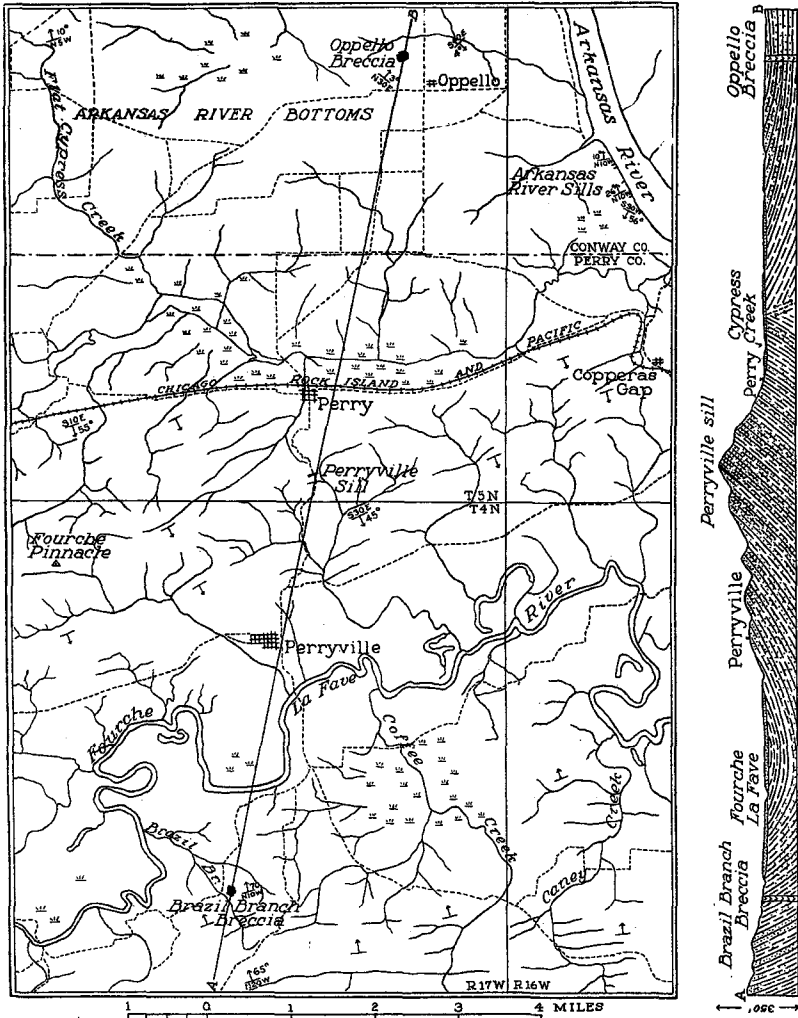


FIGURE 7.—Map of the hachured area shown on Figure 6. The rocks shown in the structure section at the right, except the recent alluvium, belong to the Atoka formation.

on a map prepared for the Arkansas Geological Survey in 1889 by H. E. Williams. The outcrop was at Thompson and Wiley's "gold mine," most of the openings of which were in the bed of Hurricane

Creek. When the locality was visited the bed of the stream was so much choked with débris that even the location of the old mine could not be ascertained definitely, and no igneous rocks were seen.

The mark $\times$ 2 on Figure 6 indicates approximately the location of a mass of peridotite, samples of which were sent to the Arkansas Geological Survey for identification. This rock was encountered in a well dug in T. 5 N., R. 26 W., probably in Section 4, but the man who sent in the sample was out of the State when the area was visited, and the exact location of the well could not then be determined.

Locality No. 3 is southeast of the village of Divide, in either Section 18 or 19, T. 5 N., R. 18 W. According to Mr. Sadler the rock obtained here is darker than the breccia found at Oppello but is otherwise very similar. It is so dark that it was mistaken for coal, and when an attempt was made to ignite it, the rock fused to glass, just as the Oppello breccia does. It therefore seems likely that there is in this area another plug of the Oppello or Brazil Branch type, but it was impossible to find the outcrop or samples of the rock.

The peridotite sill in Scott County was also visited, and, owing to the great erosion during the flood of 1927, the sill was for the first time well exposed. The enclosing rock is black clay shale of the Atoka formation. Both the country rock and the sill have an average dip of 74° , N. 18° W. The peridotite was well weathered at the surface and down to a depth of 20 to 30 inches, but rounded masses of unweathered material were found in the disintegrated zone. The bed of Freedom Creek, in which the sill is best exposed, was also strewn with cobbles of unweathered peridotite, which were standing up moderately well in the stream wash, but which showed a marked diminution in size downstream. The largest fragment seen measured 5 by 13 by 26 inches. The contact of the igneous material with the shale is sharp, and even at the contact the shale has not been appreciably altered. About 32 inches above the main sill there is a 10-inch bed of badly weathered material that looks like an igneous breccia and is somewhat similar to the rock in the Perryville sill. No peridotite was found on the projected strike of the sill, but some fragments found in a cotton patch in the SW. $\frac{1}{4}$ of the SE. $\frac{1}{2}$ of Sec. 35, T. 4 N., R. 26 W., may represent another sill.

STRATIGRAPHY AND STRUCTURE

The surface beds in the area shown in Figure 7 belong to the Atoka formation. These beds are presumably underlain here by the same rather complete section of Paleozoic sedimentary rocks that appear beneath the Atoka in areas on the south and southwest. If so, the thickness of the beds cut by the intrusion is at least 15,000 feet and may be more than 25,000 feet. Figure 7 includes a

structure section through the two volcanic necks. All the beds shown in the figure belong to the Atoka formation except the recent alluvium, which is a veneer in the bottoms of the larger streams. The breccia at Oppello was evidently intruded into essentially horizontal beds, whereas that at Brazil Branch was intruded into steeply inclined beds. The fault north of Cypress Creek is concealed by alluvium, but its downthrow is apparently on the north.

SILLS

LOCATION AND FIELD RELATIONS

Arkansas River sills.—On the southwest bank of the Arkansas River at a point where the river flows southeastward, about 5 miles south-southeast of Morrilton, in the NE. $\frac{1}{4}$ of Sec. 16, and the SW $\frac{1}{4}$ of Sec. 8, T. 5 N., R. 16 W. (see Fig. 7) there are four sills, here called the Arkansas River sills and numbered 1 to 4, the southernmost sill being No. 1.

Arkansas River sill No. 1 crops out as a row of deeply weathered boulders, whose relation to the enclosing shale has been somewhat obscured by river débris. The dip of the shale at this point, however, is 26° , N. 10° W., and the distribution of the boulders indicates that the igneous mass is interbedded. The sill is probably not more than 11 inches thick, and the adjacent shale appears to be unaltered. Although the beds here dip to the north, this sill is very near the crest of the Redemption anticline, for the dip a short distance to the south is 56° , S. 30° W.

Sill No. 2 crops out in the bank of the river about 965 feet north of No. 1. Its thickness ranges from 3 to 5 feet, but there may be two layers of igneous material separated by a thin bed of shale. The dip here is essentially the same in amount and direction as at the first sill, and the general relations are similar. About 230 feet north, sill No. 3 also crops out in the river bank, but the dip of the beds at this point has diminished to 17° , N. 10° W. Arkansas River sill No. 4 appears about 2,000 feet still farther north, where the beds dip 10° , N. 10° W. This layer is 24 to 30 inches thick, but as it weathers rapidly and appears only at the water's edge, it is likely to be overlooked. A 16-inch bed of granular black micaceous material may represent a fifth sill, for it is macroscopically similar to sill No. 4, but it is so badly weathered that satisfactory sections of it could not be made. This stratum lies stratigraphically 10 feet above sill No. 4 and is directly overlain by a 15-inch coal bed, which is unaltered.

The Perryville sill (?).—A sill is exposed in the recently cut new highway between Perry and Perryville, a little more than a mile north of Perryville. The rock weathers very rapidly, and the relation of the sill to the beds enclosing it is very obscure, but it appears on

both sides of the highway with the same strike as that of the sedimentary beds. No other sills were found in the neighborhood. The main igneous mass has weathered to a compact white clay, in which are embedded angular fragments of quartzite and sandy shale. The breccia apparently occurs in indefinite layers, several of which are at least two feet thick. Associated with the breccia is a dense, white, laminated, clay-like rock resembling bentonite. Bauxitic surface material seen down the slope from the igneous outcrop may have been derived from it.

The partly covered section in which the rocks occur is about 27 feet thick. The igneous material lies stratigraphically just above medium-bedded saccharoidal sandstone and below a thick series of poorly exposed alternating beds of sandstone and shale of the Atoka.

PETROGRAPHIC CHARACTER OF THE SILLS

Arkansas River Sill No. 2 is composed of monchiquite. Macroscopically the rock is made up of a dense gray to black groundmass containing phenocrysts of biotite, glassy black augite, a dull-black amphibole, yellowish-brown olivine, and white, vitreous apatite. The phenocrysts average from a sixteenth to an eighth of an inch in maximum dimension. The biotite, which is in part euhedral, is the most abundant mineral. Irregular grains of pyrite are scattered through the rock.

Microscopically the phenocrysts of biotite, olivine, augite, apatite, and occasionally of amphibole, are set in a groundmass of calcite. The olivine is found in unaltered euhedral to subhedral grains showing parallel extinction; the apatite occurs either as euhedral crystals (the pyramidal terminations of which are more or less rounded) or as irregular fragments. The biotite occurs either in euhedral or subhedral crystals. Most of the crystals of pyroxene are euhedral, but the amphibole generally occurs in irregular masses. The pyrite occurs in euhedral grains or in very irregular patches. The groundmass is composed of ragged, interlocking crystals of calcite, through which are scattered patches of pyrite. Microlites and stubs of unidentified minerals are also rather numerous.

Arkansas River sills Nos. 1 and 3.—Sills Nos. 1 and 3 are composed of ouachitite, which differs from the monchiquite mainly in its complete lack of olivine or in its alteration products. In addition there are minor differences, probably of no great significance, such as the presence in the ouachitite or magnetite rather than pyrite. The augite and biotite phenocrysts of sill No. 1 are surrounded by reaction rims of leucoxene. A red iron oxide is abundant in the groundmass of sill No. 3. Veinlets of calcite cut the ouachitite, and in places the calcite is distinctly fibrous parallel to the vertical crystallographic axis.

Arkansas River Sill No. 4 is so much altered that the original rock can not be determined with certainty. Macroscopically it is of medium texture, in contrast to the typical fine-grained ouachitite, and it is dotted with grains of biotite and magnetite. Under the microscope apatite, magnetite, and biotite are seen set in a groundmass of calcite. The mineral composition suggests an altered ouachitite, but the texture suggests a syenite.

Specimens from the Perryville sill (?) are so greatly altered that only the apatite remains unchanged. In the hand specimen this rock is a white, compact clay, in which are embedded white euhedral crystals of apatite and small angular fragments of gray-black shale and somewhat rounded pieces of dense, quartzitic sandstone or, more rarely, of sandy shale. No igneous inclusions were found in the matrix, although a diligent search for them was made throughout the outcrop.

The associated dense, white, laminated clay-like substance, which has some of the features of a bentonite, may be simply a part of the badly weathered groundmass of the sill itself. On the other hand, there are the alternate possibilities that either the entire section represents a Pennsylvanian tuff or that the rock is a part of another plug of the Oppello type. This question can not be answered until better exposures are found and less completely weathered material is available for study.

The rock does not swell in water, but according to Ross⁸⁹ many bentonites do not. Under the microscope the rock consists of small flakes of a micaceous mineral whose approximate indices, determined by a comparison with Canadian balsam, are $\alpha=1.53$, $\gamma=1.56$. The indices are too low for muscovite and suggest montmorillonite, a mineral characteristic of bentonite. The thin section, moreover, shows tension gaps similar to those in certain bentonites, but glass relict structure and volcanic minerals were not seen. This material does not resemble any of the sedimentary rocks of the region in which it is found.

BRECCIAS

THE OPPELLO BRECCIA

LOCATION AND FIELD RELATIONS

The rock here described as the Oppello breccia crops out about a mile west of Oppello, in the N. $\frac{1}{2}$ of the SE. $\frac{1}{4}$ Sec. 2, T. 5 N., R. 17 W., on the farm of W. J. Sadler. The country rock includes typical sandy shale and shaly sandstone of the Atoka formation, which lie essentially flat at this place. The land near the breccia is flat, is rather poorly drained, and is covered with a fairly thick mantle of

⁸⁹ Ross, C. S., Altered Paleozoic volcanic materials and their recognition: Bull. Am. Assoc. Petrol. Geol., vol. 12, pp. 143-164, 1928.

soil. The natural outcrops of the beds are therefore few and poorly exposed. The dip at a place several hundred feet west of the exposure is 3° , N. 30° E., and that at two places about the same distance to the north and to the northeast is 4° , S. 10° E. These readings may or may not suggest a regular dip of the country rock in toward the breccia, for the rocks on which they were measured are very irregularly bedded, so that the true attitude of the strata is hard to determine, but they certainly indicate that the igneous mass has not domed the beds near it. A fourth exposure of the country rock, which is not more than 50 feet east of the breccia, is covered with the water of a small stream, and the dip cannot be determined. The rock at this place, however, shows no evidence of metamorphism.

The matrix of the breccia is physically very strong, for only comparatively large charges of dynamite shatter it, but it is non-resistant chemically. The igneous mass therefore does not crop out naturally, and its size can be inferred only from the distribution of the inclusions, which remain behind after the groundmass has been completely weathered. The areal extent of this material, however, and the distribution of the encircling sedimentary outcrops indicate that the igneous plug has a diameter of 300 to 500 feet.

The granite included in the breccia represent the only certain surface occurrence of this rock in Arkansas.

PETROGRAPHIC CHARACTER

Macroscopically the Oppello breccia is composed of both angular and rounded fragments of shale, sandstone, and ouachitite and of a lesser amount of fragments of alkaline syenite and aegerite granite, which are set in a dense gray groundmass containing conspicuous crystals of biotite and, less commonly, black, glassy grains of pyroxene. The fragments of shale are very black, those of sandstone are gray when fresh and reddish-brown when altered, and most of the fragments of ouachitite bear a reddish-brown peripheral ring about a tenth of an inch thick around a gray core. The syenite and the granite are medium grained, semi-porphyrific rocks composed of interlocking white and greenish-black grains. Some of the fragments are very angular; others, especially those of ouachitite, are strikingly spherical, their form apparently having been produced by the friction caused by the churning within the volcanic neck. The fragments range in size from microscopic grains to pieces 4 inches in diameter.

The groundmass makes up about 25 per cent of the rock. It is composed of a very dense gray material, in which are set euhedral crystals of biotite and less commonly of pyroxene. In altered specimens the groundmass is nearly white, and in some places it has been stained yellow by limonite.

Microscopically the fragments may be classified as of two general types, fragments of adjacent country rock and fragments of igneous rock involved in the volcanism. The fragments of the adjacent country rock are shale and sandstone. The shale is a very dense clastic rock consisting mainly of angular fragments of feldspar and quartz, but in many specimens containing accessory flakes of mica, which lie parallel to the bedding and are rather abundant. Irregular patches of pyrite, limonite, leucoxene, and calcite may also be seen, but much of the shale is so dense that its minerals cannot be determined under the microscope. The sandstone is mineralogically similar to the shale, differing from it only in the size of the particles.

The fragments of igneous rock are mainly ouachitite but include some alkaline syenite and aegirite granite. The ouachitite is similar to the sill rock already described, for it contains phenocrysts of biotite, augite, and apatite set in a groundmass of calcite. The rock contains irregular patches of pyrite, as well as analcite, which occurs either as hexagonal grains or as vugs associated with calcite. The accessory minerals include titanite, kaolin, and leucoxene. The alkaline syenite is composed of alkali feldspar and such accessories as aegirite, biotite, garnet (brown in thin section), pyrite, and analcite. One type of the rock contains a great deal of calcite. The aegirite granite is made up of albite phenocrysts set in a groundmass of euhedral orthoclase (which is slightly perthitic) interstitial quartz, and aegirite. The aegirite occurs either in aggregates of many grains that extinguish individually or in groups of isolated grains showing simultaneous extinction. A very unusual amphibole with the following pleochroism was noted: $X =$ very light brown, $Y =$ light purple with a brown tinge, and $Z =$ light greenish-blue; $X < Y = Z$. It is probably a soda-iron amphibole.

Embedded in the groundmass of the breccia are numerous crystals, particularly of biotite, and less abundant are crystals of augite, apatite, and feldspar. Many of these crystals are nearly euhedral. The groundmass itself, which is partly altered to calcite and kaolin, is clouded and is not generally resolvable under the microscope. A number of facts, however, indicate that the matrix is pulverized rock: (1) wherever it is coarse enough to be resolvable it is composed of angular, birefracting fragments; (2) there are no flow lines around the larger fragments, such as are seen in many flow breccias; (3) the groundmass has not been so much altered as the groundmass of the ouachitite sills (which is now calcite), a fact that implies a physical or a chemical difference; (4) many of the fragments are distinctly rounded, as though by friction, and none of them show embayments such as are produced by magmatic corrosion. It is therefore con-

cluded that the non-resolvable groundmass of the breccia is pulverized rock rather than devitrified glass that congealed in place.

THE BRAZIL BRANCH BRECCIA

LOCATION AND FIELD RELATIONS

The rock here described as the Brazil Branch breccia crops out in the W. $\frac{1}{2}$ of the SE. $\frac{1}{4}$ of Sec. 29, T. 4 N., R. 17 W.; about 3 miles south by west of Perryville. The country rock is dark sandy shale or dense, black slaty shale of the Atoka formation, whose dip in this vicinity averages about 70° , N. 10° W.; but 100 yards east of the exposure of the breccia the beds are apparently overturned and the dip is 85° , S. 10° E. The exposure occurs in the valley of Brazil Branch (see Fig. 7) a perennial tributary of Fourche la Pave River. The breccia is somewhat covered by soil and old stream débris, but has apparently not been submerged for many years. The natural outcrop is very poor, but Mr. J. R. Myers, the owner of the land on which it occurs, has blasted a small pit in the rock and exposed it to the depth of several feet. This pit was cleaned out and several others were dug. All encountered fragments of ouachitite and syenite at slight depths. Several of the brecciated boulders blasted out of the pit are as much as 3 feet in their largest dimension. The rock in the pit is naturally massive. At all places where it has been exposed for some time the groundmass has weathered so rapidly that the inclusions now stand out on the surface in jagged relief.

The dimension of the intrusive mass from east to west at its outcrop is small, and the sedimentary rocks on both sides are well-bedded and unmetamorphosed and have the normal dip within 250 feet of the test pit. Upstream, or southward, the sedimentary walls of the valley converge, so that the igneous material cannot extend far in that direction, but its actual southern limit is obscured by the stream wash. The country on the north is much flatter and the soil is thicker, so that the rock may extend for some distance in that direction. A thorough examination, however, failed to find any igneous surface material. Another outcrop of the same material was said to occur upstream from the one described, but a diligent search failed to reveal its presence.

PETROGRAPHIC CHARACTER

Macroscopically the Brazil Branch breccia is composed primarily of angular fragments of black shale set in a gray to black groundmass containing crystals of biotite. Less common fragments are ouachitite, nephelite-aegirite syenite, and shonkinite. The nephelite-aegirite syenite is a white rock speckled with black grains of aegirite. Where the rock is fresh it contains greasy grains of nephelite, either as distinct hexagonal phenocrysts, not over 4 mm. in diameter, or as irregu-

lar grains interstitial with feldspar. One fragment of this rock measures nearly a foot in its maximum dimension, and the freshness of one of its surfaces indicates that it is only a part of a large inclusion.

In the hand specimen this breccia differs from that at Oppello in two respects: (1) the fragments of the breccia at Brazil Branch are mainly shale, whereas the breccia at Oppello contains numerous fragments of sandstone and ouachitite; (2) many of the fragments in the Oppello breccia are rounded, but no rounded fragments are seen in the breccia at Brazil Branch.

Microscopically the black shale is difficult to resolve under the microscope, but it contains minute flakes of mica, most of which lie parallel to the bedding, and specks and dust of magnetite. Much of the material may be chlorite.

The nephelite-aegirite syenite is composed primarily of alkali feldspar and aegirite. It contains both orthoclase and albite. Orthoclase is the dominant feldspar and is greatly kaolinized. The albite appears very fresh, lacks polysynthetic twinning, and is found either as perthitic streaks in the orthoclase or as independent grains. The aegirite occurs commonly as aggregates and has the typical right-angle cleavage, yellowish-green pleochrism, and low extinction angle. Minor accessory minerals are amphibole, titanite, nephelite, and apatite. The amphibole is of the peculiar type seen in the aegirite granite found in the Oppello breccia. The analcite occurs in small rounded or hexagonal grains, which are pink in transmitted light and isotropic under crossed nicols. A variety of the nephelite-aegirite syenite shows a distinctly banded structure. A biotite shonkinite inclusion is a fine-grained black rock consisting dominantly of biotite but containing pleochroic green amphibole and kaolinized orthoclase. The ferromagnesian minerals are distinctly dominant, and apatite and magnetite are accessories. A fragment of ouachitite is composed of phenocrysts of pyroxene, biotite, apatite, and amphibole embedded in a groundmass of calcite speckled with magnetite. Small blebs of garnet found in some places show hexagonal outlines. This ouachitite is unique in that its crystals of pyroxene commonly have cores of aegirite-augite surrounded by zones of augite—the reverse of the usual arrangement.

The groundmass in the particular slides studied differs considerably from that of the breccia at Oppello. It is composed primarily of interlocking grains of calcite, but it includes some chloritic material and many small garnets. The garnets are isotropic, are ordinarily hexagonal in section, and have an index greater than the index of calcite. Many of them have brown cores. The occurrence of garnets in ouachitite appears to be unusual, but similar brown cores in

microscopically colorless garnets have been found in alkaline syenite in Arkansas. The matrix contains scattered subhedral crystals of brown hornblende, biotite, aegirite-augite, magnetite, and apatite, an assemblage strongly suggesting that the matrix is an altered amphibole ouachitite. The matrix of the Oppello breccia apparently consists of pulverized rock.

AGE OF BRECCIAS AND SILLS

It is obvious that the breccias must be younger than the fragments of igneous rock found in them and younger than the sedimentary beds they cut. The igneous fragments are ouachitite, nephelite syenite, aegirite granite, and biotite shonkinitite. These fragments are exactly the same unusual types of rock that are found in the areas in Fourche Mountain, Saline County, Magnet Cove, and Potash Sulphur Springs, in Arkansas, and it seems reasonable to suppose that they originated at the same time. Miser⁹⁰ has shown that these peculiar alkaline rocks are younger than early Cretaceous and older than late Cretaceous. The breccias found near Oppello and at Brazil Branch were therefore probably formed during the period of mid-Cretaceous volcanism in Arkansas, and as the sills consist of rock of essentially the same type, they were doubtless formed at the same time.

ORIGIN OF THE BRECCIAS

The breccias are clearly igneous. The angularity of their fragments, their large content of comagmatic igneous material, such as ouachitite, nephelite syenite, aegirite granite, biotite shonkinitite, and their content of such magmatic minerals as biotite, augite, and apatite amply demonstrate their igneous origin.⁹¹

Unfortunately, their precise structural relations to the surrounding sediments have not yet been discovered. In their original paper the writers considered a number of working hypotheses concerning the origin of the breccias and reached the conclusion that they filled old volcanic necks. Certain facts favor this hypothesis: (1) Similar jumbled assemblages of rocks, which are in part of igneous origin, are found in many volcanic necks, as described by Geikie,⁹² who states that these assemblages include a large percentage of fragments of country rock; (2) in general appearance and lithology the breccias are very similar to certain phases of the breccia found in the perido-

⁹⁰ Miser, H. D., New areas of diamond-bearing peridotite in Arkansas: U. S. Geol. Survey Bull. 540, pp. 534-546, 1912.

⁹¹ Pirsson, L. V., The microscopical study of volcanic tugs: a study for students: Am. Jour. Sci., vol. 40, pp. 191-211, 1925.

⁹² Geikie, Archibald, The ancient volcanoes of Great Britain, vol. 1 and vol. 2, pp. 76, 292, 293, 1897.

tite neck in Pike County, Arkansas;⁹³ (3) a very similar breccia is found in association with the nephelite syenite sill at Beemerville, New Jersey, where small volcanic necks are filled with volcanic breccias like those at Oppello and Brazil Branch.⁹⁴

An outcropping bed of sandstone found about 50 feet from the breccia at Oppello lies practically flat and is unmetamorphosed. At first thought one might suppose that the sediments around a volcanic neck would be altered and disturbed, but Geikie cites many well-exposed volcanic plugs that have metamorphosed the horizontal beds of the adjacent wall rock for only short distances, such as 10 to 30 feet.⁹⁵ The size of the metamorphic aureole around the Pike County peridotite neck has not been reported, but the description of the adjacent country rock indicates that it is small.

The size and shape of the necks at Oppello and Brazil Branch are unknown, but they appear to be relatively small, perhaps not over 500 feet in diameter. The Pike County neck, including the associated peridotite, is 2,250 feet in its maximum diameter, and several of the intrusive necks at Beemerville are still smaller, one being not over 400 feet in diameter.⁹⁶ The peridotite and breccia-filled plugs in southern Ste. Genevieve County, Missouri, average about 300 feet in diameter,⁹⁷ and Geikie has recorded a neck whose largest diameter is only 60 feet.⁹⁸

The ouachitite and monchiquite sills may be offshoots from volcanic necks.

The possible relations of these breccias to other similar intrusive masses have been considered in our original paper and need not be repeated here.

POSSIBILITY OF FINDING DIAMONDS OR GAS

The only volcanic neck in Arkansas that has been described is in Pike County, in which tuff, breccia, and peridotite are found. The diamonds occur mainly in the peridotite breccia, and only very sparingly in the intrusive peridotite. Apparently, however, diamonds are always genetically associated with peridotite, and as no peridotite has been found in the Oppello or Brazil Branch breccias, there is no reason to suspect the presence of diamonds in either. It may be desirable, however, to study these breccias more carefully in

⁹³ Miser, H. D., and Ross, C. S., Diamond-bearing peridotite in Pike County, Arkansas: Smithsonian Report, pp. 261-272, 1923.

⁹⁴ Spencer, A. C., and others: U. S. Geol. Survey Geol. Atlas, Franklin Furnace folio (No. 161), 1908.

⁹⁵ Geikie, Archibald, The ancient volcanoes of Great Britain, vol. 8, pp. 76, 279, 292, 295, 296; figs. 212 and 310, 1897.

⁹⁶ Miser, H. D., New areas of diamond-bearing peridotite in Arkansas: U. S. Geol. Survey Bull. 504, 1912.

⁹⁷ Weller, Marvin, personal communication, December 1, 1928.

⁹⁸ Geikie, Archibald, op. cit.

order to determine positively whether or not they contain peridotite, The preliminary studies made seem to indicate that it must occur in very small quantities or not at all.

As these intrusive masses are small and as the adjacent country rock is neither appreciably altered nor structurally disturbed, these igneous bodies probably affect only very slightly the possibility of obtaining gas. The intrusive bodies here described are in areas that are structurally unfavorable to the occurrence of gas, so that they have very little adverse bearing on the possible production of gas in the Arkansas Valley.

STRUCTURE OF THE PALEOZOIC AREA OF ARKANSAS

GENERAL FEATURES

The natural physiographic divisions of the Paleozoic area of Arkansas differ not only in topographic expression but in the character, age, and structure of the rocks.

The surface beds of the Ozark province consist chiefly of dolomite, limestone, chert, sandstone, and shale, which range in age from Ordovician to Pennsylvanian. The competent beds greatly predominate over the non-competent beds, especially at the lower horizons, where shale is rare. The beds lie essentially horizontal but show a slight regional dip to the south. This regional dip is almost negligible near the Missouri boundary, but it becomes progressively greater toward the south. In the Boston Mountains there are a number of southward-dipping monoclinical terraces, and in places the regional dip is as great as 8 degrees. Minor folding and normal faulting have modified the regional dip at a number of places in the Ozark region, but faults are not numerous. The youngest beds in the Paleozoic area crop out on the higher summits of the southern Boston Mountains; the oldest are found in the northeastern part of the Salem plateau, in Arkansas.

All the rocks in the Ouachita Mountain province are of sedimentary origin with the exception of a few igneous intrusions. One of the largest of the intrusive bodies is at Magnet Cove, Hot Spring County; another is at Potash Sulphur Springs, Garland County. Other smaller bodies, which consist only of dikes or sills, are in Saline and Montgomery counties. The igneous rocks consist of nephelite syenite and related alkaline rocks, which were intruded into the sedimentary beds late in early Cretaceous time or early in late Cretaceous time. The sedimentary beds consist chiefly of shale, sandstone, chert, and novaculite, which range in age from Cambrian to Pennsylvanian and which have a minimum thickness of at least 25,000 feet. Late in the Carboniferous period, probably during mid-Pennsylvanian time, these rocks were subjected to intense lateral compression, which produced numerous westward-trending nearly parallel, intricate close folds and many thrust faults. As the beds of shale in the section are thick, however, faulting is less common than would normally be expected in view of the intensity of the deformative forces. The beds are more commonly overturned than inclined at angles as low as 25 degrees.

The structure of the entire province is that of a great complex anticline, or anticlinorium, which, although it is folded into many smaller synclines and anticlines, is in general folded upward rather than downward. The axis of the principal anticline extends from a point near Little Rock slightly south of west to the vicinity of Mena. As a consequence of the antichinal structure the oldest beds are exposed chiefly near the axis of this major anticline, and the younger beds crop out to the north and south, on the flanks. One traversing the Ouachita province from north to south, however, observes considerable alternation of younger and older beds, due to the complex folding and faulting of the anticlinorium.

The Arkansas Valley province lies between the Ozark plateaus on the north and the Ouachita Mountains on the south. Its structure therefore includes some of the features of both the bounding provinces. In fact, the boundaries between these provinces are established arbitrarily, for the structure of the Arkansas Valley merges indistinctly on the north into the southward monoclinial slope of the Boston Mountains, and toward the south the structure of the valley area becomes more and more similar to the close-folded Ouachita type. Near the northern border of the Arkansas Valley the faulting is normal, the folds are gentle, and most of the dips south of the anticlinal crests are steeper than those north of them. Near the southern border of the province thrust faulting is common, the folds are pronounced, and the dips north of the axes of the anticlines are steeper than those south of them. The true intermediate structural character of the central part of the Arkansas Valley is shown by the occurrence of both normal and thrust faults in close proximity, by the increase in the number of symmetrical folds, and by the character of the folding itself, which is intermediate between the close folding on the south and the gentle open folding on the north. The Arkansas Valley province, unlike the Ouachita province, has been folded down to form a synclinalorium.

The rocks of the Arkansas Valley are nearly all of sedimentary origin; they include only a few bodies of igneous rock. Most of the sedimentary rocks exposed consist of shale and sandstone; conglomerate is uncommon, and calcareous rocks are rare. The formations exposed belong to the Carboniferous system, and nearly all to the Pennsylvanian series, but a few Mississippian rocks crop out near the southern edge of the province. The beds in the Arkansas Valley consist dominantly of shale, which is less resistant to pressure than the beds of the Ouachita Mountains, and much less resistant than those of the Ozark plateaus. Thus, although the Arkansas Valley

is farther from the source of the deformative forces than the Ouachita area, its beds are in places just as greatly deformed as those in that area and are much more complexly folded than those in the Ozarks.

Most of the sediments that now form the rocks of the Ouachita and Arkansas Valley areas were evidently derived from a land mass on the south. This land mass, commonly called Llano,¹ or Llanoria,² must have been large and must have stood high in order to furnish the immensely thick mass of elastic sediments that form the Paleozoic rocks laid down in the Ouachita geosyncline. The fact that where Llanoria once stood, there is now a thick series of Cretaceous and younger beds shows that the land mass there subsided in post-Paleozoic pre-Cretaceous time. This subsidence may have caused the thrust that folded the beds in the Ouachitas and the Arkansas Valley.³ This folding occurred in post-Allegheny pre-Trinity time, for it involves beds equivalent to the eastern Allegheny group, and the Trinity beds rest with angular unconformity upon the upturned edges of the Paleozoic beds at the Cretaceous-Paleozoic border. According to Moore,⁴ however, the adjacent Arbuckle Mountains were folded in mid-Pennsylvanian or Hercynian time, and the folding in the Ouachitas may have been contemporaneous. The Ouachita area was not folded at the end of Mississippian time, although it may have been slightly deformed. At that time, however, there was a mountain-making movement in Llanoria, whose elevation resulted in the deposition of the thick elastic sediments of late Mississippian and early Pennsylvanian age in the Ouachita Mountain and Arkansas Valley provinces.

After Llanoria subsided its northern edge served as the northward-moving jaw of a vise whose opposing immovable jaw was the dominantly calcareous, resistant beds of Ozarkia. Caught between these jaws were the sediments of the Ouachita and Arkansas Valley provinces, all of which had been deposited in the Ouachita geosyncline. The results of the closing of the vise are diagrammatically shown in sections C-D, E-F, and G-H of Plate XXXIII. The beds nearest the moving jaw were most intensely deformed, being folded

¹ Willis, Bailey, A theory of continental structure applied to North America: *Geol. Soc. America Bull.*, vol. 18, pp. 394-398, 1907. Schuchert, Charles, Paleogeography of North America: *Geol. Soc. America Bull.*, vol. 20, p. 448 et seq., pl. 49, 1910. Ulrich, E. O., Revision of the Paleozoic system: *Geol. Soc. America Bull.*, vol. 22, pp. 435, 476, 1911.

² Dumble, E. T., The geology of east Texas: *Univ. of Texas. Bull. No. 1869*, pp. 11-13, 1920. Powers, Sidney, The Sabine Uplift: *Am. Assoc. Petro. Geologists Bull.*, vol. 4, No. 2, p. 125, 1920. Miser, H. D., Llanoria, the Paleozoic land area in Louisiana and eastern Texas: *Am. Jour. Sci.*, vol. 2, pp. 61-89, 1921. (Contains extensive bibliography on subject.) Honess, C. W., Geology of the southern Ouachita Mountains of Oklahoma: *Oklahoma Geol. Survey Bull.* 32, p. 258 et. seq. 1923.

³ Honess, C. W., op. cit. p. 258.

⁴ Moore, R. C., Folding in southern Oklahoma oil fields: *Am. Assoc. Petroleum Geol. Bull.*, vol. 5, p. 38, 1921.

upward into the Ouachita anticlinorium, which is shown at or near the south ends of the sections; the beds in the Arkansas Valley were less complexly downfolded into a synclinorium, which is shown near the middle of the sections; and the Ozark area, a part of which served as the stationary jaw of the vise, was merely uplifted as a unit, the beds being very slightly folded or warped, and normal faulted after the compressive force abated, during the following period of tension.

The four structure sections shown in Plate XXXIII are drawn as follows:

Section A-B: From the Oklahoma line 4 miles south of Fort Smith directly eastward to Judsonia, along the boundary between Ts. 7 and 8 N.

Section C-D: From the southern boundary of the De Queen quadrangle directly northward to the Arkansas-Missouri line along the boundary between Rs. 29 and 30 W.

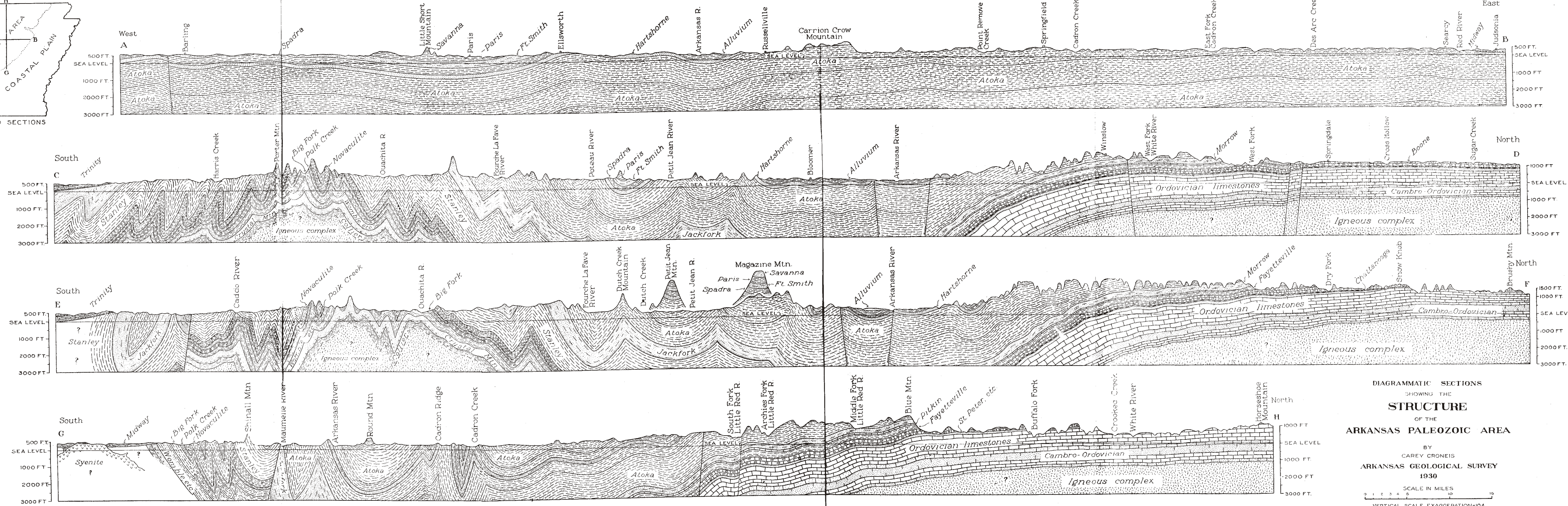
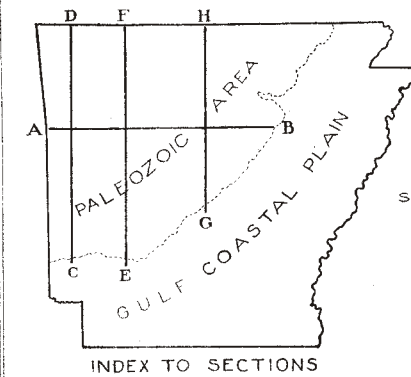
Section E-F: From the southeast corner of the Caddo Gap quadrangle directly northward to the Arkansas-Missouri line.

Section G-H: From a point near Bauxite, on the boundary between the Benton and Little Rock quadrangles, directly northward to the Arkansas-Missouri line.

The topography in each section is accurately shown for all points except those in an unsurveyed area in the Boston Mountain between the Magazine Mountain and the Eureka Springs quadrangles, in Section E-F. In this section the position and height of the highest hills and the location and elevation of the principal valleys are thought to be essentially correct, but the minor topographic features may not be shown accurately. The horizontal scale of the drawing is 1: 500,000, or essentially 8 miles to the inch, and the vertical scale is 4,000 feet to the inch. The vertical exaggeration is therefore 10.4, which, although rather great, cannot be avoided in view of the length of the sections and the relatively slight differences in the relief. The base of each section is 3,000 feet below sea level. Because of the differences in scale the dip of the strata is shown as too great in areas where the dip is low, and the width of outcrop is exaggerated where the dip is high. The positions indicated for the outcrops, however, are approximately correct.

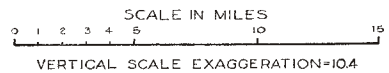
In all of Section A-B, and in those parts of the other sections north of the Arkansas River, the thickness of the formations may be ascertained fairly well from the vertical scale, and the depth indicated to a certain horizon at any given point is essentially accurate. The thicknesses of the formations south of Arkansas River and their depth beneath the surface are not shown so accurately, but their general relations are properly indicated. Minor structural features have not been shown on any of the sections.

In Section G-H the Chattanooga shale is not shown because,



DIAGRAMMATIC SECTIONS
SHOWING THE
STRUCTURE
OF THE
ARKANSAS PALEOZOIC AREA

BY
CAREY CRONEIS
ARKANSAS GEOLOGICAL SURVEY
1930



although it is found at some places, it is not a reliable horizon marker in the extreme eastern Ozarks. The thickness of the Collier shale, which is the oldest formation exposed in the Ouachita Mountains, is not known, for its base has not been seen. The nature of the rocks beneath the sedimentary beds in the uplift is not certainly known. In the sections these rocks are indicated as an igneous complex of unknown nature.

In areas north of the Arkansas River the name Atoka is used for all beds that lie between the base of the Hartshorne and the top of the Morrow. South of the river beds of Morrow age are included at the base of the Atoka. "Fayetteville, etc.," is used for the beds between the Boone limestone below and the Pitkin limestone above; "Chattanooga" for the beds between the base of the Boone and the top of the Silurian; "St. Peter, etc.," for the beds between the top of the Silurian and the base of the St. Peter; "Ordovician limestones" for the beds between the base of the Jefferson City and the base of the St. Peter; and "Cambro-Ordovician" for the beds between the basement complex and the base of the Jefferson City.

In the Ouachita area "Womble, etc.," is applied to the beds between the Crystal Mountain sandstone and the Bigfork chert; "Polk Creek, etc.," to the beds between the Bigfork chert and the Arkansas novaculite. The Hot Springs sandstone is included with the Stanley shale. On account of the complexity of the structure and the differences between the vertical and the horizontal scale of the sections the formations in this area appear thinner in the section than they actually are, and most of their outcrops are made too wide.

The heavy lines in the Atoka formation in Sections A-B, C-D, and E-F are used to facilitate the portrayal of the structure in that very thick formation. The uppermost line is drawn at a horizon 1,500 below the upper surface of the Atoka and the next line below is drawn at a horizon 3,000 feet below its upper surface. In section G-H a few of the thicker beds of sandstone in the Atoka are shown. Although these beds of sandstone are shown as continuous, probably no one *bed* is persistent over a large area, though some sandy *zones* may have considerable areal extent.

STRUCTURE OF THE OZARK PROVINCES

GENERAL FEATURES

All the rocks in the Ozark plateaus of Arkansas were laid down in an essentially horizontal position, and they have undergone no great deformation since their deposition. The general structure of the entire Ozark region is that of an irregular, flattened dome. The strata everywhere dip away from the St. Francis Mountains, of Missouri, which form the eccentric crystalline nucleus of the highlands.

The Arkansas Ozarks form the southern and southwestern parts of the dome, and consequently the prevailing dip in northern Arkansas is south or southwest. The inclination of the beds, however, is slight, particularly near the northern border of the State, where the beds are essentially horizontal. In the Salem plateau the regional southerly dip is commonly disguised by minor folds. In the Springfield plateau the dip is also concealed at some places by minor structural irregularities, but in general a dip of 1 to 2 degrees to the south prevails. Still farther south, in the Boston Mountains, the southerly dip increases to as much as 5 degrees or more, but the folding also becomes more pronounced toward the south, so that the regional dip is interrupted at several places or is modified by folds or faults.

For the purpose of simplifying the description, the Ozark area is here regarded as that part of the area of Paleozoic rocks in Arkansas which lies north of T. 12 N., although most of its southern boundary actually extends farther south than that.

FOLDS

Most of the folds of the Ozark provinces, unlike those of the Arkansas Valley, are short, and many of them are so small as to make their individual description impracticable. On the large structure map (Pl. I, A) folds in the area north of T. 12 N. appear to be rare in comparison with the great number shown farther south. The difference, however, is due in large part to the fact that the area north of T. 12 N. was not mapped in detail. In part, however, the difference is real, for large folds are almost as rare in the Ozark provinces as the map indicates, although small flexures are common.

In the southern part of the Boston Mountains the character of the folds is not much different from that of the folds in the northern Arkansas Valley except that the folding is less pronounced. The folding diminishes in intensity toward the north so gradually that it is impossible to determine from the structure just where the Arkansas Valley province ends and the Boston Mountains begin. In the northern part of the Boston Mountains, however, and in the Salem and Springfield plateaus the folds are shorter, their axes are less well defined, their dips are lower, and their trend is much less uniform than in areas farther south. Furthermore, in the area north of the Boston Mountains no definite structural plan can be discovered. The larger monoclinal folds in the southern Ozarks, however, do have a general westward trend and are relatively simple; those farther north have various trends, some extending nearly due north, and they are complicated by transverse flexures, irregular basins, and domes; and many of them are faulted.

As a rule the folding is somewhat more pronounced in the lower beds than in the upper ones. In the eastern part of the Ozark area there is some evidence that the beds were slightly flexed at the end of Ordovician time. Farther west, particularly in the Harrison quadrangle, there is evidence of slight crustal disturbances contemporaneous not only with the Taconic deformation but with the post-Batesville deformation. In addition, the various structural features that had already been formed by Pitkin time were accentuated slightly at the end of Mississippian time, and also after the deposition of the Morrow sediments. Most of the folding and faulting, however, took place after the deposition of the youngest beds (Atoka) in the region, and it affects equally all the rocks of the Ozark provinces. The oldest and the youngest beds in the area therefore have about the same structure, although detailed mapping in almost all parts of the area shows that structural contours drawn on the top of the Boone, the top of the Fayetteville, or the top of the Pitkin or the Brentwood are all somewhat different. The time of the main folding in the Ozark area was undoubtedly the same as that in the Arkansas Valley and Ouachita provinces. Evidence available in Arkansas, however, indicates only that the movements were post-Allegheny and pre-Cretaceous. It is probable, however, that some deformation took place in mid-Pennsylvanian or Hercynian time, and that the region was further flexed during the late Paleozoic period of mountain-making.

The paucity of folds shown on Plate I does not indicate that structural features favorable to the accumulation of oil and gas are rare in the Ozark area. On the contrary, small flexures with good closures are relatively common, but detailed field work and accurate topographic maps are needed for their delineation.

In the latitude of Winslow there are a number of unmapped small folds in a zone extending from the Oklahoma boundary eastward to the Batesville district. Most of these are short, elliptical anticlines having closures of from 75 to 300 feet. The surface rocks ordinarily are not older than the Morrow group, and hence an adequate covering is provided for a number of the older potential producing horizons. One such anticline near Winslow was tested by the Gruber well, which was drilled to the top of the Ordovician limestone but did not penetrate to the St. Peter sandstone. The log of the Gruber well shows a succession of beds similar to those which should be found in most wells drilled near or somewhat north of the crest of the Boston Mountains.

The Gruber well was accurately logged, so that, although the cuttings were not examined, the correlations given are regarded as essen-

tially correct. The driller maintains that a small well could have been brought in at 855 feet, where there was a show of oil and gas.

Record of the Gruber Well No. 1, in Sec. 24, T. 13 N., R. 30 W., near Winslow, Washington County, Arkansas. (Summarized.)

Formation	Bed	Thickness in feet	Depth in feet
Surface.....	Clay and rock.....	5	5
Atoka.....	Sand and shale.....	485	490
Base of Atoka.....	Heavy sandstone.....	120	610
Morrow.....	Lime, shale and sand.....	150	760
Pitkin.....	Heavy limestone.....	60	820
Wedington.....	Sand and some lime; show of oil and gas at 855.....	65	885
Fayetteville.....	Shale.....	145	1030
Boone.....	Lime and chert.....	355	1385
Chattanooga.....	Shale.....	22	1407
Sylamore.....	Sand and some lime; sulphur water.....	38	1445
	Lime.....	5	1450

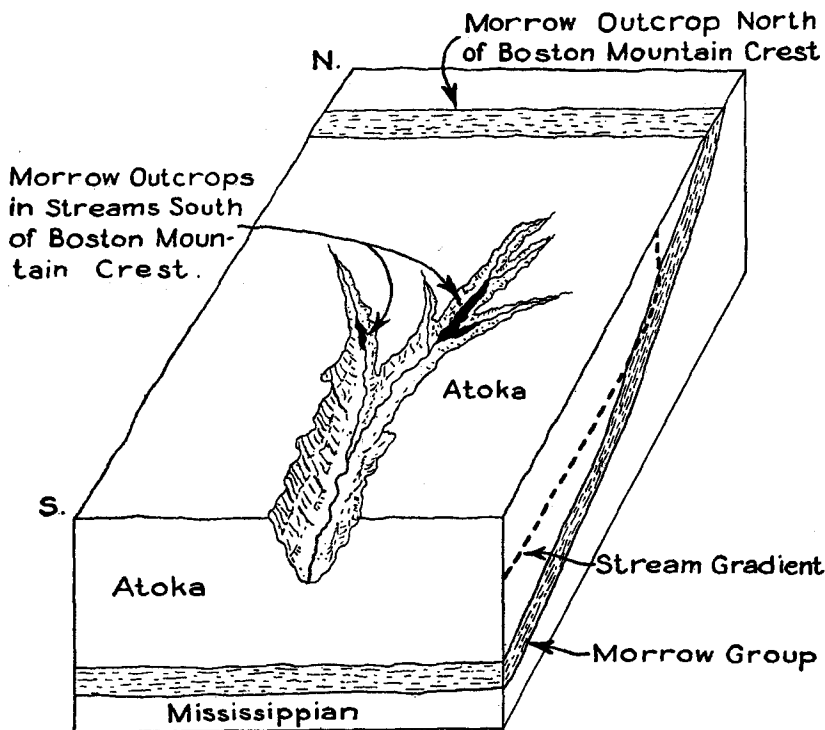


FIGURE 8.—Block diagram showing windows of beds of the Morrow group exposed near the headwaters of streams flowing south on the southern slope of the Boston Mountains.

The windows are due to the fact that the stream gradient is steeper than the dip of the Morrow beds.

A similar though more pronounced dome occurs in the vicinity of Low Gap and Sunset, and still others are found in southern Madison County, but they were not mapped in this survey. Several of similar anticlines just south of the crest of the mountains are indicated by windows of the Morrow group exposed at the headwaters of the southward-flowing streams. Not all of these windows, however, are the results of anticlinal structure; most of them have been formed because the gradient of the streams becomes steeper near their headwaters and because the beds of the streams therefore dip downstream at an angle greater than the regional southerly dip. For this reason the stream exposes at some places the underlying beds as shown in Figure 8.

No structural features are shown on the large map in the extreme northwestern part of the State, but a number of minor folds, which have very ill-defined axes, occur there. The surface rock over large areas belongs to the Boone formation, which makes the determination of the true structure additionally difficult. A few wells have been drilled in this general area, and one of them, at Mount Comfort, 5 miles northwest of Fayetteville, has yielded sufficient gas to supply a farmhouse since about 1917, although the well is only 300 feet deep. The gas is obtained from the lower part of the Boone formation, into which it probably migrated from the Chattanooga shale.

A well south of Prairie Grove, which was started on the lower Fayetteville shale, reached the pre-Cambrian at a depth of 2,485 feet. Neither oil nor gas was found, but the well was not properly located on the anticline. The log of the Prairie Grove well is given here for reference.

*Log of well drilled in the NE. $\frac{1}{4}$ of the SW. $\frac{1}{4}$, Sec. 30, T. 15 N., R. 31 W.,
1½ miles south of Prairie Grove, Washington County, Arkansas.*

Surface:	Formation	Thickness in feet	Depth in feet
Soil.....		3	3
Fayetteville:			
Brown shale.....		7	10
Brown shale.....		5	15
Limestone.....		6	21
Batesville:			
Water sand.....		1	22
Boone:			
Hard lime or chert.....		28	50
Soft lime or chert.....		270	320
Hard flint.....		10	330
Chattanooga:			
Hard black shale.....		25	365
Sylamore:			
Hard limestone.....		22	387
Hard sandy shell.....		23	410

Formation	Thickness in feet	Depth in feet
Upper Ordovician limestone?:		
Hard limestone.....	30	440
White sandy shale.....	6	446
Hard sandy shale.....	14	460
White water sand.....	9	469
White fine sand.....	13	482
Hard white limestone.....	88	570
St. Peter:		
Hard white sand.....	100	670
White sand.....	35	705
Everton:		
White limestone.....	160	865
Water sand; fresh.....	5	870
Cotter:		
Hard white limestone.....	290	1160
Sand shell with pebbles.....	20	1180
Hard white limestone.....	100	1280
Sand.....	20	1300
Hard white limestone.....	205	1505
Jefferson City?:		
Hard coarse sand.....	45	1550
Hard lime shell.....	25	1575
Hard white sand.....	25	1600
Hard white limestone; base of Jefferson City?.....	80	1680
Hard porous lime.....	10	1690
Hard sand lime shell.....	10	1700
Hard white sand.....	13	1713
Hard lime shell.....	7	1720
Hard white sand.....	50	1770
Water sand.....	15	1785
White lime, dark streaks.....	95	1880
White sand.....	90	1970
Hard white lime.....	75	2045
White sand; water.....	25	2070
Hard white lime.....	25	2095
Lowest Ordovician and Cambrian:		
White sand, sharp.....	165	2260
Hard white lime.....	75	2335
Blue shale.....	1	2336
Hard white lime.....	124	2460
Blue lime and sand.....	25	2485
Pre-Cambrian granite:		
Top of red sand.....		2485

Although cuttings from the Prairie Grove well were not examined, the correlations are thought to be reasonably accurate to the base of the St. Peter. Below that horizon they are guesses, but it is fairly certain that formations which crop out in northern Arkansas were penetrated to a depth of 1,600 feet. Thus 800 to 900 feet of lowest Ordovician and Cambrian strata were encountered before the "basement" was reached. The "red sand" at 2,485 is red granitic arkose,

and drilling was continued into the granite itself for some distance, although exactly how far is unknown.

Another well, drilled 5 miles southwest of Bentonville by the Arkansas Publicity Bureau, was started near the top of the Boone formation and also reached crystalline rock. In this well, gas was reported from sand at depths of 890, 955, 1,122, 1,342, and 2,225 feet, as well as from limestone at 1,977 and 2,210 feet. A show of oil was reported in a sand just above the "syenite," which was reached at 2,365 feet. Another show of oil, however, was reported from 2,400 to 2,425 feet, which apparently was well within the igneous basement, and this report throws suspicion on the validity of most of the others. The log given by the driller is shown below.

Log of well drilled by Arkansas Publicity Bureau in NE. $\frac{1}{4}$ of SE. $\frac{1}{4}$ Sec. 5, T. 19 N., R. 31 W.

	Depth in feet
Soil.....	0- 10
Lime.....	10- 25
Lime carrying zinc.....	25- 35
Lime, sandy.....	35- 45
Water sand.....	45- 50
Lime.....	50- 75
Sandy lime.....	75- 90
Sand.....	90- 96
Lime and flint.....	96- 100
Sand.....	100- 105
Lime.....	105- 115
Flint.....	115- 120
Lime.....	120- 125
Flint.....	125- 185
Chalky lime.....	185- 190
Flint.....	190- 200
Sandy lime.....	200- 205
Carrying water.....	205- 220
Sandy lime.....	220- 230
Flinty lime.....	230- 245
Lime.....	245- 255
Brown lime.....	255- 275
Flinty lime.....	275- 290
Dark sandy lime.....	290- 315
Flint.....	315- 320
Sandy lime.....	320- 325
White lime.....	325- 340
Flinty lime.....	340- 370
Hard lime.....	370- 394
Black shale.....	394- 455
Lime.....	455- 485
Shale.....	485- 499
Lime.....	499- 503
Water sand.....	503- 512
Dark lime.....	512- 516

	Depth in feet
Black lime.....	516- 520
Hard lime.....	520- 523
Shells and flint.....	523- 547
Lime.....	547- 603
Black lime.....	603- 620
Fossil lime.....	620- 641
Sand and slate.....	641- 651
Lime rock.....	651- 658
Lime and shells.....	658- 670
Slate.....	670- 672
Lime.....	672- 681
Sandy lime.....	681- 700
Gritty lime.....	700- 740
Lime.....	740- 750
Hard sand.....	750- 765
Sandy lime.....	765- 775
Water sand.....	775- 781
Sand rock.....	781- 790
Flint.....	790- 808
Sand.....	808- 812
Shale.....	812- 820
Hard sand.....	820- 828
Lime.....	828- 842
Slate.....	842- 890
Gas sand.....	890- 920
Lime.....	920- 930
Sandstone.....	930- 940
Slate.....	940- 948
Flint.....	948- 950
Shale.....	950- 955
Gas sand.....	955- 980
Dark gray sand.....	980-1000
Lime.....	1000-1025
Gray sand.....	1025-1030
Slate.....	1030-1048
Gritty lime.....	1048-1060
Dark brown sand.....	1060-1105
Lime.....	1105-1122
Sand and gas.....	1122-1138
Sandy lime.....	1138-1145
Sand.....	1145-1165
Lime.....	1165-1175
Water sand.....	1175-1185
Gray sand.....	1185-1192
Dark sand.....	1192-1200
Water sand.....	1200-1342
Sand and gas.....	1342-1375
Gritty lime.....	1375-1395
Water sand.....	1395-1412
Limestone.....	1412-1420
Water sand.....	1420-1485

	Depth in feet
Soft sand.....	1485-1551
Sandy lime.....	1551-1562
Lime.....	1562-1580
Hard white lime.....	1580-1694
Gritty lime.....	1694-1699
Sand rock.....	1699-1703
White lime.....	1703-1726
Sandstone.....	1726-1822
White lime.....	1822-1840
Blue lime.....	1840-1880
Darker lime.....	1880-1920
Brown shale.....	1920-1956
Shelly sand.....	1956-1977
Dark soft lime; gas.....	1977-1988
Black lime.....	1988-2006
Sandy lime, black.....	2006-2008
Gray lime.....	2008-2020
Black lime.....	2020-2040
Gray lime.....	2040-2046
Dark and gray lime.....	2046-2101
Blue lime.....	2101-2120
Lighter blue sandy lime.....	2120-2141
White sand.....	2141-2162
Water sand, yellow.....	2162-2181
Water sand, blue cast.....	2181-2190
Cavey sand, blue cast.....	2190-2191
Sand, yellow cast.....	2191-2205
Sand, blue cast.....	2205-2210
Lime, dark; gas.....	2210-2225
Red sand rock; some gas.....	2225-2350
Dark sandy shale.....	2350-2352
Dark sand; some oil.....	2352-2365
Syenite.....	2365-2400
Darker; oil showing.....	2400-2425
Lighter, softer; began caving badly, work discontinued.....	2425-2430

In 1908 and 1909 the Kaney and Butler well No. 1 was drilled at Monte Ne, but it obtained neither oil nor gas. The driller's log of the Kaney and Butler well is given below.

Log of Kaney and Butler well No. 1, in the SW. $\frac{1}{4}$ SE. $\frac{1}{4}$ Sec. 28, T. 19 N., R. 29 W.

	Depth in feet
Drift gravel.....	18
Flint.....	28
White lime.....	47
Gray lime.....	57
Brown lime.....	61
Black slate.....	110
Gray sand.....	131
White sand.....	151

	Depth in feet
Gray sand.....	156
White sand.....	173
Gray sand.....	183
Blue lime.....	193
Gray lime.....	198
White lime.....	203
Gray lime.....	218
Brown lime.....	224
White lime.....	230
Blue lime.....	235
White lime.....	250
Lime shells.....	255
Gray lime.....	295
Brown lime.....	305
Gray lime.....	315
Brown lime.....	345
Gray lime.....	423
Gray lime.....	460
Gray lime.....	493
White lime.....	506
Blue lime.....	515
Gray lime.....	522
Gray lime.....	537
White lime.....	560
White lime.....	567
White lime.....	577
White lime.....	597
Gray lime.....	602
Gray lime.....	641
Gray lime.....	685
Dark gray lime.....	725
Dark gray lime.....	738
Gray lime.....	758
Gray sand.....	764
White sand.....	808
Brown sand.....	790
Dark brown sand.....	812
White lime.....	820
Dark brown lime.....	831
Light gray lime.....	839
Very dark gray lime.....	864
Brown lime.....	871
Gray lime.....	880
Brown lime.....	915
Dark gray lime.....	924
Brown lime.....	931
White lime.....	940
Brown lime.....	946
Gray lime.....	998
Brown lime.....	1003
Dark gray lime.....	1011

	Depth in feet
Gray lime.....	1015
Sand.....	1021
Sand.....	1032
White sand.....	1065
Lime and flint.....	1089
Gray lime.....	1108
White lime.....	1148
Gray lime.....	1159
White lime.....	1183
White sand.....	1190
Gray lime, total depth.....	1212

In addition to the wells already listed a test well was carefully drilled by the Washington County Mining Company at Fayetteville, the record of which, including a detailed description of the cuttings, is given below.

Washington County Mining Company's well at Fayetteville, in Sec. 15, T. 16 N., R. 30 W.

	Thickness in feet	Depth in feet
Soil.....	20	20
Disintegrating shale.....	44	64
Black shale, in part calcareous.....	114	178
Black shale containing carbonate of lime; the record says this shale is very hard.....	7	185
Limestone and black shale, the shale probably from a higher point in the boring.....	6	191
Gray and white limestone; some fragments of black shale from a higher level.....	7	198
Flint and gray limestone; some fragments of shale.....	90	288
Flint and light gray limestone; rusty from oxidized iron pyrites.....	24	312
Chert and carbonate of lime; light-colored, almost white, containing minute fragments of oxidized pyrite.....	36	348
Chert and carbonate of lime, like the preceding.....	38	386
Limestone, very light colored, about 50 per cent chert..	20	406
Limestone, now rusty; original color probably much lighter.....	14	420
Limestone of a light drab-gray color; the record says it is very hard.....	40	460
Principally chert with oxidized pyrite.....	24	484
Compact chert with calcareous streaks and containing numerous crystals of pyrites.....	22	506
Limestone; dark gray, almost black, with reddish brown tinge; base of the Boone chert and limestone.....	6	512
Black Chattanooga shale with crystals of copper pyrites; the record says, "it smells of oil".....	46	558
Light gray limestone with fragments of shale.....	12	570
Coarse-grained quartzitic sandstone resembling the Sylamore sandstone.....	30	600

	Thickness in feet	Depth in feet
White sandstone, homogeneous, fine grained, saccharoidal.....	100	700
Cream-colored (from rust) sandstone; original color probably white.....	40	740
Sandstone, somewhat lighter in color than the preceding.....	70	810
Limestone (the powder is of a rusty white or cream color) with grains of sand probably from a higher point in the boring; very pyritiferous.....	44	854
Gray limestone, pyritiferous, magnesian (?) shaly.....	11	865
Pyritiferous siliceous dolomite.....	5	870
Dark gray limestone, with grains of sand and fragments of shale probably from a higher level; much pyrite.....	5	875
Magnesian limestone, less pyrite than stratum immediately above.....	10	885
Light gray, now rusty, limestone.....	10	895
Gray limestone.....	10	905
Light gray (nearly white) limestone.....	5	910
No sample; the record says, "white, hard lime".....	5	915
Light gray limestone, now with much iron rust.....	10	925
No sample; the record says, "lighter lime".....	10	935
Light gray limestone, now somewhat rusty.....	15	950
Light gray limestone, less rusty than the preceding.....	20	970
Light cherty limestone.....	5	975
Light gray cherty limestone with bright green particles (copper carbonate from decomposed copper pyrite).....	5	980
Light gray cherty limestone.....	5	985
No samples; record has "lime and flint".....	15	1000
Light gray limestone with chert (?).....	25	1025
Light gray limestone with chert (?), the latter less abundant than in the preceding.....	15	1040
Limestone and flint, as in stratum immediately above....	20	1060
No sample; recorded as "lime and flint".....	10	1070
White limestone.....	5	1075
Light gray limestone.....	10	1085
Light gray limestone with flint, somewhat rusty.....	5	1090
Similar to those preceding, but with less flint.....	10	1100
Very light gray limestone.....	10	1110
No sample; recorded as "white lime".....	15	1125
Very light gray limestone.....	15	1140
Light gray limestone.....	20	1160
Light gray limestone with some chert and pyrite.....	40	1200
Gray limestone and flint.....	10	1210
Gray siliceous limestone; 22.31 per cent of insoluble matter.....	10	1220
Gray siliceous limestone; 13.57 per cent of insoluble matter.....	10	1230
Magnesian limestone, dolomite; 17.64 per cent of insoluble matter.....	10	1240

	Thickness in feet	Depth in feet
Light gray limestone, now somewhat rusty.....	10	1250
Limestone; 14.52 per cent of insoluble matter.....	25	1275
Light gray limestone with a little flint, rusty.....	10	1285
Limestone; 8.74 per cent of insoluble matter.....	25	1310
Light gray cherty limestone, containing oxidized pyrite; 21.24 per cent of insoluble matter.....	15	1325
Limestone; 22 per cent of insoluble matter.....	35	1360
Gray limestone, darker than in second stratum above....	40	1400
Brownish gray or drab limestone; 4.06 per cent of insoluble matter.....	10	1410
Light gray limestone with some flint.....	10	1420
White or very light gray limestone with a little flint....	15	1435
Limestone, slightly darker than the preceding, with a little flint.....	10	1445
Drab-gray limestone, somewhat rusty.....	5	1450
Light drab-gray limestone.....	10	1460
Drab-gray limestone with very little flint.....	20	1480
Drab-gray limestone, very rusty, at bottom of well.....		

Summary by formations

	Thickness in feet
Soil.....	20
Fayetteville shale.....	165
Boone chert and limestone.....	327
Chattanooga shale.....	46
Sylamore sandstone, etc	922
St. Peter sandstone	
Magnesian limestones, etc.	
Total.....	1480

In the Batesville district the folds, according to Miser,⁵ are small. The anticlines are ill-defined, irregular domes, and the synclines are indefinite, shallow basins. Only a very few wells have been drilled in this part of the State, and in general exploration should be discouraged. The log of a well drilled at the Southern mine, near Cushman, is included here, however, since it indicates the type of rock which may be expected should future tests be made.

Log of the well at the Southern mine, near Cushman, Independence County, Arkansas

	Depth in feet
Fragments of chert and limestone in residual clay.....	50
Joachim and Platin limestones.....	290
Joachim limestone.....	300
St. Peter sandstone.....	425
Calcareous sandstone with interbedded gray limestone and sandstone.....	470
Massive gray and brown limestone with disseminated sand grains.....	508

⁵ Miser, H. D., Deposits of manganese ore in the Batesville district: U. S. Geol. Survey Bull. 734, p. 46.

	Depth in feet
Massive gray limestone with sand grains (82 feet) running into chocolate brown limestone with sand grains (15 feet).....	605
Slightly calcareous gray sandstone.....	614
Highly calcareous gray sandstone.....	696
Massive chocolate brown and gray limestone.....	715
Massive gray limestone.....	785
Massive gray limestone harder than last.....	900
Slightly sandy gray limestone passing at its base into white sandstone (51 feet).....	955
Sandy dark gray limestone.....	1000
Fine grained, calcareous, gray sandstone becoming coarser at the base.....	1130
Massive gray limestone with sand grains.....	1155
Fine grained white sandstone.....	1180
Sandy gray limestone running into fine grained white sandstone.....	1200
Massive chocolate-brown limestone.....	1275
Massive gray limestone with fine sand grains.....	1350
Massive gray limestone with coarser sand grains.....	1380
Massive gray limestone.....	1410
Fine-grained sandstone (white).....	1430
Massive gray limestone with grains of sand.....	1475
Fine-grained calcareous gray sandstone.....	1530
Fine-grained calcareous white sandstone.....	1670
Shaly gray limestone with thin strata of green shale passing at its base into a shaly calcareous sandstone (2 feet).....	1722
Very fine grained, calcareous gray sandstone with thin beds of black shale.....	1925
Cream-colored or gray limestone.....	2040

The Southern mine well was started just below the base of the Boone limestone and had not reached the igneous basement at a depth of 2,040 feet. The lower part of the record is similar to the lower part of the Prairie Grove well log, and the interval between the base of the Boone and the igneous basement is at least as great. In both wells this interval is much greater than in the Witter well, described elsewhere in this report.

North and northeast of the Batesville area only the older Ordovician rocks crop out, and drilling projects in this region should be strongly discouraged. The subsurface geology of this part of Arkansas is known only by inference, for no wells have been drilled there. The log of a water well drilled at Branson, Taney County, Missouri, however, is included here through the courtesy of Mr. H. S. McQueen of the Missouri Bureau of Mines and Geology. This well was started in the Jefferson City formation, which also crops out in northeastern Arkansas, and penetrated a section of rock very similar to that which will be encountered in northeastern Arkansas should test wells be drilled there.

Log of water well at Branson, Tancy County, Missouri

	Depth in feet
Gravel and clay.....	40
Chert, brown and gray, dolomite, fine grained, fragments heavily iron stained.....	45
Dolomite, light gray to buff, fine grained to argillaceous with considerable light gray and brown chert; fragments iron stained but not as heavily as above (2 samples).....	55
Dolomite, light buff, dense, argillaceous, some white chert.....	60
Dolomite, light buff to gray, dense, argillaceous with light gray chert.....	65
Chert, light gray to blue gray, and dolomite, dense, some red mud; cuttings heavily iron stained.....	70
Dolomite, light gray to buff, argillaceous, few fragments of chert..	75
Dolomite, light buff, dense, argillaceous, with light-gray and blue-gray oolitic chert (2 samples).....	85
Dolomite, buff, dense.....	90
Like 90.....	95
Dolomite, light buff to bluish gray, dense, argillaceous; a few fine fragments of chert.....	100
Dolomite, dark bluish gray, dense, very argillaceous, a few fragments of black shale.....	110
Dolomite, light gray; dense and dark blue; finely crystalline; a few fragments of chert.....	115
Dolomite, dark-bluish gray, with some lighter gray fragments; dense, slaty, very argillaceous; a few fragments of oolitic chert (6 samples).....	145
Dolomite, brownish gray, fine grained, with small amount of light colored chert.....	150
Dolomite, bluish gray, fine grained, with dark-gray oolitic chert..	155
Dolomite, light gray, dense, argillaceous, with light gray and dark brownish gray chert.....	160
Dolomite, brown, fine grained, with oolitic chert.....	165
Dolomite, dark bluish gray, dense, very argillaceous, with small amount chert and calcite (7 samples).....	200
Dolomite, light gray to bluish gray, dense, argillaceous, with considerable chert; small amount of sand.....	205
Dolomite, light bluish gray; dense, argillaceous.....	210
Dolomite, light bluish gray, dense, argillaceous; some chert (2 samples).....	220
Chert, light gray to brown, oolitic, waxy, with brown dolomite... 225	
Dolomite, brown, dense, argillaceous, with light gray and blue gray, oolitic and waxy chert (3 samples).....	240
Dolomite, light gray to brownish gray, dense, argillaceous with light gray chert (7 samples).....	275
Dolomite, dark bluish gray, dense, argillaceous, with fine light gray to coarse iron-stained chert (3 samples).....	290
Dolomite, light gray, dense, argillaceous, with light gray chert..	300
Dolomite, light bluish gray, dense to fine grained; argillaceous; a few fragments of iron-stained chert (2 samples).....	310
Dolomite, light bluish gray, finely crystalline, granular, with some gray chert (2 samples).....	320

	Depth in feet
Like 310.....	325
Dolomite, dark brown, finely crystalline, with some light-colored chert.....	330
Dolomite, gray, finely crystalline, with light-gray chert (2 samples).....	340
Like 330.....	345
Like 340 (4 samples).....	365
Like 345.....	370
Dolomite, light bluish gray, fine grained and finely crystalline and granular; a few fragments containing embedded grains of sand; some gray and blue-gray, dense oolitic and sandy chert; calcite (6 samples).....	400
Dolomite, light gray, finely crystalline, slightly sandy with light-bluish gray, oolitic, sandy and dense chert; pyrite (2 samples).....	410
Dolomite, dark brown, finely crystalline, with light, slightly sandy chert; calcite; pyrite (2 samples).....	420
Dolomite, light brownish gray, finely crystalline, with consider- able dead light gray chert and live grayish-blue chert.....	425
Like 410.....	430
Dolomite, light gray finely crystalline, with considerable light gray sandy chert and free sand.....	435
Like 425.....	440
Like 435.....	445
Like 420.....	450
Dolomite, light brownish gray, finely crystalline, sandy, with con- siderable sandy chert and free rounded grains of sand (2 samples).....	460
Dolomite, light brownish gray, finely crystalline, with light gray to bluish gray oolitic to sandy chert, some sand (7 samples).....	495
Dolomite, light gray finely crystalline with one-third of origi- nal sample fine to medium rounded grains of sand; chert and black shale.....	500
Dolomite, light gray, finely crystalline; light gray, slightly sandy chert; some sand; pyrite.....	505
Dolomite, darker gray than above, fine grained; some light gray chert; sand; pyrite.....	510
Sand, white, fine grained, subangular to rounded, clear and frosted grains; some fine-grained gray dolomite, particu- lary at 525-535 (5 samples).....	535
Dolomite, light bluish gray, fine grained, argillaceous; some light-gray chert; some sand, probably from above.....	540
Dolomite, light gray, finely crystalline, pyritic, small amount of chert; calcite; some sand from above.....	545
Dolomite, light gray to buff, the buff color being due to iron from oxidation of drill steel; fine grained to finely crystal- line, with light gray, slightly sandy chert; some sand (5 samples).....	570
Sand, fine, rounded clear and frosted grains, with white, slightly sandy chert. About one-fourth of sample is gray dolomite; few fragments of pyritic gray shale.....	575

	Depth in feet
Dolomite, grayish brown, fine grained, and sand like above about half of each; some chert; a few fragments of shale (4 samples).....	595
Sand, white, fine; angular to rounded grains.....	600
Dolomite, brown, finely crystalline, with some sand and chert. Considerable oxidized drill steel (2 samples).....	610
Dolomite, light gray to bluish gray, finely crystalline, slightly sandy, with rounded grains of sand and a small amount of light gray, often sandy to oolitic chert; pyrite (9 samples).....	665
Dolomite, light gray, finely crystalline, with considerable light gray to white oolitic chert; some drusy quartz and pyrite....	660
Like 655 (2 samples).....	670
Dolomite, gray, fine grained, sandy, with small amount of sand, drusy quartz, and light chert.....	675
Dolomite, light gray, finely crystalline, with dead-white chert....	680
Dolomite, light gray, finely crystalline, with considerable dead- white to live bluish-gray chert (2 samples).....	690
Dolomite, light gray, finely crystalline, with white chert; few grains of sand (2 samples).....	700
Dolomite, light gray to light brownish gray, crystalline, with dead-white chert and calcite; few crystals of pyrite (9 samples).....	745
Dolomite, light bluish gray, finely crystalline, with live, light gray and bluish gray chert (2 samples).....	755
Like 745 (2 samples).....	765
Dolomite, light brownish gray, finely crystalline, with live bluish gray and dead-white chert (4 samples).....	785
Dolomite, light gray, crystalline, with considerable dead-white chert (3 samples).....	800
Dolomite, light bluish gray, finely crystalline, with dead-white chert (4 samples).....	820
Dolomite, light to dark bluish gray, finely crystalline, with con- siderable dead-white and live dark-bluish gray chert (6 samples).....	850
Dolomite, dark gray, finely crystalline, with much dead-white chert; small amount blue gray chert; pyrite; some angu- lar quartz.....	855
Dolomite, light brownish gray, finely crystalline, with small amount of light gray chert; samples at 875 and 885 rusted from oxidation of drill steel (6 samples).....	885
Dolomite, dark gray, crystalline, granular, with small amount of white chert; calcite (3 samples).....	900
Dolomite, dark gray, finely crystalline, slightly granular, with dead-white chert; calcite (3 samples).....	915
Dolomite, dark bluish gray, finely crystalline, with dead-white and gray chert, calcite (6 samples).....	945
Dolomite, dark bluish gray, crystalline, with dead-white and gray chert; calcite (3 samples).....	960
Dolomite, dark gray, finely crystalline, with light gray and "dead" and "live" oolitic chert; pyrite; calcite; some angular quartz.....	1005

	Depth in feet
Sand, white, fine to medium rounded and frosted grains; small amount of white chert and dolomite at 1010 (3 samples)....	1020
Sand, white, fine, generally rounded; frosted to clear grains; some grains crushed; few fragments of sandy dolomite in cuttings, particularly from 1040 to 1050 feet (6 samples)...	1050
Sand, white, fine rounded and crushed grains; some dolomite....	1055
Sand as above, with bluish-gray finely crystalline dolomite.....	1060
Dolomite, bluish gray; finely crystalline, with some sand.....	1065
Dolomite, light gray, finely crystalline, with considerable sand..	1070
Dolomite, light gray, finely crystalline, with small amount of sand, few particles of chert and light-green shale; some pyrite and oxidized drill steel (10 samples).....	1120
Dolomite, light gray, finely crystalline, with a few grains of quartz sand, a few fragments of green shale and white chert; pyrite (5 samples).....	1145
Dolomite, light gray, finely crystalline, with a few sand grains, small pieces of white chert and green shale; some pyrite (5 samples).....	1170
Dolomite, light gray, finely crystalline, with a few sand grains, some chert, and pyrite (6 samples).....	1200

Summary by formations

	From	to	Thickness
Ordovician system:			
Jefferson City formation	0	490	490
Roubidoux formation.....	490	600	110
Gasconade formation.....	600	1060	460
Gunter sandstone member.....	1005	1060	55
Ozarkian system:			
Proctor formation (base not reached).....	1060	1190	130

In the following pages only the more pronounced folds are described in detail.

CARROLLTON DOME

The Carrollton dome is an elliptical anticlinal structure whose axis, unlike that of most of the anticlines of the Ozark area, extends essentially northward from the NW. $\frac{1}{4}$ Sec. 36, T. 18 N., R. 22 W. to the SW. $\frac{1}{4}$ Sec. 35, T. 19 N., R. 22 W. The northern part of the anticline has a more northwesterly trend than the southern part and is not nearly so pronounced.

The maximum amount of doming of the pre-Fayetteville formations is not less than 400 to 500 feet, but the base of the Hale sandstone has been elevated only 150 feet above its level in adjacent exposures. The base of the Atoka (Winslow) formation has been affected even less. Much of the deformation is therefore post-Batesville and pre-Hale in age; some of it is post-Hale and pre-Atoka; and the dome was accentuated only very slightly after the deposition of the Atoka.

The Carrollton dome is an ideal reservoir for the accumulation of oil and gas. Unfortunately the Boone is the surface formation at

its crest so that most of the potential producing beds have been removed. A well drilled on the dome at an unknown date is reported to have yielded about 1,000,000 cubic feet of wet gas from the Syl-

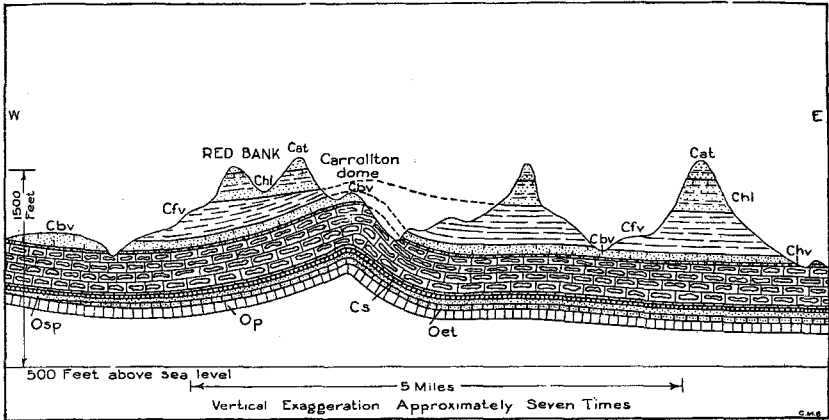


FIGURE 9.—Section from west to east across the Carrollton dome 4 miles south of Carrollton.

Op, Powell limestone; Oet, Everton formation; Osp, St. Peter sandstone; Cs, Sylamore sandstone; Cbn, Boone limestone; Chv, Hindsville limestone; Cbv, Batesville sandstone; Cfv, Fayetteville shale; Chl, Hale sandstone; Cat, Atoka (Winslow) formation. (Modified after Purdue and Miser.)

more sandstone. The sand was less than 2 feet thick and was reached at a depth of about 400 feet. Further tests of this dome are desirable, but the wells should be drilled to the St. Peter sandstone.

CLIFTY ANTICLINE

The axis of the Clifty anticline extends from about the center of Sec. 9, T. 18 N., R. 27 W., in an undulating eastward course to the SW. $\frac{1}{4}$ Sec. 7, T. 18 N., R. 25 W. This anticline is most pronounced in Secs. 1 and 12, T. 18 N., R. 27 W. It has a relatively short, steep, but irregular slope toward the Clifty Creek faults, on the north; a long gradual slope toward the Brush Creek fault, on the south; an irregular indefinite slope toward the Price Mountain syncline, on the west; and an irregular and rather steep slope toward the Moody Hollow fault, on the east. Throughout most of its length the Boone formation is the surface rock, but near its crest, in the NE. $\frac{1}{4}$ Sec. 11, T. 18 N., R. 27 W., erosion has exposed a window of the St. Joe limestone.

Most of the promising producing beds have been removed from the Clifty anticline, but it is structurally favorable to the accumulation of oil and gas, and if the St. Peter proves productive anywhere in northern Arkansas this anticline should be carefully drilled.

OSAGE ANTICLINE

The axis of the Osage anticline extends from the SE. $\frac{1}{4}$ Sec. 16, T. 13 N., R. 23 W. northwestward to the Missouri boundary, in the

The dome is bounded on the south by the Compton and Sneed's Creek faults, as shown in Figures 12 and 13. The Batesville sandstone and the underlying rocks are arched to a height of from

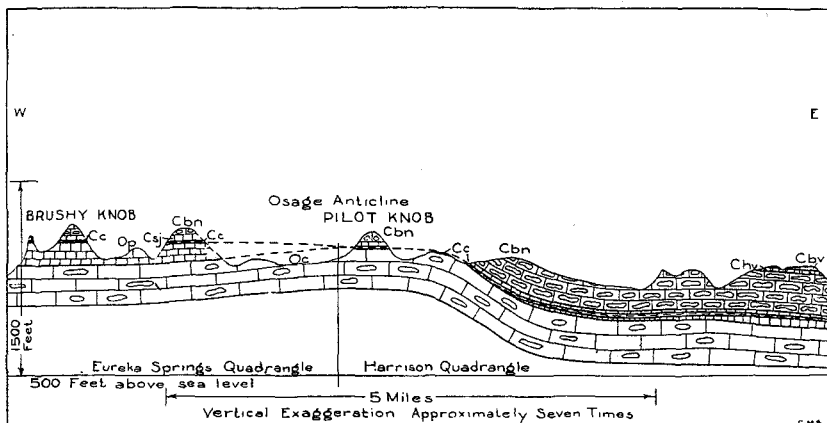


FIGURE 11.—Section from west to east across the Osage anticline through Pilot Knob, north of the north end of the Green Forest fault.

Oc, Cotter dolomite; Op, Plattin limestone; Cc, Chattanooga shale; Csj, St. Joe limestone; Cbn, Boone limestone; Chv, Hindsville limestone; Cbv, Batesville sandstone. (Modified after Purdue and Miser.)

400 to 600 feet above their level in adjacent areas, but the Morrow and younger rocks are not arched to a height of more than 250 feet. The dome has been so extensively faulted that any hydrocarbons once

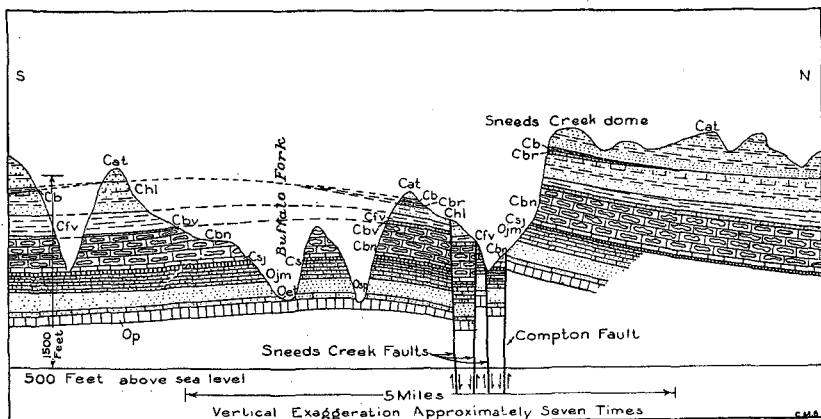


FIGURE 12.—Section from north to south across the Sneed's Creek dome and the Compton and Sneed's Creek faults.

This section is about 2 miles west of that shown in Figure 13. Op, Plattin limestone; Oet, Everton limestone; Osp, St. Peter sandstone; Ojm, Joachim limestone; Cs, Sylamore sandstone; Cjs, St. Joe limestone; Cbn, Boone limestone; Cbv, Batesville sandstone; Cfv, Fayetteville shale; Chl, Hale sandstone; Cb, Blythe shale; Cbr, Brentwood limestone; Cat, Atoka (Winslow) formation. (Modified after Purdue and Miser.)

trapped in it have probably escaped. Moreover, streams have cut so deeply into the southern flank of the dome that they have exposed most of the potential producing horizons. The chances of obtaining

either oil or gas in commercial quantities from this dome are not good, and its exploration should be discouraged.

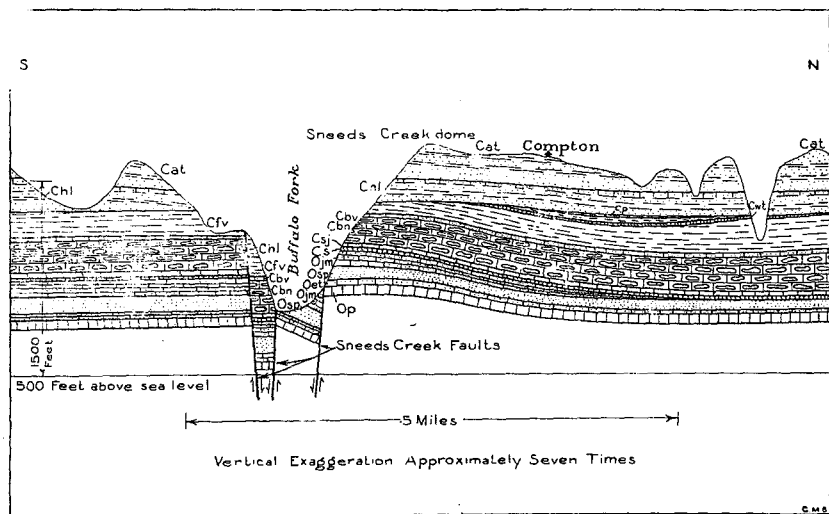


FIGURE 13.—Section from north to south across the Sneeds Creek dome and the Sneeds Creek faults through the village of Compton.

The section is about 2 miles east of that shown in Figure 12. Symbols same as in previous figure. (Modified after Purdue and Miser.)

WHARTON ARCH

The Wharton arch is a broad anticlinal feature south of Reed Creek fault and south of Huntsville. It is shown in section in Figure 14. It has good closure on the north, south, and west, but it apparently rises rather than plunges toward the east. The anticline trends east-west, but its axis can not easily be determined. Superimposed upon it are a number of small basins and elevations, and some of these elevations are favorable to the accumulation of oil or gas.

One of the most prominent of these minor structural features is a relatively symmetrical dome which lies chiefly in Secs. 7 and 8, T. 16 N., R. 26 W. The closure is perhaps between 75 and 100 feet, and the Wedington sandstone is the surface rock near the apex of the arch. An oil seep in an asphaltic sandstone on the southern flank of this dome, in the south half of Sec. 17, T. 16 N., R. 26 W., has attracted some attention. The oil, however, is seeping from a sandstone in the lower part of the Atoka formation, and as this formation has been eroded from the top of the arch it will not be encountered by wells drilled on the dome.

In 1922-1924 the War Eagle Oil and Gas Company drilled a well to a depth of 2,340 feet, or 36 feet into the pre-Cambrian rocks in Sec. 13, T. 15 N., R. 26 W., a few miles south of the Wharton arch.

Although this well was started in the Hale formation, it reached the igneous basement at a shallower depth than the H. Banks No. 1 well (drilled in Sec. 6, T. 16 N., R. 27 W.), which was started much lower

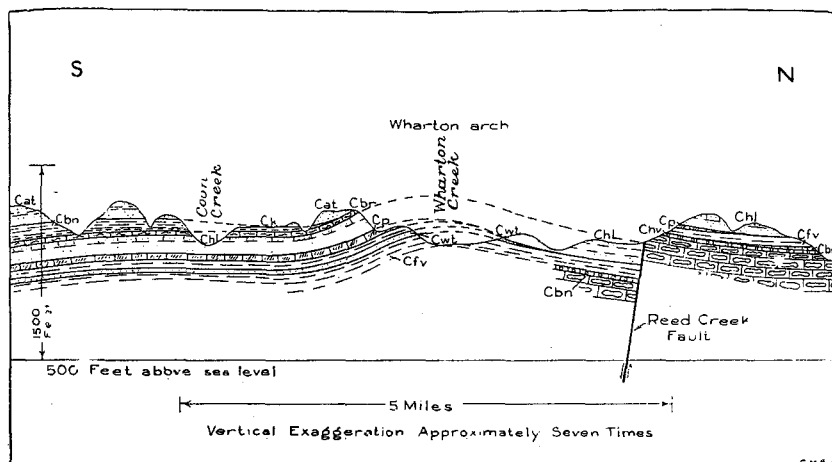


FIGURE 14—Section from north to south through the Wharton arch and Reed Creek fault south and east of Huntsville.

Cbn, Boone limestone; Chv, Hindsville limestone; Cbn, Batesville sandstone; Cfd, Fayetteville shale; Cp, Pitkin limestone; Chl, Hale sandstone; Cb, Bloyd shale; Cbr, Brentwood limestone; Cat, Atoka (Winslow) formation. (Modified after Purdue and Maser.)

stratigraphically. This fact, and evidence afforded by other wells that have reached the "basement," suggest that this general area is located on a "high" in the pre-Cambrian rocks and indicates that further exploration is perhaps warranted.

The log of the War Eagle Oil and Gas Company's well near Witter is given below.

Log of the War Eagle Oil and Gas Company's well in Sec. 13, T. 15 N., R. 26 W., near Witter, Madison County, Arkansas. (Summarized.)

Formation	Bed	Thickness in feet	Depth in feet
Surface.....	Sandy gravel.....	8	8
Hale.....	Sand and shale; show of oil and gas.....	48	56
Pitkin.....	Heavy lime.....	47	103
Fayetteville.....	Shale and sand, show of oil and gas; salt water.....	166	269
Batesville and Hindsville.....	Sand and lime; several oil shows.....	89	358
Boone.....	Lime, chert, and some sand; some gas.....	262	626
Chattanooga.....	Shale.....	28	654
St. Clair.....	Limestone.....	16	670
Jasper and Joachim.....	Sand and lime.....	62	732
St. Peter.....	Sandstone.....	216	948
Ordovician and Cambrian.....	Sand and lime; show of oil at 966.....	1333	2286
Pre-Cambrian.....	Rhyolite; total depth.....	34	2320

The log of the Witter well shows a greater thickness of St. Peter and a smaller interval than usual between this sand and the Chattanooga. Some of the sandy limestones above the St. Peter may have been included with it. The Sylamore, if present, is very thin and more calcareous than usual, but in most other respects the section encountered in the well is fairly normal. The interval between the St. Peter and the rhyolite, however, is only 1,338 feet, which is much less than it is in any other well in northern Arkansas that has been drilled to the "basement complex."

Some of the "shows" reported were undoubtedly real, but the oil said to have come from the rhyolite was probably obtained from some other horizon, although it may have been found at the unconformity between the rhyolite and the Cambrian sediments.

PRICE MOUNTAIN SYNCLINE

The Price Mountain syncline extends from the north end of the Price Mountain fault northeastward to the NE. $\frac{1}{4}$ Sec. 26, T. 21 N., R. 27 W. The syncline is also seen at a number of places along the southeast side of the Price Mountain fault, especially in the vicinity of Fayetteville. The same zone of downfilling manifests itself at several places in the Winslow quadrangle as far south as the Cove Creek faults, but the syncline is apparently not continuous throughout that distance. At points where it is most pronounced it is likely to be faulted on its northwest limb.

FAULTS

Normal faults are relatively common in the Ozark plateaus, especially along the southern edge of the Springfield plateau and in the northern part of the Boston Mountains. In the southern part of the Boston Mountains they may be equally numerous, but that region has not been so carefully studied, and the presence of a single formation at the surface makes their recognition in that area somewhat more difficult than in areas farther north. In both the northern plateaus, however, the faults are also hard to determine where thick formations, such as the Cotter or the Boone, crop out over large areas. In such regions fault breccias are found at a number of places where the fault trace cannot be determined. Such fractures are relatively unimportant, however, since they are not large enough to bring into contact beds of different formations.

It seems certain, therefore, that a number of faults are not shown on the large structure map (Pl. I, A). The map is most likely to be deficient in this respect in Townships 13, 14, and 15 N., and in Baxter, Fulton, Sharp, Lawrence, and Randolph counties. On the other hand, the most detailed work in the Batesville manganese area

revealed only a few small faults, and prospecting for lead and zinc in the Yellville quadrangle, where faults are carefully sought for as sites of ore deposits, has shown that faulting is not so prominent in the general Ozark region as might be supposed.

The faults are all of the normal type, and their planes are inclined at high angles. They trend dominantly westward but many of them extend some degrees north of east or north of west. Several, however, trend almost directly northeast or northwest, and a very few extend more nearly northwest than westward. Most of the faults have a maximum displacement of not over 350 feet, and the average displacement is much less. A very few faults show horizontal displacement but no appreciable vertical movement. In some places the compressive forces produced differential movement of the strata and gave rise to breccias, particularly in the Cotter and Boone formations, although in the Boone fracturing and fissuring are more common. Such breccias, formed by lateral movement that was taken up in varying degree by individual beds, should not be mistaken for fault breccia, which they may greatly resemble.

Most of the faults in the Ozark area are downthrown on the south, and the beds on the upthrown side are commonly dragged down near the fault, whereas the downthrown beds are turned up near the fault plane. The steepest dips in the entire area are ordinarily found in this structural position, and in a few such places, as in the northern part of the city of Fayetteville, the beds may be turned on end. South of the syncline that commonly parallels the fault trace there is ordinarily an anticline. This is a structural principle which may be profitably noted by oil and gas prospectors.

At several places block faulting has occurred between pairs of essentially east-west faults and the downfaulted block, or graben, is commonly tilted to the north, or, more rarely, it may have a synclinal structure. The tilt to the north is the result of the greater displacement along the northern of the two faults. Along the southern fault in such places, the beds are, of course, downthrown north of the trace, but the general effect of both faults is to lower the rocks south of the fault zone in respect to those north of it. Individual faults that are downthrown north of their traces are rare, and their displacement is small.

The faults are the results of tension that accompanied or directly followed the flexing of the beds of the Ozark region near the end of the Paleozoic era. They are probably contemporaneous with the normal faults of the Arkansas Valley, or very slightly younger than the thrust faults of that area.

The larger faults of the Ozark plateaus are described in the following pages. Many of them were recognized by members of the old

Arkansas Geological Survey. Most of the diagrams that show their structural features are slightly modified after Purdue and Miser.

BATESVILLE FAULTS

There are two faults near the city of Batesville, which are here called the Batesville faults. The longer of these extends from Rudells' Mill, on Mill Creek, at about the center of Sec. 13, T. 13 N., R. 7 W., northeastward to the Pfeiffer spur, at the west center of Sec. 3, T. 13 N., R. 6 W. The downthrow is south of the fault trace, and at most places the displacement is at least 100 feet. North of the fault line the Boone formation is exposed; south of it the Batesville sandstone and the Moorefield shale crop out. The angle of dip of the fault plane is unknown, but apparently it is high.

The shorter fault extends from the SW. $\frac{1}{4}$ Sec. 13, T. 13 N., R. 7 W. northwestward to the NW. $\frac{1}{4}$ Sec. 15, T. 13 N., R. 7 W. The downthrown side is south of the fault trace. The displacement is sufficient to bring the Batesville sandstone and Moorefield shale into contact with the Boone formation, but nowhere is it greater than 75 feet. Toward its west end the fault gradually dies out, but its southeast end is concealed by the alluvium of White River.

BRUSH CREEK FAULT

The Brush Creek fault extends from the NE. $\frac{1}{4}$ Sec. 29, T. 17 N., R. 29 W. northeastward to about the center of Sec. 18, T. 17 N., R. 28 W., where it turns southeastward and terminates at the Drakes Creek fault, near the center of the north half of Sec. 14, T. 16 N., R. 27 W. The downthrown side is south of the fault trace, and the displacement ranges from 100 to at least 300 feet. Near the Drakes Creek fault the Atoka (Winslow) formation has been downfaulted against the Hale sandstone, but farther west the displacement increases, so that north of Goshen the Atoka and Boone formations are in contact.

East of the junction of the Brush Creek and White River faults the two are essentially parallel, and the area between them is a downfaulted block, which is tilted to the north. Throughout much of the graben, however, the structure is synclinal, the syncline extending eastward beyond the east end of the White River fault and determining largely the course of Brush Creek.

South of the syncline just described is an anticline that trends northwest and that contains gas. In 1929 the Independent Oil and Gas Company's H. Banks well No. 1, in the NE. $\frac{1}{4}$ of the NE. $\frac{1}{4}$ Sec. 6, T. 16 N., R. 27 W., obtained from just below the base of the Boone formation a flow of gas that was generally estimated at about

1,000,000 cubic feet a day. The driller's log of the Banks No. 1 well is given below.

Log of Independent Oil & Gas Co., H. Banks Well No. 1, northeast corner of SE. $\frac{1}{4}$ NE. $\frac{1}{4}$ Sec. 6, T. 16 N., R. 27 W., Madison County, Arkansas.

	Depth in feet
Mississippi lime.....	0- 15
Hard dark flint.....	0- 5
Hard white lime.....	5- 15
Hard whitewater sand.....	15- 30
Hard white lime.....	30- 260
Sand and lime; show of gas at 2BW.....	260- 290
Hard white lime; slight show of gas at 310 feet.....	290- 310
Black shale; est. 1 million feet of gas; slight show of oil at 320 feet.....	290- 310
Sand (Wilcox); show of gas; slight increase of gas at 405 feet.....	365- 438
Hard light sand and lime.....	438- 445
Soft dark shale; break.....	445- 448
Hard gray lime; hard shells.....	448- 460
Sand ("Wilcox"); show of oil; some gas.....	460- 630
Hard gray "Arbuckle lime".....	630-2441
Hard red and gray granite wash.....	2441-2504
Hole full of fresh water at.....	2504-2515

The H. Banks well was started on the Boone formation, whose base was reached at 310 feet. The Chattanooga shale was encountered at 310 and extended to 350 feet. The St. Clair, Jasper, and Joachim limestones make up the interval from 350 to 465, and the St. Peter was found from 465 to 615 feet. The Everton formation was encountered from 615 to 630 feet and the Powell limestone from 630 to 750 feet. In the deeper part of the well, according to Mr. H. S. McQueen,⁶ of the Missouri Bureau of Mines and Geology, the H. Banks No. 1 well "appears to have encountered a section comparable to the known section and drill records in southern Missouri. What appears to be the Gunter sand, at the base of the Gasconade formation, was drilled at a depth of slightly more than 2,000 feet. The underlying 300 feet or more of sediments have been referred to the Eminence formation. Pre-Cambrian rhyolite was encountered at 2,397."

The log of the H. Banks No. 1 well is somewhat similar to that of the War Eagle Oil and Gas Company's well near Witter, which was drilled about 13 miles to the southeast. The Witter well however, was started 316 feet higher stratigraphically than the H. Banks No. 1 well, yet it reached the rhyolite at 2,286 feet, 111 feet higher than in that well. Stating this fact in another way, the interval between the base of the Boone and the pre-Cambrian in the Witter well is 1,660 feet, but in the H. Banks No. 1 it is 2,087 feet. This

⁶ Letter to G. C. Pranner, dated June 27, 1929.

indicates a rather notable thinning of the early Paleozoic beds near Witter and suggests a "high" in the old pre-Cambrian basement. The interval between the base of the Boone and the igneous complex in a well drilled near Prairie Grove, in the NE. $\frac{1}{4}$ of the SW. $\frac{1}{4}$ Sec. 30, T. 15 N., R. 31 W., is 2,155 feet, and at the deep well at the Southern mine, near Cushman, the same interval is more than 2,040 feet. These figures seem to substantiate the idea that the interval in the H. Banks No. 1 well is similar to that to be expected in most wells drilled in the same latitude in northern Arkansas, and that in the Witter well the interval is notably short.

BUFFALO FAULTS

A rather complicated set of faults in the vicinity of Jasper and along Little Buffalo Fork has been called the Buffalo faults. The major fault zone extends from Jasper northeastward to the north half of Sec 9, T. 16 N., R. 20 W., but for a part of the distance the

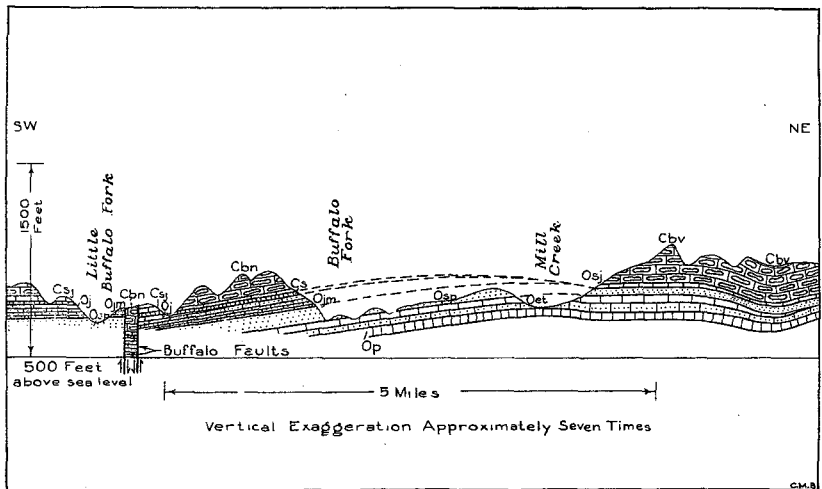


FIGURE 15.—Section from northeast to southwest through the Buffalo faults.

Op, Plattin limestone; Oet, Everton formation; Osp, St. Peter sandstone; Ojm, Joachim limestone; Oj, Jasper limestone; Cs, Sylamore sandstone; Csj, St. Joe limestone; Cbn, Boone limestone; Cbv, Batesville sandstone. (Modified after Purdue and Miser.)

disturbance is expressed by a fold and the beds are not displaced. In the NE. $\frac{1}{4}$ Sec. 24, T. 16 N., R. 21 W., the fault branches into two prongs, between which lies a very narrow downdropped block. The downthrown side of the fault zone is generally south of the line of displacement, but the downthrow is north of the east prong of the branched part of the fault. At most places the displacement is sufficient to bring the Boone formation into contact with the Joachim limestone.

A mile northwest of this fault zone, and parallel with it, there is

another fault, which extends from the southwest half of Sec. 29, T. 16 N., R. 21 W., northeastward to the NW. $\frac{1}{4}$ Sec. 13, T. 16 N., R. 21 W. The downthrow is on the south, and the maximum displacement, which is about 300 feet, brings the Boone formation into contact with the St. Peter sandstone. On the southern boundary of Sec. 14, T. 16 N., R. 21 W. there is a small fault parallel to the larger one, with a downthrow of 50 feet of its trace. Near the south end of this fault there are three other short faults, all of which extend northeastward at different angles. The northern fault is downthrown west of its trace, the middle one south of the line of movement, and the southern fault shows only horizontal displacement. Farther northeast, along this same line of disturbance, in Secs. 12 and 13, T. 16 N., R. 21 W., there is another short fault, which has a displacement of about 100 feet. The downthrown side here is northwest of the fault trace.

The structural and stratigraphical features of the eastern forked Buffalo fault are shown in Figure 15.

CLIFTY CREEK FAULTS

The Clifty Creek faulted zone extends from the headwaters of Rockhouse Creek, in the SW. $\frac{1}{4}$ Sec. 35, T. 19 N., R. 26 W., slightly north of west to the East Fork of Little Clifty Creek, in the SW. $\frac{1}{4}$ Sec. 18, T. 19 N., R. 27 W. The two easternmost faults are somewhat unusual in that they are downfaulted north of their traces rather than on the south. In the southernmost and larger of these two faults the Boone formation has been downthrown against the Sylamore sandstone near the west end of the fault, and near the east end the St. Joe member of the Boone has been brought into contact with the Everton limestone. The average displacement, however, is not more than 50 feet.

The westernmost of the three Clifty Creek faults has the same trend as the other two, but it is apparently continuous with neither, for its downthrown side is south of its trace. In this fault the St. Joe limestone has been downfaulted against the Powell limestone and hence the displacement locally must be at least 75 feet. The fault is a little more than two miles long.

COMPTON FAULT

The Compton fault extends from the SE. $\frac{1}{4}$ Sec. 1, T. 16 N., R. 23 W. northeastward for about 2 miles to the NE. $\frac{1}{4}$ Sec. 5, T. 16 N., R. 22 W. The downthrown side of the fault is south of its trace, and the displacement is sufficient in some places to bring the Boone formation into contact with the Everton limestone. The maximum displacement therefore exceeds 300 feet, but toward the southwest it

diminishes, and the fault passes into a monocline, which is conspicuous at the head of South Fork of Osage Creek.

The relation of the Compton fault to the Sneeds Creek dome and the Sneeds Creek faults is shown in Figure 12.

CROOKED CREEK FAULT

The Crooked Creek fault extends from the SE. $\frac{1}{4}$ Sec. 25, T. 19 N., R. 20 W., southeastward at least to the NW. $\frac{1}{4}$ Sec. 4, T. 18 N., R. 19 W., and it probably continues into the Yellville quadrangle, although it has not been mapped there. This fault is unusual in that its downthrown side is north of the trace. The displacement is small, but at some places it is sufficient to bring the Boone formation into contact with the Everton limestone. In Sec. 32, T. 19 N., R. 19 W., the displacement probably averages about 50 feet.

DRAKES CREEK FAULT

The Drakes Creek fault is one of the longest and most conspicuous faults in the northern Ozark area. The extent of this fault south of the southern boundary of the Eureka Springs quadrangle has not been ascertained definitely, but it is known to extend from the SE. $\frac{1}{4}$ Sec. 12, T. 15 N., R. 28 W., northeastward to the SW. $\frac{1}{4}$ of Sec. 33, T. 17 N., R. 26 W. At the north end of the fault, along Holman Creek, it passes into a monocline, but the Moody Hollow fault continues the displacement along the same line farther northeast.

The downthrown side of the fault is southeast of its trace, and the displacement, which is slight near its north end, increases to about 400 feet in the vicinity of the village of Drakes Creek. Near this village the Atoka (Winslow) formation has been downfaulted against the Fayetteville shale.

Within the angle made by the Drakes Creek and Reed Creek faults the general structure is anticlinal, and a part of the area may be regarded as structurally suitable for the accumulation of oil or gas.

EVANSVILLE FAULT

The Evansville fault extends from the NW. $\frac{1}{4}$ Sec. 23, T. 13 N., R. 33 W., southeastward to the north half of Sec. 31, T. 13 N., R. 31 W. The downthrown side of this fault, unlike that of most of the Boston Mountain faults, is north of the fault line. The displacement is in general less than 100 feet, but at some places the Kessler limestone has been downfaulted against the upper Fayetteville shale.

The Cove Creek fault crosses the Evansville fracture in the SE. $\frac{1}{4}$ Sec. 27, T. 13 N., R. 32 W., and in this general area the displacement is somewhat complicated. In the southwest quadrant made by the above described intersection the Fayetteville shale crops out, the Hale

sandstone occurs next to the fault lines in the northwest and southeast quadrants, and the Atoka (Winslow) formation crops out in the northeast quadrant.

GLADE FAULT

The Glade fault extends from the NW. $\frac{1}{4}$ Sec. 36, T. 20 N., R. 28 W., northeastward to the SW. $\frac{1}{4}$ Sec. 17, T. 20 N., R. 27 W. The downthrow is southeast of the trace, and the displacement locally is sufficient to bring the Boone formation in contact with the Cotter dolomite. The average displacement, however, is about 100 feet.

The Glade fault lies along the same line of disturbance as the Price Mountain faults, but the two are not connected, for the beds in the area between the two faults have been folded into a syncline. At some places, however, as at the cross roads in the western part of Sec. 33, T. 19 N., R. 28 W., the beds in the intervening area are faulted, so that the two main faults are structurally very closely related. This zone of faults and synclines is about 60 miles long. The Glade fault, as defined in this report, lies near the north end of the zone, the Cove Creeks faults near its south end and the Price Mountain and Onda faults between the two.

GREEN FOREST FAULT

The Green Forest fault extends from the NE. $\frac{1}{4}$ Sec. 33, T. 19 N., R. 23 W., slightly west of north to about the center of Sec. 30,

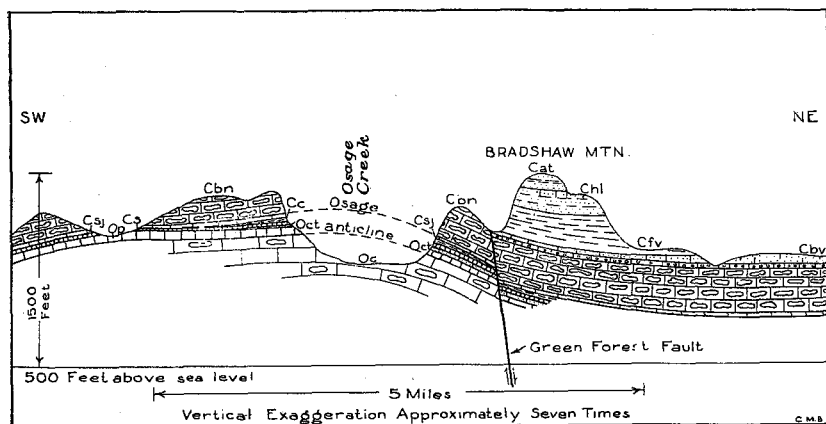


FIGURE 16.—Section from southwest to northeast across the Osage anticline and the Green Forest fault south of the town of Green Forest.

Os, Cotter dolomite; Op, Powell limestone; Oet, Everton formation; Cs, Sylamore sandstone; Cc, Chattanooga shale; Csj, St. Joe limestone; Cbn, Boone limestone; Chv, Hindsville limestone; Cbv, Batesville sandstone; Cfv, Fayetteville shale; Chl, Hale sandstone; Cat, Atoka (Winslow) formation. (Modified after Purdue and Miser.)

T. 20 N., R. 23 W. The fault extends along the northeast limb of the Osage anticline, roughly parallel to its axis. The downthrown side of the fault is northeast of its trace, and the displacement is at least 300 feet at the northwest end of Bradshaw Mountain, where the

Atoka (Winslow) formation has been downfaulted against the Boone formation. Toward the ends of the fault, however, the displacement diminishes rapidly, and at most places it is only sufficient to bring the Batesville sandstone into contact with the Boone formation.

The position of the Green Forest fault with reference to the Osage anticline, as well as its structural and stratigraphical features, are well shown in Figure 16.

HURRICANE FAULT

The Hurricane fault extends from the west half of Sec. 7, T. 16 N., R. 19 W., eastward at least to the southeast corner of Sec. 9, T. 16 N., R. 19 W. The fault is about half a mile south of the St. Joe fault and is essentially parallel to it. It has about the same strike and the same structural relations as the Mill fault, which lies farther east, but the movement was probably taken up by a fold between the two.

The area between the Hurricane fault and the St. Joe fault is a graben having a synclinal structure. The displacement in the Hurricane fault is sufficient to downthrow the Fayetteville shale north of the trace against the Boone formation south of it and amounts to about 200 feet.

Purdue and Miser describe two Hurricane faults, but in this report the northern of the two displacements is called the St. Joe fault, for it is continuous with that fault farther east.

LONG CREEK FAULT

The Long Creek fault extends from Blevins Hollow, in the SE. $\frac{1}{4}$ Sec. 2, T. 20 N., R. 22 W., slightly west of north along the valley of Long Creek to the NW. $\frac{1}{4}$ Sec. 35, T. 21 N., R. 22 W. The downthrown side of the fault lies west of its trace, and the displacement averages less than 50 feet. In places, however, the Boone formation has been downthrown against the Cotter dolomite.

MILL FAULT

The Mill fault extends from the SE. $\frac{1}{4}$ Sec. 8, T. 16 N., R. 18 W. slightly south of east to the SW. $\frac{1}{4}$ Sec. 18, T. 16 N., R. 17 W. This fault is essentially parallel to the St. Joe fault, which lies about half a mile to the north. The area between the two fractures is a downfaulted block having a synclinal structure. The nearly straight part of Mill Creek valley immediately west of St. Joe has been developed in the graben just described.

The downthrown side of the Mill fault lies north of its trace, as do most of the southernmost faults of pairs of nearly parallel east-west faults in the Ozark province. In the Mill fault the displacement is sufficient to downthrow the Batesville sandstone against the Boone formation, but at most places it is probably less than 50 feet.

MOODY HOLLOW FAULTS

The Moody Hollow faults may be regarded as the northeastern extension of the Drakes Creek zone of faulting. The southern and longer of the two Moody Hollow faults extends from the NW. $\frac{1}{4}$ Sec. 12, T. 17 N., R. 26 W. northeastward to the SE. $\frac{1}{4}$ Sec. 2, T. 18 N., R. 25 W.; the shorter one extends from the NW. $\frac{1}{4}$ Sec. 30, T. 19 N., R. 24 W. northeastward to the NW. $\frac{1}{4}$ Sec. 20, T. 19 N., R. 24 W. The downthrown side of both faults is on the southeast, and the displacement where the southernmost fault crosses Kings River is about 100 feet. Near the south end of the longer fault the Fayetteville shale has been brought into contact with the Boone formation, but farther north the St. Joe limestone has been faulted against the Cotter dolomite.

This fault does not appear to cross Pine Creek as a definite displacement, but it passes into a syncline at the mouth of Canfield Hollow and reappears again as a separate fault on the northeast part of Pension Mountain. The northern fault, however, has very little displacement.

ONDA FAULTS

The principal Onda fault extends from the SE. $\frac{1}{4}$ Sec. 19, T. 14 N., R. 31 W. northeastward to the NE. $\frac{1}{4}$ Sec. 16, T. 14 N., R. 31 W. The fault lies along the same line of disturbance as the Price Mountain, Glade, and Cove Creek faults and is structurally similar to them. The downthrown side is southeast of the trace, but the displacement is slight, probably averaging less than 50 feet.

The fault described above terminates in a fault that extends westward along the southern edge of Secs. 19 and 20, T. 14 N., R. 31 W. The downthrow in this fault is on the south, and the displacement is about 50 feet.

OSAGE FAULT

The Osage fault extends from the SW. $\frac{1}{4}$ Sec. 21, T. 17 N., R. 23 W. almost directly eastward across the South Fork of Osage Creek to the SE. $\frac{1}{4}$ Sec. 23, T. 17 N., R. 23 W. The downthrow side is south of the fault trace, and the maximum displacement is less than 100 feet. At several points, however, the Fayetteville shale has been brought into contact with the Boone formation.

PENTERS BLUFF FAULT

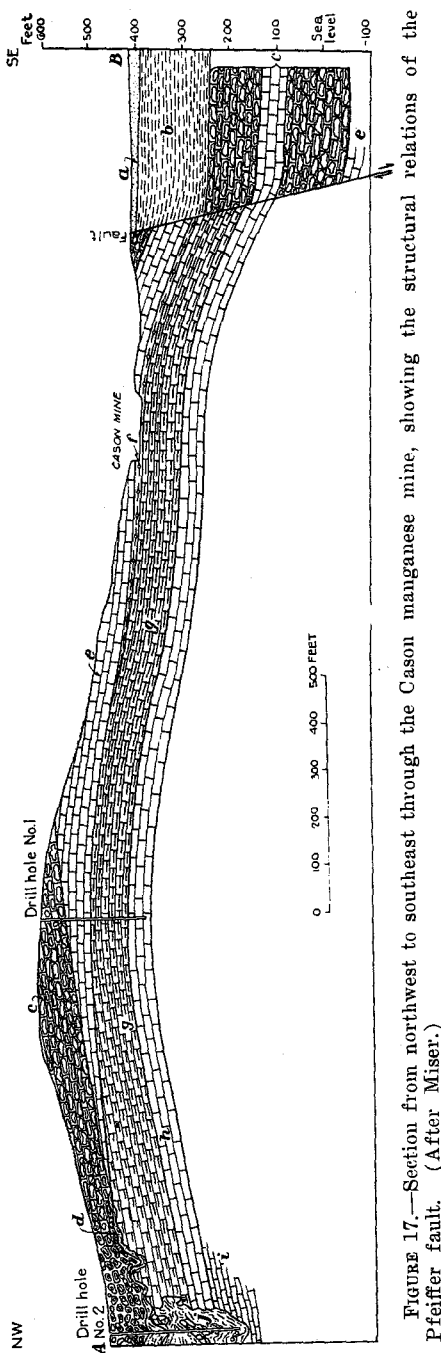
The Penters Bluff fault extends from the SW. $\frac{1}{4}$ Sec. 5, T. 14 N., R. 8 W. northeastward at least to West Lafferty Creek, in the SE. $\frac{1}{4}$ Sec. 10, T. 14 N., R. 8 W. The fault trace crosses White River a short distance south of Penters Bluff station. The fault may extend

farther west in Stone County than is here indicated, but west of White River its features are somewhat obscured by the Boone chert, which crops out on both sides of the fault line.

The downthrown side of the fault is south of its trace, and the displacement is at least 250 feet near Penters Bluff, where the Fernvale limestone has been faulted against the Plattin limestone. East of Penters Bluff the displacement decreases until, at West Lafferty Creek, it is inconsequential. Opposite Penters Bluff, on the west bank of White River, the Boone formation is brought into contact with the Plattin limestone for a short distance, but still farther west only the Boone formation is cut by the fault.

PFEIFFER FAULT

The Pfeiffer fault extends from the NW. $\frac{1}{4}$ Sec. 5, T. 13 N., R. 6 W. northeastward about to the SW. $\frac{1}{4}$ Sec. 21, T. 14 N., R. 5 W. This fault which is the longest in the Batesville district, is downthrown south of its trace and has a displacement of at least 400 feet throughout much of its length. Like many of the Ozark faults, the Pfeiffer fault is apparently a faulted monocline. The beds just north of the fault at most places dip from 10 to 20 degrees south, and the beds south of the fault also dip



southward, though at lower angles. These relations are well shown in Figure 17.

The formations exposed north of the fault include the Platin, Kimmswick, and Fernvale limestones, the Cason shale, the St. Clair limestone, and the Boone chert. South of the fault, however, only the Boone chert and Batesville sandstone are exposed. The Pfeiffer fault is structurally closely related to the easternmost of the Batesville faults.

PILOT MOUNTAIN FAULT

The principal Pilot Mountain fault extends from the NW. $\frac{1}{4}$ Sec. 17, T. 16 N., R. 17 W., in a generally eastward course, to the SW. $\frac{1}{4}$

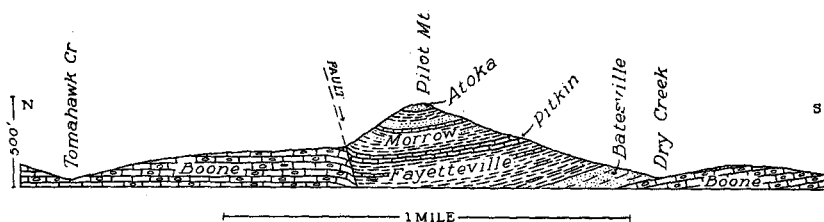


FIGURE 18.—Section from north to south through the Pilot Mountain fault near the west end of Pilot Mountain, 2 miles northeast of St. Joe.

Sec. 12, T. 16 N., R. 17 W. The downthrown side of the fault lies south of its trace, and the displacement, which is sufficient to bring the Hale formation into contact with the Boone formation, may be in places more than 250 feet. The Pilot Mountain fault is structurally similar to the principal Tomahawk fault but is complicated near its east end by a short parallel fracture, which lies south of its end, and by a connecting cross fault. The small parallel fault is also downthrown south of its trace, and the downthrow is west of the cross fault.

The structural and stratigraphic relations of the Pilot Mountain fault are shown in Figure 18.

POLK BAYOU FAULTS

The Polk Bayou faults are two or possibly three short parallel displacements that cross Polk Bayou from east to west in the southern part of Sec. 31, T. 15 N., R. 6 W., about $4\frac{1}{2}$ miles northeast of Cushman. The fault traces are about 250 feet apart, and the area between them has been downfaulted at least 100 feet. The Joachim and Platin limestones crop out in the graben, and the St. Peter sandstone is exposed both north and south of the faulted block. The length of the faulted zone has not been determined accurately, but it appears to be at least half a mile long. The structural and stratigraphical relations of the Polk Bayou faults are shown in Figure 19.

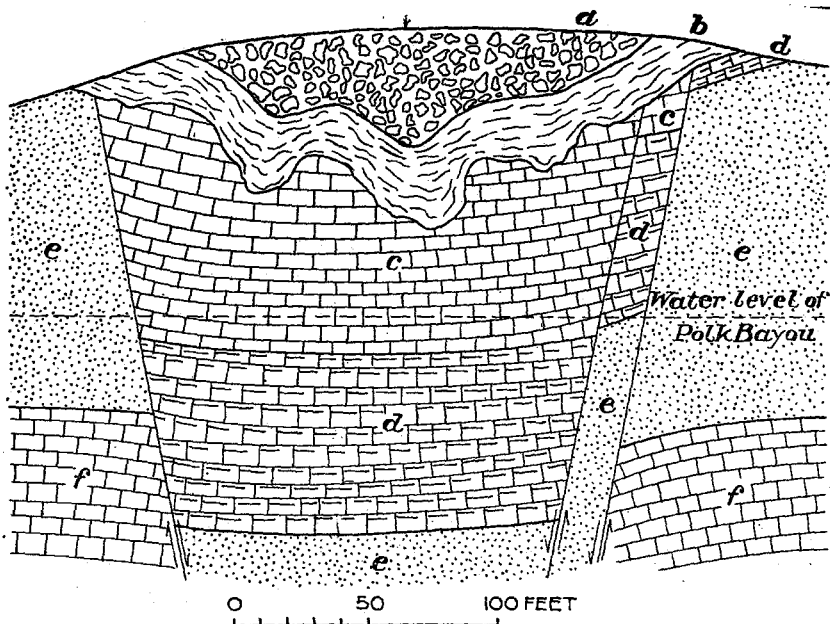


FIGURE 19.—Section from north to south through the Montgomery manganese prospect, showing the structural features of the Polk Bayou faults. (After Miser.)

a, fractured chert; b, residual clay; c, Plattin limestone; d, Joachim limestone; e, St. Peter sandstone; f, magnesian limestone. The arrow shows the location of the prospect.

PRICE MOUNTAIN FAULT

The Price Mountain fault extends from the NE. $\frac{1}{4}$ Sec. 20, T. 16 N., R. 30 W., northwestward to the east half of Sec. 2, T. 17 N., R. 29 W., but the fault, as here defined, is only the central part of a much longer zone of disturbance that includes the Glade fault on the north and the Onda and Cove Creek faults on the south.

The downthrow of the Price Mountain fault is southeast of its trace, and the maximum displacement is as much as 300 feet. The average displacement, however, is less than 200 feet. At the junction of the Price Mountain and White River faults the Atoka (Winslow) formation has been downfaulted against the Boone formation, but more commonly some division of the Morrow group lies in contact with the Fayetteville formation. The beds south of the trace have been thrown into a syncline which at some places, as in the northern part of the city of Fayetteville, is rather closely folded. At both ends the fault passes into synclines.

PUMPKIN CREEK FAULT

The Pumpkin Creek fault extends from about the center of Sec. 31, T. 15 N., R. 7 W. northeastward to the SE. $\frac{1}{4}$ Sec. 29, T. 15 N., R. 7 W. Although the fault is less than two miles long it has a max-

imum displacement of at least 200 feet at a point near its northeast end. At this end the Boone chert is brought into contact with the St. Peter sandstone. Near the west end of the fault, where the Joachim limestone is downfaulted against the St. Peter sandstone, the displacement diminishes to about 50 feet.

The Pumpkin Creek fault is similar to the other faults of the Batesville district in that the downstream side is south of the trace and the beds just north of the fault dip toward the south. The dip of the fault plane has not been ascertained, but it appears to be high.

REED CREEK FAULT

The Reed Creek fault extends from about the center of Sec. 22, T. 17 N., R. 26 W. southeastward to the SE. $\frac{1}{4}$ Sec. 32, T. 17 N., R. 25 W. The downthrow is south of the trace, and the displacement locally is sufficient to downfault the Brentwood limestone against the Boone formation, and for a considerable distance the Hale sandstone is in contact with the Boone.

The Reed Creek fault lies almost at right angles to the course of the Drakes Creek zone of faulting. The triangular area between the two faults has been downfaulted and is in places structurally favorable for the accumulation of oil and gas. In this area, which is somewhat promising, the lower potential producing horizons are at many places fairly well covered, and the carbon ratios are relatively low for northern Arkansas. The structural and stratigraphic relations of the Reed Creek fault are shown in Figure 14 (p. 189).

RHEA FAULT

The Rhea fault enters Arkansas in the SW. $\frac{1}{4}$ of Sec. 30, T. 15 N., R. 33 W., and extends northeastward to the SW. $\frac{1}{4}$ Sec. 33, T. 16 N., R. 32 W. This fault has somewhat the same general strike as the White River fault and may be, as some geologists have thought, a continuation of it, although the evidence that the two are connected is not good. The downthrown side of the Rhea fault lies south of its trace, and the displacement near the village of Rhea, where the Fayetteville shale is in contact with the middle Boone formation, is probably about 100 feet. Farther southwest, in the Winslow quadrangle, the displacement is sufficient only to bring the Wedington sandstone against the lower Fayetteville shale, and the fault becomes indistinct a short distance west of the Arkansas-Oklahoma boundary.

RUSH CREEK FAULTS

The principal Rush Creek fault extends from the SE. $\frac{1}{4}$ Sec. 27, T. 18 N., R. 16 W. southeastward to the SW. $\frac{1}{4}$ Sec. 11, T. 17 N.,

R. 15 W. The course of Rush Creek is determined throughout most of its length by this fracture. The downthrown side of the fault is south of its trace and the maximum displacement is about 350 feet.

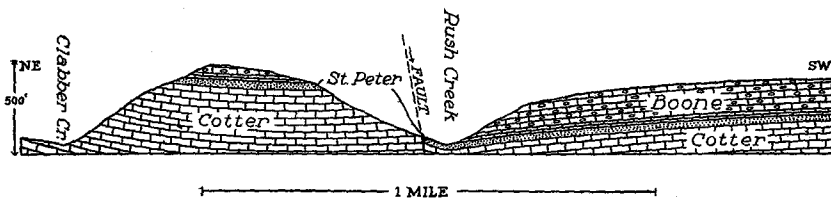


FIGURE 20.—Section from northeast to southwest through the Rush Creek fault near Rush Creek post-office. Modified after Adams.

The Boone formation, which appears on top the hill north of Rush has been downfaulted, so that it crops out in the valley on the south side of the fault. The beds just south of the fault have been thrown into a narrow but rather pronounced syncline, as shown in Figure 20.

At a number of places the course of the fault is indicated by fault breccia. The faulting is apparently not confined to a single fracture, for south of the main fault there is a similar but smaller fracture at the old Climax mine. Other small faults parallel to the main one have been observed in the old Morning Star and White Eagle mines.

At its southeastern end the main fault passes into a monoclinical fold.

SNEEDS CREEK FAULTS

The Sneeds Creek faults consist principally of four essentially parallel southeastward-trending faults on the Buffalo Fork of White River near mouth of Sneeds Creek. The two northernmost of these faults join the Compton fault at their west ends. The area between these two faults is downfaulted sufficiently to bring the Hale sandstone into contact with the Boone formation. The area between the two southernmost of the four main faults is also a graben, and in places the movement has been great enough to throw the Atoka (Winslow) formation down against the Fayetteville shale. The area between the two middle faults has been elevated in relation to the grabens to the north and south.

These major faults are complicated by several minor cross faults and are terminated on the east by a small north-south fault and monocline. All these faults are structurally closely related to the Sneeds Creek dome, on whose southeast flank they are found.

In addition to the faults already mentioned two short faults occur about 1 to $1\frac{1}{2}$ miles southeast of the major faults and roughly parallel them. The northernmost of these two faults is downfaulted south of its trace and has a displacement of about 50 feet; the southern one is downfaulted on the north and has a displacement of about

100 feet. The area between the two faults is therefore also a graben and is structurally similar to those just described, although it has subsided much less.

The structural and stratigraphical relations of the Sneed's Creek faults are shown in Figures 12 and 13.

ST. JOE FAULT

The St. Joe fault as here described extends from the northern part of Sec. 7, T. 16 N., R. 19 W., slightly south of east to the northern part of Sec. 18, T. 16 N., R. 17 W., where it turns northeastward and terminates in the NW. $\frac{1}{4}$ of Sec. 1, T. 16 N., R. 17 W. The part of the fault that extends into the Harrison quadrangle was described as the northernmost of the two Hurricane faults by Purdue and Miser, but the east end of the same fault had been called the St. Joe fault by G. I. Adams.

The St. Joe fault is downthrown south of its trace, and the displacement, which is greater in the Yellville quadrangle than in the Harrison quadrangle, ranges from about 175 to 325 feet. At several places the Boone formation has been brought into contact with the Cotter dolomite, the Powell limestone, the Joachim limestone, or the St. Peter sandstone. Near the west end of the fault the Fayetteville shale has been downfaulted against the Boone formation. Some of the structural and stratigraphical relations of the St. Joe fault near the town of St. Joe are shown in Figure 21 and Plate XXXIV.

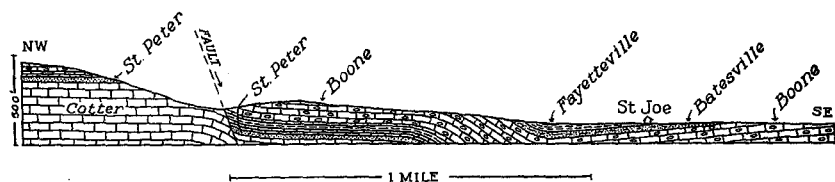


FIGURE 21.—Section from northwest to southeast through the St. Joe fault and monocline at St. Joe.

Some beds belonging to the Powell formation are included at the top of the Cotter dolomite.

The Hurricane fault parallels the St. Joe fault near its west end, and the Mill fault appears in the same relation for a considerable distance farther east. In the graben between these faults and the St. Joe fault the beds have a synclinal structure. Farther east, in the vicinity of St. Joe, there is no delimiting fault on the south, but the structure is that of a rather pronounced monocline. Along the fault line the beds just north of the trace dip to the south rather sharply, and those south of it have also been turned up near the line of movement.

TOMAHAWK FAULTS

The principal Tomahawk fault extends from its point of junction with the main St. Joe fault, in the SE. $\frac{1}{4}$ Sec. 2, T. 16 N., R. 17 W. southeastward to the SW. $\frac{1}{4}$ Sec. 9, T. 16 N., R. 16 W. The downthrown side of the fault lies south of its trace. The displacement is sufficient to bring the Pitkin limestone into contact with the Boone formation and probably reaches a maximum of 350 feet.

Several other small faults, which lie south and southeast of the main fault, are downfaulted on the north, so that a graben-like area of Batesville, Fayetteville, and Pitkin rocks is found between them and the main fault. Another graben is found between two faults about two miles southeast of Tomahawk, the northernmost and longest of which crosses Gulf Hollow almost from east to west.

WHITE RIVER FAULT

The White River fault extends from the SE. $\frac{1}{4}$ Sec. 36, T. 17 N., R. 31 W., slightly north of east to the northern part of Sec. 19, T. 17 N., R. 28 W., where it swings southeastward and terminates in the NE. $\frac{1}{4}$ Sec. 26, T. 17 N., R. 28 W. The White River fault crosses the Price Mountain and Brush Creek faults. West of its intersection with the Price Mountain fault the downthrow is on the south, and the displacement is sufficient to bring the Wedington sandstone into contact with the Boone formation. The rocks on the downthrown side are folded into a shallow syncline.

Between the Price Mountain and Brush Creek faults the White River fault is also downthrown south of its trace, but east of its junction with the Brush Creek fault its downthrown side is north of its trace. In this area the block between the Brush Creek and White River faults is a synclinal graben, which at some places has been depressed 300 feet.

YARDELLE FAULTS

The Yardelle faults are two displacements that extend nearly westward in the southeastern part of the Harrison quadrangle. The longer and southernmost of the two extends from the SW. $\frac{1}{4}$ Sec. 5, T. 16 N., R. 20 W. eastward to the village of Yardelle, in the NW. $\frac{1}{4}$ Sec. 4, T. 16 N., R. 19 W. The other fault, which lies from a quarter to a half a mile to the north, is about 2 miles shorter. The area between the two faults is a graben which has subsided about 300 feet. The general structure of the downfaulted block is that of a complicated syncline. The displacement in many localities has been sufficient to bring the Fayetteville shale into contact with the lower part of the Boone formation.



A. THE BOONE, MOOREFIELD, AND BATESVILLE FORMATIONS AS EXPOSED ON THE DOWNTOWN SIDE OF THE ST. JOE FAULT JUST NORTH OF ST. JOE

The Moorefield, which is less than two feet thick at this locality, appears between the heavy limestone below and the rather flaggy sandstone and shale of the Batesville above.



B. FOLDED LOWER BEDS OF THE FAYETTEVILLE SHALE NORTH OF ST. JOE JUST SOUTH OF LOCALITY SHOWN IN A

Shows the fissility of the formation and the type of vegetation common to its outcrop.

STRUCTURE OF THE ARKANSAS VALLEY PROVINCE

GENERAL FEATURES

The Arkansas Valley province, which is a trough both structurally and topographically, lies between the essentially flat-lying rocks of the Boston Mountains on the north and the complexly folded strata of the Ouachita Mountains on the south. Its structure therefore partakes of some of the characteristics of both its bounding provinces. Its beds are rather close folded near its southern border, but the folds become progressively more open toward the Boston Mountains. Thrust faulting is characteristic near the Ouachitas, whereas normal faulting occurs near the northern edge of the valley. The down-thrown side of the average fault in the southern part of the province is north of its trace, but farther north, toward the Boston Mountains, the average fault is downthrown south of its trace. Most of the anticlines south of Arkansas River are steeper on their north flanks, but those north of the river are steeper on their south flanks.

The structure in the southern part of the valley is well expressed topographically, but the relation between topography and structure becomes more and more obscure toward the north. Near the Ouachita Mountain area steep anticlinal ridges and flat-topped synclinal mountains are the most characteristic topographic features, but such eminences, except in the area east of Morrilton, are rare north of Arkansas River.

The general trend of the structure is essentially eastward, but south of a line drawn from Bonanza to Judsonia it is typically directed slightly toward the northeast. In the vicinity of Fort Smith the trend is northeastward, but northwest of Van Buren it is directed slightly toward the northwest. In the area northeast of Russellville there is a rather notable variation from the general structural trend. Northwest and north of that town the trend is northwestward, but northeast of it, in the vicinity of White Oak Mountain, it swings back toward the northeast. The surface traces of the structure thus swing in an arc whose convex side is toward the south. Considered in plan, therefore, the structural axes in the Arkansas Valley have the appearance of waves advancing from the southeast against a northern shore marked by a promontory, on either side of which the waves extend farther up the strand, but on which their force is somewhat dissipated. As a matter of fact, the force that produced the folds was directed from the south against the resisting force of the Ozark positive element, and the folds were bent around the southward-extending White Oak Prong,⁷ as it may be called. East

⁷ Miller, W. Z., manuscript.

of the prong the folds become progressively shallower and wider; west of it they become somewhat deeper and narrower.

The anticlines of the Arkansas Valley are, generally speaking, fairly continuous from the Oklahoma boundary to the Mississippi lowlands, but they are commonly offset from one another at their ends. The synclines show the same offset, but they appear to be somewhat more continuous than the anticlines. In some places the offsetting is very obvious; in others it is inferred rather than observed. A syncline may begin at the termination of a plunging anticline. This alternation of syncline and anticline is particularly evident in the area southeast of Fort Smith. A number of anticlines are forked, well-defined synclines lying between the prongs, and some synclines are "swallow-tailed," with anticlines occurring between the forks.

ANTICLINES

GENERAL CONDITIONS

The Arkansas Valley province is a synclinorium that is folded into a number of smaller synclines and anticlines. These smaller features are of the greatest importance in a delineation of potential areas of gas production, and consequently, for the purposes of this report, they have been studied in some detail in the field and are rather fully described in the following pages.

The axes of the anticlines of the Arkansas Valley, broadly speaking, extend eastward, but many trend somewhat north of east, and a few trend southeastward. They range in length from a few miles to more than 40 miles, but most of them are less than 20 miles long. In general the anticlines rise toward the east and plunge toward the west, but many are doubly plunging. Some are domed locally, so that they are structurally ideal for the accumulation of either oil or gas.

Many of the anticlines in the southern part of the valley are close-folded and resemble those in the Ouachita Mountain area, whereas those adjacent to the Boston Mountains are much more open folded. Most of those south of Arkansas River are steeper north of their crests, and some are thrust-faulted along their axes, but farther north many of the structures are essentially symmetrical, and those adjacent to the Boston Mountain province are generally steeper on their south flanks.

All these anticlines have been named and are described in the text in alphabetic order. Their names are given on the large structure map accompanying this report, so that any one who is interested in a certain area may determine the names of the anticlines there from the map and may turn to their descriptions in the text, where the gas-producing possibility of each structure has been considered. In

order to facilitate the structural descriptions the anticlines discussed are those in Rs. 2 to 12, N. inclusive, and they therefore include a number which really belong either to the Boston Mountain province on the north or to the Ouachita Mountain province on the south.

ADA ANTIOLINE

Location.—The axis of the Ada anticline extends from the N. $\frac{1}{2}$ Sec. 13, T. 5 N., R. 19 W., northeastward to about the SE. $\frac{1}{4}$ Sec. 34, T. 6 N., R. 17 W., but its east end is obscured by the alluvium of Arkansas River.

Structural features.—The anticline is bounded on the north by the Pontoon syncline, and on the south by the Poteau and Meniffee synclines. The surface rocks in its western part belong to the Hartshorne sandstone, but those east of Petit Jean Mountain belong to the Atoka formation.

The anticline is essentially symmetrical, but the dips south of its axis are perhaps slightly higher, on the average, than those on the north flank. The dips north of the axis range from 4 to 12 degrees and average about 7 degrees, whereas those south of it range from 5 to 15 degrees, and probably average about 8 degrees. The anticline plunges slightly to the west in the vicinity of Divide, but the amount of closure is not great. The eastern termination of the anticline lies in the bottoms of Arkansas River where its structural features can not be determined.

An igneous plug on the extreme southeastern flank of the anticline, near Oppello, described elsewhere in this report, has had no effect on the structure of the anticline.

Exploration.—The anticline has not been tested for oil or gas, but it is structurally favorable for their accumulation. The initial well should be drilled near the axis, preferably near the village of Ada. The igneous intrusion cannot be regarded as more than a very slightly adverse element of the structure.

AETNA ANTIOLINE

Location.—The axis of the Aetna anticline extends from about SE. $\frac{1}{4}$ Sec. 12, T. 8 N., R. 28 W., southeastward for about 4 miles and then northeastward to the SW. $\frac{1}{4}$, Sec. 4. T. 8 N., R. 26 W., in the vicinity of Roseville, from which place the structure undoubtedly continues eastward for some distance, though its course is lost beneath the alluvium of Arkansas River.

Structural features.—The anticline is bounded on the north by the Smith Creek syncline and on the south by the Paris syncline. The surface rocks all belong to the Hartshorne sandstone, and the

structure is topographically expressed by the anticlinal hill that extends westward from Roseville.

The anticline is a broad elliptical dome, which is essentially symmetrical. The dips north of the axis range from 2 to 8 degrees and average about 5 degrees; those south of the crest range from 2 to 10 degrees and average between 5 and 6 degrees. Southeast of Peter Pender there is a small normal fault that trends northeastward. This fault appears to be downthrown on the south side and in places, as in Sec. 19, T. 8 N., R. 27 W., the dips south of the fault trace are as high as 20 degrees. The anticline is fairly well closed at its west end and there appears to be a pronounced closure near Roseville.

Exploration.—The Ozark Natural Gas Company drilled to a depth of 1,669 feet on the J. N. Reaves lease in the SE. $\frac{1}{4}$ of the NE. $\frac{1}{4}$ Sec. 15, T. 8 N., R. 27 W., nearly at the crest of the anticline, and obtained 750,000 cubic feet of gas from a sand at a depth of 1,601 to 1,669 feet under an initial rock pressure of 615 pounds. The log of this well is given below.

Log of Ozark Natural Gas Company's Reaves well, in the SE. $\frac{1}{4}$ of the NE. $\frac{1}{4}$ of Sec. 15, T. 8 N., R. 27 W.

	Depth in feet
Soil and clay.....	0- 20
Shale.....	20- 335
Sand.....	335- 355
Shale.....	355- 440
Shale and shells.....	440- 475
Sand.....	475- 495
Shelly.....	495- 540
Shale.....	540- 720
Shale and shells.....	720- 775
Sand.....	775- 870
Shale and shells.....	870- 952
Sand.....	952-1004
Sandy shale.....	1004-1055
Sand.....	1055-1080
Shale and shells.....	1080-1122
Shale.....	1122-1217
Sand.....	1217-1256
Shale.....	1256-1265
Sand.....	1265-1480
Shale.....	1480-1570
Sand.....	1570-1669

750,000 cubic feet of gas at 1601 feet.

Some features of this log make it seem doubtful whether it is an accurate record, but the well was started in the Hartshorne sandstone and terminated in the Atoka formation.

Future exploration of the Aetna anticline is desirable, but wells should be drilled to at least 4,000 feet if necessary.

ALMA ANTICLINE

Location.—The axis of the Alma anticline extends from about the center of Sec. 29, T. 9 N., R. 31 W., northeastward to about the center of Sec. 11, T. 9 N., R. 30 W.

Structural features.—The Alma anticline is bounded on the north by the Alma syncline and on the south by the Catcher syncline. It is not particularly prominent and is essentially symmetrical at the surface, but its north limb appears to be slightly steeper than its south limb. The dips north of the axis range from 2 to 6 degrees; those south of the axis range from 1 to 7 degrees. The anticline shows at the surface some evidence of closure at both ends.

Exploration.—The Alma gas field has been developed on this anticline, whose subsurface crest lies north of its surface axis. The details of this anticline are discussed in the description of the Alma field.

ALTUS ANTICLINE

Location.—The axis of the Altus anticline extends from the NE. $\frac{1}{4}$ Sec. 26, T. 9 N., R. 27 W. northeastward to about the NE. $\frac{1}{4}$ Sec. 13, T. 9 N., R. 26 W., but both the east and west ends of the anticline are poorly defined.

Structural features.—The anticline is bounded on the north by the Webb City syncline and on the south by the Smith Creek syncline. The surface rocks belong chiefly to the Hartshorne and Atoka formations.

The structure is relatively indefinite throughout most of its course and it may be faulted near its crest. The dips north of the axis range from 2 to 7 degrees, whereas those south of it range from 3 to 9 degrees, the structure being therefore somewhat asymmetrical. The anticline is only poorly closed at its east end and appears to rise rather than plunge toward the west at its west end.

Exploration.—The Altus anticline has been drilled to shallow depths at several places in prospecting for coal, but neither oil nor gas has been obtained in these tests. It has not been explored for the avowed purpose of finding oil or gas, however, and, although it is somewhat favorable for their accumulation, its exploration may well be deferred until more promising anticlines have been tested.

APPLETON ANTICLINE

Location.—The axis of the Appleton anticline extends from about the center of Sec. 5, T. 9 N., R. 19 W., eastward for a distance of about 3 miles and then southeastward to the NE. $\frac{1}{4}$ Sec. 31, T. 9 N., R. 17 W.

Structural features.—The anticline is bounded on the north by the Hector syncline and by the extreme east end of the Turnersville syncline and on the south by the Lee Mountain syncline. The surface rocks all belong to the Atoka formation.

The anticline is by no means prominent, and its axis has not been determined exactly, though it is given approximately on the structural map. The dips vary between 2 and 9 degrees, but are generally under 5 degrees. The structure is not markedly asymmetrical, but the average dip is probably slightly higher on the south flank than on the north.

Exploration.—In 1918-1919 the Gravel Hill Oil Company drilled a well at Gravel Hill, in Sec. 5, T. 9 N., R. 19 W., to a depth of 2,185 feet, but obtained neither oil nor gas in commercial quantities. The well, however, was drilled at the extreme west end of the anticline, where the westward plunge is relatively marked, and it cannot be regarded as a fair test. On the other hand, the anticline is much less favorable for the accumulation of gas than many others in the Arkansas Valley, and it may be wise to defer its further exploration until some of the more promising anticlines have been tested. Future wells should be drilled near the axis, and preferably away from the east and west ends.

ARMADA ANTICLINE

Location.—The axis of the Armada anticline extends from about the NW. $\frac{1}{4}$ Sec. 18, T. 12 N., R. 30 W. eastward to the NE. $\frac{1}{4}$ Sec. 18, T. 12 N., R. 29 W.

Structural features.—The anticline is bounded on the north by the Frisco syncline and on the south by the Chester syncline. The surface rocks all belong to the Atoka formation.

The anticline is slightly asymmetrical, its south flank being somewhat steeper than its north. The dips north of the axis average about 3 degrees; those south of the axis average nearly 5 degrees. The anticline is fairly well closed at its west end, but the closure at its east end is inconspicuous.

Exploration.—The anticline has not been drilled for oil or gas, but its structure is reasonably favorable for their accumulation, though it is among the less promising anticlines in the general area, and drilling on it may well be deferred until some of the other anticlines have been tested.

ATKINS ANTICLINE

Location.—The axis of the Atkins anticline extends from the NW. $\frac{1}{4}$ Sec. 12, T. 6 N., R. 20 W., northeastward to the N. $\frac{1}{2}$ Sec. 26, T. 7 N., R. 18 W., where it is obscured by the alluvium of Arkansas River.

Structural features.—The Atkins anticline is bounded on the north by the Shinn syncline and on the south by the Pontoon syncline. All the surface rocks belong to the Atoka formation.

The structure is pronounced and is distinctly asymmetrical. On the south limb of the anticline, 5 or 6 miles from its axis, the dips range from 3 to 7 degrees, but as the axis is approached the dips increase to as much as 12 to 18 degrees. The north limb is much steeper, the dips generally being from 10 to 40 degrees, and more rarely, as south of Atkins, as high as 70 degrees. The north limb is much shorter than the south and flattens rapidly, so that the dip is very much diminished within a mile of the axis.

It is impossible to ascertain definitely whether the Atkins anticline is a continuation of the Pine Ridge anticline, for their axes are covered by recent sediments of Arkansas River southeast of Dardanelle. The general trend of both anticlines, however, where their courses can be observed, indicates that they are offset. The two anticlines are, of course, closely related to each other and to the Morrilton anticline, but although these three extend along the same structural line, they may not be continuous with one another.

Exploration.—The Atkins anticline has not been tested for oil or gas, but parts of it have been leased for tests. The anticline has considerable closure at its west end and probably closes on the east, though the eastward plunge is by no means prominent. The collecting area of the anticline covers at least 75 square miles, and the structural conditions are favorable for the accumulation of gas.

Exploration should be confined to the area near the axis, but because of the steep northern limb the initial test well should be sunk some distance south of the axis, the exact distance to depend upon the depth to which the well is to be drilled and the inclination of the strata near the well. The initial well should be drilled to a depth of at least 3,500 feet.

BACKBONE ANTICLINE

Location.—The axis of the Backbone anticline extends from the Oklahoma boundary, in the western part of Sec. 5, T. 6 N., R. 32 W., eastward to about the center of Sec. 6, T. 6 N., R. 30 W., but the anticline also extends southwestward into Oklahoma for nearly 20 miles.

Structural features.—The anticline in Arkansas is bounded on the north by the Central and Jenny Lind synclines, and on the south by the Greenwood syncline. The surface rocks belong to the Atoka, Hartshorne, and Spadra formations, the Atoka outcropping over a relatively large area south of the axis and the Hartshorne and Spadra appearing in bands that extend from east to west on the north flank.

The structure is best expressed topographically by Backbone Ridge, which is formed of southward-dipping beds of Atoka sandstone that crop out south of the axis.

The anticline, which is faulted essentially at its axis, is somewhat asymmetrical, but its asymmetry now is less marked than it once was because of the great erosion near its crest. The dips north of the axis range from 8 to 50 degrees; those south of it range from 8 to 40 degrees. The anticline plunges to the east in the vicinity of Greenwood, where the fault dies out. The fault, which is of the thrust type, has a great displacement, which is graphically shown in Figure 22.

Exploration.—The Backbone anticline has not been tested for oil or gas, though its structure is rather favorable for their accumulation. One of the reasons why the anticline has not been explored, no doubt, is the fact that it is faulted, but the faulting alone cannot be regraded as altogether unfavorable, though it will tend to increase the hazard of drilling. Wells should be drilled south of the axis and should be carried through the fault plane into the downthrown beds of Atoka sandstone on the north, which should be effectively sealed by the thick beds of shale on the south side of the fault. It may be well, however, to defer drilling the Backbone anticline until the results of the exploration of more of the unfaulted anticlines are at hand.

BAYOU METO ANTICLINE

Location.—The axis of the Bayou Meto anticline extends from about the center of Sec. 15, T. 4 N., R. 13 W., slightly north of east to the E. $\frac{1}{2}$ Sec. 6, T. 4 N., R. 9 W., where its course is lost under a cover of Tertiary sediments.

Structural features.—The anticline is bounded on the north by the Preston and Conway synclines, and on the south by the Cato syncline. The surface rocks all belong to the Atoka formation. The structure is well expressed topographically by a series of anticlinal ridges that extend eastward from the vicinity of Adams Lake, northeast of Mayflower, to the Paleozoic-Tertiary boundary.

The anticline is asymmetrical in that its north limb is steeper than its south. The dips north of the axis range from 4 to 90 degrees and diminish regularly toward the Conway syncline; those south of the axis range from 18 to 33 degrees and show no regular diminution toward the Cato syncline. The anticline is well closed at its west end, but whether it is closed at its east end cannot be determined because of the cover of Tertiary sediments.

This is one of the anticlines on which measurements were made by

J. C. Branner⁸ and others in calculating the thickness of the Carboniferous sediments in Arkansas.

Exploration.—In 1910 the McFarland Oil Company drilled to a depth of 1,500 feet on the McFarland lease, in the NE. $\frac{1}{4}$ of NW. $\frac{1}{4}$ Sec. 13, T. 4 N., R. 11 W., about 2 miles south of the axis of the Bayou Meto anticline, but obtained neither oil nor gas in commercial quantities. The log of this well is not available. The Gold Creek Oil & Gas Company, under permit issued July 9, 1926, to D. L. Bower, drilled a well to a depth of 3,780 feet on the Stermer lease, in Sec. 17, T. 4 N., R. 13 W., but obtained neither oil nor gas in commercial quantities. The log of the Stermer well follows:

*Log of Stermer No. 1 well of Gold Creek Oil and Gas Company in NW. cor.
NW. $\frac{1}{4}$ SE. $\frac{1}{4}$ Sec. 17, T. 4 N., R. 13 W.*

	Depth in feet
Yellow clay.....	0 - 2 $\frac{1}{2}$
Red clay.....	2 $\frac{1}{2}$ - 24 $\frac{1}{2}$
Black shale.....	24 $\frac{1}{2}$ - 65 $\frac{1}{2}$
Lime rock. Some water at 67 feet.....	65 $\frac{1}{2}$ - 67
Black shale. A little gas at 131 feet.....	67 - 131
Black lime.....	131 - 153
Gumbo.....	153 - 161
Soft shale. Oil showing at 188 feet.....	161 - 188
Hard gray lime.....	188 - 205
Black shale.....	205 - 220
Gray lime. A little gas at 223 feet.....	220 - 223
Gray shale. Little more gas.....	223 - 260
Gray lime. A heavy flow of water at 260 feet.....	260 - 263
Light-blue lime.....	263 - 280
Hard black lime. A gas showing at 384 feet.....	280 - 387
Gumbo.....	387 - 398
Shale and gumbo mixed. A showing of gas at 433 feet.....	398 - 436
Blue shale.....	436 - 448 $\frac{1}{2}$
Gumbo.....	448 $\frac{1}{2}$ - 475 $\frac{1}{2}$
Hard black shale.....	475 $\frac{1}{2}$ - 489 $\frac{1}{2}$
Gumbo.....	489 $\frac{1}{2}$ - 612 $\frac{1}{2}$
Shale. Showing of oil at 743 $\frac{1}{2}$ feet.....	612 $\frac{1}{2}$ - 746 $\frac{1}{2}$
Gumbo.....	746 $\frac{1}{2}$ - 827 $\frac{1}{2}$
Soft blue shale. Little showing of oil at 828 feet.....	827 $\frac{1}{2}$ - 831 $\frac{1}{2}$
Gumbo. Little showing of gas at 880 feet.....	831 $\frac{1}{2}$ - 883 $\frac{1}{2}$
Black lime.....	883 $\frac{1}{2}$ - 906 $\frac{1}{2}$
Gumbo.....	906 $\frac{1}{2}$ - 998 $\frac{1}{2}$
Hard bright shale.....	998 $\frac{1}{2}$ - 1044 $\frac{1}{2}$
Shale and slate. Hit hard lime rock and set casing at 1257 feet, 10 inches.....	1044 $\frac{1}{2}$ - 1260 $\frac{1}{2}$
Hard lime rock.....	1260 $\frac{1}{2}$ - 1285 $\frac{1}{2}$
Blue lime.....	1285 $\frac{1}{2}$ - 1367 $\frac{1}{2}$
Soft greasy shale.....	1367 $\frac{1}{2}$ - 1711 $\frac{1}{2}$
Black lime.....	1711 $\frac{1}{2}$ - 3375 $\frac{1}{2}$
Light hard lime.....	3375 $\frac{1}{2}$ - 3407 $\frac{1}{2}$

⁸ Branner, J. C., Am. Jour. Sci., vol. 2, 4th ser., 1896, pp. 232-234.

	Depth in feet
Soft, black, greasy shale and muck. Hit oil sand and made good showing of high-grade oil and set casing, 8¼-inch, at 3,311 feet.....	3407½-3414½
Lime rock. Struck a crevice at about 98 feet and bailed a lot of 41 gravity oil.....	3414½-3526½
Gumbo. Just breaking out of gumbo into lime rock..	3526½-3780½

The log of this well shows a typical section of alternating beds of sandstone and shale of the Atoka formation.

In addition to the wells mentioned, a well was drilled by B. F. Thompson, Trustee, in 1923, to an unknown depth on the Esther Copelin lease, in Sec. 6, T. 4 N., R. 9 W., essentially on the axis of the anticline, but it obtained neither oil nor gas in commercial quantities. This well was probably drilled too far north of the crest, for it was carried through steeply inclined beds.

Further exploration should be confined to the area just south of the crest, and wells should be drilled to a depth of at least 3,500 feet. It may be well, however, to postpone further tests of this anticline until some of the less closely folded anticlines have been drilled.

BIG CREEK ANTICLINE

Location.—The axis of the Big Creek anticline extends from the NE. corner of Sec. 4, T. 7 N., R. 30 W., slightly north of east to the SE. ¼ Sec. 31, T. 8 N., R. 29 W.

Structural features.—The anticline is bounded on the north by the Lavaca syncline and on the south by the Central syncline. The surface rocks belong chiefly to the Spadra formation, but the Fort Smith sandstone also occurs over a small area on the western part of the anticline.

The anticline, which is a minor one, is essentially symmetrical, but the dips on its south flank are slightly higher than those on its north flank. The dips north of the axis average about 3 degrees; those south of the axis probably average about 4 degrees. The anticline, which shows some closure at its east end, may also plunge to the west at its west end, but the evidence is not conclusive.

Exploration.—In 1924 the Panuco Exploration Company drilled to a depth of 3,235 feet on the J. D. Measles lease, in the NE. ¼ of the NE. ¼, Sec. 1, T. 7 N., R. 30 W. Some gas was obtained from this well, the log of which is given below:

Log of the Panuco Exploration Company's John D. Measles Well No. 1 in the NE. ¼ of the NE. ¼, Sec. 1, T. 7 N., R. 30 W.

	Depth in feet
Hard.....	0- 14
Black slate.....	14- 60
Broken lime.....	60- 120

	Depth in feet
Sandy slate. Water at 160-170 feet; a little gas.....	120- 160
Hard sand (8¼-inch casing).....	160- 320
Black slate.....	320- 328
Hard sand, gray.....	328- 368
Sandy shale.....	368- 420
Black slate.....	420- 500
Gray slate.....	500- 540
Black slate.....	540- 590
Gray slate.....	590- 620
Lime.....	620- 622
Black slate.....	622- 670
Gray slate.....	670- 687
Gray lime.....	687- 705
Gray slate.....	705- 820
Gray lime, hard.....	820- 858
Gray sand.....	858- 880
Broken lime.....	880-1025
Black shale, soft.....	1025-1045
Gray slate.....	1045-1085
Gray lime.....	1085-1105
Gritty slate.....	1105-1140
Sand, water.....	1140-1145
Slate, hard.....	1145-1160
Sandy lime.....	1160-1245
Black slate, gritty; 1,497 feet of 6½-inch No. 20 casing.....	1245-1340
Black slate.....	1340-1500
Sandy lime.....	1500-1547
Blue slate.....	1547-1552
Gray sand.....	1552-1572
Gray slate.....	1572-1645
Gray sand.....	1645-1664
Gray sand. Show of gas at 1690 feet.....	1664-1805
Gray sandy lime, very hard.....	1805-1825
Black slate.....	1825-1827
Gray sand, hard.....	1827-1841
Black sandy lime.....	1841-1850
Gray lime.....	1850-1870
Broken lime.....	1870-1890
Gray sand.....	1890-1910
Sandy lime.....	1910-1950
Black slate.....	1950-1966
Brown slate.....	1966-2005
Gray slate.....	2005-2030
Gray slate.....	2030-2034
Sandy lime, hard.....	2034-2040
Sand, white, hard.....	2040-2090
Sand, dark and coarse. Show of gas.....	2090-2110
Gray sand, hard.....	2110-2140
Shells and slate. Small show of oil.....	2140-2190
Brown shale.....	2190-2240
Lighter shale.....	2240-2280
Shells and shale.....	2280-2310

	Depth in feet
Sand.....	2310-2330
Black slate.....	2330-2360
Gray slate and shells.....	2360-2390
Gray sand. Little oil at 2,410 feet; no gas with oil.....	2390-2450
Broken lime.....	2450-2480
Gray lime.....	2480-2520
Gray sand.....	2520-2540
Gray sand; $\frac{1}{4}$ million gas at 2558 to 2564 feet; gas stayed; did not blow down.....	2540-2600
Gray sand.....	2600-2630
Gray sand.....	2630-2695
Gray sand.....	2695-2745
Broken sand.....	2745-2760
Gray sand.....	2760-2780
Broken sand and slate.....	2780-2800
Broken sand and slate.....	2800-2825
Broken sand and slate.....	2825-2910
Brown shale.....	2910-3067
Lime.....	2067-3072
Shale, brown.....	3072-3090
Gray sand, 1 bailer water per hour.....	3090-3097
Gray slate.....	3097-3177
Gray slate.....	3177-3230
Flack lime.....	3230-3235

The Big Creek anticline, though small, probably merits further exploration. Wells should be drilled near the axis and should be prepared to drill to a depth of 4,500 feet.

BISWELL HILL ANTICLINE

Location.—The axis of the Biswell Hill anticline extends from the NE. $\frac{1}{4}$ Sec. 28, T. 7 N., R. 31 W., northeastward for about 5 miles and then continues southeastward to about the NE. $\frac{1}{4}$ Sec. 27, T. 7 N., R. 29 W.

Structural features.—The anticline is bounded on the north by the Central syncline and on the south by Jenny Lind and Greenwood synclines. Most of the surface rocks belong to the Hartshorne and Spadra formations. The structure finds topographic expression in Biswell Hill, a dome-like eminence that is both structurally and topographically high, and its encircling ridges, most conspicuous of which, perhaps, is Tennessee Ridge.

The anticline is an elliptical dome, which is essentially symmetrical. The dips north of the axis range from 3 to 17 degrees, but perhaps average somewhat higher than those south of the axis, which range from 2 to 20 degrees. The anticline plunges to the east south of Bloomer, where its closure is very well defined. It also has good closure in the vicinity of old Randolph post office, near its west end.

Exploration.—At least two and probably three test wells have been

drilled on the Biswell Hill anticline, but accurate information concerning them has not been obtained. Although they were drilled near the crest they were not drilled deeper than 2,500 feet, and therefore they cannot be regarded as adequate tests. The anticline seems worthy of further exploration, but wells should be drilled to a depth of at least 4,000 feet in order to reach the productive sand of the Mansfield area.

BULL CREEK ANTICLINE

Location.—The axis of the Bull Creek anticline extends northeastward from some indefinite point between the north and south forks of the Conway syncline probably to the NE. $\frac{1}{4}$ Sec. 29, T. 6 N., R. 8 W., but its west end is obscured by the alluvium of White Oak, Little Cypress, and Cypress creeks, and its east end lies beneath the Tertiary deposits of the Mississippi Valley.

Structural features.—The anticline lies between the prongs of the forked Conway syncline and trends more nearly northeastward than most of the associated structures. The anticline is markedly asymmetrical, the dips south of the crest averaging very much higher than those north of it. The dips north of the crest range from 3 to 15 degrees and probably average about 10 degrees; those south of the crest range from 11 to 47 degrees, and many of them reach the larger figure. The dips north of the axis apparently diminish slightly away from the crest, but those south of the axis are lower near it and increase rapidly away from it. The anticline appears to have good closure at its west end.

The topographic expression of this anticline may be seen in the low ridges north and west of Beebe.

Exploration.—It has been reported that Skene and Wisby drilled a well to a depth of 1,400 feet on the R. L. Horn lease, at the center of Sec. 6, T. 5 N., R. 9 W., but obtained neither oil nor gas in commercial quantities. This well, however, was poorly located with respect to the structure, and cannot be regarded as an adequate test. The anticline may be further explored farther east. The initial well should be drilled a very short distance north of the crest and should be carried to a depth of at least 3,500 feet.

CADRON ANTICLINE

Location.—The axis of the Cadron anticline extends from the vicinity of Cadron Creek, in Sec. 33, T. 6 N., R. 15 W., slightly north of east to the SE. corner of Sec. 11, T. 6 N., R. 10 W., where it divides into two forks. The north fork continues northeastward at least to the S. $\frac{1}{2}$ Sec. 33, T. 7 N., R. 9 W., and may swing eastward and then southeastward to Sec. 8, T. 6 N., R. 8 W. The south fork continues from its point of junction with the main structure southeastward

to the N. $\frac{1}{2}$ Sec. 27, T. 6 N., R. 9 W., and may extend as far east as Sec. 25.

Structural features.—The anticline is bounded on the north by the Menifee syncline and on the south by the Conway syncline. The Antioch syncline lies between the two eastern forks of the structure. The surface rocks all belong to the Atoka formation.

The anticline is very prominent throughout its entire course, and its topographic expression is very noticeable in the ridges north and east of Conway. One of these, Center Ridge, marks the position of the antilinal axis for about 25 miles. Cadron Ridge is formed of steeply dipping beds of sandstone on its south flank, and the unnamed ridge north of Center Ridge is formed of northward-dipping beds of sandstone on its north flank.

The anticline is asymmetrical, the dips on its south flank averaging higher than those on its north flank. The dips south of the axis range from 4 to 90 degrees, and in places the beds are overturned, so that they are inclined at high angles toward the north. The average dip is more than 50 degrees. The dips north of the axis range from 2 to 87 degrees, but the beds are not overturned, and their average dip is probably less than 40 degrees. The dips on the north limb diminish gradually and regularly from the crest northward to the Menifee syncline; those on the south limb are as high or higher a mile south of the axis than they are at the crest, but they too show a marked diminution toward the axis of Conway syncline. On both sides of the axis the dips diminish progressively toward the east.

Few of the dips on either side of the axes of the two forks are more than 12 degrees, and the average dip is about 8 degrees. Both forks appear to be somewhat steeper on their south than on their north flanks, but in neither is the asymmetry marked.

Exploration.—The main part of the Cadron anticline has not been tested for oil or gas, but a well, which is noted in the description of the Menifee syncline, has been drilled far down on its northern flank. The north fork of the anticline, however, has been tested by the Central Arkansas Oil and Gas Company, which drilled a well to a depth of 2,804 feet on the J. A. Cheate lease, in the NW. $\frac{1}{4}$ NW. $\frac{1}{4}$ Sec. 7, T. 6 N., R. 9 W. Neither oil nor gas was obtained in commercial quantities. An abbreviated log of this well follows:

Log of Central Arkansas Oil and Gas Company's Cheate Well No. 1, in NW. $\frac{1}{4}$ of the NW. $\frac{1}{4}$ of Sec. 7, T. 6 N., R. 9 W.

	Depth in feet
Soil.....	0—2
Red sand.....	2—120
Limy shale.....	120—1000
Black slate.....	1000—1300

	Depth in feet
Limy shale, gray.....	1300-1620
Sea shore sand.....	1620-1685
Limy shale, gray.....	1685-2400
Black shale.....	2400-2804

The cuttings taken from this well are not available for study, but the great thicknesses of shale encountered indicates that the well was still being drilled in the Atoka formation when it was abandoned. Whether further exploration of the anticline should be encouraged or not is a difficult question. The anticline is very closely folded in its western part, which should be avoided. In Ranges 11 and 10 W., however, the dips are not much greater than those on the Morrilton anticline, near Plummerville, which was productive. Further exploration should be limited to this eastern part of the anticline, and the wells should be drilled near its crest and carried to a depth of at least 3,500 feet, where the bottom of the Atoka formation should be reached.

CASA ANTICLINE

Location.—The axis of the Casa anticline extends from about the SE. $\frac{1}{4}$ Sec. 2, T. 4 N., R. 23 W., eastward in an undulating course to about the center of Sec. 30, T. 5 N., R. 18 W., but at its east end it is probably continuous with the Redemption anticline, and at its west end it is only slightly offset from the Dutch Creek anticline.

Structural features.—The Casa anticline is bounded on the north by the Poteau syncline and on the south by Fourche la Fave syncline. The surface rocks all belong to the Atoka formation. Between the towns of Casa and Ola the anticline is complicated by a number of minor structural features, but the major anticlinal outline is nowhere completely obscured. Southeast of Danville the anticline is expressed topographically by Danville Mountain, a fairly typical though somewhat complicated anticlinal ridge, but farther east the north limb of the anticline is represented almost entirely by lowlands, and only the southward-dipping beds of sandstone south of the axis are resistant enough to form conspicuous ridges.

Both limbs of the anticline are highly inclined, but the north flank is somewhat shorter than the south, and the dips north of the axis average slightly higher than those south of it. The dips north of the crest decrease markedly toward the Poteau syncline, but the high dips south of the crest are maintained practically to the Fourche la Fave syncline. The dips on the north limb range from 5 to 90 degrees, and locally the beds may be overturned; those south of the crest range from 22 to 85 degrees. In the eastern part of its course the axis of the anticline lies in the valley of Cypress Creek, where

many of its structural details are obscured, but there is some evidence of faulting near the crest of the anticline. It is impossible to ascertain whether the inferred fault is of the normal or thrust type, but its downthrow is on the north.

Exploration.—The Casa anticline has not been tested for oil and gas, and its future exploration should be deferred at least until the results of tests of the more favorable anticlines are available.

CASS ANTICLINE

Location.—The axis of the Cass anticline extends from the NW. $\frac{1}{4}$ Sec. 27, T. 12 N., R. 27 W. northeastward for about 4 miles and then turns more directly eastward to the NW. $\frac{1}{4}$ Sec. 3, T. 12 N., R. 23 W., from which point it extends into T. 13 N., which was not surveyed.

Structural features.—The anticline is bounded on the south by the Archey syncline, but the limiting structure on the north is not known. The east end of the anticline may join the west end of the Hurricane Creek anticline, but the possible connection in T. 13 N. was not studied.

The anticline is essentially symmetrical in its eastern part but is considerably complicated by faulting in its western part, particularly near Cass. The dips in R. 25 W. and farther east, on either side of the axis, range from 2 to 10 degrees, but the average dip is less than 5 degrees. The dip north of the axis is possibly less than that on the south, but the difference is slight.

Beginning at the eastern boundary of R. 26 W., the dips, particularly those south of the axis, increase toward the west, so that near Cass they are more than 25 degrees, and the anticline is faulted, the downthrown side being on the south. In the vicinity of Cass the anticlinal character of the structure becomes obscured, and the relation suggests a faulted terrace.

Exploration.—The Cass anticline has not yet been tested for oil or gas, but its structure is relatively favorable to their accumulation. Future exploration should be confined to the area near the axis, and the initial well should be drilled structurally as high as possible on domes along the crest. The faulting near Cass cannot be regarded as entirely condemnatory of the anticline, but the initial well should not be drilled in the faulted area itself. The anticline should not be drilled until some of the more promising structures have been explored.

CECIL ANTICLINE

Location.—The axis of the Cecil anticline extends from Arkansas River at Arbuckle's Island, in the N. $\frac{1}{2}$ Sec. 31, T. 9 N., R. 29 W..

northeastward to the E. $\frac{1}{2}$ Sec. 11, T. 9 N., R. 27 W., but the course of the anticline is not clearly defined northeast of Cecil, and it may continue westward from Arbuckle's Island to join the Massard Prairie anticline.

Structural features.—The anticline is bounded on the north by the Alston syncline and on the south by the Mill Creek fault. The surface rocks belong chiefly to the Hartshorne sandstone, but the Atoka formation is exposed on the north flank and a small area of Spadra shale occurs on the south flank. The anticline is well-expressed topographically by the River Ridge, in the western part of its course, but it is poorly expressed near its east end.

The anticline is essentially symmetrical, but the dips south of the axis apparently average somewhat higher than those north of it. The dips north of the crest range from 2 to 7 degrees and average about 3 degrees; those south of the crest range from 2 to 10 degrees and probably average about 4 degrees. The anticline apparently plunges to the west near its west end, but the closure at its east end is not pronounced.

Exploration.—In 1916-1918 the Travelers Oil Company drilled a test well to a depth of 2,400 feet on the J. K. Ford lease, in Sec. 29, T. 9 N., R. 27 W., but the test was unsuccessful. The log of this well, which was drilled about 3 miles south of the anticlinal axis, and the same distance west of the west end of the Altus anticline, is not available. In addition, the Kennedy Oil and Gas Company, in 1920-1921, drilled to a depth of 2,700 feet on the Terry lease, in Sec. 18, T. 9 N., R. 28 W., but obtained neither oil nor gas in commercial quantities. The log of the Terry well is given below.

*Log of Kennedy Oil and Gas Company's Terry Well, in
Sec. 18, T. 9 N., R. 28 W.*

	Depth in feet
Soil.....	0- 8
Yellow sand.....	8- 18
Black slate.....	18- 98
Black sand.....	98- 113
Black slate.....	113- 200
White sand.....	200- 250
Black slate.....	250- 285
Black sand.....	285- 385
Black slate.....	385- 400
Black limey sand.....	400- 440
Black slate.....	440- 460
Black limey sand.....	460- 500
Black slate.....	500- 570
Black sandy slate.....	570- 620
Black slate.....	620- 630
Hard sandy slate.....	630- 670
Limey slate.....	670- 700

	Depth in feet
Shelly slate.....	700- 710
Hard white sand.....	710- 750
Black slate.....	750- 800
Sand, fine, hard.....	800- 815
Slate, black.....	815- 840
Slate and shells.....	840- 940
Black slate.....	940- 955
Gray sand.....	955- 975
Fine hard white sand.....	975-1040
Shelly slate.....	1040-1060
Sand.....	1060-1070
Slate, black.....	1070-1080
White sand.....	1080-1110
Black sand.....	1110-1120
Slate and shells, black.....	1120-1150
Black shale.....	1150-1210
Sand.....	1210-1270
Slate	1270-1445
Sand, broken.....	1445-1495
Slate and shells.....	1495-1650
Sand, broken.....	1650-1665
Hard shell.....	1665-1680
Brown slate.....	1680-1900
Hard gray sand.....	1900-1950
Black slate and shells.....	1950-2000
Hard gray sand.....	2000-2100
Slate and sand and shells.....	2100-2125
Hard sand.....	2125-2185
Slate formation.....	2185-2305
Sand; salt water in very top.....	2305-2355
Black shale.....	2355-2390
Black shale with some grit; very solid with hard shells turning to very black sand.....	2390-2590
Black shale, soft.....	2590-2610
Gray sand.....	2610-2620
Black hard sand.....	2620-2700

The Ford well was drilled so far from the axis that it did not fairly test the anticline, and the Terry well, although satisfactorily located, was not drilled deep enough to test it adequately. The anticline is therefore considered worthy of further exploration. Wells should be drilled near the axis, preferably on the western part of the anticline, and should be carried to a depth of at least 4,000 feet.

CEDARVILLE ANTICLINE

Location.—The axis of the Cedarville anticline extends from the SW. $\frac{1}{4}$ Sec. 21, T. 10 N., R. 32 W., northeastward to the NW. $\frac{1}{4}$ Sec. 5, T. 10 N., R. 31 W.

Structural features.—The anticline is bounded on the north by the

Uniontown syncline and on the south by the Rudy syncline. The surface rocks belong to the Atoka formation.

The structure is essentially symmetrical, but the south limb is perhaps slightly steeper than the north. The dips north of the axis range from 2 to 8 degrees and average between 4 and 5 degrees; those on the south flank range from 2 to 9 degrees and average about 5 degrees. The anticline becomes indistinct at both ends, and there is little or no evidence of closure.

Exploration.—In 1920 the Sasnakra Oil and Gas Company drilled to a depth of 2,325 feet on the Segar lease in the SE. $\frac{1}{4}$ of the NW. $\frac{1}{4}$ of Sec. 22, T. 10 N., R. 32 W., and obtained a number of showings of gas. The log of the Sasnakra well, which was drilled near the crest of the structure, is given below.

*Log of Sasnakra Oil and Gas Company's Segar well, in the
SE. $\frac{1}{4}$ NW. $\frac{1}{4}$ Sec. 22, T. 10 N., R. 32 W.*

	Thickness in feet.	Depth in feet.
Yellow sand.....	25	0- 25
Black shale. Water at 65 feet.....	35	25- 90
Lime.....	30	60- 90
Black shale.....	60	90- 150
Lime.....	15	150- 165
Slate.....	10	165- 175
Sand.....	20	175- 195
Slate.....	100	195- 295
Hard lime.....	50	295- 345
Sand.....	5	345- 350
Lime.....	15	350- 365
Sand.....	25	365- 390
Slate.....	25	390- 415
Lime.....	30	415- 445
Slate.....	5	445- 450
Lime.....	10	450- 460
Slate.....	40	460- 500
Black sand.....	30	500- 530
Slate.....	85	530- 615
Black sand.....	35	615- 650
Slate.....	35	650- 685
Lime.....	15	685- 700
Slate.....	10	700- 710
Lime.....	85	710- 795
Shale.....	45	795- 840
Lime.....	50	840- 890
Slate.....	50	890- 940
Lime.....	5	940- 945
Slate.....	15	945- 960
Sandy lime.....	25	960- 985
Black shale.....	10	985- 995
Lime.....	15	995-1010
Slate.....	40	1010-1050

	Thickness in feet	Depth in feet
Lime.....	20	1050-1070
Slate.....	100	1070-1170
Hard sandy lime.....	20	1170-1190
Slate.....	35	1190-1225
Lime.....	5	1225-1230
Slate.....	10	1230-1240
Gas sand.....	40	1240-1280
Black slate.....	22	1280-1302
Lime.....	33	1302-1335
Slate.....	70	1335-1405
Sandy lime; wet gas.....	125	1405-1530
Shale.....	30	1530-1560
Lime.....	15	1560-1565
Shale.....	25	1565-1590
Lime.....	54	1590-1674
Hard sand.....	70	1674-1744
Shale.....	66	1744-1810
Lime.....	10	1810-1820
Slate.....	20	1820-1840
Sand.....	40	1840-1880
Lime.....	10	1880-1890
Shale.....	10	1890-1940
Sandy flint.....	15	1940-1955
Slate.....	5	1955-1960
Lime.....	20	1960-1980
Slate.....	18	1980-1998
Gas sand.....	72	1998-2070
Black sand.....	17	2070-2087
Hard sand.....	28	2087-2115
Broken sand.....	45	2115-2160
White sand.....	18	2160-2178
Broken sand.....	12	2178-2190
Hard sand.....	10	2190-2200
Sandy shale.....	40	2200-2240
Shale.....	10	2240-2250
Gas sand.....	5	2250-2255
Shale and shells.....	15	2255-2270
Hard lime.....	50	2270-2320
Bottom of well.....	5	2320-2325

Most of the "lime" in the upper part of the section is probably sandstone, and all the "slate" is shale. The base of the Atoka was reached at 1,530 feet, and the Boone limestone was reached at 2,270 feet. Gas was reported at depths of 1,240, 1,405, 1,998, 2,250, and 2,325 feet, and the gas from a depth of 1,405 feet was reported as "wet."

Despite the number of horizons at which, apparently, some gas was found further tests of the anticline would be somewhat more hazardous than the average test. Additional wells, however, should be drilled near the crest and northeast of the Sasnakra location. The

tests should be drilled to the St. Peter sandstone, which will be reached at 2,750-3,000 feet.

CENTER RIDGE ANTICLINE

Location.—The axis of the Center Ridge anticline extends from the W. $\frac{1}{2}$ Sec. 13, T. 8 N., R. 16 W., northeastward to the SE. $\frac{1}{4}$ Sec. 18, T. 11 N., R. 10 W.

Structural features.—The anticline is bounded on the north by an obscure unnamed syncline, which lies between it and the Lick Mountain anticline, and by the Formosa syncline; and is bounded on the south by the Fairbanks syncline.

The anticline is asymmetrical, the dips on the south limb being greater, on the average, than those on the north limb, but the asymmetry is most marked near Center Ridge and is slight east of Bee Branch. The dips on the north flank range from 1 to 8 degrees and average about 3 degrees; those on the south flank range from 3 to 12 degrees and probably average about 5 degrees. The anticline is not definitely closed at its east end and apparently rises, rather than plunges, toward the east. At its western termination, however, there is clear evidence of closure.

Near the village of Center Ridge the anticline makes a relatively abrupt turn to the south, and it may be composed of two parts, which are somewhat offset at that place. A short distance northwest of Center Ridge the dips are in places as high as 20 degrees west, and the anticline is probably faulted at or near its crest.

Exploration.—The Center Ridge anticline has not been tested for oil or gas, but its structure is reasonably favorable to their accumulation. Wells should be drilled slightly north of the crest and carried to a depth of at least 3,500 feet. The western part of the anticline appears the most favorable for a test well, but the entire anticline should be examined carefully for evidence of local doming before the position of the well is determined. The probable fault near Center Ridge should not be regarded as condemning the entire anticline.

CHOCTAW ANTICLINE

Location.—The axis of the Choctaw anticline extends from the Oklahoma boundary at the SE. $\frac{1}{4}$ Sec. 12, T. 2 N., R. 33 W. northeastward to the SE. $\frac{1}{4}$ Sec. 24, T. 3 N., R. 31 W., but it is continued westward as a fault that forms one of the larger structural features in southeastern Oklahoma.

Structural features.—The Choctaw anticline is bounded on the north by the Poteau syncline and on the south by the Waldron syncline. The surface rocks all belong to the Atoka formation. The

structure is well expressed topographically by the valley of Poteau River, which flows parallel to the axis of the anticline, although it lies somewhat north of it. The northward-dipping beds on the north flank form a series of low ridges south of Poteau Mountain; Grass Ridge and Walker Mountain, south of the axis, are formed of southward-dipping beds; and Round Mountain is made by the upturned edges of beds of sandstone that mark the eastward plunge of the anticline.

The structure is essentially symmetrical, though the dips north of the axis are probably somewhat higher, on the average, than those south of it. The dips north of the crest range from 3 to 60 degrees and diminish regularly toward the axis of the Poteau syncline. The dips south of the crest range from 8 to 50 degrees, but they do not decrease rapidly toward the limiting syncline on the south. The eastward plunge at Round Mountain is pronounced, and here the anticline is apparently somewhat offset from the Hon anticline, the effect being expressed in Chalybeate Mountain.

The Choctaw fault, which is so prominent in Oklahoma, can not easily be traced in Arkansas, for it regularly becomes less evident eastward from the Oklahoma boundary.

Exploration.—In 1919-1921 the Choctaw anticline was apparently drilled by the Bollinger Oil Company to a depth of 2,516 feet on the Denton lease, in what is believed to be the NW. $\frac{1}{4}$ of the SW. $\frac{1}{4}$ Sec. 29, T. 3 N., R. 31 W., although the location could not be verified. Neither oil nor gas was obtained in commercial quantities in this well, the log of which follows:

Log of Bollinger Oil Company's well, 12 miles west of Waldron

	Depth in feet
Mud.....	0- 15
Hard shale.....	15- 35
Water sand.....	35- 44
Hard gumbo.....	44- 510
Dry sand.....	510- 530
Black shale.....	530- 900
Hard blue shale.....	900- 920
Slate.....	920-1170
Blue shale.....	1170-1190
Shale.....	1190-1290
Shale, with mixture of tin and iron.....	1290-1305
Shale.....	1305-1550
Brownish shale.....	1550-1680
Shale.....	1680-1715
Gray lime shell.....	1715-1725
Oil sand.....	1725-1732
Shale.....	1732-1762
Gray lime shell.....	1762-1774

	Depth in feet
Shale.....	1774-1820
Shale, gray lime.....	1820-1826
Shale.....	1826-1850
Shale.....	1850-1858
Slate.....	1858-1938
Black shale.....	1938-1958
Slate.....	1958-2078
Black shale.....	2078-2098
Slate.....	2098-2148
Black shale.....	2148-2158
Shell.....	2158-2163
Slate.....	2163-2313
Black shale.....	2313-2383
White shale.....	2383-2413
Shale.....	2413-2503
White shale.....	2503-2508
Oil sand.....	2508-2516

The Bollinger Company's well was apparently drilled directly on the crest of the anticline and was consequently drilled for most of its depth in beds on the north or downthrown side of the fault. The log records a typical succession of Atoka sandstone and shale, although the shale is in part reported as "gumbo" and "slate." What has been said of the faulted Backbone anticline applies also to the Choctaw anticline, except that the rocks in the Choctaw are more sharply folded, and the prospect for oil and gas is even less favorable than in the Backbone anticline.

CLINTON ANTICLINE

Location.—The axis of the Clinton anticline extends from the NW. $\frac{1}{4}$ Sec. 19, T. 9 N., R. 17 W. northeastward to about the NE. corner Sec. 24, T. 12 N., R. 10 W., but its course for a part of that distance is somewhat obscure.

Structural features.—The Clinton anticline is bounded on the north by the Hector and Scotland synclines and on the south by the Formosa syncline. At its west end it is offset from the Appleton anticline, but the two are structurally related.

The anticline is asymmetrical throughout most of its course, the dips south of the crest averaging higher than those north of it. This anticline is, no doubt, that which was described by Newsom⁹ as the Red River monocline, but except in its northeastern part the axis of the Clinton anticline lies some distance north of the monoclinical trace as located by Newsom.

The dips north of the axis range from 2 to 6 degrees and average about 3 degrees; those south of the axis range from 2 to 15 degrees and probably average about 5 degrees, though the dips on both

⁹ Newsom, J. F., Am. Geologist, vol. 20, pp. 4-11, 1897.

flanks diminish toward the east. There is some evidence of slight closure at the west end of the anticline, but at its east end it apparently rises toward the northeast. At a few places, particularly on the south flank of the anticline, minor faults parallel the axis of the major fold, and some of the beds near these faults have southward dips as high as 40 degrees. These faults, none of which is very long or shows great displacement, are apparently downthrown on the south side.

Exploration.—According to information on file at the office of the Arkansas Geological Survey the Eagle Oil and Gas Company drilled two wells on the H. E. Stubblefield lease, in the NE. $\frac{1}{4}$ NW. $\frac{1}{4}$ Sec. 20, T. 10 N., R. 15 W., in 1923-1924. The first well drilled was carried to a depth of 1,834 feet, and the second to a depth of 1,924 feet, but neither well obtained oil or gas in commercial quantities. The logs of these wells are not available, and it is not certainly known whether two wells were drilled or whether the report of the second well is the result of a permit issued to deepen the first. Early in 1929, however, the State Developing Company obtained a permit to drill its Stubblefield Well No. 1 in the SW. corner of the NE. $\frac{1}{4}$ of the NW. $\frac{1}{4}$ Sec. 20, T. 10 N., R. 15 W. This well is being drilled very close to the first two, and all three are located practically on the axis of the anticline. The log of the Stubblefield well, which should be carried to a depth of at least 3,500 feet, should be examined critically before further exploration of the anticline is attempted.

DABNEY ANTICLINE

Location.—The axis of the Dabney anticline extends from about the center of Sec. 26, T. 12 N., R. 23 W., eastward to a point somewhere near the center of Sec. 36, T. 12 N., R. 15 W.

Structural features.—The Dabney anticline is bounded on the north by the Archey syncline and on the south by the Solo and Okay synclines. Although it is long, it is not very prominent. The dips on either side of the axis range from 2 to 8 degrees, but the average dip is probably not more than 4 degrees. There is some evidence of closure at the west end of the anticline, but the plunge is slight, and the closure at the east end is little or no more pronounced. At a number of places, however, the axial pitch is so great as to produce small domes. Although detailed exploratory work was not done on this anticline, one such dome apparently occurs near the point where the axis of the anticline crosses West Fork of Illinois Bayou and another a few miles east of the town of Dabney, north of Rex.

Exploration.—It appears that this anticline has not yet been tested for oil or gas, but its structure is fairly favorable for their accumu-

lation. Exploration should be confined to a small area near the crest, and the wells should be drilled on the local domes, such as those already mentioned. Some oil or gas may be expected from the Atoka formation, but the Morrow and older formations will be encountered even in fairly shallow wells. Indeed, the Morrow is near or at the surface in the deeper stream valleys that cut through the anticline, such as the West Fork of Piney Creek, south of Fort Douglas.

DARCY ANTICLINE

Location.—The axis of the Darcy anticline extends from the SW. $\frac{1}{4}$ Sec. 7, T. 8 N., R. 12 W., northeastward to the N. $\frac{1}{2}$ Sec. 7, T. 9 N., R. 8 W., where it turns slightly to the southeast and continues through Pangburn to about the center of Sec. 22, T. 9 N., R. 6 W.

Structural features.—The Darcy anticline is bounded on the north by the Pearson and Hiram synclines, and on the south by the Guy, Greenbrier, and Clearwater synclines. Although rather well defined throughout its course, the anticline is nowhere prominent. The dips on the north flank range from 1 to 7 degrees, but the average dip is probably less than 3 degrees. The dips on the south flank range from 2 to 5 degrees, but the average dip is about the same as the average on the north limb. North of Guy, near the west end of the axis, the anticline has definite though not pronounced closure. At the east end, however, there is no good evidence of closure, and the anticline gradually dies out southeast of Steprock.

Exploration.—The Darcy anticline has not yet been tested for oil and gas, but its structure is relatively favorable for their accumulation. Wells should be drilled near the crest of the anticline and should be carried to a depth of at least 3,500 feet.

DENMARK ANTICLINE

Location.—The axis of the Denmark anticline extends from about the NW. $\frac{1}{4}$ Sec. 15, T. 10 N., R. 7 W. eastward to the center of Sec. 12, T. 10 N., R. 6 W., and may continue farther eastward, for the area east of R. 6 W. was not surveyed.

Structural features.—The Denmark anticline is bounded on the north by the Floral syncline and on the south by the Hiram syncline. It is not prominent, and at some places its axial trend is obscure. The dips north of the crest range from 3 to 7 degrees and those south of it range from 3 to 6 degrees, but the average dip on both flanks is about the same. The anticline plunges gently toward the west at its west end, where there is considerable closure. Whether there is closure also at the east end has not been ascertained.

Exploration.—The Denmark anticline has not been tested for oil

or gas, but its structure is favorable to their accumulation. Wells should be drilled near or on the crest and should be carried to a depth of at least 3,500 feet, where the drill should be in the Mississippian or should have passed through it.

DOVER ANTICLINE

Location.—The Dover anticline extends from Sec. 10, T. 9 N., R. 22 W., southeastward to Sec. 30, T. 9 N., R. 19 W., but it may connect the Solgohachia anticline on the east with the Ludwig anticline on the west.

Structural features.—The Dover anticline is bounded on the south by the Clarksville syncline and the north prong and handle of the Ouita syncline, and on the north by the Lee Mountain syncline. The surface rocks all belong to the Atoka formation.

The anticline is essentially symmetrical, the dips on either side of the axis ranging from 3 to 10 degrees. It apparently has a slight plunge to the west at its west end. Whether it continues southeastward across T. 8 and 9 N., R. 19 W. to join the Solgohachia anticline could not be ascertained in the time available, but it seems to plunge eastward southeast of Moreland.

If the west end of the Dover anticline were moved slightly northward and the east end of the Ludwig anticline were moved slightly southward the two would appear to be continuous, but there is no good field evidence of their continuity.

Exploration.—The Dover anticline has not been tested. It is structurally favorable to the accumulation of gas, however, and is worthy of a test, though it is not so promising as some other anticlines in the Arkansas Valley. The test well should be drilled near the axis of the anticline and should be carried to a depth of at least 3,500 feet.

DUTCH CREEK ANTICLINE

Location.—The axis of the Dutch Creek anticline extends from the SE. $\frac{1}{4}$ Sec. 36, T. 3 N., R. 29 W., northeastward to about the NE. $\frac{1}{4}$ Sec. 13, T. 4 N., R. 23 W., but the anticline extends southwestward into T. 2 N., which was not surveyed in detail.

Structural features.—The Dutch Creek anticline is bounded on the north by the Waldron and Poteau synclines and on the south by the Fourche la Pave syncline. The surface rocks all belong to the Atoka formation. The structure is well expressed topographically by Dutch Creek Mountain, which is a typical anticlinal ridge, the beds on its south side dipping south and those on its north side dipping north.

The anticline is rather asymmetrical throughout, the dips north of

the axis generally being higher than those south of it, but at many places the asymmetry is not strongly marked. The dips on the north flank range from 4 to 90 degrees and at some places the beds may be overturned; those on the south flank range from 15 to 70 degrees. The dips north of the anticlinal axis decrease regularly toward the limiting synclines, where they are relatively low. The dips south of the anticlinal crest also decrease toward the axis of the limiting syncline but they are still relatively high at that axis. At its east end the anticline is apparently offset from the west end of the Casa anticline, and a small unnamed syncline lies between the two.

Exploration.—In 1927-1928 the Blue Ball Oil and Gas Company drilled on government land in the SE. $\frac{1}{4}$ of the NE. $\frac{1}{4}$ Sec. 1, T. 3 N., R. 26 W., almost on the crest of the anticline. A short distance south of the well the dip is 35 degrees S. 10 degrees W.; north of the well the dip is about 45 degrees N. 50 degrees W. On August 18, 1927, the well had penetrated about 800 feet of rock, mostly hard sandstone, and had found a show of oil and a flow of water at 421 feet. The log of the well is not available nor is its later history known, but neither oil nor gas in commercial quantities was found.

In 1920-1921 Ed Coalman drilled a well to a depth of 2,631 feet on the Tidwell lease, in Sec. 21, T. 4 N., R. 24 W., but obtained neither oil nor gas, although the well was drilled essentially on the axis of the anticline. The log of this well is not available, but it did not completely penetrate the Atoka formation. The dip near the well is about 60 degrees N. 10 degrees W.

In 1921-1922, O. C. Moffett drilled a well to a depth of 3,000 feet on the Webster lease, in Sec. 28, T. 4 N., R. 24 W., but obtained only a showing of gas and oil. The log of this well is given below.

Log of Moffet No. 1 well, in Sec. 28, T. 4 N., R. 24 W.

	Depth in feet
Surface soil.....	0- 12
Blue slate.....	12- 170
Sand.....	170- 190
Black slate.....	190- 592
Gray slate.....	592- 622
Black slate.....	622- 644
Black sand.....	644- 845
Black slate, show of oil.....	845- 962
Gray slate.....	962-1280
Gray slate.....	1280-1320
Black slate.....	1320-1465
Gray sand, gas show.....	1465-1480
Black shale.....	1480-1665
Black lime rock.....	1665-1695
Black slate.....	1695-1720
Black sand.....	1720-1740

	Depth in feet
Gray sand.....	1740-1764
Dark shale.....	1764-2015
Dark lime rock.....	2015-2068
Gray sand.....	2068-2380
Dark shale.....	2380-2540
Sand.....	2540-2600
Light shale.....	2600-2660
Lime rock, gray and hard.....	2660-2730
Black shale.....	2730-2980
Dark shale.....	2980-3000

The Moffett well was properly drilled some distance south of the anticlinal axis. The amount of shale and "slate" encountered is noteworthy, but the "lime rock" reported is probably dense sandstone containing only a little calcareous material.

Wells sunk on this anticline should be drilled a short distance south of its crest, and should be carried to a depth of at least 3,500 feet. The result of the drilling already done, however, is discouraging. The sandstones encountered are dense, hard, and only slightly porous, and the beds have in places been closely folded. Further exploration on this anticline is scarcely justified.

ENDERS ANTICLINE

Location.—The axis of the Enders anticline extends from about the SE. $\frac{1}{4}$ Sec. 7, T. 7 N., R. 14 W., northeastward to the center Sec. 18, T. 8 N., R. 11 W., but at its west end and throughout much of its length its course is somewhat obscure.

Structural features.—The Enders anticline is bounded on the north by the Guy syncline and on the south by the Greenbrier syncline. The surface rocks all belong to the Atoka formation.

The anticline is not markedly asymmetrical, but the dips south of its axis are consistently somewhat higher than those north of it. The dips south of the axis range from 2 to 12 degrees and probably average about 5 degrees. Those north of the axis do not exceed 6 degrees and probably average less than 4 degrees. The anticline plunges at each end, but the closure is small.

The topographic expression of the Enders anticline is not conspicuous, but the eastward-trending ridge a mile north of Greenbrier is formed of southward-dipping beds of sandstone, which are exposed on the south flank of the anticline.

Exploration.—The Enders anticline has not been drilled for oil or gas, but its structure is favorable to their accumulation. Wells should be drilled a short distance north of the crest and should be carried to a depth of at least 3,500 feet, where they will not have reached the Morrow formation.

EVANS MOUNTAIN ANTICLINE

Location.—The axis of the Evans Mountain anticline extends from the NE. $\frac{1}{4}$ Sec. 36, T. 10 N., R. 18 W. northeastward to about the center of Sec. 23, T. 10 N., R. 17 W.

Structural features.—The anticline is bounded on the north by the south fork of the Okay syncline, and on the south by the Hector syncline. The surface rocks all belong to the Atoka formation. The anticline is a rather poorly defined, essentially symmetrical, elongated dome. The dips on both sides of the axis range from 2 to 4 degrees and probably average about 3 degrees. The west end of the anticline is offset more than a mile from the east end of the Retta anticline, but the two are rather closely related structurally. The eastern closure of the anticline is fairly well marked, but the western closure is poorly defined.

Exploration.—The anticline has not been tested for oil or gas, but it is structurally somewhat favorable to their accumulation. Its exploration, however, should be postponed until the more promising anticlines in the Arkansas Valley have been tested.

FLORAL ANTICLINE

Location.—The axis of the Floral anticline extends from the NE. $\frac{1}{4}$ Sec. 17, T. 11 N., R. 8 W., eastward to the SW. $\frac{1}{4}$ Sec. 8, T. 11 N., R. 7 W.

Structural features.—The Floral anticline is bounded on the north by the Cadron syncline and on the south by parts of the Pearson and Floral synclines. The anticline is not prominent, and it shows little evidence of closure at either end. It is essentially symmetrical, the dips north of the axis ranging from 2 to 5 degrees and those south of it ranging from 3 to 5 degrees and perhaps averaging slightly higher than those on the north.

Exploration.—This anticline has not been tested for oil or gas, but its structure is somewhat favorable to their accumulation. Exploration of the anticline, however, should be postponed until further information has been obtained by drilling on some more promising anticlines.

GAME HILL ANTICLINE

Location.—The axis of the Game Hill anticline extends from the SW. corner Sec. 1, T. 7 N., R. 29 W. eastward to the SE. corner Sec. 11, T. 7 N., R. 27 W., from which point it may continue southeastward to join the Pine Ridge anticline.

Structural features.—The Game Hill anticline is bounded on the north by the Paris syncline and on the south by the Central, Greenwood, and Six Mile synclines. The surface rocks at the crest of the

anticline belong to the Spadra formation, but the Fort Smith sandstone crops out on the flanks. Game Hill is a topographic expression of the structure, as is Rocky Ridge, northwest of Caulksville.

The anticline is slightly asymmetrical, the dips north of the axis being somewhat higher than those south of it. The dips on the north limb range from 2 to 10 degrees and average about 5 degrees; those on the south limb also range from 2 to 10 degrees, but they average about 4 degrees. The anticline is apparently closed at both ends, but the western closure is not pronounced. A small fault, which has slight displacement, has been described by Collier¹⁰ as occurring on the north flank of the anticline, but the evidence of the existence of this fault is not conclusive. If a fault does occur in the area described it is of the normal type, the downthrown side is on the north, and the displacement is less than 50 feet.

Exploration.—In 1921-1922 the River Oil and Gas Company drilled a well on the O'Neal lease, in SW. $\frac{1}{4}$ of NW. $\frac{1}{4}$ Sec. 10, T. 7 N., R. 28 W., but obtained neither oil nor gas. According to reports, however, the well was drilled to a depth of only 340 feet. This anticline is worthy of further exploration, but wells sunk on it should be carried to a depth of 4,500 feet. The wells should be drilled near the axis and preferably east rather than west of the village of Branch.

The possibility that the anticline is faulted as noted above cannot be regarded as adverse to its exploration for gas and oil.

HARTFORD ANTICLINE

Location.—The axis of the Hartford anticline extends from the Oklahoma line, at the SE. $\frac{1}{4}$ Sec. 24, T. 4 N., R. 33 W., northeastward to about the SE. $\frac{1}{4}$ Sec. 25, T. 5 N., R. 30 W. The anticline extends for about 10 miles into Oklahoma.

Structural features.—The Hartford anticline is bounded on the north by Sugarloaf syncline and on the south by Poteau syncline. The surface rocks belong to the Atoka, Hartshorne, Spadra, and Fort Smith formations. The oldest beds are exposed in its eastern part and the younger beds crop out from Hartford westward to the Oklahoma boundary. The anticline is well expressed topographically by Coops Ridge and the encircling hills.

The anticline is essentially symmetrical, but the dips north of the axis perhaps average slightly higher than those south of it. The dips on the north flank range from 3 to 30 degrees, and those on the south flank range from 3 to 20 degrees, but the asymmetry is not conspicuous near the crest. The anticline plunges to the east near its east end, where the closure is well defined. The plunge to the west is scarcely less noticeable in the vicinity of Hartford.

¹⁰ Collier, A. J., U. S. Geol. Survey Bull. 326, p. 42, 1907.

Exploration.—According to information supplied by Harry E. and Leigh Kelley, of Fort Smith, the first producing gas well in Arkansas was drilled on the Hartford anticline. This well is the Duncan No. 2 of the Choctaw Oil and Gas Company, which is in what is now the Mansfield gas field proper. It was completed in March, 1902, at a depth of 1,125 feet. It had an initial production of 550,000 cubic feet a day and is still producing. A number of other wells that have been drilled on this anticline, in the Mansfield gas field, are described elsewhere in this report.

HEBER SPRINGS ANTICLINE

Location.—The axis of the Heber Springs anticline extends from the NW. corner of Sec. 21, T. 8 N., R. 14 W. northeastward to the N. $\frac{1}{2}$ Sec. 1, T. 10 N., R. 9 W.

Structural features.—The Heber Springs anticline is bounded on the north by the Fairbanks syncline and on the south by the Guy and Pearson synclines. Throughout most of its course it is essentially an anticlinal terrace. The dips on the north flank range from 1 to 6 degrees but probably average about 2 degrees; those on the south flank range from 1 to 10 degrees and average nearly 5 degrees. There is some evidence of closure at the west end of the anticline, but near its east end it appears to rise toward the east rather than to plunge in that direction.

At several places zones of minor faulting and folding parallel the axis of the anticline. One such zone lies south of Martinville, another north of it, and a third south of Fairbanks. The details of the faulting are obscure, for all the beds involved in the movement are alike, but the displacement appears to be small, and the down-thrown side is on the south.

Exploration.—The Heber Springs anticline has not been tested for oil or gas, but its structure is rather favorable for their accumulation. The lack of definite closure at its east end and the low dips on its north flank, however, indicate that its exploration should be postponed until the more favorable anticlines in the Arkansas Valley have been tested.

HON ANTICLINE

Location.—The axis of the Hon anticline extends from about the SE. $\frac{1}{4}$ Sec. 18, T. 3 N., R. 30 W. slightly north of east to about the SE. $\frac{1}{4}$ Sec. 12, T. 3 N., R. 29 W.

Structural features.—The anticline is bounded on the north by the Poteau syncline and on the south by Waldron syncline. The surface rocks all belong to the Atoka formation.

The anticline is not markedly asymmetrical, but the dips on the

north flank probably average somewhat higher than those on the south flank. The dips on the north flank range from 4 to 90 degrees, and those on the south flank range from 4 to 70 degrees. The dips on both sides of the axis decrease regularly toward the axes of the limiting synclines. The anticline plunges toward the east at its east end, where there is good closure, but the evidence for closure at the west end is not conclusive.

The anticline is topographically expressed near its west end by Chalybeate Mountain, which is a rather typical anticlinal ridge, but the structural axis east of the South Fork of Poteau River runs through the lowlands north of Waldron. The west end of Hon anticline is apparently slightly offset from the east end of the Choctaw anticline in the area between Round and Chalybeate mountain, but the two anticlines are closely related and may be connected.

Exploration—The Hon anticline has not been tested for oil or gas, and its exploration should be deferred until the less closely folded anticlines have been drilled. If, however, it is proposed to test the anticline the initial well should be drilled near its crest and should be carried to a depth of 3,500 feet. The part of the anticline that lies northeast of Waldron is regarded as the most favorable.

HURRICANE CREEK ANTICLINE

Location.—The axis of the Hurricane Creek anticline extends from the NE. $\frac{1}{4}$ Sec. 5, T. 12 N., R. 21 W., southeastward for about 8 miles and then swings northeastward to the SE. $\frac{1}{4}$ Sec. 4, T. 12 N., R. 19 W. Its course north of T. 12 N. has not been determined, but the anticline may be an eastern extension of the Cass anticline; and its axis may extend farther northeast than is indicated above.

Structural features.—The Hurricane Creek anticline is bounded on the south by the Archey syncline, but the limiting structure on the north has not been ascertained. The anticline appears to be essentially symmetrical, the dips both north and south of the crest ranging from 2 to 5 degrees, but the average dip is probably less than 4 degrees. There is no evidence of closure at either end of the anticline as here defined, and therefore the suggestion is made that this anticline is only a part of a longer one.

Exploration.—The anticline has not yet been explored for oil and gas, yet it is a potential reservoir for either, but many other anticlines are more promising, and tests of this one may wisely be deferred until the results of the exploration of others are available.

JETHRO ANTICLINE

Location.—The axis of the Jethro anticline extends from about the center of Sec. 26, T. 11 N., R. 29 W. slightly north of east to the E. $\frac{1}{2}$ Sec. 19, T. 11 N., R. 27 W.

Structural features.—The Jethro anticline is bounded on the north by the Archey syncline and on the south by the White Rock syncline. Most of the surface rock belongs to the Atoka formation.

The anticline is an essentially symmetrical, elliptical, dome-like arch, which has fairly good closure at its west end and some closure at its east end. The dips north of the axis range from 2 to 7 degrees and average about 4 degrees; those south of the axis range from 2 to 6 degrees and average between 3 and 4 degrees.

Exploration.—In 1927-1928 the Empire Oil and Gas Company drilled a well to a depth of 3,700 feet on the Patrick lease, in the SE. $\frac{1}{4}$ of NW. $\frac{1}{4}$ Sec. 19, T. 11 N., R. 27 W., and obtained about 350,000 cubic feet of gas (generally reported as a million cubic feet) from a sandy limestone at a depth of 2,470 feet. The log of the Patrick well, as determined in detail from a study of the cuttings by Max Littlefield and Hugh McClellan, is given below:

Log of Empire Oil and Gas Company's Patrick No. 1 well, 660 feet north, 660 feet west of center of Sec. 19, T. 11 N., R. 27 W.

	Depth in feet
Sand (Hartshorne).....	0- 20
Black shale.....	20- 57
Shaly sand.....	57- 120
Sandstone, white, fine, friable, coarse at base.....	120- 150
Black shale.....	150- 160
Sandstone.....	160- 163
Dark gray shale.....	163- 247
Sand.....	247- 253
Gray, silty shale.....	253- 266
Sand.....	266- 270
Shaly sand.....	270- 290
Black, fine shale.....	290- 340
Sand.....	340- 400
Shale and fine, tight sandstone.....	400- 420
Fine, tight sandstone.....	420- 445
Fine sandstone.....	445- 500
Black shale.....	500- 505
Sandstone.....	505- 525
Shale and fine, tight sandstone.....	525- 535
Sand, medium texture, some siderite.....	535- 585
Black shale.....	585- 590
Sandstone, medium to coarse; chert rare.....	590- 735
Shale and fine sand.....	735- 970
Fine sand.....	970- 980
Shale and fine sand.....	980-1065
Shale.....	1065-1153

	Depth in feet
Black, shaly sand.....	1153-1175
Blue-gray shale.....	1175-1200
Fine sand and dark shale.....	1200-1245
Silty shale.....	1245-1265
Blue-gray shale.....	1265-1275
Dark shale and fine sand.....	1275-1378
Blue-gray, silty shale.....	1378-1388
Fine, shaly sand.....	1388-1394
Fine, shaly sand.....	1394-1400
Black shale.....	1400-1522
Fine, calcareous sandstone.....	1522-1528
Sandstone, fine.....	1528-1544
Black shale.....	1544-1630
Sandstone, calcareous.....	1630-1650
Sandy shale.....	1650-1662
Shale.....	1662-1675
Sand.....	1675-1690
Shale.....	1690-1700
Shaly sandstone; base of Winslow.....	1700-1710
Boyd shale, black shale; Morrow group.....	1710-1758
Sandy, argillaceous limestone.....	1758-1770
Blue shale.....	1770-1795
Coarse, fossiliferous limestone; Kessler limestone.....	1795-1820
Sandy blue and black shale.....	1820-1886
Blue shale.....	1868-1912
Sandy shale.....	1912-1923
Blue shale.....	1923-1965
Black silty shale.....	1965-1980
Shaly, fossiliferous limestone; top of Brentwood.....	1980-2000
Coarse, fossiliferous limestone.....	2000-2010
Shaly limestone.....	2010-2015
Blue shale.....	2015-2020
Shaly limestone.....	2020-2025
Sandy limestone; base of Brentwood.....	2025-2034
Gradation zone; sandy, calcareous shale; top of Hale.....	2034-2070
Medium sand, calcareous.....	2070-2080
Blue shale.....	2070-2103
Medium sand, calcareous.....	2103-2105
Blue to black, silty, micaceous shale.....	2105-2165
Sandy black shale.....	2165-2200
Sand, medium to fine, tight.....	2200-2218
Blue to black, silty shale; base of Hale.....	2218-2258
Brown, black, white limestone; coarse, fossiliferous.....	2258-2262
Blue and black, calcareous shale.....	2262-2310
Shale, limestone and shaly limestone; oolites common.....	2310-2325
Calcareous shale.....	2325-2348
Brown to black limestone, shaly, oolitic; probably Pitkin limestone.....	2348-2450
Black shale, silty, non-calcareous.....	2450-2460
Fine, cemented sand.....	2460-2465
Limestone, brown, oolitic.....	2465-2475
Sand and sandy shale.....	2475-2515

	Depth in feet
Black shale.....	2515-2528
Medium sand, friable; may be cavings.....	2528-2530
Black shale, non-calcareous; base of Fayetteville.....	2530-2635
Limestone, coarse, mottled, brown and white; Mayes.....	2635-2655
Black, calcareous, silty shale.....	2655-2690
White limestone, 50 per cent; chert, 50 per cent; cloudy, translucent; Boone limestone.....	2690-2848
Limestone with gray dendrites, probably manganese.....	2848-2853
Dense, white limestone, 50 per cent; bluish, translucent chert, 50 per cent.....	2853-2975
Blue, fine limestone.....	2975-2980
Devonian erosional zone; dense, cherty, sandy limestone; coarse rounded sand, 50 per cent.....	2980-3030
Limestone, clean, white, coarsely crystalline; St. Clair.....	3030-3270
Shale, light, greenish-gray, slightly calcareous; Cason shale.....	3270-3302
Limestone, coarse, white, with black flakes; typical Fern- vale.....	3302-3342
Limestone, colored black by vegetable matter; chert, 50 per cent; dark brown, translucent, opaque, rounded sand, 5 per cent.....	3342-3368
St. Peter sandstone, fine to medium; sand chiefly well rounded and sorted.....	3368-3565
Limestone, dense, white; sand, 30 per cent.....	3565-3570
Sandstone, fine to medium, chiefly rounded.....	3570-3646
Limestone, dense, white, not dolomite; sand, 30 per cent; probably top of Everton.....	3646-3652
Interbedded white, dolomitic lime and rounded sand; Everton formation.....	3652-3700

A few of the determinations in the above record may be uncertain, but the larger ones are correct. The Patrick well is therefore of great importance in that it encountered essentially the same Ordovician, Silurian, Devonian, and Mississippian beds that are found in eastern Oklahoma. In addition, the log of this well, studied in the light of the information obtained by the Stewart test well drilled on the Watalula anticline, gives conclusive proof of the great thickening of the Atoka formation south of the Boston Mountains.

The Jethro anticline probably merits further exploration, but owing to the essential failure of the carefully drilled Patrick well the tests must be regarded as somewhat hazardous. That well, however, was apparently not drilled as high as possible on the anticline, and further test wells might wisely be drilled farther west. All wells should be carried down to the St. Peter sandstone, which should be reached at a depth of about 3,500 feet.

KNOXVILLE ANTICLINE

Location.—The axis of the Knoxville anticline extends from the SE. $\frac{1}{4}$ Sec. 31, T. 9 N., R. 22 W., a short distance northwest of Knoxville, southeastward to the SE. $\frac{1}{4}$ Sec. 19, T. 8 N., R. 20 W.

Structural features.—The Knoxville anticline is bounded on the north by the Clarksville syncline and by the north limb of the Ouita syncline, and on the south by the south limb of the Ouita syncline and the eastern extension of the Seranton syncline. The surface rocks over the east-central part of the anticline belong to the Atoka formation, but the Hartshorne sandstone crops out in its western part and on its flanks.

The anticline is elliptical in outline and doubly plunging, and its closure is probably more than 500 feet. The anticline is therefore structurally ideal for the accumulation of oil and gas. It is somewhat asymmetrical, the dips on the south limb averaging slightly higher than those on the north, but the difference is of little consequence. In R. 22 W., moreover, the relations seem to be reversed, for the dips on the north limb appear to be higher than those on the south. The anticline is relatively flat topped, and the dips increase rather than decrease away from its axis. Near the axis the dips range from 3 to 6 degrees, but at a distance of a mile or more on either side of the axis the dips increase until they range from 8 to 15 degrees. (See Pl. XXXV, A.) The plunge at the east end of the anticline is somewhat more pronounced than that at its west end.

A small fault in Secs. 9 and 10, T. 8 N., R. 21 W. (See Pl. XXXV, B), parallels the axis of the anticline, but it does not necessarily indicate that the anticline is not a potential reservoir for oil or gas. The downthrown side of the fault apparently lies south of the fault trace.

The topographic expression of the Knoxville anticline is pronounced. The Ouita Ridge, which is composed of southward-dipping beds of Hartshorne sandstone, flanks the structure on the south, and the part of the anticline that is structurally high is also topographically high.

Exploration.—Despite the structural perfection of the Knoxville anticline as a reservoir, the results of its exploration have been somewhat discouraging. In 1922 the Piney Oil and Gas Company drilled a well to a depth of 3,500 feet on the J. W. Watkins lease, in Sec. 4, T. 8 N., R. 22 W., and obtained small quantities of gas at several horizons. The log of the Watkins well is given below.

Log of Watkins well No. 1 of the Piney Oil and Gas Company (subsidiary of Columbia Carbon Co.), in Sec. 4, T. 8 N., R. 22 W.

	Depth in feet
Subsoil.....	0— 17
Cabin Creek sandstone.....	55— 120
Sand, hard, gray.....	120— 135
Sand, light, water.....	17— 55
Sand, light water shale, broken, 4 feet.....	135— 172
Shale, blue.....	172— 225



A. DIP SLOPE OF HARTSHORNE SANDSTONE, WHICH DIPS DUE SOUTH AT AN ANGLE OF 14 DEGREES ON THE WEST SIDE OF THE MILL CREEK GORGE THROUGH OUITA RIDGE



B. SECTION OF A SMALL FAULT IN A ROAD CUT NEAR THE CREST OF THE KNOXVILLE ANTICLINE

	Depth in feet
Sand, brown.....	225- 235
Shale, brown.....	235- 302
Sand, brown.....	302- 316
Shale, brown.....	316- 428
Sand, light, medium hard.....	428- 472
Sand, soft; a little water at 505 feet.....	472- 510
Shale, blue.....	510- 620
Sand.....	620- 635
Shale, dark brown.....	635- 715
Sand.....	715- 740
Shale, dark brown.....	740- 865
Sand, hard.....	865- 885
Shale, brown.....	885-1130
Sand, gray, hard.....	1130-1185
Shale, brown.....	1185-1334
Sand, hard, brown.....	1334-1363
Shale.....	1363-1370
Sand, hard.....	1370-1415
Shale, brown.....	1415-1421
Sand, hard.....	1421-1450
Gas at 1450.....	1450-1540
Sand, more gas.....	1540-1575
Shale, broken.....	1575-1581
Sand; gas at 1595 feet; total in 3 pays, 400,000 cubic feet.....	1581-1595
Sand, hard, gray.....	1595-1650
Shale, brown.....	1650-1755
Sand, broken.....	1755-1810
Shale, brown.....	1810-1830
Sand.....	1830-1855
Shale, brown.....	1855-2000
Shale.....	2000-2110
Sand.....	2110-2145
Shale, blue.....	2145-2292
Sand and some water.....	2292-2302
Shale, brown.....	2302-2391
Sand and shale.....	2391-2401
Shale, caved and cemented.....	2401-2425
Sand, hard.....	2425-2451
Sand and shale, broken, caved, cemented.....	2451-2539
Sand, medium good.....	2539-2580
Sand, broken.....	2580-2720
Shale, dark, caved, cemented.....	2720-2781
Sand and shale.....	2781-2805
Shale, broken, caved, cemented.....	2805-2993
Sand.....	2993-3020
Shale, dark brown.....	3020-3072
Sand, black.....	3072-3085
Sand, white; 250,000 cubic feet of gas.....	3085-3235
Shale, dark.....	3235-3240
Sand, dark.....	3240-3300
Sand and shale, black.....	3300-3350
Not reported.....	3350-3500

The well was started fairly high in the Hartshorne formation, passed through it, and finished in the Atoka, in which formation practically all of it was drilled. The test, however, was not at all conclusive, for the well was drilled too far down on the anticline. Indeed, there is at least 400 feet of closure above the site of the well.

In 1927-1928 the Natural Gas and Fuel Corporation drilled a well on the Wharton lease, in the NE. $\frac{1}{4}$ of NE. $\frac{1}{4}$ Sec. 7, T. 8 N., R. 21 W., to a depth of 4,053 feet, and obtained a show of gas at 3,290 feet. This well was started in the Hartshorne formation and passed through 95 feet of it before entering the Atoka. The base of the Atoka had apparently not been reached at 4,053 feet, for the log shows the alternation of sandstone, shale, and shaly sandstone, with practically no lime, that is typical of the Atoka. The log of the Wharton well is given below.

Log of Natural Gas and Fuel Corporation's Wharton No. 1 well, in NE. $\frac{1}{4}$ of NE. $\frac{1}{4}$ Sec. 7, T. 8 N., R. 21 W.

	Depth in feet
Surface.....	0- 4
Sand.....	4- 25
Hard white sand.....	25- 95
Blue shale.....	95- 135
Sandy shale.....	135- 160
Sandy shale.....	160- 195
Shale and shells.....	195- 215
Dark shale.....	215- 240
Black shale.....	240- 315
Shale.....	315- 323
Sandy lime.....	323- 330
Sandy lime.....	330- 365
Shale.....	365- 380
Lime shells.....	380- 382
Hard sand.....	382- 407
Very hard sand.....	407- 420
Very hard white sand.....	420- 430
Hard, white, grayish sand.....	430- 440
Hard, white sand.....	440- 453
Hard sand.....	453- 570
Sandy shale.....	570- 655
Blue shale.....	655-1125
Gray sand.....	1125-1164
Dark blue shale.....	1164-1176
Blue shale.....	1176-1305
Black shale.....	1305-1345
Hard gray sand.....	1345-1360
Hard sand.....	1360-1455
Shale.....	1455-1540
Broken sand.....	1540-1550
Hard, gray sand.....	1550-1555
Broken sand.....	1555-1612
Black shale.....	1612-1730

	Depth in feet
Sandy shale.....	1730-1750
Gray sand.....	1750-1784
Black shale.....	1784-1796
Gray sand.....	1796-1835
Sandy shale.....	1835-1855
Blue shale.....	1855-1890
Brown shale.....	1890-1985
Light shale.....	1985-2068
Sand.....	2068-2075
Sand.....	2080-2134
Blue shale.....	2075-2080
Blue shale.....	2134-2265
Gray sand.....	2265-2285
Blue shale.....	2285-2295
Gray sand.....	2295-2350
Sandy shale.....	2350-2365
Shale.....	2365-2490
Broken sand.....	2490-2530
Broken sand.....	2530-2555
Shale.....	2555-2616
Blue shale.....	2616-2690
Black shale.....	2690-2810
Sandy, brown shale.....	2810-2880
Sandy shale.....	2880-2925
Brown sand.....	2925-2950
Dark shale.....	2950-2967
Brown sand, hard.....	2967-2975
Hard, gray sand.....	2975-3040
Hard, white sand.....	3040-3075
Dark sand.....	3075-3090
Broken sandy shale.....	3090-3200
White sand and shale.....	3200-3205
Soft, white sand—show gas.....	3205-3290
Soft, white sand.....	3290-3295
Brown sandy shale.....	3295-3330
Sandy shale.....	3330-3420
Shale.....	3420-3515
Blue shale.....	3515-3604
Hard shell.....	3604-3615
Dark brown shale.....	3615-3618
Hard, gray sand.....	3618-3630
Hard, black sand.....	3630-3634
Hard, gray sand.....	3634-3645
Hard, white sand—little line.....	3645-3654
Hard, white sandy lime.....	3654-3659
Hard, sandy lime.....	3659-3746
Hard sand.....	3746-3780
Hard, black sand.....	3780-3790
Hard sand.....	3790-3842
Black shale.....	3842-3872
Gray sand—hole caving from about 30 feet above.....	3872-3880
Hard sand.....	3880-3891
Hard, gray sand.....	3891-3952

	Depth in feet
Medium hard, sandy shale.....	3952-3889
Sandy shale.....	3889-4007
Very hard sand.....	4007-4022
Hard sand; bottom of well.....	4022-4053

The Wharton well was apparently drilled somewhat south of the axis of the anticline, yet essentially on its top, and it is hard to understand why it obtained little or no gas if the anticline contains gas in commercial quantities. The further exploration of the anticline must therefore be regarded as rather hazardous.

Future test wells should be drilled only on the eastern extension of the anticline, near its axis. The fact that the Hartshorne and Spadra formations crop out on the west is not alone due to the difference in elevation from east to west, which amounts only to 120 feet, but in part to a slight plunge of the entire anticline westward. This fact alone should make the eastern part of the anticline somewhat attractive for a test.

The large quantity of clay shale in the Atoka section should seal effectively the fault already mentioned, but if the anticline eventually proves to be barren of gas, the fault may perhaps be regarded as in part the cause of its barrenness.

Wells may be drilled to great depths on the Knoxville anticline without exhausting the possibility of production from upper Paleozoic formations, for the Wharton well, which was drilled to a depth of more than 4,000 feet, did not penetrate the Morrow formation. It might profitably have been carried deeper.

LAFAYETTE ANTICLINE

Location.—The axis of the Lafayette anticline extends from the NE. $\frac{1}{4}$ Sec. 36, T. 10 N., R. 31 W. northeastward to the center of Sec. 19, T. 10 N., R. 29 W.

Structural features.—The Lafayette anticline is bounded on the north by the Dean Springs syncline and on the south by the Little Frog syncline.

This anticline, which is poorly defined throughout its course, is asymmetrical in that its south flank is steeper than its north flank. The dips north of the axis range from 1 to 5 degrees and average less than 2 degrees; those south of the axis range from 1 to 6 degrees and average about 3 degrees. The structure is apparently moderately well closed at both ends.

Exploration.—The Lafayette anticline appears not to have been drilled for oil or gas, although it is structurally rather favorable for their accumulation. The anticline, however, is inferior in its prospects to many others in the Arkansas Valley, and its exploration may well be deferred.

LANE HILL ANTICLINE

Location.—The axis of the Lane Hill anticline extends from the NE. $\frac{1}{4}$ Sec. 30, T. 8 N., R. 31 W. northeastward to about the center of Sec. 23, T. 9 N., R. 30 W.

Structural features.—The Lane Hill anticline is bounded on the north by the Catcher syncline and on the south by the unnamed, indefinite syncline that separates it from the Massard Prairie anticline.

The anticline is asymmetrical in that its north limb is steeper than its south limb. The dips north of the crest range from 2 to 12 degrees, although inclinations as high as 12 degrees are rare. The dips south of the crest range from 1 to 3 degrees. The structure is apparently closed at its west end and has some closure at its east end.

Exploration.—This anticline has yielded practically all the gas produced in the Kibler field and a part of that produced in the Williams field. The production and the details of the structure are given in the text describing those fields.

LATHAM ANTICLINE

Location.—The axis of the Latham anticline extends from the SW. $\frac{1}{4}$ Sec. 7, T. 10 N., R. 16 W. northeastward to the SW. $\frac{1}{4}$ Sec. 31, T. 11 N., R. 15 W.

Structural features.—The anticline is bounded on the north by the Okay syncline and on the south by the Scotland syncline. The surface rocks all belong to the Atoka formation.

The Latham anticline is structurally related to the Evans Mountain and Shirley anticlines, but it is rather definitely offset from the Evans and there is no very certain field evidence of its direct connection with the Shirley. The anticline is essentially symmetrical, and the dips on both sides of its axis average about 3 degrees. It is broadly rounded near its crest, so that the exact location of its axis is not certainly known. The closure at the east and west ends is not great.

Exploration.—The Latham anticline has not been explored for oil or gas, although its structure is fairly favorable to their accumulation. The anticline, however, is one of the less promising of those in the Arkansas Valley, and it should not be drilled until information obtained from wells drilled on others makes its test seem desirable.

LEE CREEK ANTICLINE

Location.—The axis of the Lee Creek anticline extends from the NE. $\frac{1}{4}$ Sec. 3, T. 12 N., R. 32 W. southeastward to the SW. $\frac{1}{4}$ Sec. 11, T. 11 N., R. 31 W.

Structural features.—The Lee Creek anticline lies between the north and south forks of the Cove syncline. The surface rocks all belong to the Atoka formation.

The anticline is essentially symmetrical, but its south limb is perhaps somewhat steeper than its north. The dips north of the crest range from 3 to 7 degrees; those south of the axis range from 2 to 10 degrees. The anticline is well closed at its west end, but no good evidence of prominent closure at its east end has been found.

Exploration.—The Lee Creek anticline appears not to have been tested for oil or gas, but its structure is fairly favorable to their accumulation. Wells drilled on this anticline should encounter the Boone limestone between 1,250 and 1,750 feet. Commercial production, however, cannot be expected from the relatively thin Atoka sediments, and good transportation is not yet available to this particular area, so that the exploration of the anticline may well be deferred until the more promising, less inaccessible anticlines have been tested.

LIBERTY HILL ANTICLINE

Location.—The axis of the Liberty Hill anticline extends from the SE. $\frac{1}{4}$ Sec. 2, T. 12 N., R. 33 W., southeastward to about the SW. $\frac{1}{4}$ Sec. 10, T. 12 N., R. 32 W., but the anticline has not been studied in detail, and both the east and the west end of its axis are not definitely determined.

Structural features.—The Liberty Hill anticline is bounded on the south by the Cove syncline, but the limiting structural feature on the north has not been definitely ascertained, although it is probably the Evansville fault. The surface rocks belong to the Atoka, Fayetteville, and Pitkin formations and to the Morrow group.

The anticline is somewhat asymmetrical, in that its north limb is steeper than its south, and in this respect it differs from most of the anticlines on the southern slope of the Boston Mountains. The dips north of the crest range from 2 to 9 degrees, and probably average nearly 5 degrees; those south of the crest range from 2 to 7 degrees and average between 3 and 4 degrees.

Two northeastward-trending normal faults lie essentially at right angles to the axis of the anticline on both its limbs, but apparently they do not cross the crest. The downthrown sides of both lie east of the fault line, and the displacement is small.

Exploration.—The Liberty Hill anticline has not been tested for oil or gas, but its structure is fairly favorable to their accumulation. No commercial production, however, may be expected from rocks younger than the Batesville sandstone, and any test well drilled should not be stopped short of the St. Peter sandstone. The fault-

ing mentioned is not regarded as particularly adverse to the prospect of obtaining oil or gas from this anticline, but its exploration may profitably be deferred until the results of the tests of more promising anticlines are available.

LICK MOUNTAIN ANTICLINE

Location.—The axis of the Lick Mountain anticline extends from the NW. corner of Sec. 12, T. 8 N., R. 17 W., northeastward to the SE. $\frac{1}{4}$ Sec. 20, T. 9 N., R. 15 W.

Structural features.—The Lick Mountain anticline is bounded on the north by the Formosa syncline, and on the south by the east end of Lee Mountain syncline, by a part of the Fairbanks syncline, and by an unnamed, poorly defined basin that lies between the Lick Mountain and the Center Ridge anticline. The surface rocks all belong to the Atoka formation.

The anticline is poorly defined for about 3 miles near its west end and is nowhere very prominent. It is rather asymmetrical in that the dips on its north flank average less than 4 degrees and those on its south flank range from 4 to 8 degrees and probably average at least 5 degrees. The evidence for plunge at either end of the axis is poor, and the closure is probably small.

Exploration.—The Lick Mountain anticline has not been drilled for oil or gas, and although its structure is somewhat favorable to their accumulation its exploration should be postponed until additional information is obtained from tests of more promising anticlines. The initial well should be drilled on the eastern half of the anticline.

LINVILLE ANTICLINE

Location.—The axis of the Linville anticline extends eastward from about the center of Sec. 31, T. 11 N., R. 25 W., nearly to Little Piney Creek, and then turns southeastward, terminating in the N. $\frac{1}{2}$ Sec. 32, T. 10 N., R. 19 W.

Structural features.—The Linville anticline is bounded on the north by the Payne syncline and by the west end of the Hector syncline, and on the south by the Philpott and Turnersville synclines. The surface rocks belong to the Atoka formation.

The anticline has a rather indefinite axis, and in the southeastern part of T. 11 N., R. 22 W., it appears to plunge to the east. The anticline is asymmetrical, the dips on its south flank averaging considerably higher than those on the north. The dips on the south generally range from 4 to 15 degrees, but in Secs. 34, 35, and 36, T. 11 N., R. 24 W. they run as high as 55 degrees. These high dips in this area suggest faulting, but no good evidence of faulting was found.

The dips north of the axis are generally less than 5 degrees. These low dips suggest an antilinal terrace.

From Linville eastward for 6 to 8 miles the anticline is faulted, but the displacement is not great.

Exploration.—The Linville anticline has not yet been tested, but its structure is favorable to the accumulation of oil and gas, and it may be worthy of exploration. Wells should be drilled near the axis, preferably slightly north of it, and should be located with reference to favorable variations in the structure, such as differences in axial pitch.

The fact that the anticline is faulted at its west end cannot be construed as entirely unfavorable, but the evidence of closure at that end is not good. The east end of the anticline is apparently well closed.

LUDWIG ANTICLINE

Location.—The axis of the Ludwig anticline extends from about the NW. $\frac{1}{4}$ Sec. 18, T. 10 N., R. 24 W. slightly south of east to the NW. $\frac{1}{4}$ Sec. 30, T. 10 N., R. 22 W.

Structural features.—The Ludwig anticline is bounded on the north by the Philpott syncline and on the south by Clarksville syncline. Most of the surface rocks belong to the Hartshorne formation, but the Atoka, Spadra, and Fort Smith formations are also exposed over small areas. The anticline has no pronounced topographic expression.

The anticline is somewhat asymmetrical in that the dips north of its axis average slightly higher than those south of it. The dips north of the axis range from 2 to 13 degrees and average about 7 degrees; those south of it range from 2 to 12 degrees and average between 5 and 6 degrees. The anticline is fairly well closed at its west end, but the closure at its east end is not conspicuous. A minor fault may occur on the north flank of the anticline, in the southern part of Secs. 7 and 8, T. 10 N., R. 23 W., where there is some evidence that the beds have been displaced. The south flank of the anticline south of Ludwig is complicated by a number of irregularities, the local dips being to the east, or even to the north.

Exploration.—The Ludwig anticline has been successfully drilled for oil and gas. Several fairly large gas wells have been completed, and the area is now called the Clarksville field, which is considered in detail elsewhere.

MASSARD PRAIRIE ANTICLINE

Location.—The axis of the Massard Prairie anticline extends from a point near the Oklahoma boundary, in the SE. $\frac{1}{4}$ Sec. 20, T. 7 N., R. 32 W., northeastward to about the SE. $\frac{1}{4}$ Sec. 26, T. 9 N., R. 30 W.

Structural features.—The Massard Prairie anticline is bounded on the north by the Fort Smith syncline and by the unnamed, indefinite syncline that separates it from the Lane Hill anticline, and on the south by the Central syncline and the Massard fault.

The anticline is a low, inconspicuous fold, which is essentially symmetrical. The dips north of the axis range from 2 to 8 degrees and average about 4 degrees; those south of the axis range from 2 to 7 degrees and average between 3 and 4 degrees. The anticline is apparently well closed near its west end, but there is no good evidence of closure at its east end.

Exploration.—The Massard Prairie anticline has been successfully drilled for gas, which it produces in both the Massard Prairie and Williams fields. The details of the structure, of the drilling operations, and of the production are described more fully in the text on those fields.

MAUMELLE ANTICLINE

Location.—The axis of the Maumelle anticline extends from about the SW. $\frac{1}{4}$ Sec. 28, T. 3 N., R. 15 W. slightly south of east to the NW. $\frac{1}{4}$ Sec. 13, T. 2 N., R. 12 W.

Structural features.—The Maumelle anticline is bounded on the north by the Marche syncline and on the south by the Big Rock syncline. Most of the surface rocks north of the crest belong to the Atoka formation, but the Jackfork sandstone is exposed over a small area in its western part. South of the faulted crest the Stanley shale is the chief formation exposed, but the Jackfork formation crops out in several small areas. The anticline is not well expressed topographically, but the Maumelle Pinnacles are formed of steeply dipping beds on its south flank.

The anticline is asymmetrical, its south limb generally being steeper than its north. The dips north of the crest range from 20 to 65 degrees and average between 35 and 40 degrees; those south of the crest range from 4 to 85 degrees and probably average between 40 and 50 degrees. The dips on both sides of the axis, however, diminish toward the east, and the diminution is more rapid south of the axis than north of it, so that northeast of Little Rock the north flank is steeper than the south. The west end of the anticline has not been studied in detail, but there is no good evidence for closure there. The anticline is apparently well-closed, however, near its east end.

The anticline is probably faulted just north of its crest, but the fault trace is difficult to locate, and its position is inferred from the distribution of the formations. The fault, which is of the high-angle thrust type, is described elsewhere as the Maumelle fault.

Exploration.—The Maumelle anticline appears not to have been tested for oil or gas, and its structure is not particularly favorable to their accumulation or retention. Future exploration of this structure is considered inadvisable.

MEADOW MOUNTAIN ANTICLINE

Location.—The axis of the Meadow Mountain anticline extends from about the SE. $\frac{1}{4}$ Sec. 35, T. 12 N., R. 31 W. eastward to the SW. $\frac{1}{4}$ Sec. 34, T. 12 N., R. 29 W., but both the east and the west ends are poorly defined.

Structural features.—The Meadow Mountain anticline is bounded on the north by the Chester syncline and on the south by the Warloop syncline. The surface rocks all belong to the Atoka formation.

The anticline is asymmetrical in that its south flank is steeper than its north. The dips north of the crest average about 3 degrees; those south of the crest range from 2 to 13 degrees and probably average between 5 and 6 degrees. There is little evidence of prominent closure at either end of the anticline.

Exploration.—The Meadow Mountain anticline has not been tested for oil or gas, but its structure is fairly favorable to their accumulation. The lack of definite east and west closures, however, makes drilling somewhat more hazardous than usual, and it may be well to defer testing this anticline until the results of the exploration of others are available.

MORRILTON ANTICLINE

Location.—The axis of the Morrilton anticline extends from some indefinite location in the Point Remove Creek bottoms eastward to the center of the N. $\frac{1}{2}$ Sec. 15, T. 6 N., R. 17 W., where it first can be located accurately, thence slightly north of east to Sec. 35, T. 8 N., R. 11 W.

Structural features.—The Morrilton anticline is bounded on the south by the Pontoon and Menifee synclines and on the north by the Greenbrier syncline. The surface rocks all belong to the Atoka formation.

The anticline is not only pronounced, but its topographic expression is very apparent, particularly in an area several miles west of Morrilton, where it plunges to the west and where the ridges made by the heavy beds of sandstone on the limbs of the anticline stand out in a semicircle. Barrow Mountain, just east of Morrilton, is another prominent circular ridge produced by this plunge, and Greenbrier Ridge, east of Cadron Creek, marks the axis of the anticline for about 10 miles.

The anticline is much more pronounced in its central and western parts than in its eastern part, where it apparently rises rather

than plunges. It is markedly asymmetrical from its west end to R. 14 W., the dips on the south limb ranging from 6 to 45 degrees, whereas those on the north limb are generally considerably less and are ordinarily under 25 degrees. In the SW. $\frac{1}{4}$ Sec. 12, T. 6 N., R. 15 W., however, the dip is 54 degrees due north. East of R. 15 W. the dips diminish and few reach more than 10 degrees. Furthermore, the asymmetry of the anticline becomes less and less pronounced toward the east and is not noticeable east of Wooster. The anticline flattens out abruptly from its axis.

Exploration.—Three test wells have been drilled on the Morrilton anticline near Plumerville, and all obtained gas in considerable quantities. The logs of these wells are no longer available, and their exact locations were not ascertained, but gas obtained from one of the wells was used commercially in Plumerville in 1905 and 1906. Two of these wells, which were drilled by J. B. Streeter et al, were sunk on the Nesbitt lease. The first well, which was carried to a depth of 1,765 feet was drilled in the S. $\frac{1}{2}$ of Sec. 7, T. 6 N., R. 15 W., north of the anticlinal axis, and was apparently the best producer of the three. The second Nesbitt well was drilled south of the axis, probably in the N. $\frac{1}{2}$ Sec. 18, T. 6 N., R. 15 W., and was carried to a depth of 2,582 feet. The third well was drilled on the Dr. J. N. Mitchell lease, in Sec. 14, T. 6 N., R. 16 W., on the south side of the anticlinal axis. This well was carried to a depth of 1,800 feet, but according to local reports it was not so productive as the others.

At the time these wells were drilled a gas well was considered little or no better than a dry hole, and consequently little is known of the actual amount of gas obtained, but according to the reports it was fairly large. These three wells may therefore be regarded as of considerable importance, for they show that the high dips which are common in many of the anticlines in the Arkansas Valley are not in themselves adverse to successful wells. Furthermore, they indicate that the area between Plumerville and Fort Smith, in the Arkansas Valley Province, is all potential gas territory, for the general lithologic and structural conditions in these two places where gas has been obtained are not very different.

The Morrilton anticline has been tested not only by the wells drilled near Plumerville but by a well drilled in 1922 and 1923 in the SE. $\frac{1}{4}$ of the SE. $\frac{1}{4}$ Sec. 27, T. 7 N., R. 13 W., by E. A. Baker, Jr. This well was carried to a depth of 3,560 feet without obtaining either oil or gas in commercial quantities. It was drilled just north of the crest of the anticline. The log is no longer available, but the well undoubtedly terminated in the Atoka formation.

Despite the failure of this well, further exploration of the Morrilton anticline is probably justified. As the dips are steep, future

wells should be drilled close to the axis, but because of the asymmetry of the anticline they should be placed somewhat north of the surface trace of the axis in order that they may reach its subsurface crest.

On account of the rise of the anticline toward the east, gas should be expected only where there is local eastward closure or where the axis is essentially horizontal.

MOUNTAINBURG ANTICLINE

Location.—The axis of the Mountainburg anticline extends from about the SW. $\frac{1}{4}$ Sec. 10, T. 11 N., R. 30 W. northeastward to the SW. $\frac{1}{4}$ Sec. 6, T. 11 N., R. 29 W.

Structural features.—The Mountainburg anticline is bounded on the north by the Warloop syncline and on the south by the long south slope to the Dean Springs syncline. The surface rocks all belong to the Atoka formation.

The anticline is asymmetrical in that its south limb is steeper than its north. The dips north of the axis probably average less than 3 degrees; those south of the axis average more than 4 degrees. The anticline has only slight closure at both ends and is in general of minor importance.

Exploration.—The Mountainburg anticline has not been tested for oil or gas, but its structure is reasonably favorable to their accumulation. Exploration, however, should be deferred until the larger and more promising anticlines have been tested.

OLD HICKORY ANTICLINE

Location.—The axis of the Old Hickory anticline extends from the center of the north line of Sec. 19, T. 8 N., R. 17 W., almost due east to the SE. $\frac{1}{4}$ of Sec. 18, T. 8 N., R. 16 W. It may be regarded as a north fork of the Solgohachia anticline, but its point of junction with that anticline has not been definitely located.

Structural features.—The Old Hickory anticline is bounded on the north by the Lee Mountain syncline and on the south by the west end of the Fairbanks syncline. The surface rocks all belong to the Atoka formation.

The anticline is essentially symmetrical, the dips on both its flanks being commonly from 3 to 10 degrees. The anticline plunges to the west at its west end, where it is well closed. At its east end there is also a certain amount of closure, but the plunge in that direction is not pronounced; in fact, the axis is lost south of Lanty, where the beds are essentially horizontal.

Minor faulting complicates the structure about half a mile north of the antichinal axis, in the center of Sec. 14, T. 8 N., R. 17 W. The fault itself was not seen, but as the beds at some places dip 40° N.,

there must be faulting. This probable fault is not regarded as adverse to the possibility that the anticline is a reservoir of hydrocarbons.

Exploration.—This anticline has not been tested for oil or gas. Although a minor anticline, it is fairly pronounced, and it has reasonably good closure. If tested the initial well should be drilled near its axis, and preferably near Old Hickory, or possibly slightly east of it. The drill should be carried to a depth of at least 3,000 feet.

OKAY ANTICLINE

Location.—The axis of the Okay anticline extends from about the center of the N. $\frac{1}{2}$ Sec. 36, T. 11 N., R. 18 W., slightly north of east to about the northeast corner of Sec. 34, T. 11 N., R. 17 W.

Structural features.—The Okay anticline lies between the two arms of the Okay syncline. The surface rocks all belong to the Atoka formation. The anticline may represent the eastern extension of the Treat anticline, but in the valleys of East Fork and Middle Fork of Illinois Bayou it is impossible to determine exactly the structural trend.

The dips on either side of the axis probably do not average much over 2 degrees, and the anticline is of minor importance. The closure at its east end is fairly well marked, but the evidence of plunge at the west end is poor. The anticline is essentially symmetrical.

Exploration.—The Okay anticline has not been tested for oil or gas, and although its structure is somewhat favorable to the accumulation of those products it should not be explored until the more promising anticlines have been drilled.

OZARK ANTICLINE

Location.—The axis of the Ozark anticline extends from about the E. $\frac{1}{2}$ Sec. 36, T. 10 N., R. 26 W. eastward to about the center of Sec. 36, T. 10 N., R. 25 W., but both the east and the west end of the anticline are somewhat indefinite.

Structural features.—The Ozark anticline is bounded on the north by the Philpott syncline and on the south by the Webb City syncline. The surface rocks belong to the Hartshorne and Atoka formations.

The structure is essentially symmetrical, but the dips on the north flank probably average slightly higher than on the south flank, despite the fact that the south flank is shorter. The dips north of the axis range from 2 to 10 degrees and average about 5 degrees; those south of the axis range from 2 to 9 degrees and probably average between 4 and 5 degrees, although the dips south of the axis are much more irregular than those north of it. The anticline is without definite closure at its east end and is poorly closed at its west end.

Exploration.—In 1922 the Piney Oil and Gas Company drilled a

well to a depth of 2,800 feet on the J. N. Hill lease, in Sec. 3, T. 9 N., R. 25 W., but obtained neither oil nor gas. The log of this well, which was drilled some distance south of the axis of the anticline, is given below:

*Log of Piney Oil and Gas Company's J. N. Hill well No. 1, Sec. 3,
T. 9 N., R. 25 W.*

	Depth in feet
Soil.....	0- 16
Slate.....	16- 120
Lime.....	120- 160
Slate.....	160- 260
Sand.....	260- 300
Slate.....	300- 450
Lime.....	450- 500
Slate.....	500- 580
Shells.....	580- 700
Sand.....	700- 730
Slate.....	730- 800
Shells.....	800- 900
Sand.....	900- 940
Slate.....	940-1000
Shells.....	1000-1100
Slate.....	1100-1150
Lime.....	1150-1200
Sand.....	1200-1280
Slate.....	1280-1340
Sand.....	1340-1380
Lime.....	1380-1425
Slate.....	1425-1465
Lime.....	1465-1480
Slate.....	1480-1500
Sand.....	1500-1630
Slate.....	1630-1635
Lime.....	1635-1750
Slate.....	1750-1800
Sand.....	1800-2070
Slate.....	2070-2085
Sand.....	2085-2260
Lime.....	2260-2330
Sand.....	2330-2700
Slate.....	2700-2720
Sand (total depth).....	2720-2800

The Hill well was started in the Atoka formation, and the log shows the typical Atoka alternation of sandstone and shale to the bottom of the well. The "lime" reported is undoubtedly dense sandstone, and the "slate" is almost certainly shale.

The Hill well cannot be regarded as an adequate test of the Ozark anticline, which probably merits further exploration, although it cannot be rated as among the most promising in the Arkansas Valley. Wells should be drilled near the anticlinal axis and should be carried to a depth of at least 3,500 feet.

OZONE ANTICLINE

Location.—The axis of the Ozone anticline extends from the SW. $\frac{1}{4}$ Sec. 6, T. 11 N., R. 25 W. eastward to the NE. $\frac{1}{4}$ Sec. 3, T. 11 N., R. 23 W., a short distance northeast of the village of Ozone.

Structural features.—The Ozone anticline is bounded on the north by the Ragon syncline and on the south by the Payne syncline. Its west end is offset several miles from the east end of the Watalula anticline, but its east end is apparently only slightly offset from the west end of the Treat anticline, and the two may actually be connected. The surface rocks belong to the Atoka formation.

The Ozone anticline is somewhat asymmetrical, the north limb being slightly steeper than the south. The dips north of the axis range from 4 to 8 degrees; those south of the axis are generally less than 5 degrees. The axis is difficult to locate accurately, and several of the dips and strikes obtained show considerable differences from those that would normally be expected. The anticline has a slight plunge to the west at its west end, but the closure cannot be great. There is still less closure at the east end.

Exploration.—The Ozone anticline has not yet been tested. Its structure is fairly favorable to the accumulation of oil or gas, but its exploration should perhaps be deferred until some of the more promising anticlines have been drilled. Wells should be drilled a short distance south of the crest, and advantage should be taken of the pitch of the axis to place them as high structurally as possible.

PALARM ANTICLINE

Location.—The axis of the Palarm anticline extends from about the center of Sec. 8, T. 3 N., R. 14 W., southeastward to the NW. $\frac{1}{4}$ Sec. 25, T. 3 N., R. 11 W., but the west end is obscured by the alluvium of Arkansas River, and Tertiary sediments mask the axial trend near the east end.

Structural features.—The Palarm anticline is bounded on the north by the Perryville and Cato synclines and on the south by the Marche syncline. The surface rocks belong to the Atoka formation, and the structure is expressed topographically by the eastward-trending ridge south of Palarm.

The anticline is asymmetrical in that its south limb is generally steeper than its north. The dips north of the axis range from 8 to 80 degrees, but the average dip east of Arkansas River is not more than 25 degrees. The dips south of the axis range from 20 to 63 degrees, and probably average about 35 degrees. The anticline is apparently not well closed at either end.

Exploration.—In 1920-1921 the Arkansas Land and Timber Company drilled a well to a depth of 790 feet on the Crane lease, in Sec.

15. T. 3 N., R. 11 W., but obtained neither oil nor gas in commercial quantities. The log of this well, which was drilled about a mile north of the axis of the anticline, is not available. The anticline was not fairly tested by the Crane well, which was not only poorly located but was drilled to insufficient depth. Because of the steep dips, however, and the relatively impervious sandstone, this anticline is not regarded as particularly promising, although its structure is favorable to the accumulation of oil or gas. If it is to be tested the well should be drilled very near the crest and should be carried to a depth of at least 3,500 feet.

PINE MOUNTAIN ANTICLINE

Location.—The axis of the Pine Mountain anticline extends from about the Oklahoma boundary, at the SE. $\frac{1}{4}$ Sec. 35, T. 12 N., R. 33 W. southeastward to the NW. $\frac{1}{4}$ Sec. 19, T. 11 N., R. 31 W.

Structural features.—The Pine Mountain anticline is bounded on the north by the Cove syncline and on the south by Uniontown syncline. Most of the surface rocks belong to the Atoka formation, but beds of the Morrow formation are exposed near the west end of the axis.

The structure is asymmetrical, and the asymmetry is somewhat unusual in that the north flank is steeper than the south. The dips north of the crest range from 3 to 12 degrees and average more than 5 degrees; those south of the crest range from 2 to 6 degrees and average between 3 and 4 degrees. The anticline is closed at its east end, but there is no good evidence of closure at its west end.

Exploration.—The Pine Mountain anticline has not been drilled for oil or gas, but its structure is fairly favorable to their accumulation. No large production can be expected from the Atoka formation, however, and wells should be drilled at least to the Sylamore sandstone. Owing to the lack of transportation facilities it may be well to defer the exploration of this anticline until the results of the drilling of more accessible anticlines are available.

PINE RIDGE ANTICLINE

Location.—The axis of the Pine Ridge anticline extends from the N. $\frac{1}{2}$ Sec. 26, T. 7 N., R. 28 W. slightly north of east to somewhat north of the center of Sec. 13, T. 7 N., R. 25 W., from which point it continues slightly south of east to about the center of Sec. 3, T. 6 N., R. 20 W., but the exact location of its east end is obscured by the alluvium of Arkansas River.

Structural features.—The Pine Ridge anticline is bounded on the north by the Six Mile, Paris, and Shinn synclines, and on the south by the Greenwood and Magazine Mountain synclines. The surface

rocks on the south flank of the anticline belong chiefly to the Atoka formation, but those on the north flank belong to the Hartshorne, Spadra, Fort Smith, and Paris formations.

The anticline is markedly asymmetrical, the dips north of the axis being much steeper than those south of it, but the asymmetry is more pronounced east of Paris than west of it. The dips north of the crest range from 2 to 90 degrees. Some of the beds on the north flank near Paris have been overturned and dip at high angles to the south. East of the point of overturn the dips on the north flank gradually decrease for about 25 miles, but in the vicinity of Dardanelle they again become great. Except for a short distance near the west end of the anticline, and in an area south of Blaine, where for a dozen miles the dips range from 2 to 15 degrees, the beds on the north side of the crest are commonly higher than 25 degrees. Throughout most of the anticlinal course the dips decrease rapidly toward the axis of the Paris syncline, but in the vicinity of Blaine they increase toward that structure.

The dips on the south flank range from 1 to 75 degrees, but dips of more than 20 degrees are rare east of the vicinity of Paris, and at most places the angle is less than 7 degrees. In the part of the anticline that lies west of Paris the dips generally decrease southward from this axis, but in the part east of that place no such generalization is found to apply. The anticline has a rather notable plunge at its west end, where the closure is well marked by the swing of the formations, but it has been impossible to determine whether there is good closure at the east end. There is, however, some evidence of an eastward plunge in the vicinity of Dardanelle.

Whether the anticline is faulted along its crest is doubtful. The north flank is at some places so steeply inclined that, whether the beds are displaced or not, the relation simulates that of a normal fault having the downthrown side on the north, particularly because most of the dips on the south flank are relatively low as compared with those on the north. The beds near the crest are greatly distorted (see Pl. XXXVI, *B*), but close examination disclosed no good evidence of major faulting, though doubtless there have been many minor displacements of the beds. There is so much shale in the Atoka formation in this anticline and so few thick beds of sandstone that the more pliant beds have been intricately folded rather than broken. The thin beds of sandstone in the shale, however, have been so much displaced that none of them can now be traced except for short distances.

The topographic expression of the anticline is pronounced in Pine and Dardanelle ridges and is noticeable in other less prominent topographic features.

Exploration.—Several test wells have been drilled on the Pine Ridge anticline in the vicinity of Dardanelle. In 1908 Bell et al. drilled a well to a depth of 1,600 feet in Sec. 32, T. 7 N., R. 20 W., but obtained neither oil nor gas in commercial quantities. The other wells, which were drilled west of Dardanelle, can hardly be regarded as tests, for they were drilled only to a depth of about 200 feet.

Whether this anticline may be regarded as a promising source of oil or gas is uncertain, but some parts of it are favorable to the accumulation of gas. The possibility that the anticline may be faulted cannot completely condemn it as a potential reservoir, for even if it has been faulted the thick beds of shale of the Atoka formation should effectively seal off the sandstones. Any exploration, however, should avoid the area south of Paris, where the beds are most disturbed.

Test wells should be drilled some distance south of the axis of the anticline, particularly where the dip on the north flank is much greater than that on the south, and should be carried to a depth of at least 3,500 feet. Production should be obtained from the lower half of the Atoka formation. The eastern part of the anticline appears to be structurally more favorable than the western part, but the area west of R. 26 W. may be worth testing.

A permit has been issued by the State for a well to be drilled in the N. $\frac{1}{2}$ NE. $\frac{1}{4}$ Sec. 26, T. 7 N., R. 23 W. If this well is properly drilled to a depth of 3,500 feet, it should adequately test the eastern part of the anticline. The results of drilling are awaited with considerable interest.

PLANT ANTICLINE

Location.—The axis of the Plant anticline extends from the NW. corner of Sec. 2, T. 12 N., R. 15 W., southeastward for about 3 miles, and then northeastward to about the center of the north line of Sec. 2, T. 12 N., R. 14 W., but it probably extends north of T. 12 N., into an area that has not been surveyed.

Structural features.—The Plant anticline is bounded on the south by the Archey syncline, but the limiting syncline on the north is unknown. It is on the same structural line as the Cass and Hurricane Creek anticlines and may be connected with them.

The structure is essentially symmetrical, but the dips south of the axis average slightly higher than those north of it. The average dip north of the crest is less than 3 degrees, and that south of the crest is probably about 4 degrees. No closure is indicated for the part of the anticline here described, but, as mentioned above, the ends of the anticline lie somewhere north of T. 12 N.



A. SURFICIAL ANTICLINE IN THE ATOKA SANDSTONE EXPOSED IN THE VALLEY OF A SMALL STREAM A FEW MILES NORTH OF CONWAY

Note that the beds in the foreground are entirely undisturbed



B. JUMBLED BEDS OF ATOKA SHALE AND DISTORTED AND BROKEN BEDS OF SANDSTONE NEAR THE CREST OF PINE RIDGE ANTICLINE SOUTH OF PARIS

Exploration.—The Plant anticline has not been tested for oil or gas; but its structure is favorable to their accumulation. It should not be drilled, however, until information is available concerning the more promising structures in the Arkansas Valley and until more is known of the details of the structure of the anticline itself. Any oil or gas that may be obtained from this anticline will probably be found in the Morrow or older formations, as the Atoka is too thin in this area to be commercially productive.

PRAIRIE VIEW ANTICLINE

Location.—The axis of the Prairie View anticline extends from the SE. $\frac{1}{4}$ Sec. 28, T. 8 N., R. 25 W. eastward to about the SW. $\frac{1}{4}$ Sec. 26, T. 8 N., R. 22 W., but its course becomes uncertain toward its east end.

Structural features.—The Prairie View anticline is bounded on the north by the Scranton syncline and on the south by the Paris syncline. The surface rocks on the anticline belong chiefly to the Harts-horne and Atoka formations, but the Spadra shale and Fort Smith sandstone are exposed on its flanks. The anticline is well expressed topographically by Shoal Creek, Prairie View, and Snake ridges and by the dome-like anticlinal hill south of Piney Station.

The anticline is a broad, open fold in which the dips north of the axis average somewhat higher than those south of it. The dips north of the axis range from 2 to 15 degrees and average about 7 degrees; those south of it range from 2 to 9 degrees and probably average less than 5 degrees. The anticline is well closed at its west end, but there is little evidence of marked closure at its east end.

The anticline is faulted at its crest or slightly north of it, and the displacement is not less than 500 feet. About 2 miles south of the axis a small thrust fault is well exposed in a road cut just west of Old Ellsworth. (See Fig. 23, p. 336.)

Exploration.—A large number of wells have been drilled to shallow depths on the Prairie View anticline in prospecting for coal, and a few of them have yielded considerable gas. Several deeper wells have also been drilled, all of them south of both the crest and the fault trace. The log of one of these wells, drilled in 1916 to a depth of 2,650 feet in the SW. $\frac{1}{4}$ of SE. $\frac{1}{4}$ Sec. 26, T. 8 N., R. 24 W., is given below. The drillers are unknown.

Log of well drilled in SW. $\frac{1}{4}$ SE. $\frac{1}{4}$ Sec. 26, T. 8 N., R. 24 W.

	Depth in feet
Shale.....	0— 15
Lime.....	15— 50
Water sand.....	50— 60
Hard lime.....	60— 300

	Depth in feet
Slate.....	300- 705
Gas sand.....	705- 717
Slate.....	717- 960
Sandy lime and gas.....	960-1100
Slate.....	1100-1236
Gas sand.....	1236-1256
Slate.....	1256-1295
Sandy lime.....	1295-1400
Slate.....	1400-1455
Sand.....	1455-1465
Very hard lime.....	1465-1534
Soft lime.....	1534-1554
Slate.....	1554-1700
Sand.....	1700-1825
Black shale and slate.....	1825-2085
Black shale and slate.....	2085-2180
Sand.....	2180-2240
Shale.....	2240-2270
Sand.....	2270-2275
Slate.....	2275-2580
Sand.....	2580-2620
Slate.....	2620-2630
Oil sand.....	2630-2650

The "slate" of this record is undoubtedly shale, and the "lime" is probably hard sandstone. The gas showings at 717, 1,100, and 1,256 feet are probably authentic, but it is doubtful whether the sand at 2,650 feet is actually oil bearing.

Three other wells have been drilled south of the anticlinal crest, all in Sec. 27, T. 8 N., R. 24 W. One of these was drilled in 1919-1920 by J. H. Flowers, to a depth of 1,890 feet; the other two were drilled in 1921 by the Choctaw Oil and Gas Company, the first to a depth of 810 feet and the second to a depth of 1,654 feet. Neither oil nor gas was obtained in commercial quantities in any of these wells, but several promising showings of gas were reported.

The Prairie View anticline, although it is faulted and has been unsuccessfully drilled, merits further exploration. It is one of the largest anticlines in the Arkansas Valley and is structurally one of the most promising for the accumulation of oil and gas. Its proximity to the producing Ludwig anticline and the fact that the wells mentioned above were not drilled deep enough to encounter the main producing horizon of the Clarksville area are additional reasons for its future exploration.

If the major fault in the anticline is of the normal type, as seems probable, wells may be drilled slightly north of its trace and be carried through its plane into the upthrown side on the south, where the potential producing sands should be effectively sealed by the thick beds of shale involved in the fault movement. If, on the

other hand, the fault is of the thrust type, wells should be drilled some distance south of the fault trace, the distance to depend on the dip of the fault plane. Before extensive drilling is begun the actual type of fault should be ascertained by detailed field investigation. All wells should be drilled to a depth of at least 3,500 feet.

RANGER ANTICLINE

Location.—The axis of the Ranger anticline extends from the NE. $\frac{1}{4}$ Sec. 31, T. 5 N., R. 29 W. slightly north of east to the N. $\frac{1}{2}$ Sec. 4, T. 5 N., R. 23 W., from which it continues slightly south of east to the SW. $\frac{1}{4}$ Sec. 13, T. 5 N., R. 19 W.

Structural features.—The Ranger anticline is bounded on the north by the Magazine Mountain, Centerville, and Pontoon synclines, and on the south by the Poteau syncline. The surface rocks belong to the Atoka formation, except those in a narrow eastward-trending strip south of Waveland, in which the Jackfork sandstone has been exposed.

Throughout much of its length the anticline is intensely folded and to some extent is faulted, but it is rather gently folded at both its east and its west end. It is irregularly asymmetrical, being generally steeper on the north limb than on the south, but at some places, as in the vicinity of Iona and near Divide, the conditions are reversed. The dips north of the axis range from 4 to 90 degrees, and at places the beds are overturned. The dips on the south flank also range from 4 to 90 degrees, and the strata are probably overturned at a few places, but the general average of the dips on the south flank is perhaps 15 degrees lower than that on the north. Although the central part of the anticline is intensely folded, the dips diminish rapidly away from the anticlinal axis and become gentle before reaching the axes of the limiting synclines on the north and south.

A number of minor folds complicate the structure near the axis, and at several places the beds have been displaced, as is well shown by numerous zones of slickensided material. For the most part, however, owing to the great amount of shale involved in the movement in proportion to the more competent rocks, the beds have been complexly folded, stretched, and squeezed rather than faulted. As a result of the mobility of the thick sections of shale, the few thin interbedded layers of sandstone have been greatly disrupted and now appear as intensely folded and crumpled masses, which commonly occur as isolated boulders and knots of arenaceous material in a matrix of intricately distorted shale, as shown in Plate XXXVII, B. At a few places where the anticline includes considerable sandstone it assumes fairly regular form, as shown in Plate XXXVII, A.

Low, relatively sharp ridges of sandstone that trend westward constitute the topographic expression of the anticline.

Exploration.—In 1919 the Red River Oil and Gas Company drilled a well to a depth of 3,517 feet in the NW. $\frac{1}{4}$ of the NW. $\frac{1}{4}$ Sec. 26, T. 5 N., R. 28 W. This well is reported to have yielded bailers of oil at several horizons, but the report could not be verified. It is also stated that a considerable flow of gas was obtained, and this statement is apparently authenticated by the fact that when the well was visited in August, 1927, gas was escaping from the casing head. This gas was ignited and burned with a flame at least 6 inches high. Although it is said that the well was carefully plugged, there is a strong artesian flow of water around the casing-head. The log of this well is not available, but there is reason to suppose that the drill did not penetrate to the Jackfork sandstone. The well was drilled nearly on the crest of the anticline, but rather far down on its westward-plunging western part.

In 1920, according to the *El Dorado Daily News*, Pitts Brothers drilled in the same section to a depth of 2,944 feet, but the details of this well are not known; in fact, the well described above is locally called the Pitts well, so it is doubtful whether two separate test wells were drilled in this area.

In addition to the test wells already indicated four wells were drilled by the 34 Oil Producing Pool (Ran-Dan Oil Company?) between 1923 and 1925 on the R. V. Richards lease, in the NW. $\frac{1}{4}$ of the SW. $\frac{1}{4}$ Sec. 3, T. 5 N., R. 22 W. The first well was drilled to a depth of 1,751 feet; the second, which was started 30 feet from the first, ran into the initial hole at 450 feet; the third was carried to a depth of 1,980 feet; and the fourth reached a depth of 2,526 feet. None of these wells was successful, and all were drilled with considerable difficulty because the beds are essentially vertical at the wells and the drill tended to follow down a single bed. Although these wells were drilled near the axis of the anticline, the beds near Ranger are so much crumpled that no gas or oil can be expected from that part of the anticline.

The anticline shows considerable closure at both ends, and if it is to be tested further its ends rather than its more highly folded central part should be explored. Further tests of the Ranger anticline, however, may well be postponed until the more promising anticlines have been explored.

Some quartz veins occur along the axis of the anticline, but they do not contain gold in commercial amounts. The yellow mineral in the shale in the anticline is phlogopite, a mica of no economic value.



A. CREST OF THE RANGER ANTICLINE AS EXHIBITED IN FAIRLY RESISTANT, THIN-BEDDED SANDSTONE OF THE ATOKA FORMATION SOUTHEAST OF CENTERVILLE



B. INTENSELY CRUMPLED AND FRACTURED BEDS OF SANDSTONE IN CLOSELY FOLDED BEDS OF SHALE, ALL OF THE ATOKA FORMATION, NEAR THE CREST OF THE RANGER ANTICLINE SOUTH OF CENTERVILLE

REDEMPTION ANTICLINE

Location.—The axis of the Redemption anticline extends from about the NW. $\frac{1}{4}$ Sec. 29, T. 5 N., R. 17 W. slightly north of east to about the NE. $\frac{1}{4}$ Sec. 14, T. 5 N., R. 14 W., but throughout much of its length the anticline lies in the Arkansas River bottoms, and the exact position of its axis is obscured by alluvium.

Structural features.—The Redemption anticline is bounded on the north by the Manifee and Conway synclines and on the south by the Perryville and Preston synclines. The surface rocks belong to the Atoka formation.

The Redemption anticline is probably a continuation of the Casa anticline. The probable point of junction of the two lies northwest of Perry, in an area in which no dip readings are available, and for this reason two names have been applied to what may prove to be a single anticline.

The anticline is distinctly asymmetrical if the few dips available north of its crest are typical. The dips on the north flank range from 2 to 26 degrees, and the angle decreases rapidly away from the anticlinal axis, but the dips on the south flank range from 5 to 65 degrees and are generally more than 30 degrees. The dips on the south flank have a tendency to increase rather than to decrease away from the anticlinal axis, and they exhibit a rather marked diminution toward the east. This eastward diminution is of minor importance on the north flank. The anticline has considerable closure near its east end, but the structural details at its supposed west end are unknown. Southeast of Oppello, however, the anticline appears to plunge westward. The sills described under the heading "Igneous rocks" (p. 149 et seq.) lie on the north flank of the anticline, in Secs. 17 and 8, T. 5 N., R. 16 W. The intrusions have not altered the country rock, nor have they disturbed the attitude of the beds.

In a railroad cut at Copperas Gap, on the south limb of the anticline, the beds have been greatly crumpled, as can be seen in Plate XXXVIII. Not only have the beds of sandstone been faulted, but the thick beds of shale have been so greatly distorted and twisted that some of the beds of sandstone have been literally torn apart, and in subsequent movements their separated fragments have been carried to different places in the more mobile shale, so that the former position of some of the fragments of sandstone cannot be ascertained.

The anticline may be faulted near its crest, but if so the details of the faulting are obscured by alluvium. If faulted, the down-thrown side is on the north, but it is impossible to ascertain whether the fault is of the normal or thrust type.

Exploration.—The Redemption anticline has not been tested for oil or gas, but its structure is fairly favorable to their accumulation.

The south flank of the anticline, however, has been greatly crumpled, and the dips are high, so that this anticline cannot be regarded as among the most promising in the Arkansas Valley. The initial well should be drilled somewhat north of the axis and should be carried to a depth of at least 3,500 feet. The eastern part of the anticline is perhaps the most favorable part for a test well.

The presence of the Arkansas River sills cannot be regarded as condemning the entire anticline as a reservoir for oil or gas.

RETTA ANTICLINE

Location.—The axis of the Retta anticline extends from a point just south of the town of Retta, in the NW. $\frac{1}{4}$ of Sec. 20, T. 10 N., R. 18 W. southeastward for about 6 miles and then swings back northeastward and terminates in about the NE. $\frac{1}{4}$ of Sec. 6, T. 9 N., R. 17 W. Throughout its course it roughly parallels the axis of the Hector syncline.

Structural features.—The Retta anticline is bounded on the north by the south fork of the Okay syncline and on the south by the Hector syncline. The surface rocks belong to the Atoka formation.

The anticline is poorly defined. It is essentially symmetrical, the dips on both sides of its axis being generally less than 5 degrees. It seems to have some closure at its west end, where there is probably a slight westward plunge. No good evidence of an eastern closure was found.

Exploration.—The Retta anticline has not yet been tested, and until the more promising anticlines have been drilled its exploration should be deferred. It has a considerable drainage area, however, and its structure may be regarded as fairly favorable to the accumulation of gas.

ROLAND ANTICLINE

Location.—The axis of the Roland anticline extends from the Oklahoma boundary at the SE. $\frac{1}{4}$ Sec. 18, T. 9 N., R. 32 W. northeastward to the SE. $\frac{1}{4}$ Sec. 9, T. 9 N., R. 32 W. It also continues southwestward into Oklahoma for about 15 miles.

Structural features.—The Roland anticline is bounded on the north by the Uniontown and Rudy synclines, and on the south by the Fort Smith Syncline.

The anticline is asymmetrical in that its south limb is steeper than its north. The dips north of the axis range from 1 to 10 degrees and average between 3 and 4 degrees; those south of the axis range from 3 to 10 degrees and average about 7 degrees. The anticline is fairly well closed at its east end but has no western closure in Arkansas. A fault occurs along its crest in Oklahoma, and may



CONTORTED AND FAULTED BEDS OF THE ATOKA FORMATION EXPOSED IN THE RAILROAD CUT AT COPPERAS GAP, ON THE SOUTH LIMB OF THE REDBENTON ANTICLINE

occur also in Arkansas. The downthrown side of the fault, which is of the normal type, is on the south.

Exploration.—The Roland anticline has been rather extensively drilled for oil and gas, but most of the tests have been unsuccessful. In 1927-1928, however, the Citizen's Gas Company drilled a well to a depth of 2,218 feet on the Greenstreet lease, in the NE. $\frac{1}{4}$ of the SW. $\frac{1}{4}$ Sec. 18, T. 9 N., R. 32 W., and obtained several fairly good flows of gas. This well, which was drilled on the north flank of the structure, reached the Boone limestone at the surprisingly shallow depth of 2,126 feet. Gas was obtained at 1,219, 1,226, and 1,495 feet, but most of it at 1,226 feet, from a limy sandstone 15 feet thick. The total production was about 750,000 cubic feet a day at a rock pressure of 250 to 275 pounds. The log of the Greenstreet well is given below.

Driller's log of the Citizen's Gas Company's Greenstreet well No. 1 in NE. $\frac{1}{4}$ of SW. $\frac{1}{4}$ Sec. 18 T. 9 N., R. 32 W.

	Depth in feet
Sand.....	0- 25
Black shale.....	25- 40
Black lime.....	40- 175
Gray shale.....	175- 315
Broken sand.....	315- 330
Lime.....	330- 335
Sand.....	335- 360
Brown shale.....	360- 435
Lime.....	435- 438
Slate, broken lime.....	438- 460
Slate.....	460- 470
Lime.....	470- 472
Shale.....	472- 497
Brown shale.....	497- 542
Lime.....	542- 554
Brown shale.....	554- 569
Slate.....	569- 574
Lime.....	574- 578
Slate.....	578- 650
Black lime.....	650- 698
Brown shale.....	698- 700
Lime.....	700- 704
Black slate.....	704- 748
Lime.....	748- 765
Black shale.....	765- 775
Lime.....	775- 795
Brown shale.....	795- 805
Black slate.....	805- 820
Sandy lime.....	820- 834
Black shale.....	834- 875
Sandy lime.....	875- 894
Slate.....	894- 927
Lime.....	927- 961

	Depth in feet
Slate.....	961- 988
Lime.....	988- 995
Slate.....	995-1055
Sand, hard.....	1055-1075
Lime.....	1075-1080
Sandy lime.....	1080-1127
Lime.....	1127-1132
Shale.....	1132-1196
Sandy lime; first pay at 1219.....	1196-1221
Sand; 1 foot hard shell at 1225, second pay at 1226-1245; 500,000 cubic feet of gas.....	1221-1270
Lime.....	1270-1294
Sandy lime.....	1294-1298
Slate.....	1298-1334
Lime.....	1334-1337
Shale.....	1337-1342
Lime.....	1342-1347
Shale.....	1347-1365
Lime.....	1365-1366
Shale and lime shells.....	1366-1450
Shale.....	1450-1490
Gas increase.....	1490-1495
Sandy lime.....	1495-1520
Sand.....	1520-1600
Lime.....	1600-1630
Shale.....	1630-1645
Lime.....	1645-1650
Shale.....	1650-1695
Sandy lime.....	1695-1710
Lime.....	1710-1740
Sandy lime.....	1740-1755
Lime.....	1755-1815
Sandy lime.....	1815-1825
Shale.....	1825-1830
Sandy lime.....	1830-1860
Sandy lime.....	1860-1890
Black shale.....	1890-1900
Black shell.....	1900-1904
Sandy shale.....	1904-1914
Sandy lime.....	1914-1954
Sand.....	1954-1970
Lime.....	1970-1976
Sandy lime.....	1976-2000
Lime.....	2000-2005
Shale.....	2005-2050
Shale and lime.....	2050-2100

Partial log of Citizen's Gas Company's Greenstreet well No. 1, in the NE. $\frac{1}{4}$ of the SW. $\frac{1}{4}$ Sec. 18, T. 9 N., R. 32 W.

[Interpretation by Carey Croneis.]

	Depth in feet
Dark elastic shale and a little light sandstone.....	324- 330
Same as above, but more sandstone.....	330- 335
Dirty brown sandstone.....	343- 348
Darker sandstone, some pyrite.....	348- 358

	Depth in feet
Dark clastic shale.....	358- 365
Dark clastic shale, finer than above.....	380- 430
Coarse-grained shale and fine-grained sandstone.....	435- 540
Dark shale, clastic, coarsed grained.....	540- 560
Dark clastic shale.....	560- 567
Dark coarse-grained shale.....	567- 605
Dark fine-grained shale.....	605- 645
Dark sandy shale.....	650- 680
Dark sandy shale, finer than above.....	690- 700
Dark sandy shale, fine.....	700- 720
Dark fine-grained shale.....	720- 740
Dark sandy shale.....	740- 765
Dark fine-grained shale.....	765- 812
Dark sandy shale.....	812- 832
Dark fine-grained shale.....	832- 875
Dark coarse-grained shale.....	875- 894
Dark fine-grained shale.....	894- 912
Gray sandy shale.....	945- 961
Dark fine-grained shale.....	970-1055
Light gray sandstone.....	1055-1065
Sandy shale.....	1065-1075
Gray arenaceous shale.....	1070-1090
Dark sandy shale.....	1090-1100
Dark coarse-grained shale.....	1100-1110
Fine-grained shaly sandstone.....	1110-1125
Black shale and light fine-grained sandstone.....	1125-1145
Same as above, but less sandstone.....	1145-1160
Gray fine-grained sandstone.....	1160-1170
Dark shale, some sandstone.....	1170-1180
Dark fine-grained shale.....	1180-1190
Dark clastic shale.....	1190-1200
Gray sandstone, slightly calcareous.....	1205-1219
Gray fine-grained sandstone.....	1219-1248
Fine-grained sandstone and some dark shale.....	1250-1265
Dirty gray fine-grained sandstone.....	1270-1281
Fine clastic shale, dark.....	1280-1310
Fine-grained black shale.....	1310-1370
Black shale and fine-grained gray sandstone.....	1368-1378
Fine-grained gray sandstone.....	1380-1400
Fine-grained shaly sandstone.....	1400-1430
Dark gray sandy shale.....	1430-1440
Dark fine-grained shale.....	1440-1500
Gray fine-grained sandstone.....	1500-1510
Black shale with some gray sandstone.....	1510-1520
Gray fine-grained sandstone.....	1520-1525
Gray sandy shale.....	1525-1535
Dense fine-grained sandy limestone.....	1535-1545
Sandy shale, somewhat calcareous.....	1545-1565
Fine-grained blue shale.....	1568-1630
Gray calcareous shale.....	1630-1640
Black shale with pyrite.....	2050-2055
Black shale with pyrite; a few fragments of limestone.....	2055-2060

	Depth in feet
Dark shaly limestone.....	2060-2070
Dark calcareous shale.....	2070-2080
Dark fine-grained shale.....	2080-2090
Dark fine grained shale; a few fragments of limestone.....	2090-2100
Fine black calcareous shale and chert.....	2100-2115
Fine black very calcareous shale and chert.....	2118-2126
Dense gray limestone and chert; Boone.....	2126-2133
Dense gray limestone and chert; some shale.....	2133-2140
Dense gray limestone and chert; some shale.....	2140-2183
Dense gray limestone and chert; very little shale.....	2183-2195
Calcareous shale, very little chert.....	2199-2210
Very calcareous shale; very little chert.....	2210-2218
Gray shaly limestone.....	2218-2224
Some black shale, calcareous shale and chert.....	2224-2238
Shaly limestone and chert.....	2238-2255
Chert and limy shale.....	2258-2268
Chert and shaly limestone.....	2268-2310
Black shale with pyrite; Chattanooga.....	2310-2332
*Black shale and sandstone, slightly calcareous.....	2332-2337
*Sandstone and shaly limestone.....	2337-2344
*Sandstone, very slightly calcareous.....	2344-2357
*Sandstone, calcareous.....	2357-2369
*Black shale and sandstone.....	2369-2378
*Sandstone.....	2378-2380

*Some fine fragments of chert in these samples, apparently derived from beds above.

In addition to this well, five dry holes have been drilled in Sec. 16, T. 9 N., R. 32 W., on the south flank of the anticline. The test wells drilled in Oklahoma north of the axis were all failures except the Lyman No. 1 well, in the SE $\frac{1}{4}$ NW. $\frac{1}{4}$ Sec. 15, T. 11 N., R. 26 E., which produced some gas from a sandstone at a depth of 2,265 feet.

Future exploration of the anticline is probably advisable, but the large number of unsuccessful wells drilled on it indicates that the risk will be high. Wells should be drilled near the crest, and preferably north of it, where the St. Peter sandstone should be reached at depths of less than 3,000 feet.

RUDY ANTICLINE

Location.—The axis of the Rudy anticline extends from about the NE. $\frac{1}{4}$ Sec. 11, T. 9 N., R. 32 W. northeastward to about the SE. $\frac{1}{4}$ Sec. 26, T. 10 N., R. 31 W.

Structural features.—The Rudy anticline is bounded on the north by the Rudy syncline and on the south by the Mulberry fault.

The anticline, which is not well defined, is essentially symmetrical, but its north limb is marked by irregular dips, the beds on it being at some places inclined toward the south. The dips north of the axis range from 2 to 7 degrees; those south of the axis range from

2 to 6 degrees. The anticline is apparently not well closed at either end.

Exploration.—The McDonough Oil and Gas Company drilled to a depth of 3,005 feet on the Wood lease, in the NW. $\frac{1}{4}$ NW. $\frac{1}{4}$ Sec. 29, T. 10 N., R. 31 W., more than a mile north of the axis of the anticline, and obtained showing of gas at 492 and 1,760 feet. The log of the Wood well is given below:

Log of the Wood well, in the NW. $\frac{1}{4}$ of the NW. $\frac{1}{4}$ Sec. 29, T. 10 N., R. 31 W., Crawford County, Arkansas.

	Thickness in feet	Depth in feet
Surface clay.....	27	27
Atoka formation:		
Sand.....	5	32
Shale.....	2	34
Sand.....	11	45
Shale.....	13	58
Lime.....	8	66
Sand.....	109	175
Slate.....	10	185
Sand.....	15	200
Slate.....	210	410
Sand.....	130	540
Some gas at.....		492-500
Slate.....	40	580
Sand.....	20	600
Slate.....	260	860
Sand.....	20	880
Shale.....	180	1060
Sand.....	15	1075
Slate.....	65	1140
Sand.....	40	1180
Slate.....	125	1305
Sand.....	65	1370
Slate.....	15	1385
Sand.....	135	1510
Slate.....	15	1530
Sand.....	30	1560
Shale.....	200	1760
Gas sand; wet gas.....	45	1805
Shale.....	225	2030
Sand.....	76	2106
Morrow group:		
Slate.....	50	2156
Sand.....	10	2166
Shale.....	44	2210
Pitkin:		
Lime shells.....	30	2240
Black lime.....	45	2285
Fayetteville:		
Shale.....	10	2295

	Thickness in feet	Depth in feet
Wedington:		
Sand.....	40	2235
Fayetteville:		
Shale.....	40	2275
Batesville:		
Sand and shale.....	25	2400
Boone:		
White lime.....	315	2715
Chattanooga:		
Shale.....	70	2785
Sylamore:		
Sand.....	10	2795
Upper Ordovician:		
Sand, sand lime, and shale.....	175	2970
St. Peter:		
Soft sand.....	35	3005
Salt water.		

The salt water at 3,005 feet and the wet gas at 1,760 feet are interesting, but the reports of their occurrence are unverified. As the cuttings from the Wood well were not studied, the correlations suggested above are only tentative. The Mississippian and older formations are rather definitely placed however, but the boundary between the Morrow and the Atoka formations is uncertain. Perhaps some of the upper sandstones listed with the Atoka belong to the Hartshorne formation; but the northern boundary of the Hartshorne has not been traced in detail. The depths to the Boone and the St. Peter are fairly well established by this record and should be of service to future operators in this general area.

The Rudy anticline has not been fairly tested by the Wood well, but it is one of the less promising anticlines, and its further exploration may wisely be deferred until better ones have been drilled.

RUSSELLVILLE ANTICLINE

Location.—The axis of the Russellville anticline has been very indefinitely located, but it probably passes through the south side of Russellville. The western part of this anticline is obscured by the alluvium of the Arkansas River and Illinois Bayou, but it extends from the southern part of Sec. 12, T. 7 N., R. 21 W., slightly north of east to the northern part of Sec. 12, T. 7 N., R. 20 W.

Structural features.—The Russellville anticline stands between the Shinn basin on the south and Ouita syncline on the north. It has a slight but definite plunge to the west, so that the Atoka formation is the surface rock over most of its area, but the Hartshorne sandstone occurs in its western part as well as far down on its limbs.

The anticline is essentially symmetrical, but the dips probably aver-

age slightly higher on the north limb than on the south. Dips as high as 10 degrees are rare on either side of the axis, those from 4 to 7 degrees being the most common. The anticline apparently closes at both ends, but the amount of closure was not ascertained.

Exploration.—In 1918-1919 the Witherspoon Oil and Gas Company drilled a well to the depth of 2,155 feet in Sec. 10, T. 7 N., R. 20 W. on the Love lease. This test well was properly located, but it should have been carried deeper. Conflicting reports were made concerning the "showings" in this well, but apparently no oil was found and little or no gas. The failure of this particular test well, however, should not condemn the entire anticline, which has a collecting area of at least 25 square miles.

Although the Russellville anticline is not so pronounced as many others in the Arkansas Valley, its structure is moderately favorable to the accumulation of gas. Further test wells should be drilled near the axis.

SEARCY ANTICLINE

Location.—The axis of the Searcy anticline extends from the S. $\frac{1}{2}$ Sec. 6, T. 7 N., R. 8 W. northeastward to the NW. $\frac{1}{4}$ Sec. 29, T. 8 N., R. 6 W.

Structural features.—The Searcy anticline is bounded on the north by the Clearwater syncline and on the south by the Menifee syncline. The anticline, the structure of which is pronounced, particularly in that part of its course which lies just north of Searcy, is somewhat asymmetrical. The dips north of the axis range from 3 to 15 degrees, although in a zone of local folding, described elsewhere, they are as high as 36 degrees. The average dip is probably not more than 5 degrees. The dips south of the crest range from 3 to 18 degrees, and the average dip on that side is nearer 10 than 5 degrees. In fact, most of the dips on the south flank near the axis are 12 degrees or more, but they show a gradual diminution southward to the axis of the Menifee syncline, so that 2 miles south of the anticlinal crest most of the dips are less than 7 degrees.

On the north flank the diminution of dip away from the axis is, in general, still more noticeable, but in the N. $\frac{1}{2}$ Sec. 32, T. 8 N., R. 7 W., there is a small zone of local folding in which the dips are fairly high. This zone, which is faulted, though the displacement is apparently slight, strikes N. 60 degrees E., roughly parallel to the axis of the main anticline. The structure is that of a faulted anticline with dips on both sides of the crest approaching 40 degrees. The area in which this minor folding and faulting occurs is small.

In the vicinity of Center Hill the Searcy anticline plunges to the west and shows considerable closure at its west end. At its east end

the evidence of closure is not so good, for it appears to flatten out eastward, but the dips north of Judsonia indicate plunge to the east. North of Searcy the anticline is somewhat domed.

Exploration.—In 1920 the Arkansas Invincible Oil Corporation drilled a well to a depth of 3,140 feet in the NW. $\frac{1}{4}$ Sec. 29, T. 8 N., R. 6 W. This well, which was drilled on the Gravemire lease, was located just about on the crest of the anticline, but at a point where the dips are relatively low as compared to those farther west. Neither oil nor gas was obtained in this well, the log of which is given below.

Log of Gravemire well No. 1, in Sec. 29, T. 8 N., R. 6 W., White County, Ark.
[Drilled 180 feet south and 900 feet east of northwest corner of section. Drilling began July 3, 1920.]

	Depth in feet
Yellow clay.....	0- 25
Brown sand rock.....	25- 50
Blue and black shale.....	50- 80
Water sand.....	80- 85
Sandy shale.....	85- 190
Shale.....	190- 195
Coarse water sand.....	195- 206
Hard gray rock.....	206- 225
Hard lime rock.....	225- 295
Shale.....	295- 340
Light rock.....	340- 344
Sandy rock.....	344- 366
Broken sand rock and shale.....	366- 376
Light sand and rock.....	376- 389
Water sand.....	389- 404
Rock.....	404- 443
Sandy rock.....	443- 469
Broken shale and rock.....	469- 480
Light rock.....	480- 481
Broken shale and rock.....	481- 572
Shale.....	572- 640
Hard rock.....	640- 745
Shale.....	745- 755
Hard blue shale.....	755- 806
Black lime rock.....	806- 825
Water sand.....	825- 828
Lime.....	828- 884
Lime, shells and slate.....	884- 912
Lime and shale.....	912- 917
Lime, shells and slate.....	917- 977
Black shale.....	977-1047
Hard lime rock.....	1047-1190
Shale.....	1190-1217
Hard lime rock.....	1217-1225
Rock.....	1225-1232
Gray and dark lime rock.....	1232-1308
Light sand rock; 200 gallons water per hour.....	1308-1314

	Depth in feet
Light sand rock.....	1314-1326
Broken light sand rock and shale.....	1326-1337
Light lime, some sand rock.....	1337-1342
Hard, light sand rock, some lime; 1000 feet of water in hole.....	1342-1345
Light sand rock, some streaks of lime.....	1345-1348
Light sand rock; 1300 feet of water in hole.....	1348-1362
Sand rock.....	1362-1408
Slate.....	1408-1413
Black lime, hard.....	1413-1422
Soft blue slate.....	1422-1428
Black lime.....	1428-1445
Mud shale.....	1445-1473
Shale, black lime and shells.....	1473-1500
Shale, lime and shells.....	1500-1522
Shells and slate.....	1522-1533
Shale and black slate.....	1533-1537
Black slate.....	1537-1542
Black shale and mud.....	1542-1564
Blue slate and black shale.....	1564-1591
Black mud and shale.....	1591-1600
Black mud and shale.....	1600-1615
Black mud and slate; cavings.....	1615-1618
Set 78 joints 8¼-inch casing.....	1618-1648
Black and blue shale and slate.....	1618-1648
Brown lime; hole caves.....	1648-1650
Gray sand rock.....	1650-1708
Broken sand and limestone.....	1708-1728
Mud and shale, blue.....	1728-1732
Broken sand, lime, shale.....	1732-1765
Lime and gray sand.....	1765-1782
Lime and sand rock.....	1782-1804
Sand and lime.....	1804-1843
Sand limestone.....	1843-1864
Dark shale and lime.....	1864-1871
Sand and lime.....	1871-1877
Sand rock and lime.....	1877-1881
Gray lime.....	1881-1900
Shale, slate and lime.....	1900-1933
Lime and sand rock.....	1933-1948
Shale, slate, and lime.....	1948-1973
Lime.....	1973-1978
Limestone, hard.....	1978-1982
Lime.....	1982-1988
Hard shell.....	1988-1990
Blue hard lime.....	1990-1991
Black lime.....	1991-1994
White sandstone.....	1994-2017
Gray sand.....	2017-2050
Gray sandstone.....	2050-2060
Sand.....	2060-2070
Gray sandstone.....	2070-2090

	Depth in feet
Sand.....	2090-2115
Blue shale.....	2115-2123
Gray sandstone.....	2123-2130
Streaks of dark shale.....	2130-2150
Blue limy shale.....	2150-2169
White sand.....	2169-2174
White shale.....	2174-2185
Sandy lime, streaks of shale.....	2185-2230
White shale and lime.....	2230-2270
Lime, shells, and shale.....	2270-2305
Shale.....	2305-2354
Sandy shale and lime shale.....	2354-2400
Shale, lime, and shells.....	2400-2445
Black shale. Bottom of well.....	2445-3140

In the absence of cuttings it is impossible to determine the formations encountered in this well from the rather indefinite record given above. It is impossible, for instance, to interpret the oft-recurring item of "lime and shells." This item begins to be common above 1,000 feet, and as the Atoka should certainly be thicker than 1,000 feet in this anticline, it is questionable whether limestone was struck in any considerable quantity unless the Atoka changes radically in character in this area. If limestone has been incorrectly reported from shallow depths it may have been incorrectly reported to the bottom of the well, and the hole may have terminated in the Atoka formation. There is no item in the log except the many thin "limes" that makes such an interpretation untenable, and the dominance of "shale," "slate," and "sand" throughout the section supports it. Moreover, the unusual thickness of nearly 700 feet of black shale at the bottom of the hole, if correctly reported, can only be in the Atoka formation, and such a thickness of shale uninterrupted by sandstone is extraordinary, even in that formation. It is unfortunate that the cuttings from this well were not saved, for they would have been of great service in showing the subsurface geology of the eastern part of the Arkansas Paleozoic area.

Whether the failure of the Gravemire test well condemns the entire anticline is a debatable question. It is difficult to understand why such a well, drilled practically on the crest of the anticline, should not have given more favorable indications of oil or gas if either is present there. On the other hand, it may be that more favorable locations may be found farther west on the anticline, and that further exploration is warranted. Indeed, few anticlines in the entire area considered are structurally more promising than this one.

Future exploration should be limited to an area near the crest, and preferably to the region directly north of Searcy. All wells should be drilled to a depth of at least 3,500 feet.

SHIRLEY ANTICLINE

Location.—The axis of the Shirley anticline extends from about the center of Sec. 13, T. 11 N., R. 15 W., northeastward at least to the SE. $\frac{1}{4}$ Sec. 3, T. 13 N., R. 12 W., and may continue farther in that direction, but its course has not been determined north of T. 12 N. The axis may also extend southwestward beyond its western termination as given above, and it may join the Latham anticline.

Structural features.—The Shirley anticline is bounded on the north by the Archey syncline, and on the south by the Scotland syncline.

The anticline is markedly asymmetrical. The dips south of the axis range from 5 to 20 degrees; those north of the axis commonly do not exceed 7 degrees and probably average less than 5 degrees. The Shirley anticline is therefore more or less an anticlinal terrace, but the north dips are somewhat more pronounced than those in other similar anticlines on the south flank of the Boston Mountains. The dips south of the axis diminish toward the trough of the Scotland syncline; those north of the axis increase slightly toward the axis of the Archey syncline. The anticline has good closure at its west end, but no clear evidence of closure was found near its east end, which may lie outside the area surveyed.

Exploration.—The Shirley anticline has not been tested for oil or gas, but it is structurally favorable to their accumulation. The initial well should be drilled a short distance north of the crest, and advantage should be taken of any local doming. Any oil or gas obtained will be found in the Morrow or older formations, for the Atoka is nowhere thick enough along the crest of the anticline to hold either in considerable quantity.

SILEX ANTICLINE

Location.—The Silex anticline is small, and its axis has not been definitely located, but it extends from about the S. $\frac{1}{2}$ Sec. 32, T. 10 N., R. 20 W., northwestward to about the center of Sec. 20, T. 10 N., R. 21 W.

Structural features.—The Silex anticline is bounded on the south by the Lee Mountain syncline and on the north by the Turnersville syncline. The surface rocks belong to the Atoka formation.

The anticline is essentially symmetrical, the dips on either side of the axis ranging from 2 to 10 degrees. The extent of the anticline from east to west has not been determined accurately.

Exploration.—The Silex anticline has not yet been drilled, but its structure is favorable to the accumulation of gas. If tested the initial well should be drilled on the axis of the structure, preferably in the vicinity of Silex.

SOLGOHACHIA ANTICLINE

Location.—The axis of the Solgohachia anticline extends from the NW. $\frac{1}{4}$ Sec. 18, T. 8 N., R. 10 W., southeastward to the NE. $\frac{1}{4}$ Sec. 24, T. 7 N., R. 16 W. Northwest of its west end, as just defined, the anticline may possibly join the Dover anticline. The eastern part of the anticline is much more clearly defined than the western part.

Structural features.—The Solgohachia anticline is bounded on the north by the Lee Mountain and Fairbanks synclines and on the south by the Shinn and Greenbrier synclines. The anticline is not very prominent, for the dips rarely exceed 10 degrees, and are more commonly 5 degrees or less. The anticline is essentially symmetrical.

Minor faulting complicates the structure in the N. $\frac{1}{2}$ Sec. 33, T. 8 N., R. 17 W., where the dips are in places as high as 25 degrees. The trace of the fault roughly parallels the axis of the anticline, and the downthrown side is apparently on the south.

The Old Hickory anticline is probably a fork of the Solgohachia anticline, but the point of junction of the two is not definitely known, though it may be in the NE. $\frac{1}{4}$ Sec. 24, T. 8 N., R. 18 W.

Near the town of Solgohachia the anticline lies rather close to the west end of the Heber Springs anticline, but careful field study has shown that their axes are offset at least a mile.

Exploration.—In 1923 the Pea Ridge Oil Company drilled a well on the Tarkington lease, in Sec. 30, T. 8 N., R. 18 W., to a depth below 1,600 feet but obtained neither oil nor gas. This well was drilled on the southern flank of the anticline more than a mile from its axis, and it cannot be regarded as a fair test of the anticline.

Further exploration of the anticline should be confined to an area close to its axis, preferably near its east end. The Solgohachia anticline is not so promising as some others in the Arkansas Valley, but its structure is favorable to the accumulation of gas.

An artesian well drilled nearly in the center of the N. $\frac{1}{2}$ Sec. 16, T. 8 N., R. 18 W., about a mile north of the axis of the anticline, showed that the rocks and the structure at its site are favorable for flowing wells. The dip near the well is 3° , N. 20° E.

SPRINGFIELD ANTICLINE

Location.—The axis of the Springfield anticline extends from about the center of Sec. 11, T. 7 N., R. 16 W. northeastward to about the NE. corner of Sec. 29, T. 8 N., R. 14 W.

Structural features.—The Springfield anticline is bounded on the north by the Fairbanks syncline and on the south by the Greenbrier and Guy synclines. The surface rocks belong to the Atoka formation.

The anticline, which is not particularly prominent, is asymmetri-

cal, the dips south of its axis being higher than those north of it. The dips on the north flank range from 2 to 6 degrees and average less than 4 degrees; those on the south flank range from 4 to 10 degrees and average about 6 degrees. Some evidence of closure was seen at the west end of the anticline, where it is offset from the east end of the Solgohachia anticline, but none was seen at its east end.

In Sec. 3, T. 7 N., R. 15 W., there is a zone of minor folding and apparently some normal faulting, the line of which crosses the main anticline at about a right angle. There is another similar zone southeast of Martinville, in an area that lies in part between the offset ends of the Springfield and Heber Springs anticlines.

Exploration.—The Springfield anticline has not been tested for oil or gas, but its structure is reasonably favorable to their accumulation. The initial well should be drilled slightly north of the crest and should be carried to a depth of at least 3,500 feet. Because of the apparent lack of definite closure, advantage should be taken of any local doming in determining the position of the initial well.

THREE ROCKS ANTICLINE

Location.—The axis of the Three Rocks anticline extends from about the SE. $\frac{1}{4}$ Sec. 25, T. 12 N., R. 30 W. northeastward to the SE. $\frac{1}{4}$ Sec. 23, T. 12 N., R. 29 W.

Structural features.—The Three Rocks anticline is bounded on the north and the south, respectively, by the north and south forks of the Chester syncline. The surface rocks belong to the Atoka formation.

The anticline is essentially symmetrical, but its south limb is perhaps somewhat steeper than its north. The dips north of the crest range from 2 to 6 degrees and average between 3 and 4 degrees; those south of the crest range from 2 to 7 degrees and probably average somewhat more than 4 degrees. The west end of the anticline is well closed, but there is no good evidence of closure at its east end.

Exploration.—The Three Rocks anticline appears not to have been drilled for oil or gas, but its structure is fairly favorable to their accumulation. These products would have to be sought in rocks older than the Atoka, however, and as there are other untested anticlines that are closer to easy means of transportation, it is advisable to defer drilling on this anticline.

TREAT ANTICLINE

Location.—The axis of the Treat anticline extends from the NW. $\frac{1}{4}$ Sec. 11, T. 11 N., R. 23 W., where it is apparently slightly offset south of east from the east end of the Ozone anticline, to the NW. $\frac{1}{4}$ Sec. 30, T. 11 N., R. 18 W.

Structural features.—The Treat anticline is bounded on the north by the Solo syncline and on the south by the Payne syncline. The surface rocks belong to the Atoka formation.

The Treat anticline is essentially symmetrical, but the north limb is probably somewhat steeper than the south. The dips average less than 4 degrees on the south side of the axis and probably less than 5 degrees on the north side. The amount of closure at either end of the anticline is small.

Exploration.—The anticline has not yet been drilled, but its structure is favorable to the accumulation of oil or gas, though it is not so good as that of some other anticlines in the Arkansas Valley. South of Treat the anticline apparently is slightly domed, and exploration might well be concentrated on that general area. All wells should be drilled as near the axis as possible.

VACHE GRASSE ANTICLINE

Location.—The axis of the Vache Grasse anticline extends from the W. $\frac{1}{2}$ Sec. 33, T. 8 N., R. 31 W. northeastward to the SW. $\frac{1}{4}$ Sec. 15, T. 8 N., R. 29 W., east of which its course is not clear.

Structural features.—The Vache Grasse anticline is bounded on the north by the Massard fault and the Slash Ridge syncline and on the south by the Central and Lavaca synclines. The surface rocks belong chiefly to the Fort Smith formation, but the Spadra shale is exposed near the east end of the anticline.

The Vache Grasse anticline is broad and essentially symmetrical. The dips north of the axis range from 2 to 7 degrees and average about 4 degrees; those south of the axis range from 2 to 6 degrees and average between 3 and 4 degrees. The anticline is not well closed at either end and has very little topographic expression.

Exploration.—Two wells have been drilled on the Vache Grasse anticline by the Lavaca Gas Company. Well No. 1, which was drilled a short distance north of the crest, in the NW. $\frac{1}{4}$ Sec. 29, T. 8 N., R. 30 W., was carried to a depth of 2,997 feet and had an initial production of 1,250,000 cubic feet from a sand at a depth of 2,874-2,884 feet. The initial rock pressure was 220 pounds. The log of this well is not available, but a showing of gas was obtained at 2,060 feet and coal was encountered at 265-267 feet and again at 460-465 feet. This coal may prove to be of economic value.

Well No. 2, which was drilled a short distance south of the crest, in the SW $\frac{1}{4}$ SW. $\frac{1}{4}$ Sec. 29, T. 8 N., R. 30 W., was carried to a depth of 3,000 feet and had an initial production of about 300,000 cubic feet. The log of this well is also unavailable, but a coal bed having a thickness of 8 to 9 feet was recorded at a depth of 580 feet.

These wells, which were located by Dr. N. F. Drake, now yield about 27,000,000 cubic feet of gas a year and supply all the fuel needed in the town of Lavaca. Most of the gas, however, comes from Well No. 1. Both wells, but especially Well No. 2, have been troubled by water since 1925.

The Vache Grasse anticline probably merits further careful exploration, but future wells should be equipped to drill to deeper sands than those that are now producing in the wells of the Lavaca Company.

WASHBURN ANTICLINE

Location.—The axis of the Washburn anticline extends from about the Oklahoma line, in Sec. 17, T. 5 N., R. 32 W., northeastward in an undulating course to the SE. $\frac{1}{4}$ Sec. 3, T. 6 N., R. 25 W., but the west end of the anticline as defined above is obscure.

Structural features.—The Washburn anticline is bounded on the north by the Greenwood syncline and on the south by the Sugarloaf and Magazine Mountain synclines. The surface rocks belong chiefly to the Atoka formation, but the Hartshorne sandstone is exposed on the north flank, and at the west end of the anticline the Spadra and Fort Smith formations crop out over small areas.

The structure is markedly asymmetrical throughout most of its course, the dips north of the axis averaging considerably higher than those south of it. The dips on the north flank range from 3 to 90 degrees, and at a few places the beds are overturned. The dips on the south flank range from 3 to 40 degrees and probably average less than 20 degrees. The north flank of the structure is much shorter than the south flank. The dips on both sides of the axis decrease toward the limiting synclines, but the diminution is more rapid on the north than on the south. At its west end the anticline has good closure, but at its east end it rises rather than plunges toward the east.

The anticline is closely folded near its crest on the north limb, where the Hartshorne sandstone is brought down against the Atoka formation so abruptly as to suggest great faulting. The anticline has no doubt been faulted along its axis wherever competent beds occur, but most of the appearance just mentioned is a result of the extreme deformation of the thick beds of shale of the Atoka formation, as is well shown in Plate XXXIX.

The anticline is well expressed topographically by the Devil's Backbone Ridge, but its more complexly folded parts include non-resistant beds, which are exposed between ridges.

Exploration.—The Washburn anticline has been drilled since 1920 in the SE. $\frac{1}{4}$ Sec. 2, T. 6 N., R. 26 W., but the well was not reported to the State authorities and details regarding it are therefore unknown. According to local information, however, the well, which was comparatively shallow, obtained neither oil nor gas. This well was properly located a short distance south of the axis of the anticline, but it was not carried deep enough to test the anticline adequately.

Future wells sunk on this anticline should be drilled at least half a mile south of its crest, particularly where the beds on the north flank stand essentially vertical. Wells sunk near the ends of the anticline, where the dips are not high, should be drilled near the crest. The western part of the anticline should be tested, however, before further exploration in its more distorted central part is undertaken.

WATALULA ANTICLINE

Location.—The axis of the Watalula anticline extends from about the NE. $\frac{1}{4}$ Sec. 33, T. 10 N., R. 29 W. northeastward to about the NE. $\frac{1}{4}$ Sec. 24, T. 11 N., R. 26 W.

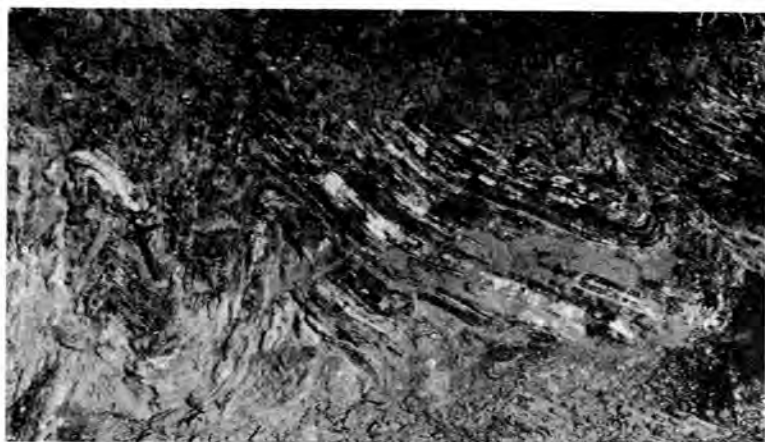
Structural features.—The Watalula anticline is bounded on the north by the White Rock and Archey synclines and on the south by the Alston, Cravens, and Philpott synclines. The surface rocks belong chiefly to the Atoka formation, but the Hartshorne and Spadra formations are exposed at the southwest end of the anticline.

The Watalula anticline is essentially symmetrical, although the dips south of the axis average somewhat higher than those north of it; but the anticline is nowhere very prominent. The dips on the north flank range from 2 to 15 degrees, but angles as high as 12 degrees are rare, and the average dip is probably between 3 and 4 degrees. The dips on the south flank range from 2 to 10 degrees and average between 4 and 5 degrees. The anticline is well-closed at its west end, but at its east end its axis apparently rises toward the east rather than plunges eastward.

Exploration.—In 1923-1929 R. A. Maraz, representing Chicago investors, drilled a well to a depth of 5,031 feet on the Stewart lease, in the northeast corner of the NE. $\frac{1}{4}$ Sec. 24, T. 10 N., R. 29 W., and obtained a flow of gas estimated at 4,000,000 cubic feet from near the bottom of the hole. Showings of gas were also reported at depths of 2,870, 4,621, and 4,787 feet. The log of this well, which was drilled nearly on the axis of the anticline, although somewhat low on its westward-plunging west end, is given below:

Log of R. A. Maraz's Stewart No. 1 well, in the NE. corner NE. $\frac{1}{4}$ Sec. 24, T. 10 N., R. 29 W.

	Depth in feet
Soil.....	0— 8
Sand.....	8— 15



A. MINOR FOLDING IN THIN-BEDDED SHALY SANDSTONE OF THE ATOKA FORMATION NEAR THE CREST OF THE WASHBURN ANTICLINE EAST OF CHISMVILLE



B. CONTORTED ARENACEOUS SHALE OF THE ATOKA FORMATION NEAR THE CREST OF THE WASHBURN ANTICLINE EAST OF CHISMVILLE

	Depth in feet
Slate.....	15- 68
Shell.....	68- 70
Shale.....	70- 345
Lime.....	345- 380
Shale.....	380- 440
Lime.....	440- 560
Slate.....	560- 570
Lime.....	570- 600
Shale.....	600- 670
Lime.....	670- 750
Shale.....	750- 780
Lime.....	780- 820
Shale.....	820- 870
Lime.....	870- 910
Lime.....	910- 940
Lime.....	940- 980
Shale.....	980-1016
Lime.....	1016-1034
Shale.....	1034-1045
Lime.....	1045-1110
Shale.....	1110-1170
Lime.....	1170-1176
Sand.....	1176-1190
Lime.....	1190-1240
Lime.....	1240-1265
Sand.....	1265-1275
Lime.....	1275-1320
Sand.....	1320-1325
Lime.....	1325-1372
Lime.....	1372-1384
Shale.....	1384-1400
Lime.....	1400-1430
Shale.....	1430-1437
Lime.....	1437-1465
Shale.....	1465-1520
Lime.....	1520-1586
Lime.....	1586-1660
Lime.....	1660-1703
Shale.....	1703-1706
Lime.....	1706-1810
Shale and shell.....	1810-1845
Sand.....	1845-1888
Lime.....	1888-1904
Slate.....	1904-1910
Lime.....	1910-1934
Shale.....	1934-1940
Sand.....	1940-1968
Lime.....	1968-1988
Slate.....	1988-1994
Sand.....	1994-2025
Slate.....	2025-2052
Lime.....	2052-2065

	Depth in feet
Lime.....	2065-2155
Shale and shells.....	2155-2350
Lime.....	2350-2360
Shale.....	2360-2370
Lime.....	2370-2425
Shale and shell.....	2425-2645
Lime.....	2645-2694
Shale.....	2694-2708
Shale.....	2708-2718
Lime.....	2718-2728
Shale.....	2728-2732
Lime.....	2732-2776
Shale.....	2776-2806
Shale.....	2806-2812
Lime.....	2812-2818
Slate.....	2818-2829
Sand—gas.....	2829-2870
Slate.....	2870-2904
Lime.....	2904-2910
Slate and shells.....	2910-2975
Lime.....	2975-2980
Shale.....	2980-3032
Shale.....	3032-3125
Lime.....	3125-3130
Flint.....	3130-3147
Sand.....	3147-3158
Slate.....	3158-3208
Lime.....	3208-3214
Slate and shells.....	3214-3316
Lime.....	3316-3362
Shale.....	3362-3369
Sand.....	3369-3410
Slate.....	3410-3416
Sand.....	3416-3480
Shale.....	3480-3524
Lime.....	3524-3530
Shale.....	3530-3538
Sand and lime.....	3538-3579
Shale.....	3579-3594
Lime.....	3594-3602
Shale.....	3602-3612
Lime.....	3612-3618
Shale.....	3618-3624
Lime.....	3624-3634
Shale.....	3634-3670
Lime.....	3670-3685
Shale.....	3685-3705
Lime.....	3705-3610
Slate.....	3710-3722
Lime.....	3722-3754
Shale.....	3754-3768
Lime.....	3768-3795

	Depth in feet
Shale.....	3795-3814
Lime.....	3814-3834
Lime and shells.....	3834-3908
Sandy lime.....	3908-3926
Lime.....	3926-4068
Sand.....	4068-4112
Shale and shells.....	4112-4175
Sand.....	4175-4205
Shale.....	4205-4225
Lime.....	4225-4240
Slate.....	4240-4260
Lime.....	4260-4263
Lime.....	4263-4268
Shale and shells.....	4268-4294
Shale.....	4294-4306
Lime, black and gray, hard.....	4306-4340
Lime, hard black.....	4340-4465
Shale, black.....	4465-4540
Lime, black.....	4540-4575
Shale and shells, black.....	4575-4593
Lime, black.....	4593-4621
Sand, black, showing gas and oil.....	4621-4629
Shale, black.....	4629-4712
Lime, black, hard.....	4712-4766
Shale and shells, black.....	4766-4787
Sand, black, showing gas and oil.....	4787-4802
Shale, black.....	4802-4856
Lime, black.....	4856-4891
Shale, black.....	4891-4956
Shale, and shells, black.....	4956-4994
Lime, gray; bottom of hole.....	4994-5031

An examination of cuttings from the lower part of the well showed that the black shale at 4,826 feet contains fossils identical with diagnostic species obtained from the Fayetteville shale. The black shale below 4,766 feet therefore almost certainly belongs to the Fayetteville shale, and the oft-recurring item of "lime" in the log, particularly the "lime" in the upper 4,000 feet of the record, probably represents sandstone. The Boone chert was not reached in this well.

The log of the Stewart well is of great importance, particularly when it is studied in conjunction with that of the Patrick well, on the Jethro anticline, for it shows conclusively that the Carboniferous sediments, and especially the Atoka sandstone and shale, thicken rapidly toward the south.

The Watalula anticline probably merits further exploration. In fact, it is understood that the Maraz interests have obtained a gas franchise for the towns of Mulberry and Ozark and plan to drill other wells to the upper gas-producing horizon. Future exploration

should be confined to an area near the crest and to the more central parts of the anticline.

It is reported that \$125,000.00 was spent on the Stewart No. 1 well, which is the deepest test well yet drilled in Arkansas.

WHITE OAK ANTICLINE

Location.—The axis of the White Oak anticline extends from about the SW. $\frac{1}{4}$ Sec. 26, T. 10 N., R. 28 W. northeastward to the NW. $\frac{1}{4}$ Sec. 17, T. 10 N., R. 26 W.

Structural features.—The White Oak anticline is bounded on the north by the North Fork of the Alston syncline and the Cravens syncline and on the south by the Alston and Philpott synclines. The surface rocks belong chiefly to the Atoka and Hartshorne formations, but the Spadra shale is exposed near the east end of the anticline.

The anticline is a broad, open fold, which is essentially symmetrical, although the dips north of the crest are slightly higher than those south of it. The dips north of the crest range from 2 to 10 degrees and average about 5 degrees; those south of the crest range from 2 to 8 degrees and average between 3 and 4 degrees. The anticline is well closed at its west end, and there is evidence of closure, which, however, is less pronounced, at its east end.

Exploration.—The White Oak anticline appears not to have been drilled for oil or gas, but its structure is favorable to their accumulation, and it is therefore worthy of exploration. The initial wells should be drilled near the crest, preferably in R. 27 W., and should be carried to a depth of at least 4,000 feet. The White Oak anticline resembles the Ludwig anticline, which has proved productive.

WYE ANTICLINE

Location.—The axis of the Wye anticline extends from the NE. $\frac{1}{4}$ Sec. 3, T. 3 N., R. 17 W. eastward to about the center of Sec. 5, T. 3 N., R. 15 W.

Structural features.—The Wye anticline is bounded on the north by the Perryville syncline and on the south by the Thornburg syncline. The surface rocks belong to the Atoka formation.

The structure is asymmetrical in that the north flank is steeper than the south. The dips north of the axis range from 14 to 80 degrees; those south of it range from 30 to 50 degrees. The east end of the anticline is not well defined, but there appears to be closure at both ends.

Exploration.—The Wye anticline has not been drilled for oil or gas, but its structure is reasonably favorable to their accumulation. The anticline is rather closely folded, however, and the rocks are

somewhat metamorphosed, so that it is not favorably regarded and its exploration is inadvisable.

YALE ANTICLINE

Location.—The axis of the Yale anticline extends from the SW. $\frac{1}{4}$ Sec. 30, T. 12 N., R. 25 W. eastward to the SW. $\frac{1}{4}$ Sec. 29, T. 12 N., R. 23 W.

Structural features.—The Yale anticline is bounded on the north by the Archey syncline and on the south by the Ragon syncline. The surface rocks belong to the Atoka formation.

At its east end the anticline is apparently somewhat offset from the west end of the Dabney anticline, but the two are closely related and may be connected. The anticline is slightly asymmetrical, but the north and not the south limb is the steeper. The dips south of the axis average less than 4 degrees; those north of it range from 5 to 11 degrees. The anticline has a slight plunge to the east at its east end, but the evidence of closure at its west end is not good.

Exploration.—The Yale anticline has not been tested, but the structural conditions are relatively favorable to the accumulation of oil and gas despite the fact that the east and west closures are not prominent. The initial well should be drilled near the axis, or a short distance south of it, and some distance from either the east or the west end.

SYNCLINES

GENERAL FEATURES

The synclines in the Arkansas Valley, although they are not regarded as potential reservoirs of either oil or gas, are of geologic significance because they delimit the anticlines. For this reason, and because they should be avoided in prospecting for oil and gas, their axes have been indicated on the large structure map (Pl. I) and they are described in the text.

The synclines, like the anticlines, have a general eastward trend. The synclines near the southern border of the Arkansas Valley are closely folded, but those farther north are more open, and they become more and more open toward the north. Those near the Ouachita Mountain province are unsymmetrical in that their south flanks are steeper than their north flanks, but many of those near the Arkansas River are essentially symmetrical. Those near the Boston Mountains are steeper on their north flanks than on their south flanks.

Most of the synclines are longer than the anticlines. They range in length from only a few miles to 50 to 75 miles. Synclines less than 20 miles long, however, are more numerous than longer ones. Most of them are deepest near their west ends and rise toward the east;

but some form basins in which the dips toward the center are nearly equal at all points around their oval circumference. Some of the longer synclines are locally deepened into basins.

The names of all of the synclines are given on the large structure map (Pl. I) and are discussed in the text in alphabetical order.

ALMA SYNCLINE

Location.—The axis of the Alma syncline extends from about the center of Sec. 20, T. 9 N., R. 31 W. northeastward to about the center of Sec. 6, T. 9 N., R. 29 W.

Structural features.—The Alma syncline is bounded on the north by the Mulberry fault and on the south by the Alma anticline.

The syncline is rather markedly asymmetrical in that its north limb is steeper than its south. The dips north of the axis range from 2 to 15 degrees; those south of the axis range from 2 to 6 degrees.

Exploration.—Several wells drilled on the south flank of the surface trace of this synclinal axis have produced gas. The details of this syncline are given in the text on the Alma gas field.

ALSTON SYNCLINE

Location.—The axis of the Alston syncline extends from about the SE. $\frac{1}{4}$ Sec. 13, T. 9 N., R. 30 W. northeastward to about the NW. $\frac{1}{4}$ Sec. 3, T. 9 N., R. 27 W., where it splits into two prongs, here described as the Philpott and Webb City synclines.

Structural features.—The Alston syncline is bounded on the north by the Watalula and White Oak anticlines and on the south by the Cecil anticline. The surface rocks belong to the Atoka, Hartshorne, and Spadra formations.

This syncline, whose western course is obscured by the alluvium of Arkansas River, is essentially symmetrical. The dips north of the axis range from 2 to 8 degrees and average about 4 degrees; those south of the axis range from 2 to 7 degrees and average between 3 and 4 degrees. A minor synclinal prong apparently extends northeastward from its point of junction with the main structure in the NE. $\frac{1}{4}$ Sec. 4, T. 9 N., R. 28 W., to about the SE. $\frac{1}{4}$ Sec. 13, T. 10 N., R. 28 W., but its course is not clearly defined.

Exploration.—The Alston syncline is unfavorable for the accumulation of oil and gas.

ANTIOCH SYNCLINE

Location.—The axis of the Antioch syncline extends from the SE. $\frac{1}{4}$ Sec. 12, T. 6 N., R. 10 W. slightly south of east to the SE. $\frac{1}{4}$ Sec. 16, T. 6 N., R. 8 W.

Structural features.—The Antioch syncline lies between the two prongs of the forked Cadron anticline, and the surface rocks belong to the Atoka formation. The syncline is a well-marked spoon-shaped basin, which is somewhat asymmetrical, the dips north of the axis being slightly higher than those south of it. The dips on the north limb range from 5 to 14 degrees and average about 8 degrees; those on the south limb range from 3 to 24 degrees and average about 6 degrees. The dips on both limbs increase toward the bounding anticlines. The syncline deepens rapidly toward the center from each end of the axis, but the western dips at its east end are steeper than the eastern dips at its west end, near the junction of the two prongs of the Cadron anticline.

Antioch Mountain and its encircling ridges form an excellent topographic expression of this syncline.

Exploration.—The Antioch syncline has not been drilled for oil or gas and there is no reason to consider it favorable for their accumulation.

ARCHEY SYNCLINE

Location.—The axis of the Archey syncline extends from the NW. $\frac{1}{4}$ Sec. 15, T. 11 N., R. 29 W. slightly north of east to the S. $\frac{1}{2}$ Sec. 34, T. 13 N., R. 13 W., and probably continues still farther eastward, but the area north of T. 12 N. has not been mapped.

Structural features.—The Archey syncline is bounded on the north by the Cass, Hurricane Creek, and Plant anticlines, and on the south by the Jethro, Watalula, Yale, Dabney and Shirley anticlines. Throughout most of its long course it is fairly well defined, although it is nowhere prominent, but at several places the dips are so low as to suggest that it may not be absolutely continuous.

The syncline is essentially symmetrical. The dips on the sides of its axis range from 2 to 12 degrees, but the average dip is probably less than 5 degrees. The dips south of the axis may possibly be somewhat higher than those north of it, but the difference is not great.

Exploration.—The Archey syncline has not been tested for oil or gas and should be avoided.

BIG ROCK SYNCLINE

Location.—The axis of the Big Rock syncline extends from about the SE. $\frac{1}{4}$ Sec. 35, T. 3 N., R. 15 W. southeastward to the NE. $\frac{1}{4}$ Sec. 16, T. 2 N., R. 11 W.

Structural features.—The Big Rock syncline is bounded on the north by the Maumelle anticline, but the limiting structure on the south has not been certainly determined. The surface rocks belong to the Stanley and the Jackfork formation, the Jackfork rocks being

exposed in the trough of the syncline. The syncline is expressed topographically by the Maumelle Pinnacles, which are formed of southward-dipping beds on the north limb, by northward-dipping beds of Shinall Mountain on the south limb, and by Big Rock Mountain, which is a typical flat-topped synclinal hill.

The syncline is irregularly asymmetrical, the north limb being steeper than the south near the west end and the south limb being steeper than the north at the east end. The dips north of the axis range from 4 to 82 degrees; those south of the axis range from 15 to 65 degrees. The dips on both sides of the axis diminish regularly toward the east, but they decrease more rapidly north of the axis than south of it.

Exploration.—Several wells sunk near Little Rock were drilled on the south limb of the Big Rock syncline. Among these are the Martin well, drilled in 1885 by Mathews and England to a depth of 800 feet in Sec. 3, T. 1 N., R. 13 W. The log of this well, which was unsuccessful, is not available. In addition, Prothro and Zunt, in 1923, drilled a well to a depth below 1,000 feet in Sec. 32, T. 2 N., R. 11 W., but obtained neither oil or gas. It is understood that plans have recently been made to deepen this well.

The Big Rock syncline is structurally unfavorable to the accumulation of oil and gas.

CALDRON SYNCLINE

Location.—The axis of the Caldron syncline extends from the SW. $\frac{1}{4}$ Sec. 4, T. 11 N., R. 8 W. eastward to the SE. $\frac{1}{4}$ Sec. 5, T. 11 N., R. 7 W.

Structural features.—The Caldron syncline is bounded on the south by the Floral anticline, but the limiting structure on the north has not been determined. The syncline is essentially symmetrical, but it is not prominent. The dips north and south of the axis range from 2 to 5 degrees and average about 3 degrees.

Exploration.—The Caldron syncline has not been tested for oil or gas and is structurally unfavorable to their accumulation.

CATCHER SYNCLINE

Location.—The axis of the Catcher syncline extends from the NE. $\frac{1}{4}$ Sec. 5, T. 9 N., R. 31 W., northeastward to about the center of Sec. 15, T. 9 N., R. 30 W., but its ends are not well defined.

Structural features.—The Catcher syncline is bounded on the north by the Alma anticline and on the south by the Lane Hill anticline.

This syncline, which is not prominent, is essentially symmetrical, although the south limb is perhaps steeper than the north. The dips

north of the axis range from 2 to 7 degrees; those south of the axis range from 2 to 12 degrees.

Exploration.—Several wells have been drilled on the Catcher syncline, and a few of those drilled on the south flank have obtained gas. The details of the production from the syncline are given in the text on the Kibler gas field.

CATO SYNCLINE

Location.—The axis of the Cato syncline extends from the SW. $\frac{1}{4}$ of Sec. 2, T. 4 N., R. 14 W. southeastward to the W. $\frac{1}{2}$ Sec. 26, T. 4 N., R. 10 W.

Structural features.—The Cato syncline is bounded on the north by the Bayou Meto anticline and on the south by the Palarm anticline. The surface rocks belong to the Atoka formation. The structure is well expressed topographically by Round Mountain and its encircling ridges, such as Reynolds Mountain and Cedar Ridge, and by the inward-dipping ridges north and south of Clear Lake.

The syncline is essentially symmetrical. The dips north of the axis range from 18 to 35 degrees and average about 25 degrees; those south of it range from 8 to 44 degrees and average between 20 and 25 degrees. The Cato syncline was used by Branner¹¹ and others to determine the thickness of the Lower Carboniferous rocks in Arkansas.

Exploration.—In 1923 the Little River Oil and Development Company drilled a well to a depth of 2,000 feet on the J. E. Springer lease, in the northwest corner of the NW. $\frac{1}{2}$ Sec. 36, T. 4 N., R. 12 W., but obtained neither oil nor gas in commercial quantities. The log of this well, which was drilled essentially on the synclinal axis, is not available. Further exploration of the Cato syncline is considered inadvisable.

CENTERVILLE SYNCLINE

Location.—The axis of the Centerville syncline extends from about the SW. $\frac{1}{4}$ Sec. 1, T. 5 N., R. 21 W. slightly south of east to the SE. $\frac{1}{4}$ Sec. 8, T. 5 N., R. 19 W.

Structural features.—The Centerville syncline is bounded on the north by the Pine Ridge and Atkins anticlines and on the south by the Ranger anticline. The surface rocks belong to the Atoka formation.

The syncline is decidedly asymmetrical, its south limb being short and very steep and its north limb long and rather gently sloping. The dips north of the axis range from 2 to 33 degrees, but inclinations as high as 33 degrees are rare and are found only close to the

¹¹ Branner, J. C., Am. Jour. Sci., vol. 2, 4th ser., pp. 232-234, 1896.

axis. The dips south of the axis range from 60 to 87 degrees. Southwest of Centerville the syncline dies out, and its east end, southwest of the village of Pontoon, is offset from the west end of the Pontoon syncline.

Exploration.—The Centerville syncline has not been tested for oil or gas and its structure is unfavorable to their accumulation.

CENTRAL SYNCLINE

Location.—The axis of the Central syncline extends from the Oklahoma boundary at the SW. $\frac{1}{4}$ Sec. 32, T. 7 N., R. 32 W. northeastward to the N. $\frac{1}{2}$ Sec. 7, T. 7 N., R. 30 W., thence southeastward to the vicinity of Potato Hill, in Sec. 29, T. 7 N., R. 28 W., where it merges indefinitely into the Greenwood syncline. The syncline continues southwestward into Oklahoma.

Structural features.—The Central syncline is bounded on the north by the Massard Prairie, Vache Grasse, Big Creek, and Game Hill anticlines and on the south by the Backbone and Biswell Hill anticlines. The surface rocks belong to the Spadra, Fort Smith, and Paris formations. The structure finds topographic expression in Wolf Hill, Donahoe, Spredding, and Bloomer ridges, in Butler and Christmas knobs, and in Potato Hill.

The syncline is a broad, open asymmetrical trough, in which the dips south of the crest average higher than those north of it. The dips north of the crest range from 2 to 8 degrees and average about 5 degrees; those south of the crest range from 2 to 17 degrees and probably average about 7 degrees. The asymmetry is inconspicuous near the synclinal axis. The deepest part of the syncline lies near its junction with the Greenwood syncline.

Exploration.—Several shallow wells have been drilled on the Central syncline in a search for coal, but no well has found either oil or gas. These shallow wells did not adequately test the syncline for oil and gas, but it is structurally unfavorable to their accumulation.

CHESTER SYNCLINE

Location.—The axis of the Chester syncline extends from about the SW $\frac{1}{4}$ Sec. 25, T. 12 N., R. 31 W. eastward to the SE. $\frac{1}{2}$ Sec. 26, T. 12 N., R. 30 W., where it splits into north and south forks. The north fork continues from its junction with the main structure northeastward to the SE. $\frac{1}{4}$ Sec. 15, T. 12 N., R. 29 W.; the south fork extends from the junction slightly south of east to the NE. $\frac{1}{4}$ Sec. 34, T. 12 N., R. 29 W.

Structural features.—The Chester syncline is bounded on the north by the Armada anticline and on the south by the Meadow Mountain

anticline, and the Three Rocks anticline lies between its two forks. The surface rocks belong to the Atoka formation.

The main syncline and its forks are asymmetrical, their north flanks being steeper than their south flanks. The dips north of the axis of the handle and north fork of the syncline range from 3 to 8 degrees and average about 5 degrees; those south of the axis of the handle and south prong range from 2 to 5 degrees and probably average about 3 degrees. The dips on the south limb of the north fork average between 3 and 4 degrees; those on the north limb of the south fork average about 5 degrees.

Exploration.—The Chester syncline has not been tested for oil or gas and its structure is unfavorable to their accumulation.

CLARKSVILLE SYNCLINE

Location.—The axis of the Clarksville syncline extends from about the NW. $\frac{1}{4}$ Sec. 6, T. 9 N., R. 24 W. eastward and southeastward in an undulating course at least to the SE. $\frac{1}{4}$ Sec. 23, T. 9 N., R. 22 W., and is probably continuous with the north fork of the Ouita syncline.

Structural features.—The syncline is bounded on the north by the Ludwig anticline and on the south by the Big Danger, Spadra, and Hartman faults. The surface rocks belong to the Hartshorne, Spadra, and Fort Smith formations. The oldest rocks are exposed toward the east end of the syncline, and the youngest crop out on Big Danger Hill. The syncline is not well expressed topographically.

The syncline is somewhat asymmetrical, the dips north of the axis averaging slightly higher than those south of it. The dips north of the axis range from 2 to 12 degrees and average between 5 and 6 degrees; the dips south of the axis range from 2 to 9 degrees and probably average about 4 degrees. The syncline is complicated on its north limb by the Clarksville fault, which is described elsewhere.

Exploration.—Several shallow wells have been drilled on the Clarksville syncline in prospecting for coal, but none of them has struck either oil or gas. The Hugo-Spadra Oil and Gas Company drilled a well to a depth of 2,240 feet on the Parks lease, in Sec. 3, T. 9 N., R. 23 W., on the south flank of the anticline, but obtained neither oil or gas. The log of this well is not available. Further exploration of this syncline is inadvisable.

CLEAR WATER SYNCLINE

Location.—The axis of the Clear Water syncline extends from the SW. $\frac{1}{4}$ Sec. 8, T. 8 N., R. 9 W. eastward in a somewhat undulating course to the SE. corner of Sec. 36, T. 9 N., R. 6 W.

Structural features.—The syncline is bounded on the north by the Darcy anticline and on the south by the Searcy anticline. The surface rocks belong to the Atoka formation.

The syncline is poorly defined throughout most of its course, especially near its east and west ends, where the dips are so low and the dip readings are so difficult to obtain that the structural trend has not been accurately determined. The syncline is somewhat asymmetrical, the dips south of the axis being higher than those north of it. Those on the south flank range from 2 to 15 degrees, but approach 15 degrees only near the axis of the Searcy anticline. Near the trough of the syncline most of the dips are less than 5 degrees. The dips north of the axis are rarely as high as 3 degrees, and although they become higher toward the Darcy anticline the rate of increase is low.

Exploration.—In 1903-1904 the Dauphan Lumber Company drilled a well to a depth of 1,600 feet on the R. A. McCain lease, in the NW. $\frac{1}{4}$ of the NW. $\frac{1}{4}$ Sec. 20, T. 8 N., R. 7 W., but obtained neither oil nor gas. The log of this well is no longer available.

Further exploration in this general synclinal area should be discouraged.

CONWAY SYNCLINE

Location.—The axis of the Conway syncline extends from the Arkansas River, in Sec. 1, T. 5 N., R. 14 W. eastward through Conway to the NW. $\frac{1}{4}$ Sec. 9, T. 5 N., R. 10 W., where it divides into two forks. The north fork extends northeastward to the NE. $\frac{1}{4}$ Sec. 35, T. 6 N., R. 9 W., and may continue still farther in that direction. The south fork extends southeastward to the SE. $\frac{1}{4}$ Sec. 16, T. 5 N., R. 9 W., from which point it probably continues eastward and northeastward for some distance under Tertiary sediments.

Structural features.—The Conway syncline is bounded on the north by the Cadron anticline and on the south by the Bayou Meto anticline, and its eastern forks enclose the Bull Creek anticline. The surface rocks belong to the Atoka formation.

The syncline is well defined throughout most of its course, but in the vicinity of Conway its south limb is rather ill defined. It is not markedly asymmetrical except in Rs. 13 and 14 W., where its north limb is much steeper than its south. East of R. 13 W. the dips on the north limb range from 4 to 68 degrees and decrease irregularly not only toward the synclinal axis but toward the east. The dips on the south limb east of R. 13 W. are perhaps somewhat higher than those on the north limb. The dips increase regularly southward toward the Bayou Meto anticline, near the axis of which they become so steep that the rocks are in places overturned. The

dips south of the synclinal axis show little or no tendency to decrease toward the east.

The structural details of both the north and south forks of this syncline have been greatly obscured by the alluvium of Cypress Creek and its tributaries, but both forks are asymmetrical. The dips on the north limb of the north fork (except far to the northwest, near the axis of the Cadron anticline) are not more than 9 degrees and are commonly less than 7 degrees. South of the axis of the north fork practically all the dips are greater than 10 degrees. The south fork is also steeper on the south limb than on the north. The dips north of its axis range from 11 to 47 degrees but become greater toward the synclinal trough; those south of the axis range from 12 to 67 degrees but increase away from the axis.

The topographic expression of the syncline is seen in the series of northward-dipping beds of sandstone exposed in the ridges south of Cypress Creek, in the southward-dipping beds of Cadron Ridge, and in Coal Hill, a mesa-like eminence of synclinal structure 3 miles south of El Paso.

Exploration.—The Conway syncline has not been tested for oil or gas and it is unfavorable to their accumulation.

COVE SYNCLINE

Location.—The axis of the Cove syncline extends from about the Oklahoma boundary, in the NW. $\frac{1}{4}$ Sec. 26, T. 12 N., R. 33 W. southeastward to the NE. $\frac{1}{4}$ Sec. 31, T. 12 N., R. 33 W., where it splits into two forks. The north fork extends northeastward for about 3 miles and then swings southeastward to the SW. $\frac{1}{4}$ Sec. 2, T. 11 N., R. 31 W. The south fork extends from its point of junction with the main structure southeastward to the NW. $\frac{1}{4}$ Sec. 18, T. 11 N., R. 31 W.

Structural features.—The Cove syncline is bounded on the north by the Liberty Hill anticline and on the south by the Pine Mountain anticline. The Lee Creek anticline lies between the two forks of the Cove syncline. The surface rocks belong chiefly to the Atoka formation, but near the Oklahoma boundary the Morrow formation, the Pitkin limestone, and the Fayetteville shale are exposed over small areas.

The syncline is essentially symmetrical, but its south fork is more pronounced than either its main structure or its north fork. The dips on either side of the axis of the south fork are commonly 5 degrees or more. Both limbs of the handle of the forked structure have an average dip of about 3 degrees. The north fork is somewhat asymmetrical, the dips on its north flank averaging about 3

degrees and those on its south flank averaging between 4 and 5 degrees.

Near the west end of the synclinal axis the structure is complicated by two eastward-trending normal faults, the northern one having considerable displacement. The beds between the two faults are down-faulted and constitute a small graben.

Exploration.—The Cove syncline has not been tested for oil or gas and is structurally unfavorable to their accumulation.

CRAVENS SYNCLINE

Location.—The axis of the Cravens syncline extends from about the center of Sec. 15, T. 10 N., R. 28 W. northeastward to the NW. $\frac{1}{4}$ Sec. 7, T. 10 N., R. 26 W.

Structural features.—The Cravens syncline is bounded on the north by the Watalula anticline and on the south by the White Oak anticline. The surface rocks belong chiefly to the Atoka formation.

The syncline is somewhat asymmetrical, the dips south of the axis being slightly higher than those north of it. The dips on the north flank range from 2 to 6 degrees; those on the south flank range from 2 to 10 degrees. The syncline is poorly defined at both its ends.

Exploration.—The Cravens syncline has not been tested for oil or gas and is unfavorable to their accumulation.

DEAN SPRINGS SYNCLINE

Location.—The axis of the Dean Springs syncline extends from about the SE. $\frac{1}{4}$ Sec. 25, T. 10 N., R. 31 W. northeastward to the NE. $\frac{1}{4}$ Sec. 24, T. 10 N., R. 30 W.

Structural features.—The Dean Springs syncline is bounded on the north by the Mountainburg anticline and on the south by the Lafayette anticline.

The syncline, which is poorly defined, is markedly asymmetrical, the north limb being much steeper than the south. The dips north of the axis range from 2 to 16 degrees, although inclinations of 16 degrees are rare. The dips south of the axis range from 1 to 5 degrees but probably average less than 2 degrees.

Exploration.—The Dean Springs syncline has not been drilled for oil or gas and its exploration is inadvisable.

FAIRBANKS SYNCLINE

Location.—The axis of the Fairbanks syncline extends from the NE. $\frac{1}{4}$ Sec. 29, T. 8 N., R. 17 W. slightly south of east to the vicinity of St. Vincent, where it swings to the northeast and continues to about the SE. $\frac{1}{4}$ Sec. 25, T. 11 N., R. 9 W.

Structural features.—The Fairbanks syncline is bounded on the north by the Old Hickory and Center Ridge anticlines, and on the south by the Solgohachia, Springfield, and Heber Springs anticlines. The syncline is at many places poorly defined and is asymmetrical, the dips north of the axis averaging higher than those south of it. The dips on the north flank range from 1 to 10 degrees and average about 5 degrees; those on the south flank range from 1 to 6 degrees and probably average less than 3 degrees.

A few minor faults, with their downthrown sides on the south, parallel the main synclinal axis, but the displacement is small. West of Martinville the syncline is poorly defined, especially in the area west of the west end of the Heber Springs anticline, where the syncline as here defined may not be continuous.

Exploration.—The Fairbanks syncline has not been tested for oil or gas and its structure is not favorable to their accumulation.

FLORAL SYNCLINE

Location.—The axis of the Floral syncline extends from about the center of Sec. 19, T. 11 N., R. 7 W. eastward to the SE. $\frac{1}{4}$ Sec. 13, T. 11 N., R. 6 W., and may continue farther in that direction, but the area east of R. 6 W. was not surveyed.

Structural features.—The Floral syncline is bounded on the north by a part of the Floral anticline and on the south by the Denmark anticline. The syncline is essentially symmetrical, but the dips on its north flank, which range from 3 to 9 degrees, are perhaps slightly higher than those on the south flank, which range from 3 to 7 degrees.

Exploration.—The Floral syncline has not been tested for oil or gas, and its structure is unfavorable for their accumulation.

FORMOSA SYNCLINE

Location.—The axis of the Formosa syncline extends from the NW. corner of Sec. 2, T. 8 N., R. 17 W. northeastward about to the center of Sec. 1, T. 11 N., R. 11 W., but its course has been obscured in several places, notably near its east end.

Structural features.—The Formosa syncline is bounded on the north by the Clinton anticline and on the south by the Lick Mountain and Center Ridge anticlines. The syncline is asymmetrical, the dips north of the axis being considerably higher than those south of it. The dips on the north limb range from 2 to 15 degrees and average at least 7 degrees, but from Choctaw eastward the dips tend to diminish. The beds on the south flank are inclined at angles of from 1 to 7 degrees, and the average dip is less than 4 degrees. South of Cleveland and south of Choctaw there are minor faults on the north

limb, parallel to the main structural trend. The downthrown side is apparently on the south, but the displacement is not great.

Exploration.—The Formosa syncline is unfavorable for the accumulation of oil or gas.

FOURCHE LA FAVE SYNCLINE

Location.—The axis of the Fourche la Fave syncline extends from the SE. $\frac{1}{4}$ Sec. 36, T. 3 N., R. 26 W. northeastward to about the NE. $\frac{1}{4}$ Sec. 24, T. 4 N., R. 18 W., but continues southwestward into T. 2 N., which was not surveyed in detail.

Structural features.—The Fourche la Fave syncline is bounded on the north by the Dutch Creek and Casa anticlines, but the limiting structure on the south is unnamed. The surface rocks belong to the Atoka formation. At its east end the syncline is apparently somewhat offset from the Perryville syncline, though the two have the same structural trend and may be connected. The syncline is well expressed topographically by the valley of Fourche la Fave River, which follows closely the synclinal axis.

The syncline is somewhat asymmetrical, the dips south of the axis being greater, on the average, than those north of it. The dips on the north flank range from 15 to 72 degrees and average less than 40 degrees; those on the south flank range from 42 to 82 degrees and average over 50 degrees. The dips decrease only slightly toward the synclinal axis, and in this respect the syncline differs from all the synclines that lie north of it.

Exploration.—The Fort Smith Lumber Company drilled a well to a depth of 2,370 feet on the Rogers lease, in the SE. $\frac{1}{4}$ of the NE. $\frac{1}{4}$ Sec. 23, T. 4 N., R. 22 W., at the west edge of the town of Plainview, but obtained only a showing of gas. The log of this well follows:

Log of Rogers No. 1 well, in Sec. 23, T. 4 N., R. 22 W.

	Depth in feet
Surface soil.....	0- 10
Slate.....	10- 60
Black, hard slate.....	60- 165
Black soft slate.....	165- 180
Black slate.....	180- 220
Gray slate.....	220- 240
Gray sand.....	240- 250
Gray slate.....	250- 350
Gray slate.....	350- 375
Blue slate.....	375- 575
Black slate.....	575- 600
Blue slate.....	600- 675
Gray slate.....	675- 725
Blue slate.....	725- 765
Sand.....	765- 775

	Depth in feet
Gray slate.....	775- 800
Black slate.....	800- 830
Gray slate and shells.....	830- 880
Black slate.....	880- 900
Gray slate and hard sand.....	900- 925
Sand.....	925- 935
Gray slate.....	935- 945
Gray sand.....	945-1100
Blue sand and shale.....	1100-1125
Black sand and shale.....	1125-1300
Sand.....	1300-1315
Black sand.....	1315-1325
Sand.....	1325-1335
Black sand.....	1335-1380
Gray sand.....	1380-1405
Black slate.....	1405-1435
Gray sand.....	1435-1500
Black slate.....	1500-1535
Gray sand.....	1535-1580
Soft slate.....	1580-1585
Gray sand.....	1585-1625
Black slate.....	1625-1655
Gray sand.....	1655-1665
Gray sand.....	1665-1715
Black slate.....	1715-1745
Gray sand.....	1745-1770
Black sand.....	1770-1800
Slate, black.....	1800-1900
Blue slate.....	1900-1965
Black sand.....	1965-1975
Black slate.....	1975-2000
Blue slate.....	2000-2015
Black sand.....	2015-2025
Blue slate.....	2025-2050
Black slate.....	2050-2085
Gray sand; gas.....	2085-2165
Black slate.....	2165-2200
Black slate and shale.....	2200-2225
Black slate; gas.....	2225-2235
Black slate.....	2235-2260
Gray sand.....	2260-2325
Black slate.....	2325-2330
Black sand.....	2330-2360
Black sand and shells; bottom.....	2360-2370

This log shows a typical succession of alternating beds of sandstone and shale of the Atoka formation. It is reported that the gas, which was obtained at depths of 2,085 and 2,225 feet, is still escaping from the casing head and burns freely upon ignition when confined, but this report was not verified. This well was drilled about 2½ miles north of the axis of the Fourche la Pave syncline. The rocks on the north limb of the syncline near Plainview seem to be

thrown into a minor anticline, on which the Rogers well was drilled. The dips near the well, however, are as high as 60 degrees, and the sandstone is dense and relatively impervious, so that the well was not favorably located.

In addition to the above well, a test well was drilled to a depth of 3,768 feet on the Delatte lease, in Sec. 28, T. 4 N., R. 22 W., but it obtained neither oil nor gas. The well was drilled about 2 miles north of the synclinal axis. The log of this well is given below:

Log of Delatte well, in Sec. 28, T. 4 N., R. 22 W.

	Depth in feet
Soil.....	0- 12
Black slate.....	12- 170
Sand.....	170- 190
Black slate.....	190- 592
Gray slate.....	592- 622
Black slate.....	622- 644
Black sand.....	644- 845
Black slate.....	845- 962
Black slate.....	962-1280
Gray slate.....	1280-1320
Black shale.....	1320-1465
Gray sand.....	1465-1480
Black.....	1480-1665
Black lime.....	1665-1695
Dark shale.....	1695-1720
Black sand.....	1720-1740
Gray sand.....	1740-1764
Dark shale.....	1764-2015
Dark lime.....	2015-2060
Dark shale.....	2060-2368
Gray sand.....	2368-2380
Dark shale.....	2380-2540
Sandy lime.....	2540-2600
Shale, light.....	2600-2660
Lime, gray, hard.....	2660-2730
Shale, dark.....	2730-2970
Lime, black.....	2970-2980
Shale, dark.....	2980-3007
Black slate.....	3007-3210
Black sand.....	3210-3235
Black slate.....	3235-3285
Black lime.....	3285-3305
Black slate.....	3305-3360
Black lime.....	3360-3370
Black slate.....	3370-3390
White lime.....	3390-3409
Black slate.....	3409-3414
White sand.....	3414-3430
Black slate.....	3430-3436
White sand.....	3436-3452
Black sand.....	3452-3498

	Depth in feet
White sand.....	3498-3506
Gray sand.....	3506-3545
Black shale.....	3545-3572
White lime.....	3572-3580
Black sand.....	3580-3590
Black shale.....	3590-3684
Gray lime.....	3684-3694
Black shale.....	3694-3704
Dark sand.....	3704-3740
White sand.....	3740-3745
Black shale.....	3745-3768

The "slate" of the record is probably only very slightly metamorphosed shale, and the "lime" is undoubtedly a hard, slightly calcareous sandstone, but the log shows a typical succession of Atoka sediments. The syncline does not merit further exploration.

FORT SMITH SYNCLINE

Location.—The axis of the Fort Smith syncline extends from about the SW. $\frac{1}{4}$ Sec. 5, T. 8 N., R. 32 W. northeastward to about the center of Sec. 25, T. 8 N., R. 32 W., but is not well defined.

Structural features.—The Fort Smith syncline is bounded on the north by the Roland anticline and on the south by the Massard Prairie and Lane Hill anticlines.

The syncline, which is a broad, shallow basin, is asymmetrical, its north limb being steeper than its south. The dips north of the crest range from 3 to 10 degrees; those south of the crest range from 2 to 8 degrees.

Exploration.—The axial part of the Fort Smith syncline has not been drilled for oil or gas and is unfavorable to their accumulation.

FRISCO SYNCLINE

Location.—The axis of the Frisco syncline extends from about the center of Sec. 8 T. 12 N., R. 30 W. eastward to the SW. $\frac{1}{4}$ Sec. 7, T. 12 N., R. 29 W.

Structural features.—The Frisco syncline is bounded on the north by the Frisco fault and on the south by the Armada anticline. The surface rocks belong to the Atoka formation.

The syncline is somewhat asymmetrical, its north flank being steeper than its south flank. The dips north of the axis range from 3 to 6 degrees and average about 4 degrees; those south of the axis range from 2 to 5 degrees and average about 3 degrees.

Exploration.—The Frisco syncline is structurally unfavorable to the accumulation of oil or gas.

GREENBRIER SYNCLINE

Location.—The axis of the Greenbrier syncline extends from the vicinity of Blackville southeastward to the N. $\frac{1}{2}$ Sec. 31, T. 7 N., R. 16 W., its westernmost definitely ascertained location, from which it continues slightly north of east to the vicinity of Greenbrier, where it turns more definitely northeastward and extends to the E. $\frac{1}{2}$ Sec. 24, T. 8 N., R. 11 W.

Structural features.—The Greenbrier syncline is bounded on the north by the Solgohachia and Enders anticlines and on the south by the Morrilton anticline. Its western extension is almost completely obscured by the alluvium of Point Remove Creek, and its course south of Springfield lies largely in the bottoms of Cadron Creek and its tributaries. Horseshoe Mountain, just west of the village of Greenbrier, is a topographic expression of the structure, as are the ridge-enclosed valleys east and west of it.

The syncline is irregularly asymmetrical, the dips on the south flank being greater than those on the north flank in the western part of its course; but in the vicinity of Greenbrier and east of that village the dips on the north flank are somewhat higher than those on the south flank. The dips on the north flank range from 2 to 12 degrees; those on the south flank range from 2 to 54 degrees. The dips on both flanks decrease toward the synclinal axis and become low in its vicinity. Near Greenbrier the syncline plunges to the west, and throughout most of its course it exhibits a slight tendency to rise toward the east.

Exploration.—The Greenbrier syncline has not been tested for oil or gas and is not favorable for their accumulation.

GREENWOOD SYNCLINE

Location.—The axis of the Greenwood syncline extends from the Oklahoma boundary at the W. $\frac{1}{2}$ Sec. 31, T. 6 N., R. 32 W. northeastward to about the NW. $\frac{1}{4}$ Sec. 36, T. 7 N., R. 25 W. The Central syncline may be regarded as a branch of the Greenwood syncline, which it joins in Sec. 29, T. 8 N., R. 28 W.

Structural features.—The Greenwood syncline is bounded on the north by the Backbone, Biswell Hill, Game Hill, and Pine Ridge anticlines and on the south by the Washburn anticline. The surface rocks exposed along the axis of the syncline belong to the Atoka, Hartshorne, Spadra, Fort Smith, and Paris formations, the oldest beds cropping out in its eastern part and the youngest in the southern part of T. 7 N., Rs. 28 and 29 W.

The syncline has rather marked topographic expression, which is seen in the southward-dipping beds of Sand Ridge, north of Hackett

and Excelsior; in the northward-dipping beds of the Devil's Backbone, on the south limb of the syncline; and in butte-like synclinal mountains and hills such as Pilot Mountain and Pine, Metcalf, and Potato Hill, though Potato Hill actually lies north of the main syncline.

The syncline is irregularly asymmetrical throughout its course, the dips on the south limb generally averaging higher than those on the north, but at some places the conditions are reversed. The dips north of the axis range from 3 to 75 degrees but average less than 20 degrees; those south of the axis range from 2 to 90 degrees, and at a few places, as south of Greenwood, the beds are overturned. The syncline is deepest in the Potato Hill area, where the Hartshorne coal is at least 1,600 feet beneath the surface. At Greenwood, however, the same coal is not more than 600 feet below the surface. The coal-bearing rocks have been eroded from the east end of the syncline.

Exploration.—The Greenwood syncline has been drilled to shallow depths in prospecting for coal but has not been explored for oil, or gas and is structurally unfavorable to their accumulation. Future exploration should be confined to more promising areas.

GUY SYNCLINE

Location.—The axis of the Guy syncline extends from about the SE. corner of Sec. 9, T. 7 N., R. 15 W. northeastward to the NE. $\frac{1}{4}$ Sec. 7, T. 8 N., R. 11 W., but throughout most of its course the syncline is poorly defined, particularly near its west end, where southern dips are common and the syncline is faintly developed or non-existent.

Structural features.—The Guy syncline is bounded on the north by the Heber Springs and Darcy anticlines and on the south by the Enders anticline. The surface rocks belong to the Atoka formation.

The syncline is asymmetrical, the dips north of the axis being higher than those south of it, particularly south of Martinville, although elsewhere along the synclinal axis the asymmetry is not strongly marked. The dips on the north flank range from 2 to 10 degrees; those on the south flank do not exceed 6 degrees and are generally not more than 3 degrees.

The beds are somewhat disturbed along a line roughly paralleling the structural axis in Secs. 27, 23, and 24, T. 8 N., R. 14 W., yet the dips change but little in this area, and if there is faulting the displacement is not great.

Exploration.—The Guy syncline has not been tested for oil or gas, and its structure is unfavorable for their accumulation.

HECTOR SYNCLINE

Location.—The axis of the Hector syncline extends from an indefinite location about in the SW. $\frac{1}{4}$ Sec. 17, T. 10 N., R. 19 W., south-eastward to a point about 2 miles northeast of Appleton, where it turns northeastward and continues to its end in the NE. $\frac{1}{4}$ of Sec. 26, T. 10 N., R. 17 W. At its end it is offset more than a mile from the west end of the Scotland syncline.

Structural features.—The Hector syncline is bounded on the north by the Retta anticline and on the south by the Clinton anticline. The surface rocks belong to the Atoka formation. The syncline is not a pronounced one, and its axis in a part of its extent is poorly defined. It is essentially symmetrical, the dips on either side of the axis being about the same, and generally ranging from 2 to 7 degrees. The syncline is more pronounced in its western than in its eastern part where the dips are commonly less than 4 degrees.

Exploration.—No test wells appear to have been drilled on the Hector syncline, and exploration should be limited to areas that are structurally more favorable.

HIRAM SYNCLINE

Location.—The axis of the Hiram syncline extends from about the SW. corner of Sec. 34, T. 10 N., R. 8 W. northeastward at least to the SW. corner of Sec. 15, T. 10 N., R. 6 W., and probably continues in that direction at least to the village of Denmark, but its east end is not prominent.

Structural features.—The Hiram syncline is bounded on the north by a part of the Denmark anticline and on the south by the Darey anticline. It is essentially symmetrical, the dips north of the axis ranging from 2 to 6 degrees and those south of the axis ranging from 2 to 5 degrees.

Exploration.—According to information available to the Arkansas Geological Survey two wells have been drilled on or near the Hiram syncline. Both were drilled on the W. W. Martindill lease, one in the NE. $\frac{1}{4}$ of the NE. $\frac{1}{4}$, and the other in the SE. $\frac{1}{4}$ of the NE. $\frac{1}{4}$ of Sec. 3, T. 9 N., R. 8 W. Neither well obtained oil or gas in commercial quantities. The log of Martindill well No. 2, which was drilled to a depth of 1,490 feet by the White County Oil Company, is given below:

Log of Martindill well No. 2, drilled by White County Oil Company in the SE. $\frac{1}{4}$ NE. $\frac{1}{4}$ Sec. 3, T. 9 N., R. 8 W.

	Depth in feet	Thickness in feet
Clay.....	0- 40	40
Quicksand.....	40- 100	60
Soft rock.....	100- 120	20

	Thickness in feet.	Depth in feet.
Shells and gumbo.....	120- 150	30
Soft rock and muddy gravel.....	150- 225	75
Soft slate; at this point 10-inch casing set.....	225- 275	50
Soft muddy slate, with streak of sandstone from 10 to 15 feet thick. At this point 8-inch casing set, shutting off all fresh water at 410 feet.....	275- 410	135
Slate.....	410- 415	5
Hard sand.....	415- 515	100
Soft black sand full of water.....	515- 550	35
Black slate.....	550- 565	15
Slate.....	565- 605	40
Shell and slate. At this point casing shut off all water.....	605- 635	30
Slate under casing.....	635- 660	25
Slate with streaks of sand.....	660- 735	75
Hard sand.....	735- 810	75
Black slate with streaks of sand.....	810- 885	75
Hard rock.....	885- 905	20
Slate.....	905-1370	465
Hard sand, getting softer.....	1370-1475	75
Bit in hole.....	1475-1490	15

The well appears to have stopped in the Atoka formation. The other test well was drilled to a depth of 1,800 feet by A. L. and J. C. Gullan, but the log could not be obtained. Both wells were poorly located structurally, but the syncline does not warrant further exploration.

JENNY LIND SYNCLINE

Location.—The axis of the Jenny Lind syncline extends from about the NW. $\frac{1}{4}$ Sec. 31, T. 7 N., R. 31 W. eastward to the NW. $\frac{1}{4}$ Sec. 32, T. 7 N., R. 30 W.

Structural features.—The Jenny Lind syncline is bounded on the north by the Biswell Hill anticline and on the south by the Backbone anticline. The surface rocks belong to the Hartshorne and Spadra formations.

The syncline is markedly asymmetrical, the dips south of the axis averaging considerably higher than those north of it. The dips north of the axis range from 2 to 10 degrees; those south of the axis range from 5 to 50 degrees. The syncline becomes very ill defined at both its east and its west end.

Exploration.—The Jenny Lind syncline has not been drilled for oil or gas and is structurally unfavorable for their accumulation.

LAVACA SYNCLINE

Location.—The axis of the Lavaca syncline extends from the vicinity of the town of Lavaca, in the NE. $\frac{1}{4}$ Sec. 33, T. 8 N., R. 30 W.,

eastward to about the NE $\frac{1}{4}$ Sec. 33, T. 8 N., R. 29 W., from which it may continue eastward and join the Paris syncline.

Structural features.—The Lavaca syncline is bounded on the north by the Vache Grasse anticline and on the south by Big Creek anticline. The surface rocks belong to the spadra and Fort Smith formations.

The syncline is a gentle, essentially symmetrical basin, in which the dips north of the axis range from 3 to 8 degrees and those south of it range from 2 to 6 degrees. The syncline becomes ill defined west of Lavaca as well as near its east end, and at no place is it prominent.

Exploration.—The Lavaca syncline has not been drilled for oil and gas and is structurally unfavorable to their accumulation.

LEE MOUNTAIN SYNCLINE

Location.—The axis of the Lee Mountain syncline extends from the NW. $\frac{1}{4}$ Sec. 36, T. 10 N., R. 22 W. (somewhat north and west of its termination as indicated on the map), southeastward to the northwest corner of Sec. 13, T. 8 N., R. 17 W., where its course is obscured by low dips and poor exposures. Throughout much of its extent it has been impossible to determine accurately the position of the synclinal axis, but it is thought to be fairly well indicated on the large structure map.

Structural features.—The Lee Mountain syncline is bounded on the south by the Dover, Solgohachia, and Old Hickory anticlines and on the north by the Silex and Appleton anticlines. The syncline is not markedly asymmetrical, but the dips are perhaps slightly higher on the north limb than on the south. A few dips as high as 10 degrees were measured, but dips of more than 5 degrees are unusual. In fact, at many places the dips are so slight that it is almost impossible to measure them without detailed mapping.

A number of faults parallel the syncline, but all appear to be superficial. The most noticeable is on the north limb, not far from the axis, in Secs. 9 and 10, T. 9 N., R. 20 W. The downthrown side is on the south, and the dip south of the trace is southwestward at an angle of 5 or 6 degrees.

Exploration.—In 1920-1922 the Muskogee Oil Company drilled on the H. L. Thompson lease, in Sec. 14, T. 9 N., R. 20 W., to a depth of 3,410 feet without finding either oil or gas. This well was drilled essentially on the axis of the syncline, though at a place where the beds are disturbed by minor folding. Further tests of this syncline are inadvisable.

LITTLE FROG SYNCLINE

Location.—The axis of the Little Frog syncline extends from the SE. $\frac{1}{4}$ Sec. 36, T. 10 N., R. 31 W. northeastward to the NW. $\frac{1}{4}$ Sec. 25, T. 10 N., R. 29 W.

Structural features.—The Little Frog syncline is bounded on the north by the Lafayette anticline and on the south by the Mulberry fault.

The syncline, which is poorly defined throughout most of its course, is essentially symmetrical, but its north limb is probably somewhat steeper than its south. The dips north of the axis range from 2 to 11 degrees; those south of it range from 2 to 8 degrees.

Exploration.—The Little Frog syncline has not been drilled for oil or gas and is structurally unfavorable to their accumulation.

MAGAZINE MOUNTAIN SYNCLINE

Location.—The axis of the Magazine Mountain syncline extends from about the SW. $\frac{1}{4}$ Sec. 24, T. 5 N., R. 30 W. northeastward to the NW. corner Sec. 29, T. 6 N., R. 20 W.

Structural features.—The Magazine Mountain syncline is bounded on the north by the Washburn and Pine Ridge anticlines and on the south by the Ranger anticline. The surface rocks belong largely to the Atoka formation, but on Magazine Mountain the formations up to and including the Savanna are exposed. The structure is well expressed topographically by three synclinal eminences along its axis, Chickalah and Magazine Mountains and Jennings Hill. At its west end it gives way to the Hartford anticline and is somewhat offset from the Sugarloaf syncline, but it lies along the same structural line as the Sugarloaf syncline. At its east end, as here defined, the syncline is lost beneath the alluvium of Arkansas River, but it may continue southeastward and join the Pontoon syncline. If so, an anticline lies between the Centerville syncline and the junction of the two synclines mentioned.

The Magazine Mountain syncline is markedly asymmetrical throughout most of its course, the dips south of the axis being considerably higher than those north of it, but near the synclinal axis itself the asymmetry is not marked. The dips on the north flank range from 3 to 40 degrees and probably average less than 20 degrees.

The dips are generally less than 8 degrees near the axis, but they gradually increase toward the axis of the Washburn anticline. On the south limb the dips range from 3 to 90 degrees and the beds are in places overturned. This limb is shorter than the north limb, and the dips increase rapidly from the synclinal axis southward to the

Ranger anticline. The dips on both sides of the synclinal axis show a gradual diminution toward the ends of the syncline.

Exploration.—In 1925 J. H. Flowers drilled a well to a depth of 1,200 feet on the N. L. White lease, in the SE. $\frac{1}{4}$ SW. $\frac{1}{4}$ Sec. 13, T. 6 N., R. 27 W., about midway between the axes of the Magazine Mountain syncline and the Washburn anticline, but obtained neither gas nor oil. In addition, according to the records of Harry E. Kelley, the Choctaw Oil and Gas Company, in about 1901, drilled two wells near Blue Mountain. The exact locations of these wells have not been ascertained, but they were drilled on the south flank of the syncline and possibly nearer the axis of the Ranger anticline than that of the syncline north of it. The logs of these wells are given below:

Log of Choctaw Oil and Gas Company's well No. 8, south of Blue Mountain Town.

	Depth in feet
Soil and clay.....	0- 15
Shale.....	15- 540
Black sand.....	540- 600
Shale.....	600- 695
Gray sand.....	695- 770
Light shale.....	770- 800
Hard gray sand.....	800- 810

Log of Choctaw Oil and Gas Company's well No. 9, south of Blue Mountain Town.

	Depth in feet
Soil and clay.....	0- 16
Shale.....	16-1120
Sandy shale.....	1120-1128
Black shale.....	1128-1400
Sandy shale.....	1400-1520
Shale.....	1520-1590
Hard sand, flinty.....	1590-1610
Hard sand.....	1610-1630
Crooked hole.....	1630-1654

The great thickness of shale in both these wells is noteworthy. Both were poorly located structurally, and neither obtained oil or gas. None of the three wells mentioned was carried deep enough to form a proper test, but the syncline as a whole is unfavorable for the accumulation of oil and gas.

MARCHE SYNCLINE

Location.—The axis of the Marche syncline extends from about the NW. $\frac{1}{4}$ Sec. 19, T. 3 N., R. 14 W., slightly south of east to about the center of Sec. 6, T. 2 N., R. 11 W., but the east end of the syncline is poorly defined.

Structural features.—The Marche syncline is bounded on the north by the Palarm anticline and on the south by the Maumelle anticline.

The surface rocks belong to the Atoka formation. The syncline is not well expressed topographically, but it finds expression in Purdham Hill and the flat-topped hills at Camp Pike, which are rather typical synclinal eminences.

The syncline is not markedly asymmetrical, but its north limb is perhaps somewhat steeper than its south. The dips north of the axis range from 20 to 63 degrees; those south of it range from 18 to 50 degrees. Near the west end of the syncline the beds at its axis stand essentially vertical.

Exploration.—In 1918 Wayman and Wayman drilled a well to a depth of 3,410 feet on the Wayman lease, in Sec. 5, T. 2 N., R. 12 W., a short distance south of the synclinal axis, but obtained neither oil nor gas in commercial quantities. Further exploration of the Marche syncline is inadvisable.

MENIFEE SYNCLINE

Location.—The axis of the Meniffee syncline extends from the SE. $\frac{1}{4}$ Sec. 7, T. 5 N., R. 17 W. northeastward to about the center of Sec. 15, T. 7 N., R. 7 W., just south of Searcy, where the axial trend is obscured beneath Tertiary sediments of the Mississippi Valley.

Structural features.—The Meniffee syncline is bounded on the north by the Ada, Morrilton, and Searcy anticlines, and on the south by the Redemption and Cadron anticlines. The surface rocks belong to Atoka formation.

The Meniffee syncline is one of the longest single synclines in Arkansas, and if it is continuous with the Poteau syncline, as it may prove to be, the combined syncline extends completely across the area of the Paleozoic rocks in Arkansas, a distance of at least 175 miles. The exact position of the synclinal axis is difficult to determine in the western part of its course, for there are few exposures of bed rock west of the village of Meniffee. This lack of exposures also makes it uncertain whether the Poteau and Meniffee synclines are part of a single structure. The two appear to be slightly offset in the E. $\frac{1}{2}$ Sec. 13, T. 5 N., R. 18 W., but they are very closely related and lie along the same structural line.

The syncline is very irregularly asymmetrical, but the dips south of the axis are generally higher than those north of it. Between Meniffee and Oppello, however, the relations are apparently reversed, for the dips north of the axis are somewhat higher than those south of it. The dips on the north flanks range from 4 to 45 degrees and show a gradual diminution eastward from the vicinity of Morrilton. Those on the south flank range from 4 to 87 degrees and decrease both east and west of an area north of the axis of the Cadron anticline, southeast of Meniffee. On both flanks the dips increase rapidly away

from the axis toward the bounding anticlines, and near its trough the syncline is essentially symmetrical and the dips are generally less than 10 degrees.

The deepest part of the syncline lies in the vicinity of Holland, where its plunge is expressed topographically by the horseshoe-shaped plateau, with its escarpment of inward-dipping strata, upon which the village stands.

Exploration.—Several wells have been drilled on the Menifee syncline, but none obtained oil or gas in commercial amounts. In 1921 Harrod and Stilley drilled a well to a depth of 3,500 feet on the Parrette lease, in Sec. 34, T. 6 N., R. 16 W., less than a mile from the synclinal axis. The well was unsuccessful. In 1922-1924 the Conway Oil and Gas Company drilled a well to a depth of 3,000 feet on the Durham lease, in Sec. 14, T. 6 N., R. 13 W., about a mile south of the synclinal axis, but did not obtain oil or gas. The logs of these wells are not now available.

In 1912 a test well was drilled on the Stevenson lease, in the SW. $\frac{1}{4}$ of SE. $\frac{1}{4}$ Sec. 14, T. 7 N., R. 7 W. The log of this well, which was drilled to a depth of 1,960 feet, is given below.

Log of Stevenson No. 1 well, in the southwest corner of the SE. $\frac{1}{4}$ Sec. 14, T. 7 N., R. 7 W.

	Depth in feet
Clay and gravel.....	0- 9
Quicksand.....	9- 17
Hard lime.....	17- 60
Shells and slate.....	60- 70
Lime.....	70- 150
Shells and lime.....	150- 290
Hard lime.....	290- 350
Slate.....	350- 375
Shells and lime.....	375- 390
Hard lime.....	390- 600
Shells and slate.....	600- 610
Hard lime.....	610- 760
Sharp sand; show of oil.....	760- 780
Hard lime.....	780- 812
Slate; 10-inch casing set at 815 feet.....	812- 835
Lime.....	835- 838
Slate.....	838- 910
Lime, slate and shells.....	910-1170
Hard lime.....	1170-1190
Slate.....	1190-1335
Hard white shell.....	1335-1345
Shelly shale.....	1345-1360
Soft slate.....	1360-1365
Hard lime.....	1365-1369
Hard white sand; show of oil rainbow.....	1369-1410
Lime streaked.....	1410-1508
Hard lime.....	1508-1539

	Depth in feet
Black slate.....	1539-1608
Hard sandy lime; two showings of oil rainbow.....	1608-1775
Black shale.....	1775-1840
Hard sand, dark and light.....	1840-1960

The tools were lost at 1,960 feet, and the hole was plugged and abandoned. After the 10-inch casing was set at 815 feet no water was encountered, and water had to be supplied for the drill. The showing of oil reported at 760 feet is said to have consisted of a skim of oil on the slush pond and along the drain. The showings of oil reported at 1,410 and 1,775 feet were said to be not so good as the showing at 760 feet. It is not now possible to ascertain whether or not the reports of these showings were well founded.

Despite the "lime" reported at several horizons, the well was no doubt finished in the Atoka formation. Further drilling on the Menifee syncline is not advisable.

OKAY SYNCLINE

Location.—The Okay syncline is forked, splitting into westward-extending north and south prongs at about the center of Sec. 31, T. 11 N., R. 16 W., from which point the main axis extends eastward to the center of Sec. 30, T. 11 N., R. 15 W. The axis of the north prong continues from its junction with the handle of the fork north-westward to the northeast corner of Sec. 26, T. 11 N., R. 18 W., and the south prong extends slightly south of west to the northwest corner of Sec. 1, T. 10 N., R. 18 W.

Structural features.—The Okay syncline is bounded on the north by the Dabney anticline and on the south by the Evans Mountain and Latham anticlines, and its two prongs enclose the Okay anticline. The surface rocks belong to the Atoka formation.

The syncline, which is not prominent, is essentially symmetrical throughout, although the dips north of the axis of the north prong, which average between 3 and 4 degrees, are somewhat higher than those south of that axis, where the average dip is less than 3 degrees. The dips on either side of the main axis average about 4 degrees, but those of the south prong are slightly lower and are possibly somewhat higher south than north of its axis.

Exploration.—This compound syncline has not been tested for oil and gas, and its structure is unfavorable to their accumulation. Future exploration in this region should be centered on the anticlines, and such synclinal areas as this one should be avoided.

OUITA SYNCLINE

Location.—The Ouita syncline is forked, its prongs extending westward and northwestward from their point of divergence in the SW. $\frac{1}{4}$ Sec. 21, T. 8 N., R. 20 W. The axis of the south fork extends westward to the E. $\frac{1}{2}$ Sec. 29, T. 8 N., R. 21 W., where its course is obscured by the alluvium of the Arkansas River. The handle continues from the point of its junction with the prongs eastward to Sec. 31, T. 8 N., R. 19 W. The northern prong extends northwestward from the handle at least to the N. $\frac{1}{2}$ Sec. 30, T. 9 N., R. 21 W., and probably continues into the Clarksville syncline.

Structural features.—The south fork and handle of the Ouita syncline are bounded on the south by the Russellville anticline. The Dover anticline bounds the syncline north of the north fork and handle. The Knoxville anticline lies between the two forks.

The Spadra shale is the surface rock from the junction of the two forks of the syncline westward along the axis of the south fork to a point southwest of Mill Creek, where the Fort Smith formation is exposed over an area of several square miles. The handle of the syncline is marked by an eastward-trending tongue of Hartshorne sandstone, and the north fork has preserved some of the Hartshorne sandstone near the handle. West of Illinois Ridge an eastward-trending tongue of Spadra shale has been preserved along the axis. The surface rock elsewhere belong to the Atoka formation.

The dips on the sides of the handle and on the south fork are fairly low, those of about 5 degrees being most common.

The syncline is slightly asymmetrical, however, for the southerly dips north of the axis average somewhat higher than the northerly dips south of the axis. In fact, the dips increase away from the axis of the south fork as the axis of the Knoxville anticline is approached, and north of the Mill Creek-London highway they are generally higher than 10 degrees.

The north fork of the syncline is perhaps more symmetrical than the south fork, but the northerly dips south of its axis average slightly higher than those north of it. Dips of 4 to 7 degrees are most common north of its axis, and dips of 5 to 9 degrees are common south of it.

Exploration.—This compound syncline has not been drilled except for coal, and any project to test it for oil or gas should be discouraged.

PARIS SYNCLINE

Location.—The axis of the Paris syncline extends from about the SE. $\frac{1}{4}$ Sec. 36, T. 8 N., R. 29 W. very slightly south of east to the center Sec. 1, T. 7 N., R. 22 W.

Structural features.—The Paris syncline is bounded on the north by the Aetna and Prairie View anticlines and on the south by the Game Hill and Pine Ridge anticlines. The surface rocks belong chiefly to the Spadra, Fort Smith, and Paris formations, but the Hartshorne sandstone occurs on the south limb of the structure and on the north flank south of the Prairie View anticline. The Savanna formation caps Short and Little Short Mountains near the town of Paris.

The syncline is markedly asymmetrical, the dips south of the axis being considerably higher than those north of it, but near the synclinal axis the asymmetry is not pronounced. The dips north of the axis range from 2 to 14 degrees and average about 5 degrees; those south of it range from 2 to 90 degrees, and at some places, as south of Paris, the beds are overturned. The dips increase rapidly away from the synclinal axis toward the bounding anticlines on the south, but the increase away from the axis toward the north is very gradual. The syncline becomes much less pronounced toward its ends.

The deepest part of the syncline is the Paris basin, where the Hartshorne coal lies at least 1,250 feet beneath the surface, or possibly deeper. In the general Paris area the structure is well expressed topographically by the Short Mountains, which are typical mesa-like synclinal hills. At the west end of the syncline, as here described, the synclinal axis is vaguely defined. It lies along the same general line as the Lavaca syncline, and the two may be parts of a single syncline. At its east end the course of the Paris syncline is lost beneath the alluvium of Arkansas River, so that it is impossible to tell whether the Paris syncline is a continuation of either the Ouita or the Shinn synclines or is separate from both.

Exploration.—In 1917-1919 the McDonough Oil and Gas Company drilled a well to a depth of 2,700 feet on the John Ford lease, in Sec. 27, T. 8 N., R. 28 W., a short distance north of the axis of the syncline, but obtained neither oil nor gas. The log of this well is not available.

In 1915 the Paris Mineral Oil and Gas Company drilled to a depth of 1,677 feet in the NW. $\frac{1}{4}$ SE. $\frac{1}{4}$ Sec. 36, T. 8 N., R. 26 W., a short distance north of the synclinal axis, but obtained neither oil nor gas. The log of this well is given below.

Log of the Paris Mineral Oil and Gas Company's well, in the center of the north line of the NW. $\frac{1}{4}$ SE. $\frac{1}{4}$ Sec. 36, T. 8 N., R. 26 W.

	Depth in feet
Kidney slate.....	0- 15
Slate.....	15- 25
Hard sand rock.....	25- 58
Black shale.....	58- 98
Hard rock.....	98- 102

	Depth in feet
Hard shale.....	102- 142
Sand rock.....	142- 222
Slate.....	222- 322
Sand and slate.....	322- 722
Sand and rock.....	722- 802
Slate.....	802- 862
Hard sand rock.....	862- 874
Sand and slate.....	874-1034
Gray sand.....	1034-1124
Hard sandstone.....	1124-1671
Shale.....	1671-1677

It is interesting to note that no coal is recorded in this log, though undoubtedly several beds of coal were encountered. According to reports filed with the Arkansas Geological Survey, this well was carried to a depth of 2,980 feet in 1921, but the log of its lower part is not available. Neither oil nor gas was obtained. No future exploration of this syncline is desirable.

PAYNE SYNCLINE

Location.—The axis of the Payne syncline extends from the SW. $\frac{1}{4}$ Sec. 25, T. 11 N., R. 26 W. eastward to about the center of Sec. 32, T. 11 N., R. 18 W.

Structural features.—The Payne syncline is bounded on the north by the Ozone and Treat anticlines and by the east end of the Watalula anticline and on the south by the Linville and Retta anticlines. The east end of the syncline may be continuous with the south fork of the Okay syncline, but the field evidence is not conclusive on this point.

The structure is asymmetrical, the dips on the south limb being somewhat higher than those on the north. The dips south of the axis range from 2 to 15 degrees but average less than 5 degrees; those north of the axis range from 2 to 10 degrees but average less than 4 degrees. In the area south of Ozone the dips on either side of the axis are much steeper than at any other place along the syncline.

Exploration.—The Payne syncline has not been tested for oil or gas, and future exploration should be so directed as to avoid this and similar synclines.

PEARSON SYNCLINE

Location.—The axis of the Pearson syncline extends from about the SW. $\frac{1}{4}$ Sec. 20, T. 8 N., R. 13 W. northeastward to about the center of Sec. 3, T. 10 N., R. 8 W.

Structural features.—The Pearson syncline is bounded on the north by the Heber Springs anticline and on the south by the Darcy anticline. It is nowhere prominent, and most of its course is rather ill

defined. The dips on the north flank range from 2 to 10 degrees and are in general considerably higher than those on the south flank, where they range from 1 to 6 degrees but average less than 3 degrees. The syncline probably joins the Guy syncline at its west end, but the alluvium of the North Fork of Cadron Creek, which roughly follows the synclinal axis, obscures the structural details.

Exploration.—In 1921-1923 the Heber Oil and Gas Company drilled a well to a depth of 1,591 feet on the Magness lease, in the NW. $\frac{1}{4}$ of the NE. $\frac{1}{4}$ Sec. 14, T. 10 N., R. 9 W., but obtained neither oil nor gas in commercial quantities. In 1923-1925 the Cleburne Oil, Gas and Mining Company drilled another well on the same lease 600 feet southwest of the first. The depth of the second well is not known, but it also was unsuccessful. Its log is essentially the same as that of Magness No. 1, which is given below.

Log of Magness No. 1 well, drilled in the NW. $\frac{1}{4}$ NE. $\frac{1}{4}$ Sec. 14, T. 10 N., R. 9 W., Cleburne County.

	Depth in feet
Soil; yellow clay.....	1- 6
Water sand.....	6- 21
Black slate.....	21- 36
Black lime.....	36- 48
Broken lime; shelly.....	48- 80
Soft coal.....	80- 84
Broken lime.....	84- 90
Lime and boulders.....	90-114
Gray hard lime.....	114-168
Black pack sand.....	168-188
Gray lime.....	188-326
Black shale.....	326-350
White sandy grit formation.....	350-490
Black grit slate formation.....	490-520
Gray lime, hard.....	520-600
Gray hard sand.....	600-630
Blue and brown sand, hard; some water.....	630-715
Slate formation, sandy.....	715-725
Gray sandy lime.....	725-731
Brown sand; soft sugar effect; oil and gas.....	731-745
White lime formation.....	745-765
Blue or brown shale.....	765-800
White lime formation.....	800-805
Blue shale, soft.....	805-870
White lime, hard.....	870-895
Water sand formation.....	895-950
Blue shale, hard.....	950-998
Dark limestone, hard.....	998-1008
Blue shale, soft.....	1008-1052
Dark limestone, hard.....	1052-1080
Blue shale, soft.....	1080-1105
White lime, hard.....	1105-1125
Blue shale.....	1125-1145

	Depth in feet
White lime, hard.....	1145-1170
White shale.....	1170-1188
Sandy formation.....	1188-1235
Water sand.....	1235-1292
Gray lime, hard.....	1292-1298
Black slate, grit.....	1298-1370
Dark sand, broken; gas.....	1370-1375
Dark sandy formation, hard.....	1375-1400
White slate.....	1400-1485
White lime, hard.....	1485-1503
Black slate formation; grit.....	1503-1535
White lime.....	1535-1555
Brown or black formation.....	1555-1587
White lime formation; on top oil sand.....	1587-1591

In the absence of the well cuttings it is impossible to say definitely what formations were encountered by the drill, but despite the appearance of "lime" in the record at a number of horizons it is unlikely that the Atoka formation was completely penetrated.

Granting that oil and gas may accumulate in a syncline in which the sands are water-free, the Pearson syncline has perhaps been adequately tested, and the results of the tests do not encourage future exploration.

PERRYVILLE SYNCLINE

Location.—The axis of the Perryville syncline extends from about the SE. $\frac{1}{4}$ Sec. 19, T. 4 N., R. 17 W. northeastward to about the center of Sec. 3, T. 4 N., R. 14 W.

Structural features.—The Perryville syncline is bounded on the north by the Redemption anticline and on the south by the Wye and Palarm anticlines. The surface rocks belong to the Atoka formation, and the syncline is rather poorly expressed topographically by the valley of Fourche la Fave River. At its west end the syncline is apparently somewhat offset from the Fourche la Fave syncline, but more detailed examination may show that the two are continuous.

The Perryville syncline, which is rather closely folded, is asymmetrical, its south limb being steeper than its north limb. The dips on the north limb range from 5 to 65 degrees but show little diminution toward the synclinal axis; those on the south limb range from 8 to 80 degrees, and in places the beds may be overturned. The dips diminish regularly toward the east on both sides of the axis.

Exploration.—The Perryville syncline is structurally unfavorable for the accumulation of oil or gas and its exploration is inadvisable.

PHILPOTT SYNCLINE

Location.—The axis of the Philpott syncline extends from its point of junction with the Alston syncline, in the NW. $\frac{1}{4}$ Sec. 3, T. 9 N.,

R. 27 W., northeastward in an undulating course to a point about a mile north of Harmony, from which point it continues southeastward to about the SE. $\frac{1}{4}$ Sec. 13, T. 10 N., R. 22 W. The west end of the syncline is somewhat indefinite.

Structural features.—The Philpott syncline is bounded on the north by the White Oak, Watalula, and Linville anticlines, and on the south by the Ozark and Ludwig anticlines. The surface rocks belong to the Atoka, Hartshorne, Spadra, and Fort Smith formations. The younger beds are exposed in the deepest part of the syncline, south of Mulberry Mountain; the older beds are exposed in its eastern part and around the edges of the younger formations in the western part. Near its west end the syncline is fairly well expressed topographically by the Philpott basin, north of Philpott Ridge, but the topography near its east end is only a very poor reflection of the syncline.

The Philpott syncline, which is the northernmost prominent one north of Arkansas River in Arkansas, is markedly asymmetrical throughout most of its course. The dips on the north flank range from 2 to 23 degrees and inclinations of more than 12 degrees are relatively common; the dips on the south flank range from 2 to 12 degrees and probably average not more than 6 degrees.

Exploration.—Although the syncline has been rather extensively drilled to shallow depths in prospecting for coal, neither oil nor gas has been obtained in any of the tests. No exploration for the purpose of finding oil or gas has been made, however, and as the syncline is unfavorable to their accumulation, future drilling should be confined to other and more promising areas.

PONTOON SYNCLINE

Location.—The axis of the Pontoon syncline extends from the E. $\frac{1}{2}$ Sec. 10, T. 5 N., R. 19 W. northeastward to the SW. $\frac{1}{4}$ Sec. 28, T. 6 N., R. 17 W.

Structural features.—The Pontoon syncline is bounded on the north by the Atkins anticline and the west end of the Morrilton anticline and on the south by the east end of the Ranger anticline and by the Ada anticline. The exact course of the syncline is obscured at its east end by the alluvium of Arkansas River and at its west end by the bottoms of Petit Jean River, but it may be a continuation of the Centerville syncline, to the west. The surface rocks belong to the Hartshorne sandstone, which caps Petit Jean Mountain, and to the Atoka formation, which crops out on the lower slopes and the lowlands at both ends of the syncline.

The Pontoon syncline is well expressed topographically by the northern part of Petit Jean Mountain, which is a mesa-like eminence

drained by a westward-flowing stream that practically follows the axis of the syncline. Cedar Falls (see Pl. XL) is also near the synclinal axis at the west end of the mountain.

The north flank of the syncline is much longer than the south. The dips north of the axis range from 2 to 14 degrees but probably average less than 5 degrees; those south of the axis range from 4 to 12 degrees and average about 7 degrees. The dips near the axis of the syncline, however, are considerably higher on the south than on the north flank. This fact is expressed topographically by the long, gentle slope from Cedar Creek to the north escarpment of the mountain and by the shorter, steeper rise between the stream and the southern edge of the mountain.

Exploration.—The syncline has not been tested for oil or gas and is structurally unfavorable to their accumulation.

POTEAU SYNCLINE

Location.—The axis of the Poteau syncline extends from about the center of Sec. 13, T. 3 N., R. 33 W. northeastward in an undulating course to the SE. $\frac{1}{4}$ Sec. 13, T. 5 N., R. 18 W., where it is apparently somewhat offset from the west end of the Menifee syncline, though the two lie along the same structural line and may be continuous. The syncline also extends into Oklahoma for a distance of about 20 miles.

Structural features.—The Poteau syncline is bounded on the north by the Hartford, Ranger, and Ada anticlines, and on the south by the Choctaw, Hon, Dutch Creek, and Casa anticlines. The surface rocks range from the Atoka to Savanna formations, inclusive, the older beds being exposed in the central and eastern areas and the youngest on the summit of Poteau Mountain, near the Oklahoma boundary. The Poteau syncline is well expressed topographically by Poteau, Round, White Oak, and Petit Jean¹² Mountains, which lie along the synclinal axis in Sebastian and Scott counties, and by the horseshoe-shaped Alpin Ridge and the southern part of Petit Jean Mountain in Yell, Perry, and Conway counties. Between the two areas mentioned above, however, the course of Petit Jean River roughly coincides with that of the axis of the syncline, so that the topographic expression of the structure ranges from synclinal mountains at the ends to a valley near the middle.

Throughout most of its course the south flank of the syncline is shorter than the north flank, and the dips south of the axis are somewhat higher than those north of it. The asymmetry of the syncline, however, is generally not great, and north of Ola and Casa the north

¹² There are two Petit Jean mountains in Arkansas, one southwest of Morrilton and the one referred to above, which is northeast of Waldron.



CEDAR FALLS, ON PETIT JEAN MOUNTAIN

The falls are about 105 feet high, and the cauldron-like basin into which the water descends is rimmed with massive beds of sandstone of the upper part of the Atoka formation, but the beds below the overhanging ledge are more shaly. The Hartshorne sandstone crops out higher on the mountain and is not shown in this view.

limb is not only shorter than the south, but the dips north of the axis probably average somewhat higher than those south of it. Although the axis gradually rises toward the east, the Hartshorne sandstone is brought low enough near its east end to cap Petit Jean Mountain.

Exploration.—At several places the Poteau syncline has been drilled to relatively shallow depths in prospecting for coal, but neither oil nor gas has been found by these tests. In addition, a shallow well was drilled in Sec. 4, T. 4 N., R. 24 W. to a depth of 645 feet, but this also was unsuccessful. The log of the well follows.

Log of well north of Dutch Creek in Sec. 4, T. 4 N., R. 24 W.

	Depth in feet
Sand rock.....	0- 5
Shale.....	5- 40
Gravel and water.....	40- 50
Sand and grit.....	50- 160
Shale, dark.....	160- 190
Sand.....	190- 205
Shale, light.....	205- 265
Sand.....	265- 355
Gritty shale.....	355- 375
Shale.....	375- 480
Sand.....	480- 560
Very gritty shale.....	560- 630
Fine shale.....	630- 645

Further exploration of the Poteau syncline for oil or gas is not advisable.

PRESTON SYNCLINE

Location.—The axis of the Preston syncline extends from the center of Sec. 2, T. 4 N., R. 14 W., northeastward to the NW. $\frac{1}{4}$ Sec. 22, T. 5 N., R. 13 W.

Structural features.—The Preston syncline is bounded on the northwest by the Redemption anticline and on the southeast by the Bayou Meto anticline. The surface beds at the top of Round Mountain probably belong to the Hartshorne sandstone and represent the easternmost extent of that formation; the beds exposed on the lower slopes of the mountain belong to the Atoka formation. The mountain itself is a topographic expression of the Preston syncline and of a part of the Cato syncline. The Preston syncline may be regarded as the north fork of the Perryville syncline and the Cato syncline as its elongated south fork.

The dips on the northwest flank of the syncline range from 3 to 21 degrees and become higher toward the northwest; those on the southeast flank range from 8 to 16 degrees and also become higher away from the synclinal axis. In fact, Round Mountain is surrounded

by a number of ridges composed of inward dipping beds, the dips of all of which decrease inward.

Exploration.—The Preston syncline has not been drilled for oil or gas and is structurally unfavorable for their accumulation.

RAGON SYNCLINE

Location.—The axis of the Ragon syncline extends from the NE. $\frac{1}{4}$ Sec. 1, T. 11 N., R. 26 W. eastward to the SW. $\frac{1}{4}$ Sec. 32, T. 12 N., R. 23 W., where it is apparently somewhat offset from the west end of the Solo syncline, though the two synclines are closely related.

Structural features.—The Ragon syncline is bounded on the north by the Yale anticline and on the south by the Ozone anticline. The surface rocks belong to the Atoka formation.

The syncline is somewhat asymmetrical, the dips south of the axis being slightly higher than those north of it, but the syncline is not prominent and all the dips are relatively low. The dips north of the axis are rarely more than 4 degrees, and those south of it are rarely more than 7 degrees.

Exploration.—No wells have been drilled on the Ragon syncline, which should be avoided in future exploration.

RUDY SYNCLINE

Location.—The axis of the Rudy syncline extends from the S. $\frac{1}{2}$ Sec. 9, T. 9 N., R. 32 W. northeastward to the NW. $\frac{1}{4}$ Sec. 24, T. 10 N., R. 31 W.

Structural features.—The Rudy syncline is bounded on the north by the Cedarville anticline and on the south by the Roland and Rudy anticlines.

The syncline is not markedly asymmetrical, but its north limb is somewhat steeper than its south. The dips north of the axis range from 2 to 9 degrees and average about 5 degrees; those south of the axis range from 2 to 7 degrees and average about 3 degrees. The dips on the south limb are irregular and at some places the beds are inclined to the south.

Exploration.—The Rudy syncline is structurally unfavorable to the accumulation of oil or gas and its exploration is not advisable.

SCOTLAND SYNCLINE

Location.—The axis of the Scotland syncline extends from the SW. $\frac{1}{4}$ Sec. 18, T. 10 N., R. 16 W. northeastward, approximately through Scotland and Clinton, at least to the SE. $\frac{1}{4}$ Sec. 1, T. 12 N., R. 10 W., and it may continue in that direction, but the area north of T. 12 N. was not surveyed.

Structural features.—The Scotland syncline is bounded on the north by the Latham and Shirley anticlines and on the south by the Clinton anticline. This syncline is evidently a part of the structural feature described by Newsom¹³ as the Clinton monocline, but the axis of that feature as located by Newsom coincides neither with that of the Shirley nor that of the Latham anticline, nor with that of the Scotland syncline as described in this report, although its structural trend is not far removed from that of the Scotland syncline.

The Scotland syncline is asymmetrical, the dips north of the axis being higher than those south of it. The dips on the north flank range from 4 to 20 degrees and in places near faults are still higher; those on the south flank range from 2 to 6 degrees. The dips on both sides of the axis tend to decrease toward the east, especially in the area east of the village of Shirley. Several faults parallel the synclinal axis on the north flank. The dips near these faults are generally more than 10 degrees, but the displacement of all of them is thought to be small, though it can not be determined because of the similarity of the beds involved. The syncline gradually dies out west of Scotland.

Exploration.—The Scotland syncline has not been tested for oil or gas and is structurally unfavorable to their accumulation.

SCRANTON SYNCLINE

Location.—The axis of the Scranton syncline extends from about the center of Sec. 15, T. 8 N., R. 25 W., eastward to about the SW. $\frac{1}{4}$ Sec. 11, T. 8 N., R. 23 W., but its exact eastern extent is made uncertain by the alluvium in the Arkansas River Valley.

Structural features.—The Scranton syncline is bounded on the north by the Spadra and Big Danger faults and on the south by the Prairie View anticline. The surface rocks belong to the Spadra, Fort Smith, and Paris formations. The beds of the Paris formation are exposed in the deepest part of the syncline, south of Morrison Bluff. The eastern part of the syncline is mantled with recent deposits of Arkansas River.

The syncline is a broad, asymmetrical basin in which the dips south of the axis are higher than those north of it, but near the axis itself the asymmetry is not great. The dips north of the axis range from 2 to 13 degrees, although dips as high as 13 degrees are rare; those south of the axis range from 2 to 15 degrees and probably average 7 degrees.

Exploration.—A number of shallow wells have been drilled on this syncline in prospecting for coal, but in none of these tests has either

¹³ Newsom, J. E., *Am. Geologist*, vol. 20, pp. 11-13, 1897.

oil or gas been obtained. In addition, Prall and Hickey, in 1922, drilled a well to a depth of 1,430 feet on the Graves lease, in the SE. $\frac{1}{4}$ of the SW. $\frac{1}{4}$ Sec. 14, T. 8 N., R. 25 W., essentially on the axis of the syncline, but the well was unsuccessful. Further exploration of this syncline for oil or gas is inadvisable.

SHINN SYNCLINE

Location.—The axis of the Shinn syncline extends from the vicinity of Old Norristown, in the SE. $\frac{1}{4}$ Sec. 19, T. 7 N., R. 20 W., eastward and then slightly northeastward across T. 7 N., Rs. 19 and 18 W. to the bottom land northeast of Blackville, where its course is obscured by alluvium.

Structural features.—At its west end the Shinn syncline lies between the Pine Ridge anticline on the south and the Russellville anticline on the north, but farther east the Atkins anticline appears on the south and the Solgohachia anticline on the north. The Shinn syncline may be the western extension of the Greenbrier syncline, but it has been impossible to connect the two owing to the lack of exposures in the Point Remove Creek bottoms.

The syncline plunges to the west, and the surface rocks south of Russellville therefore consist of a rim of Hartshorne sandstone surrounding a small central area of Spadra shale, an area known to coal operators as the Shinn basin. East of Sec. 26, T. 7 N., R. 20 W., the Atoka is the surface rock on the syncline.

In the western part of the syncline—that is, between Norristown and Pottsville—the rocks on the south limb stand at high angles and in places may be overturned, the dips averaging 30 to 40 degrees. The dips decrease eastward and also toward the axis of the limiting syncline. From Pottsville eastward to the point where the syncline crosses Point Remove Creek the dips generally are not so high on the south limb, but they increase rapidly toward the axis of the Atkins anticline. The dips south of the axis of the syncline are generally less than 10 degrees.

The dips north of the synclinal axis are uniformly less than those south of it. In the Shinn basin proper the dips are ordinarily less than 10 and more than 5 degrees to the south. East of Pottsville the dips diminish slightly, but an inclination of 6 degrees southward is rather common.

Exploration.—Several test wells have been drilled for coal in the Shinn basin proper. Shafts show that the maximum depth to the coal is more than 600 feet. No oil or gas was found in this exploration work.

In 1919-1920 the Quinton Oil and Gas Company drilled a test well

to a depth of 1,630 feet in Sec. 1, T. 7 N., R. 18 W., which is about a mile north of the synclinal axis, but found neither oil nor gas. Further exploration of this syncline for oil or gas is not justified.

SIXMILE SYNCLINE

Location.—The axis of the Sixmile syncline extends from about center of Sec. 22, T. 7 N., R. 28 W. northeastward to the NW. corner of Sec. 14, T. 7 N., R. 27 W.

Structural features.—The Sixmile syncline is bounded on the north by the Game Hill anticline and on the south by the Pine Ridge anticline. The surface rocks belong to the Fort Smith formation. The axis of the syncline throughout most of its length is roughly paralleled by the valley of Sixmile Creek, which is the most pronounced topographic expression of the syncline.

The syncline is asymmetrical, the dips south of the axis being higher than those north of it. The dips north of the axis range from 2 to 10 degrees; those south of it range from 2 to 35 degrees, although dips as high as 35 degrees are unusual.

Exploration.—The Sixmile syncline is structurally unfavorable to the accumulation of oil or gas, and its exploration is not advisable.

SLASH RIDGE SYNCLINE

Location.—The axis of the Slash Ridge syncline extends from the SW. $\frac{1}{4}$ Sec. 7, T. 8 N., R. 29 W. northeastward to the SW. $\frac{1}{4}$ Sec. 3, T. 8 N., R. 29 W.

Structural features.—The Slash Ridge syncline is bounded on the north by the Mill Creek fault and on the south by the Vache Grasse anticline. The surface rocks belong to the Spadra and Fort Smith formations.

This syncline, which extends eastward from the Massard fault line, is essentially symmetrical. The dips north of the axis range from 2 to 4 degrees; those south of it range from 1 to 4 degrees.

Exploration.—This syncline has not been tested for oil or gas, and it is structurally unfavorable for their accumulation.

SMITH CREEK SYNCLINE

Location.—The axis of the Smith Creek syncline extends from the SE. $\frac{1}{4}$ Sec. 1, T. 8 N., R. 28 W. northeastward at least to the SW. $\frac{1}{4}$ Sec. 29, T. 9 N., R. 26 W., and may continue still farther in that direction, but in the eastern part of its course it is not only ill-defined but is somewhat obscured by alluvium.

Structural features.—The Smith Creek syncline is bounded on the north by Altus syncline and on the south by Aetna anticline. The

surface rocks belong chiefly to the Hartshorne sandstone, but the Spadra shale is exposed on the northern border of the syncline.

The syncline, which is at no place particularly prominent, is slightly asymmetrical. The dips on the north flank range from 1 to 5 degrees and probably average about 3 degrees; those on the south flank range from 2 to 8 degrees and average between 4 and 5 degrees.

Exploration.—In 1915 Hutchinson and Decies drilled a well to a depth of 2,000 feet on the L. D. Terry lease, in the NW. $\frac{1}{4}$ of the SW. $\frac{1}{4}$ Sec. 34, T. 9 N., R. 27 W., about half a mile north of the synclinal axis, but obtained neither oil nor gas in commercial quantities. The log of this well is no longer available.

Further exploration of the Smith Creek syncline should not be undertaken.

SOLO SYNCLINE

Location.—The axis of the Solo syncline extends from the NE. $\frac{1}{4}$ Sec. 35, T. 12 N., R. 23 W., slightly south of east to the N. $\frac{1}{2}$ Sec. 28, T. 11 N., R. 18 W., where its east end is apparently somewhat offset from the west end of the north fork of the Okay syncline.

Structural features.—The Solo syncline is bounded on the north by the Dabney anticline and on the south by the Treat anticline. The surface rocks belong to the Atoka formation.

The syncline is nowhere very prominent, but in the vicinity of Treat the dips on either side of the axis range from 4 to 12 degrees. The dips elsewhere are generally less than 5 degrees. The syncline is only slightly asymmetrical, but the dips on the north limb probably average somewhat higher than those on the south.

Exploration.—The syncline has not been tested, and any attempt to explore it should be discouraged.

SUGARLOAF SYNCLINE

Location.—The axis of the Sugarloaf syncline extends from the Oklahoma boundary near the NW. $\frac{1}{4}$ Sec. 6, T. 4 N., R. 32 W., northeastward to the northwest corner of Sec. 22, T. 5 N., R. 30 W.

Structural features.—The Sugarloaf syncline is bounded on the north by Washburn anticline and on the south by Hartford anticline. The surface rocks range from the Atoka to the Savanna formation. The oldest beds are exposed east of Huntington and the youngest cap Sugarloaf Mountain, near the Oklahoma line.

The syncline is rather asymmetrical, the dips on the south flank averaging higher than those on the north flank, but the asymmetry near the synclinal axis itself is inconspicuous. The dips on the north flank range from 3 to 25 degrees; those on the south flank range from 3 to 30 degrees. On both flanks the dips increase regularly from the

synclinal axis toward the axes of the limiting anticline. The axis of the syncline plunges toward the west, so that the Hartshorne coal probably lies 2,000 feet beneath the summit of Sugarloaf Mountain.

Exploration.—A large number of shallow wells have been drilled on the Sugarloaf syncline in exploration for coal, but none has found either oil or gas. No well has been drilled for the avowed purpose of finding oil or gas, however, and exploration of the syncline is not advisable.

THORNBURG SYNCLINE

Location.—The axis of the Thornburg syncline extends from about the SW. $\frac{1}{4}$ Sec. 3, T. 4 N., R. 17 W. slightly south of east to the NE. $\frac{1}{4}$ Sec. 18, T. 3 N., R. 15 W.

Structural features.—The Thornburg syncline is bounded on the north by the Wye anticline, but the limiting structure on the south has not been definitely determined. The surface rocks belong to the Atoka formation.

The syncline is asymmetrical, its south limb being steeper than its north. The dips north of the axis range from 30 to 50 degrees; those south of it range from 30 to 85 degrees, and in places the beds are probably overturned.

Exploration.—The Thornburg syncline has not been tested for oil or gas, and its structure is unfavorable for their accumulation. Its exploration is inadvisable.

TURNERSVILLE SYNCLINE

Location.—The axis of the Turnersville syncline extends from an indefinite location approximately in the S. $\frac{1}{2}$ Sec. 6, T. 10 N., R. 21 W., southeastward to the SW. $\frac{1}{4}$ Sec. 33 T. 10 N., R. 19 W.

Structural features.—The Turnersville syncline is bounded on the south by the Silex anticline and by the west end of the Clinton anticline, and on the north by the essentially parallel east end of the Linville anticline.

The syncline is relatively pronounced in its extreme western part. It is slightly asymmetrical, the dips on the north limb averaging somewhat higher than those on the south. The dips on the south limb range from 5 to 15 degrees and those on the north limb from 5 to 25 degrees. The dips tend to decrease toward the axis, but the decrease is not pronounced.

The west end of the syncline is offset several miles from the east end of the Philpott syncline, but the two are structurally closely related.

Exploration.—The Turnersville syncline has not been tested for oil or gas and should not be explored for those products.

UNIONTOWN SYNCLINE

Location.—The axis of the Uniontown syncline extends from the Oklahoma boundary at the NE. $\frac{1}{4}$ Sec. 13, T. 10 N., R. 33 W., northeastward to the NE. $\frac{1}{4}$ of Sec. 3, T. 10 N., R. 32 W.

Structural features.—The Uniontown syncline is bounded on the north by the Pine Mountain anticline and on the south by the Cedarville anticline. The surface rocks belong to the Atoka formation.

The syncline is not particularly conspicuous and is essentially symmetrical, though its south limb is perhaps slightly steeper than its north. The dips north of the axis range from 2 to 7 degrees; those south of it range from 2 to 8 degrees; but there are many irregular dips on both limbs.

Exploration.—The Uniontown syncline is structurally unfavorable for the accumulation of oil or gas, and its exploration is considered inadvisable.

WALDRON SYNCLINE

Location.—The axis of the Waldron syncline extends from about the SE. $\frac{1}{4}$ Sec. 32, T. 3 N., R. 30 W. northeastward to about the center of Sec. 18, T. 3 N., R. 28 W., but it continues southwestward into T. 2 N., which was not surveyed in detail.

Structural features.—The Waldron syncline is bounded on the north by Choctaw and Hon anticlines, and on the south by Dutch Creek anticline. The surface rocks belong to the Atoka formation.

The syncline is not markedly asymmetrical, and its asymmetry disappears near the synclinal axis, but the dips on the south flank probably average somewhat higher than those on the north. The dips north of the axis range from 3 to 70 degrees; those south of it range from 4 to 75 degrees. The dips on both flanks increase regularly toward the axes of the delimiting anticlines.

The syncline is topographically expressed by the structural valley in which Waldron and Winfried are situated.

Exploration.—In 1922-23 the Scott County Oil and Gas Company drilled a well to a depth of 2,424 feet on the Work lease, in the NE. $\frac{1}{4}$ of NE. $\frac{1}{4}$ Sec. 35, T. 3 N., R. 30 W., but obtained neither oil nor gas in commercial quantities. The log of this well is not available. Further exploration of this syncline is not warranted.

WARLOOP SYNCLINE

Location.—The axis of the Warloop syncline extends from the SW. $\frac{1}{4}$ Sec. 9, T. 11 N., R. 30 W. northeastward to the NW. $\frac{1}{4}$ Sec. 6, T. 11 N., R. 29 W.

Structural features.—The Warloop syncline is bounded on the north by the Meadow Mountain anticline and on the south by the Moun-

tainburg anticline. The surface rocks belong to the Atoka formation.

The structure is rather noticeably asymmetrical, the north limb being considerably steeper than the south. The dips north of the axis range from 2 to 13 degrees; the dips south of it range only from 1 to 4 degrees. The syncline is relatively insignificant, however, and its east and west ends are ill defined.

Exploration.—The Warloop syncline has not been drilled for oil or gas and is structurally unfavorable for their accumulation.

WEBB CITY SYNCLINE

Location.—The axis of the Webb City syncline extends from its point of junction with the Alston syncline, in about the NW. $\frac{1}{4}$ Sec. 3, T. 9 N., R. 27 W., slightly south of east to about the center of Sec. 10, T. 9 N., R. 25 W., but its course near its east end is somewhat indefinite, and it may actually join the Clarksville syncline.

Structural features.—The Webb City syncline is bounded on the north by the Ozark anticline and on the south by the Cecil and Altus anticlines and the Coal Hill fault. The surface rocks belong to the Atoka and Hartshorne formations. The Pond Creek Hills form a minor topographic expression of the syncline.

The syncline is essentially symmetrical. The dips on both limbs range from 2 to 8 degrees and average about 4 degrees. The south limb, however, is better defined than the north.

Exploration.—The Webb City syncline is structurally unfavorable for the accumulation of oil or gas.

WHITE ROCK SYNCLINE

Location.—The axis of the White Rock syncline extends from about the NW. $\frac{1}{4}$ Sec. 15, T. 10 N., R. 29 W. northeastward to the NW. $\frac{1}{4}$ Sec. 29, T. 11 N., R. 27 W.

Structural features.—The White Rock syncline is bounded on the north by Jethro anticline and on the south by Watalula anticline. The surface rocks belong chiefly to the Hartshorne sandstone, but the Atoka formation is exposed over small areas near the northeast end of the syncline.

The syncline, which is ill defined at both ends, is essentially symmetrical, but the dips north of the axis apparently average somewhat higher than those south of it. The dips on the north limb range from 2 to 7 degrees and average about 4 degrees; those on the south limb range from 2 to 5 degrees and average between 3 and 4 degrees.

Exploration.—The White Rock syncline is structurally unfavorable for the accumulation of oil or gas.

FAULTS

GENERAL FEATURES

There are numerous faults in the Arkansas Valley province, but most of them unimportant in the search for oil or gas. The lack of definitely marked geologic horizons in the area makes it difficult to measure the displacement on these faults, and many of them appear to be only surficial. On the other hand, the surface expression of some faults that have displacements of more than 300 feet is so slight that were it not for the evidence furnished by drill records they would probably not have been detected in the exploration of the field. Many of the faults lie in that part of the province where coal is mined, and most of them have been discovered in prospecting for or mining coal. It therefore seems reasonable to suppose that many faults, particularly of the normal type, occur in other parts of the province but have not been detected.

Thrust faulting is most common in the southern part of the province and normal faulting is common near the Boston Mountains, but in the central part of the Arkansas Valley both types are found in close proximity. Some of the thrust faults and a few of the normal faults are of considerable significance, but the displacement in normal faults is rarely more than 500 feet. Although all the faults that occur at or near anticlinal crests complicate problems of drilling, they should not condemn entirely the areas in which they occur. In fact, because of the great thickness of shale involved in many of the fault movements, most of the porous beds have probably been effectively sealed along the fault plane. Such faults may have served to localize the accumulation of oil and gas.

The surprising feature of the Arkansas Valley is that, despite the close folding to which it has been subjected in some places, it is not more extensively faulted. No doubt many faults have not been discovered, but in some parts of the province, such as the area north of Little Rock, the continuity of the ridges precludes the possibility of great faulting.

Numerous faults, either surficial or local, have been noted in connection with the descriptions of the anticlines or synclines on whose flanks they occur, and the major faults have been indicated on the structural map and are described in alphabetical order in the following pages.

ALTUS FAULT

The Altus fault, described by Collier¹⁴ as passing through the town of Altus, was not observed in the course of the field work done for this report. According to Collier, however, the fault was located

¹⁴ Collier, A. J., U. S. Geol. Survey Bull. 326, p. 45, 1907.

only by observing the distribution of formations at the surface and the difference in the elevation of the Hartshorne sandstone on hills north and south of Altus. The features observed can also be explained by postulating the existence of an anticlinal axis along the so-called fault line, and they are thus accounted for here. It is possible, however, that the anticline may have a normal fault near its crest. If so the downthrown side of the fault is south of its surface trace, and the displacement may amount to as much as 250 feet, though it is probably less than 100 feet.

The position of this possible fault is indicated on the map by the course of the Altus anticline.

BACKBONE FAULT

Location.—The trace of the Backbone fault extends from the Oklahoma boundary, in Sec. 5, T. 6 N., R. 32 W., eastward to the N. $\frac{1}{2}$ Sec. 1, T. 6 N., R. 31 W., but the fault continues westward into Oklahoma.

Structural features.—The trace of the Backbone fault and the axis of the Backbone anticline are practically coincident, but the anticlinal axis at most places lies a short distance south of the fault.

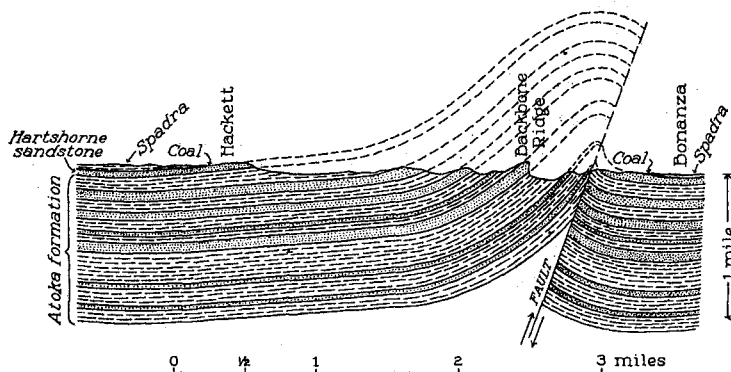


FIGURE 22.—The high angle Backbone thrust fault in section from south to north near the Oklahoma line. (Modified after Collier.)

The fault is unusual in that its plane is inclined at a high angle although the fault is of the thrust type. The downthrown side of the fault is on the north, and the maximum displacement in Arkansas is nearly 5,000 feet, so that the lower Atoka has been brought into contact with the Hartshorne sandstone. The displacement decreases in amount from the Oklahoma line eastward and is small north of Greenwood. This fault is illustrated in Figure 22.

BIG DANGER FAULT

Location.—The trace of the Big Danger fault extends from the S. $\frac{1}{2}$ Sec. 21, T. 9 N., R. 24 W. eastward to about the SE. $\frac{1}{4}$ Sec. 23,

T. 9 N., R. 23 W., but throughout most of its length there is no surface indication of its presence.

Structural features.—The Big Danger fault is of the normal type, with the downthrown side south of its trace. The displacement at the east end of Spadra Hill, as indicated by drill records, is about 300 feet, but at the west end of that hill there is little or no displacement. On the western slope of Big Danger Hill, where the fault is best expressed surficially, the displacement is less than 20 feet. As the fault line crosses only the outcrop of the Sprada shale it has no marked topographic expression.

CAULKSVILLE FAULT

The Caulksville fault is a small fracture on the north flank of the Game Hill anticline, according to Collier.¹⁵ No conclusive field evidence of the existence of this fault was found in the course of the field work on which this report is based, and it is therefore not indicated on the structure map.

The fault should be of the normal type, with the downthrown side north of its trace. The displacement cannot be more than 50 feet, and it is probably less.

CHOCTAW FAULT

Location.—The trace of the Choctaw fault extends from the Oklahoma boundary at the NE. corner of Sec. 12, T. 2 N., R. 33 W. north-eastward to about the NE. $\frac{1}{4}$ Sec. 24, T. 2 N., R. 31 W., but it extends for many miles into Oklahoma, where it is one of the major structural features in the southeastern part of that State.

Structural features.—The Choctaw fault, which is of the high-angle thrust type, with its downthrown side of the north, involves only the Atoka formation in Arkansas, and consequently the exact amount of its displacement has not been ascertained. Near the Arkansas-Oklahoma boundary, however, the displacement must be great, perhaps to be measured in thousands of feet, but it diminishes toward the east and dies out several miles southwest of Hon.

The fault trace runs parallel to the axis of the Choctaw anticline, a short distance north of it. Throughout most of its course, however, it coincides with the Valley of Poteau River, along which the surface geology is in few places well enough exposed to permit its exact location.

CLARKSVILLE FAULT

Location.—The trace of the Clarksville fault extends from about the NW. corner of Sec. 27, T. 10 N., R. 24 W. southward to the N. $\frac{1}{2}$ Sec. 3, T. 9 N., R. 22 W.

¹⁵ Collier, A. J., U. S. Geol. Survey Bull. 326, p. 42, 1907.

Structural features.—The Clarksville fault is of the normal type, with the downthrown side south of its trace. The displacement northeast of Clarksville is probably more than 500 feet, for the Fort Smith sandstone has in places been brought into contact with the Hartshorne formation. The displacement, however, diminishes toward both ends of the fault, and near its east end it gradually passes into the Dover anticline.

COAL HILL FAULT

Location.—The trace of the Coal Hill fault extends from the N. $\frac{1}{2}$ Sec. 21, T. 9 N., R. 26 W. eastward to the N. $\frac{1}{2}$ Sec. 23, T. 9 N., R. 25 W.

Structural features.—The Coal Hill fault, which is of the normal type, with the downthrown side south of its surface trace, has been located by field evidence at both its east and its west end, where beds of sandstone have been displaced. Its existence between these points is attested by numerous drill records, which prove that the workable coal in the Denning district all lies south of a certain east-west line, and by the fact that in a few mines in which the workings were extended northward the fault was actually encountered.

The displacement has not been measured accurately, but as the Spadra shale has been brought against the Atoka formation, it must amount to at least 200 feet.

DOVER FAULT

Location.—The trace of the Dover fault probably extends from the NW. $\frac{1}{4}$ Sec. 24, T. 9 N., R. 21 W. southeastward to the NW. $\frac{1}{4}$ Sec. 35, T. 9 N., R. 20 W., but the fault has actually been observed at only a few places along that line.

Structural features.—The fault occurs on the south flank of the Dover anticline and is exposed in a road cut just south of the town of Dover. Despite the fairly good exposure, however, it is difficult to determine the downthrown side of the fault, but it appears to be on the north. If so, this fault differs from the usual normal fault north of Arkansas River, whose downthrown side is generally south of the trace. On the other hand, it may be a small thrust fault, but if so its angle is unusually high. Whether the fault is of the normal or thrust type, its displacement cannot be great, and it is of only slight significance.

FRISCO FAULT

Location.—The trace of the Frisco fault extends from the N. $\frac{1}{2}$ Sec. 6, T. 12 N., R. 30 W. eastward to the NW. $\frac{1}{4}$ Sec. 12, T. 12 N., R. 30 W.

Structural features.—The Frisco fault, which is of the normal type, is typical of those commonly found on the southern slopes of the

Boston Mountains. The downthrown side is south of the fault trace, and the displacement is sufficient to bring the Atoka formation into contact with the Bloyd shale in several of the deeper valleys crossed by the fault.

HARTMAN FAULT

Location.—The trace of the Hartmann fault extends from the N. $\frac{1}{2}$ of Sec. 14, T. 9 N., R. 25 W. slightly north of east to about the center of Sec. 10, T. 9 N., R. 24 W.

Structural features.—The Hartman fault was seen in the old Allen mine, northeast of Hartman, and its course has been determined by the distribution of the Hartshorne and Spadra formations in that general area. The downthrown side of the fault lies north of its surface trace, and the local displacement is sufficient to bring the Spadra shale into contact with the Atoka formation, but throughout most of the course of the fault the displacement is probably less than 100 feet. The fault appears to be of the normal type, but as its downthrown side is on the north it may be a thrust fault.

MASSARD FAULT

Location.—The trace of the Massard fault extends from the NE. corner of Sec. 32, T. 8 N., R. 31 W. northeastward to the NE. corner of Sec. 13, T. 8 N., R. 30 W. where it passes into the Slash Ridge syncline.

Structural features.—The Massard fault, whose existence throughout most of its course can only be inferred, is apparently of the normal type, with the downthrown side south of the surface trace. The displacement may be as much as 400 feet, for near the mouth of Massard Creek the Hartshorne sandstone and Fort Smith formations are in contact. From that point, however, the displacement decreases both to the northeast and to the southwest.

MAUMELLE FAULT

Location.—The trace of the Maumelle fault is thought to extend from about the NW. $\frac{1}{4}$ Sec. 33, T. 3 N., R. 14 W. southeastward to the N. $\frac{1}{2}$ Sec. 14, T. 2 N., R. 12 W., but throughout most of its course the position of the trace has been established by inference rather than by observation.

Structural features.—The fault trace is essentially coincident with the axis of the Maumelle anticline, but in most places is slightly north of it. The displacement is unknown, but it is sufficient to bring the Stanley shale up against the Atoka formation and must therefore be measured in thousands rather than in hundreds of feet. The fault is

apparently of the high-angle thrust type, and the downthrown side is north of the trace.

MILL CREEK FAULT

Location.—The trace of the Mill Creek fault extends from the S. $\frac{1}{2}$ Sec. 36, T. 9 N., R. 30 W. eastward to the northwest corner of Sec. 36, T. 9 N., R. 28 W.

Structural features.—This fault determines the position of Mill Creek, whose valley coincides essentially with its surface trace. The downthrown side of the fault, which is of the normal type, lies north of the fault line. The displacement, which has been measured by using the Hartshorne sandstone as a reference point, averages less than 100 feet. The fault is of little or no economic significance.

MULBERRY FAULT

Location.—The trace of the Mulberry fault extends from the vicinity of Van Buren, in Sec. 19, T. 9 N., R. 31 W. northeastward to about the northeast corner of Sec. 15, T. 10 N., R. 29 W. It continues southwestward from Van Buren and extends into Oklahoma for 15 miles, according to Collier.¹⁶ The alluvium of Arkansas River, however, makes it impossible to trace the fault in Arkansas west of Van Buren, and it has not been mapped in Oklahoma.

Structural features.—The Mulberry fault is of the normal type, with the downthrown side south of the surface trace. The displacement in the vicinity of Van Buren is sufficient to bring the Fort Smith formation into contact with the Hartshorne sandstone, but farther east the Spadra is in contact with the Hartshorne, and the displacement gradually decreases in that direction. There is evidence at some places that the fault passes into a monoclinal or even an anticlinal fold, and that it is discontinuous.

The fault line has been regarded as the boundary between the gas-producing area south of it and the non-productive area north of it, but there seems to be no reason why, where the structural conditions are favorable, the Atoka should not produce gas in the area north of the fault as well as in that south of it.

PINE RIDGE FAULTS

The Pine Ridge fault, so called by Collier,¹⁷ has not been studied in detail, but it seems probable that no single fault extends along the crest of the Pine Ridge anticline for any great distance. There has undoubtedly been some local displacement, but at most places the shales involved in the movement are so thick that they were

¹⁶ Collier, A. J., U. S. Geol. Survey Bull. 326, p. 46, 1907.

¹⁷ Collier, A. J., *op. cit.*, p. 42.

intricately folded and stretched rather than broken. Only in areas where relatively thick beds of sandstone occur near the crest of the anticline does there seem to be any considerable faulting, and such areas are not continuous. For this reason all such displacements are here referred to in the plural, as the Pine Ridge "faults." This faulting is further considered in the text on the Pine Ridge anticline.

PRAIRIE VIEW FAULT

Location.—The trace of the Prairie View fault extends from about the center of Sec. 26, T. 8 N., R. 25 W. eastward to about the N. $\frac{1}{2}$ Sec. 27, T. 8 N., R. 22 W.

Structural features.—The Prairie View fault, which is believed to be of the normal type, parallels the axis of the Prairie View anticline and lies only a short distance north of it. The downthrown side is north of the surface trace, and the displacement, which is locally sufficient to bring the Spadra shale into contact with the Atoka forma-

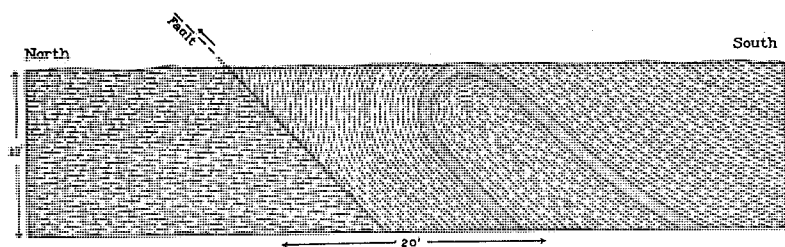


FIGURE 23.—Small high-angle thrust fault in sandy shale of the Fort Smith formation on the south flank of the Prairie View anticline as exposed in a road cut near Ellsworth.

tion, amounts at most to 500 feet, though it averages much less. From the vicinity of Prairie View the fault diminishes in importance toward the ends of the anticline, where it disappears.

The existence of the fault is shown not only by drill records and by the areal distribution of formations near its trace but by surficial evidence, yet it has been impossible to determine whether the fault is of the normal or the thrust type. In the text of Collier's report on the Arkansas coal field¹⁸ it is described as a thrust fault, but in the sections accompanying his report it is shown as a normal fault.

On the south flank of the Prairie View anticline, in the vicinity of Ellsworth, there is a small high-angle thrust fault, which is illustrated in Figure 23. Whether this fault is surficial or deep seated is not certainly known, but it is probably surficial, and it has no intimate connection with the main fault described.

¹⁸ Collier, A. J., U. S. Geol. Survey Bull. 326, p. 42, 1907.

RANGER FAULTS

The Ranger anticline is closely folded, is at places overturned toward the north, and is locally thrust-faulted near or at its crest. The faults occur only in competent beds, are discontinuous, and are of the high-angle thrust type. It is impossible to measure the displacement of any of these faults. The downthrown side of each fault is north of its trace.

SPADRA FAULT

Location.—The trace of the Spadra fault extends from the E. $\frac{1}{2}$ Sec. 29, T. 9 N., R. 25 W. northeastward to the SE. $\frac{1}{4}$ Sec. 14, T. 9 N., R. 24 W.

Structural features.—The Spadra fault, which is of the normal type, with the downthrown side south of its trace, has been located by prospect holes, by observation in coal mines, and by the distribution of formations at the surface. The escarpment that extends for several miles southwestward from Hartman may be a topographic expression of the fault. Near the east end of the fault trace the displacement is small and has caused no great difficulty, even in mines whose workings lie on both sides of the fault line. A short distance east of Hartman, however, drill records indicate that the displacement has increased to more than 200 feet, and in this area the Spadra shale has been brought into contact with the Atoka formation.

WASHBURN FAULTS

The Washburn anticline is overturned toward the north and, according to Winslow,¹⁹ is thrust faulted at or near its crest. The conditions near this fault are similar to those seen in the Pine Ridge anticline. In the vicinity of Chismville, as described and illustrated in the description of the Washburn anticline, the beds near the crest of the anticline are complexly folded and contorted. There has been some local displacement of the more competent beds, but the faults are discontinuous and not of major importance. The downthrown side of these faults is on the north.

MINOR STRUCTURAL FEATURES

JOINTS

All the competent strata in the Arkansas Valley are well jointed, particularly the thin-bedded sandstones, which upon weathering commonly break into regular blocks whose size is determined by the spacing of the joints. The master joints are essentially vertical and almost invariably strike a few degrees west of north. They are generally crossed at right angles by a secondary set of weaker joints,

¹⁹ Winslow, Arthur, Geol. Soc. Am. Bull. 2, p. 228, 1891.

which occur less regularly and are not found everywhere. (See Pl. XXXVI, A.) The space between the points of the main system ranges from several inches to several feet. The jointing, which is regarded as a result of stress caused by the weight of the overlying sediments (now removed by erosion), is not well developed in the thick beds of sandstone, and can be seen at only a few places in the beds of shale.

Near the Oklahoma boundary the strike of the master joints is N. 15°; near Russellville it is N. 5° W., and in the vicinity of Morrilton it is essentially north. At any one locality the strike of the joints is so constant, regardless of the other structural features, that it may be used to determine directions.

SURFICIAL FOLDS AND FAULTS

In the Arkansas Valley province, there are a large number of surficial folds and faults, many of which are well exposed in road cuts and in small stream valleys. Some of these that occur in regions of low dip make the determination of the major structure difficult. This difficulty is illustrated by Plate XXXVI, A. The beds seen in this view dip to the south, away from the observer, yet, but for the excellent exposure in the foreground, the observer might suppose that they dip either to the southwest or to the northeast, his choice depending on the flank of the minor anticline seen. Other folds, such as that shown in Plate XLII, are almost certainly surficial, but that assumption cannot be proved from surface observations. Still other folds, which are as prominent in section as that shown in Plate XLI, A, diminish with increase of depth, and some of them die out less than 5 feet below their crests.

Campbell²⁰ believes that such folds are caused by expansion due to weathering. They have evidently been formed since the present topographic surface was developed, for it is inconceivable that small folds like this could be formed under a heavy overburden. The effectiveness of weathering as an agent of expansion, however, has not been quantitatively tested, but it is no doubt considerable; it may be competent to form such folds as those shown in the plates.

STRUCTURE OF THE OUACHITA MOUNTAINS

GENERAL FEATURES

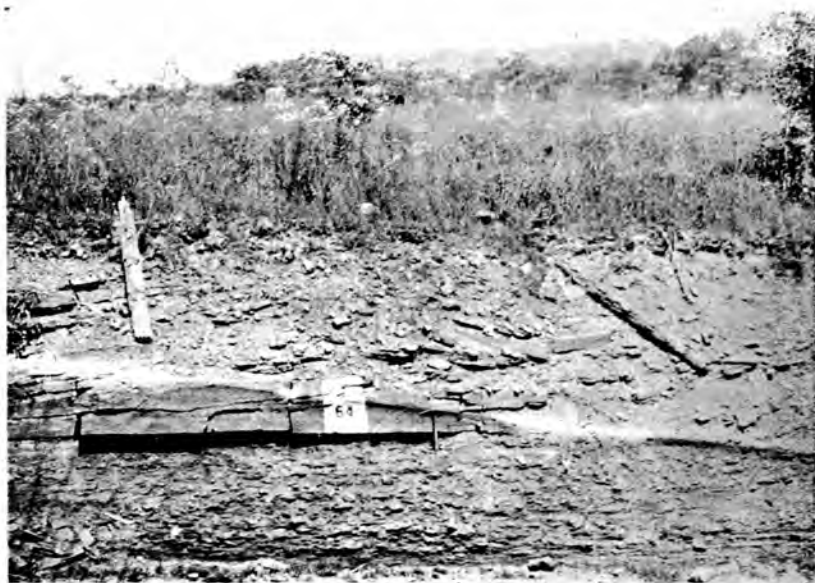
The structure of the Ouachita Mountains is of the Appalachian type and is difficult to interpret because of the similarity in the lithology not only of different parts of one formation but of entirely different formations. Interpretation is further complicated by the almost complete lack of fossils that might permit paleontologic cor-

²⁰ Campbell, M. R., Jour. Geology, vol. 14, pp. 718-721, 1906.



4. MINOR ANTICLINE IN FORT SMITH FORMATION IN A ROAD CUT A FEW MILES SOUTHEAST OF CLARKSVILLE

Note diminution of folding with depth. The beds in the bottom of this ditch are only slightly disturbed.



B. FORT SMITH FORMATION AS EXPOSED IN A ROAD CUT ALONG HIGHWAY 64 SOUTH-EAST OF CLARKSVILLE

The variation from sandstone to sandy shale shown in the photograph is common in all of the Carboniferous rocks in the Arkansas Valley.

relation. Moreover, the area is heavily wooded and the slopes are covered with talus, so that good outcrops are rare except along stream courses; and only a few roads, which might afford geologic sections, have been constructed in the region. Finally, as the region contains no valuable mineral resources very little detailed geologic work has been done in it.

The structure of the Ouachita Mountains, however, has been described by several writers, notably Griswold,²¹ Ashley,²² Purdue,²³ Miser,²⁴ Purdue and Miser,²⁵ and Honess,²⁶ to whose reports the reader is referred for more detailed descriptions than can be given here. As the Ouachita Mountain area is not here considered even possible oil and gas territory, only a general account of some of its larger structural features is given. All the main structural axes, however, are shown on Plate I, *B*.

The Ouachita Mountain province is structurally and topographically divisible into three main parts. The central part, here called the Novaculite Uplift, lies chiefly south of the Little Rock base line and forms the highest part of the province. North of it is the Fourche Range, which stands on the northern flank of the Ouachita anticlinorium but is itself made up of a great number of anticlines and synclines. South of the novaculite area is the Athens piedmont area, which lies along the southern flank of the anticlinorium and is also made up of a large number of anticlinoria and synclinoria, whose structure is nearly if not quite as complex as that of the two areas to the north but whose topography is much less rugged.

THE NOVACULITE UPLIFT

The Novaculite Uplift is made up of a series of mountains and basins, which are closely grouped along the axis of the main anticline in the Ouachita Mountain region. This axis extends from a point a few miles southwest of Little Rock slightly south of west to the vicinity of Glover, Oklahoma. The east and west ends of this anticline are concealed by overlapping post-Paleozoic deposits, and its crest is so much depressed near the Oklahoma line that the anticline appears to end at a point southeast of Mena, Arkansas. Most of the novaculite area in Arkansas lies south of the Little Rock base line, in Ranges 1 to 5 south, but its northeastern extension lies in Range 1 north. This compound range represents the axial part of

²¹ Griswold, L. S., Whetstones and the novaculite of Arkansas: Arkansas Geol. Survey Ann. Rept. 1890, vol. 3.

²² Ashley, G. H., Geology of the Paleozoic area of Arkansas south of the Novaculite region: Am. Phil. Soc. Proc., vol. 36, No. 155, pp. 217-318, 1897.

²³ Purdue, A. H., Slates of Arkansas: Arkansas Geol. Survey, 1909.

²⁴ Miser, H. D., Mangranese deposits of the Caddo Gap and De Queen quadrangles, Arkansas: U. S. Geol. Survey Bulletin 660, p. 72, 1917.

²⁵ Purdue, A. H., and Miser, H. D., U. S. Geol. Survey Geol. Atlas Hot Springs folio (No. 215), 1923.

²⁶ Honess, C. W., Geology of the southern Ouachita Mountains of Oklahoma: Oklahoma Geol. Survey Bull. 32, p. 213 et. seq., 1923.

the Ouachita anticlinorium and consists of many parallel novaculite ridges having steep, talus-strewn slopes and barren, even-topped crests. Most of the rocks in this range are Devonian or older, but Carboniferous rocks are infolded in the Mazarn Basin or synclinorium in Montgomery and Garland counties.

The Novaculite Uplift is divided into several parts by synclinoria, which are also topographic basins. The larger mountain areas or anticlinoria are the Crystal Mountains, in Garland and Montgomery counties; the Caddo Mountains, in Polk and Montgomery counties; the Cossatot Mountains, in Polk, Montgomery and Pike counties; the Trap Mountains, in Garland and Hot Spring counties; the Zigzags, in Garland County; and the Cross Mountains, which are a part of the Oklahoma, rather than the Arkansas novaculite area but which extend eastward into Polk County, Arkansas. The larger synclinoria, which separate the mountains named, are the Caddo, Mazarn, Ouachita, and Saline basins.

CADDO MOUNTAINS

The Caddo Mountains extend from the vicinity of Potter, in Sec. 8, T. 2 S., R. 31 W., slightly south of east to Caddo Gap, from which point they continue northeastward to the Ouachita River, in the eastern part of T. 2 S., R. 21 W. These mountains consist of parallel ridges 2 to 4 miles across, which stand 500 to 600 feet above the adjacent stream valleys, and rise into peaks that are about 1,000 feet higher than the valleys. The total length of the Caddo Mountains, as here defined, is about 65 miles, but the ridges east of Three Sisters Mountain are much less prominent than those farther west, and instead of being parallel they are arranged nearly en échelon. The higher peaks in the Caddo group are Blowout, Missouri, Fork, Statehouse, Fodderstack, Cogburn, Nelson, Sharptop, and Three Sisters Mountains. Most of these peaks stand 1,500 to 2,000 feet above sea level, but the highest part of the Missouri Mountains reaches an elevation of 2,212 feet.

For the greater part of their length the Caddo Mountains consist of the south flank of the central Ouachita anticline, which has been folded into a great number of anticlinal noses and short synclines, but near their west end they include a few ridges on the north flank of the main anticline and the westward-plunging nose of the main structure. The principal formation of the Caddo Mountains, and the one that gives them most of their topographic expression, is the Arkansas novaculite, but the beds include also the Missouri Mountain slate, the Polk Creek shale, and the Bigfork chert. In addition, the Stanley shale crops out in closely folded synclines at a few places, as on the southern flank of the Missouri Mountains. The structural trend and the principal axes are shown on Plate I, B.



MINOR FOLD IN ATOKA SANDSTONE NEAR ROMANCE, DUE
IN PART TO WEATHERING AND IN PART, PERHAPS, TO
EXPANSION BY HEAT

Fork Mountain is a high serrate-crested ridge that adjoins the Missouri Mountains at their west end. Its structure is complex, and some of the folds are overturned. The Arkansas novaculite is the principal formation exposed, but the Stanley shale crops out near the top of the mountain in two closely folded synclines, and the Missouri Mountain slate, the Polk Creek shale, and the Bigfork chert are exposed on the northern flanks. Although it is made up of a number of folds the major Fork Mountains structure is distinctly monoclinal, the main anticlinal axis of the Ouachita province being farther north. The synclinal bend at the east end of the mountains is sharp, and the structure is underthrust. The south limb of this syncline is expressed as a ridge that extends southeastward to join the Missouri Mountains in Sec. 33, T. 3 S., R. 28 W.

The Missouri Mountains lie in part between Fork and Statehouse mountains, but their west end extends considerably southwest of Fork Mountain. In their western extension these mountains consist of two anticlines and a sharply folded syncline. At some places this central syncline becomes obscure and the two anticlines nearly merge into a single fold. The southern anticline dies out in Sec. 29, T. 3 S., R. 29 W., but the northern one continues westward as an unbroken ridge for about 15 miles to the south side of Two Mile Mountain, in Sec. 8, T. 3 S., R. 30 W. Near its west end the anticline is overturned toward the north, so that southerly dips prevail on its northern flank. East of its junction with Fork Mountain the south side of this anticline becomes a monoclinal fold, but the southern Missouri Mountain anticline is jammed against it. These two structural features determine the topographic expression. Near Slatington, in Sec. 33, T. 3 S., R. 27 W., there is another ridge, which has a complex synclinal structure and extends eastward for about 5 miles. South of this ridge, and separated from it by a tongue of Stanley shale that is downfolded into a sharp syncline, is Statehouse Mountain.

In its most complex part Statehouse Mountain is made up of three anticlines, the southernmost of which is overturned to the south and the northernmost to the north. The Missouri Mountain slate crops out near the crests of these anticlines, but the Arkansas novaculite is the principal formation exposed. It crops out on both sides of the main anticline and in the high syncline in Sec. 1, T. 4 S., R. 7 W. A cross-section through a less complicated part of Statehouse Mountain is shown in Figure 24. The structure here changes within short distances, so that cross-sections of the same mountain taken less than a mile apart may differ not only in detail but in larger features.

Cogburn Mountain is the topographic expression of an anticline about 12 miles long. At its east end, in Sec. 7, T. 4 S., R. 26 W., it is

monoclinal, but at its west end, in Sec. 36, T. 3 S., R. 29 W., it is more closely folded. The monoclinal ridge south of Fodderstack Mountain is a continuation of Cogburn Mountain, but is commonly called Gap Mountain. Its structure, although somewhat crenulated, is fairly simple, the older beds cropping out north of the ridge and the younger south of it.

Fodderstack Mountain is an isolated ridge that extends from Sec. 10, T. 4 S., R. 26 W., eastward to Sec. 8, T. 4 S., R. 25 W. Its structure is that of a steeply dipping synclinal basin, the dips being about 70 degrees on either side of the axis. The Arkansas novaculite has been preserved in the middle of the basin and has produced the ridge.

Nelson, Strawn, White, and Sharptop mountains are topographic expressions of a series of plunging anticlines and northeastward-trending synclines just east of Caddo Gap. Their general structure, however, is monoclinal, for the Stanley shale appears on the southeast and the older Ordovician rocks on the northwest. Here again the Arkansas novaculite has produced the ridges, but the structure is less complex than that at most places in the Novaculite Uplift.

The Three Sisters Mountain is the easternmost of the prominent peaks of the Caddo Mountains. Its structure is that of a closely folded anticline and syncline, the north limb of the syncline representing the typical monoclinal structure of the Caddo Mountains. The easternmost of the Three Sisters is formed of an eastward-plunging anticlinal nose, which is rather remarkable for its symmetry and its low dips. The Caddo Mountains continue eastward from the Three Sisters, but although the dips continue to be high and the structure complex, the novaculite is apparently less resistant, for the hills become progressively lower.

COSSATOT MOUNTAINS

The Cossatot Mountains form the southwestern boundary of the Novaculite Uplift and the natural continuation of the Trap Mountains to the east, but the two novaculite mountain systems are separated by an area about 7 miles wide, in which erosion has not yet exposed the novaculite. The Cossatot Mountains lie south of the western part of the Caddo Mountains and are separated from them by the valleys of the South Fork of Caddo River, by a part of the valley of the Little Missouri, the valleys of Long Creek and Mine Creek, and the headwaters of Cossatot River. The Mountains extend from T. 3 S., R. 31 W. slightly south of east to the Caddo River, and have an extreme length of about 45 miles. In breadth they vary from a single, narrow ridge to a series of parallel ridges 6 miles wide. The highest of the novaculite hills of Arkansas are in the Cossatot Moun-



STANDING ROCK, A PERPENDICULAR LEDGE OF NOVACULITE ON BOARD CAMP CREEK, IN POLK COUNTY

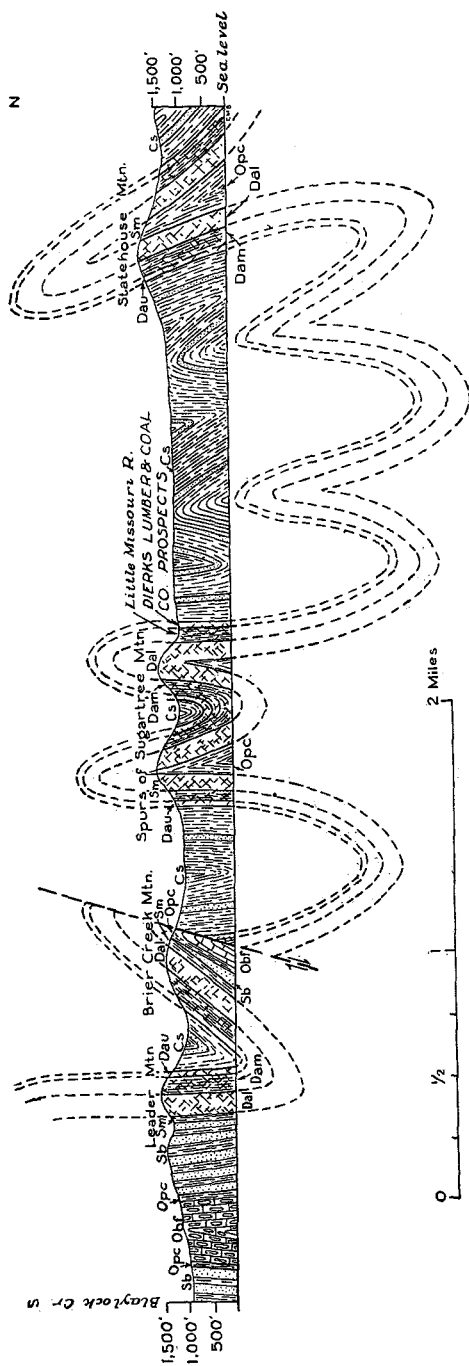


FIGURE 24.—Section from south to north through the east ends of Leader, Brier Creek, and Sugartree mountains and the west end of Statehouse Mountain, Montgomery County, Ark., showing the folding of the Arkansas novaculite.

Cs, Stanley shale; Dau, upper division of Arkansas novaculite, upper manganese horizon; Dal, Middle division of Arkansas novaculite; Dal, lower division of the Arkansas novaculite (lower manganese horizon is at the top of this division); Sm, Missouri slate; Sb, Stanley shale; Obf, Bigfork chert. The probable underground structure of the Arkansas novaculite below sea level is represented by the broken lines in the lower part of the figure, and the probable structure of the novaculite before it was eroded down to the present level is represented by the broken lines in the upper part. (After Miser.)

tains. Named from west to east the principal peaks are Wards, Bald Eagle, McKinley, Shadow Rock, Buckeye, Rachel, West and East Hannah, Tall Peak, Porter, Bushy, Raspberry, Fodderstack, Musgrove, Blaylock, Leader, Sugartree, Prior, Fancy Hill, Line, Tweedle, and Pigeon Roost. The highest of these is Raspberry Peak, which reaches an elevation of 2,360 feet, but several others, notably East Hannah, Buckeye, and Tall peaks, are more than 2,300 feet high.

Although distinctly anticlinal in structure, the Cossatot Mountains are even lower structurally on the south flank of the main Ouachita anticline than the Caddo Mountains. For this reason Carboniferous rocks have been infolded into a large number of the synclines that are superposed upon the main Cossatot anticline. A general idea of the structural types found in the Cossatot Mountains may be gained from Figure 24, which shows a cross-section through three of the ridges. An interesting structural peculiarity of the Cossatot Mountains is the occurrence of ten westward-trending anticlinal ridges at their west end and only three short anticlinal noses at their east end. The western folds are obviously not continuous, and a number of them unite toward the east. The eastern folds which would correspond with the western ones in complexity may have been formed at a higher elevation than that of the present surface, and consequently they may have been completely eroded.

A still more striking, though less apparent, structural phenomenon in the Cossatot Mountains is fan folding—that is, the anticlines north of the main axis of the Cossatot system are overturned to the north, so that most of the dips on the northern monocline are to the south, whereas the anticlines south of the axis are overturned to the south. Hence, although the Cossatot Mountains form an anticlinorium, the beds dip prevailingly toward the axis rather than away from it. The dip north and south of the structural axis is shown in Figure 25.

The complex structure of East Hannah Mountain is rather typical of that of all the Cossatot peaks. The mountains are further complicated by high-angle thrust faults, which are probably more common in the Cossatot system than in other parts of the novaculite area. The longest of these faults is between 12 and 15 miles in length, and the greatest displacement is probably hundreds of feet.

CROSS MOUNTAINS

The Cross Mountains are isolated, nearly westward-trending novaculite ridges in southwestern Polk County. They stand in the north half of T. 5 S., Rs. 31 and 32 W., and have a length of about 11 miles in Arkansas. They are separated from the Cossatot system, whose nearest ridges lie about 6 miles to the northeast, by complexly folded

non-resistant Carboniferous beds. According to Honess,²⁷ the Cross Mountain anticlinorium is the northernmost of two anticlinoria, which, with their intermediate synclinorium, comprise the Novaculite Uplift of southeastern Oklahoma. The Cross Mountains of Arkansas are therefore the eastern extension of one of the major structural features of the Oklahoma Ouachitas, but not of the Choctaw anticlinorium, which, as redefined by Honess, lies farther south. These mountains are described with the Novaculite Uplift only for convenience, for they are distinctly separate from that uplift in Arkansas.

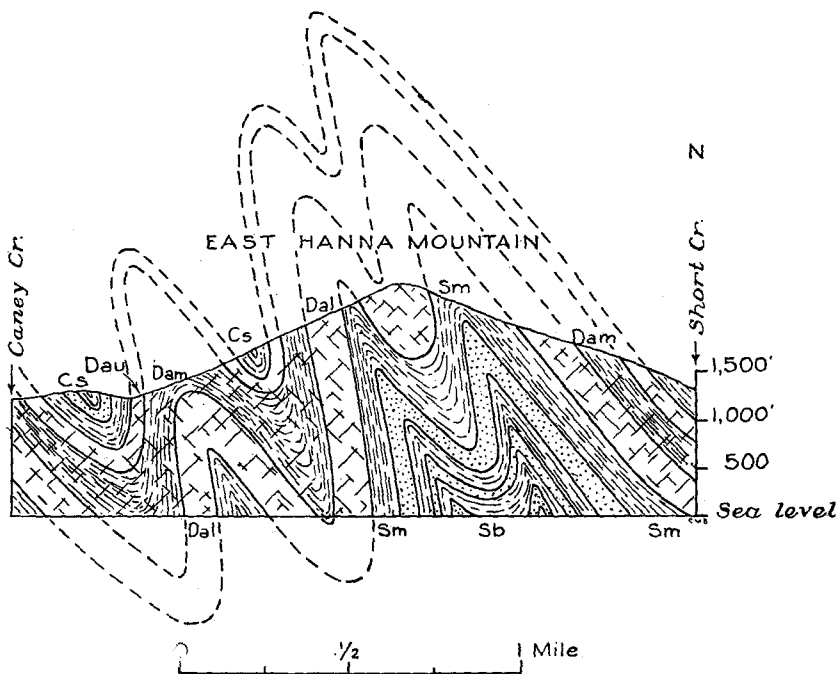


FIGURE 25.—Section from north to south through East Hanna Mountain, Polk County, Arkansas, showing the folding of the Arkansas novaculite.

Cs, Stanley shale; Dau, upper division of Arkansas novaculite; Dam, middle division of Arkansas novaculite; Dal, lower division of Arkansas novaculite; Sm, Missouri Mountain slate; Sb, Blaylock sandstone. (After Miser.)

The Cross Mountain ridge extends from the northern part of Sec. 1, T. 5 S., R. 32 W. almost directly east to the NW. $\frac{1}{4}$ Sec. 1, T. 5 S., R. 31 W. The ridge is $5\frac{1}{2}$ miles long and rises about 400 feet above the adjacent lowlands. It is typically anticlinal, but for a part of its length the anticline is overturned to the south, so that all the dips are to the north. At places the fold is so recumbent that the north dip of the south flank is as low as 40 degrees. Southwest of the Cross Mountain ridge two other short, parallel novaculite ridges originate in the northwestern part of T. 5 S., R. 32 W., and extend slightly

²⁷ Honess, C. W., *Geology of the southern Ouachita Mountains of Oklahoma*: Okla. Geol. Survey Bull. 32, p. 213, 236, et. seq., 1923.

south of west beyond the Oklahoma border. These ridges also stand about 400 feet above the surrounding country, but Whiskey Peak (Potato Hill) rises somewhat higher above the general level of the northern ridge. Both these hills are typically anticlinal.

CRYSTAL MOUNTAINS

The Crystal Mountains, so known because of the abundance of quartz crystals found there in the Crystal Mountain sandstone, extend from the southern part of T. 2 S., R. 27 W. southeastward to T. 3 S., R. 24 W., where they turn northeastward and terminate just north of Goosepond Mountain, in T. 1 N., R. 18 W. The Crystal Mountain system, unlike the other mountain groups in the Novaculite Uplift, is made up of ridges of sandstone rather than novaculite. Its two ends, however, approach very close to the northern novaculite ridges, and it is bounded on the south by the Cross and Zigzag novaculite systems. The Crystal Mountains occupy the central part of the Ouachita anticlinorium and are composed of the oldest rocks in the region. The chief formations are the Collier shale, Crystal Mountain sandstone, Mazarn shale, Blakely sandstone, and Womble shale.

The Crystal Mountain system, despite its arcuate shape, trends in general northeastward for 40 of the 60 miles of its length. This system, like the novaculite mountains, is composed of parallel ridges having a combined breadth of 3 to 4 miles. The mountains are rough, though not quite so steep-sided as those of the other systems, and many of them rise to elevations of more than 1,500 feet. High Peak, in Sec. 19, T. 3 S., R. 24 W., reaches an elevation of 1,834 feet, and is apparently the highest point in the system.

The mountains have a general anticlinal structure and some of the individual anticlines are steep-sided and have flat crests. Many of the ridges produced by this structure form small plateau-like elevations, but where the beds have been closely folded the topography is very similar to that of the novaculite ridges. The Crystal Mountains may be regarded as a relatively newly exposed central anticlinorium within a greatly eroded larger anticlinorium.

NORTHERN MOUNTAINS

The term Northern Mountains is applied to the northernmost line of novaculite ridges in the Novaculite Uplift. It is the longest but least prominent of the novaculite systems. It has a total length of about 105 miles, but it includes no high peaks. A few of its higher elevations, however, have received names, such as Prilliman Ridge, and Goosepond, Muddy, and Bald Mountains, but none of these ridges rises more than 600 feet above the adjacent valleys, and most of them stand less than 300 feet above the surrounding country. The ridges

extend from the vicinity of Board Camp post office, in Polk County, slightly north of east to the vicinity of Little Rock. For a part of this distance there are several parallel ridges, but at some places there is but a single ridge, and between Washita and Brazils post offices this ridge is not continuous.

The Northern Mountains may be regarded as the topographic expression of the northern monocline of the major Ouachita anticlinal axis. A part of their lack of continuity is due to the progressively less resistance of the Arkansas novaculite northward, but the absence of connecting anticlinal and synclinal ridges is due in part to the lack of crumpling of the northern monocline as compared with the southern one. The comparative structural simplicity of the monocline is well shown by the single straight ridge that represents the Northern Mountains for 20 miles near their west end. The east end of the mountains is similarly represented by rather continuous single ridges, but between Blocher and Brazils post offices the ridges exhibit a modified zigzag structure. At several places the anticlinal or, more rarely, the synclinal structure of the isolated ridges has been determined, but most of the structural details of the Northern Mountains are still unknown. The surface rocks range in age from the Mazarn shale to the Stanley shale, but the Arkansas novaculite is by far the most common rock.

TRAP MOUNTAINS

The Trap Mountains comprise a system of low novaculite ridges at or near the boundary of the Novaculite Uplift on the southeast. They are southwest of the Ouachita River and northeast of the Caddo River. They may be regarded as the eastward continuation of the Cossatot system. They stand southwest of the Zigzags but are joined to them at their east end by a series of low ridges. The system extends slightly north of east for about 35 miles and has a maximum breadth of about 5 miles. The ridges generally rise less than 1,100 feet above sea level and at most places about 500 feet above the adjacent valleys. Saddle, Traps, Jack, Bare and Panther Mountains are among the highest elevations. The surface rocks are the Arkansas novaculite, Missouri Mountain shale, Blaylock sandstone, Polk Creek shale, and Bigfork chert, but the Stanley shale is rather widely exposed in the synclines.

The structure of the Trap Mountains is similar in several respects to that of the Cossatot system. The ridges are the result of similar fan folding, and the number of anticlines increases away from the Caddo River toward the east, just as the anticlinal ridges of the Cossatots increase toward the west. In general, however, the structure of the Trap Mountains appears simpler, principally because the mountains have not been so deeply eroded. The anticlines that make

up the Trap Mountain anticlinorium number about thirty, which range in length from a quarter of a mile to 16 miles.

A rather conspicuous feature of the Trap Mountains is the junction at a number of places of several ridges to form a modified zigzag ridge. The ridges may actually be divided into two groups, one trending westward and the other trending southwestward. Griswold²⁸ believes that both the sets of folds that produced these somewhat diversely directed novaculite ridges are the result of compressive forces acting from the south toward the north. The westward-trending ridges, however, were formed during the earlier stages of folding, when the compressive forces were directed nearly due north, but the southwestward-trending ridges were formed later, by local shearing.

ZIGZAG MOUNTAINS

The Zigzag Mountains stand between the Saline and Mazarn basins, and may be regarded as the continuation of the Caddo Mountains east of the Ouachita River. The Zigzags extend from the vicinity of Hawes postoffice southeastward to the western edge of the Gulf Coastal Plain, a distance of about 25 miles. Throughout this distance they occupy a belt 6 to 10 miles wide, its width being determined by the length of the ridges, which stand nearly at right angles to the trend of the system. The ridges, which are rather short, terminate abruptly on the northeast in the Saline Basin and on the southwest in the Mazarn Basin. Most of the ridges stand 500 to 600 feet above the adjacent lowlands, but one point near the west end of West Mountain, 2 miles west of Hot Springs, rises to an elevation of more than 1,400 feet and thus stands about 900 feet higher than the low hills of the Mazarn Basin.

The Zigzags form a complicated part of the southern limb of the main Ouachita anticline. The Arkansas novaculite has produced the topographic expression of the ridges, but the Missouri Mountain shale, Polk Creek shale, and Hot Springs sandstone crop out over rather large areas. In addition, tongues of Bigfork chert extend southwestward from the Saline Basin into the anticlinal areas and alternate with tongues of Stanley shale, which extend northeastward from the Mazarn Basin into the synclinal parts of the mountains. Because of their position on the south limb of the Ouachita anticline, the Zigzag Mountains are bounded by older formations on the north and by younger ones on the south. The peculiar form of the mountains is due to the truncation of parallel plunging anticlines and synclines.

The forces that caused the folding of the Zigzags were directed from the southwest toward the northeast, though they may be a

²⁸ Griswold, L. S., loc. cit. p. 248.

result of local shearing late in the period of mountain making during which most of the earlier compressive forces were directed nearly due north. There may be some relation between the degree of overturning of the folds of the system and the shearing movement, for Griswold noticed that wherever the ridges strike more nearly westward the overturning of the folds toward the south becomes less prominent.

CADDO BASIN

The Caddo Basin lies between the Caddo Mountains on the south, the Crystal Mountains on the northeast, and the Northern Mountains on the northwest. It is drained chiefly by the headwaters of Caddo River, but part of it is drained by the South Fork and other branches of the Ouachita River. The topography is somewhat more diverse than that of the other basins, and the surface is more rugged.

The rocks exposed in the Caddo Basin belong to formations that are older than the Arkansas novaculite and younger than the Crystal Mountain sandstone. Chief among these formations are the Womble shale, Blakely sandstone, and Mazarn shale, but the Bigfork chert and Polk Creek shale are also exposed at several places. The folds in the Caddo Basin are not large, but are almost incredibly complex, so that many of the structural details have not yet been worked out. The Caddo Basin, however, like the Saline Basin, lies along the major structural axis of the Novaculite Uplift, and therefore older rocks are exposed in it than in any of the encircling ridges except the Crystal Mountains, in which, owing to the magnitude of the folds, still older beds crop out.

MAZARN BASIN

The Mazarn Basin forms a great synclinal depression in the Novaculite Uplift. It is bounded on the north by the Caddo and Zigzag Mountains and on the south by the Cossatot and Trap Mountains. It is thus completely surrounded by novaculite ridges except at the break between the Cossatot and Trap systems at the Caddo River near Rosboro. Most of the basin lies in Garland County, but a narrow projection extends westward for about 30 miles into Montgomery County. The greatest length of the basin is about 60 miles, and its maximum breadth is about 10 miles.

The Mazarn basin has been rather deeply dissected by erosion, so that its surface is very irregular, even though the relief is not great. Its surface is marked by low, parallel sandstone ridges and narrow valleys, most of which trend east by north. Much of the basin stands 500 to 600 feet above sea level, but the larger streams have cut their valleys 200 to 250 feet lower, and the elevation at the gorge of the Ouachita River is only about 250 feet.

The surface rocks, which belong chiefly to the Stanley formation, are closely and intricately folded, so that one traversing the basin

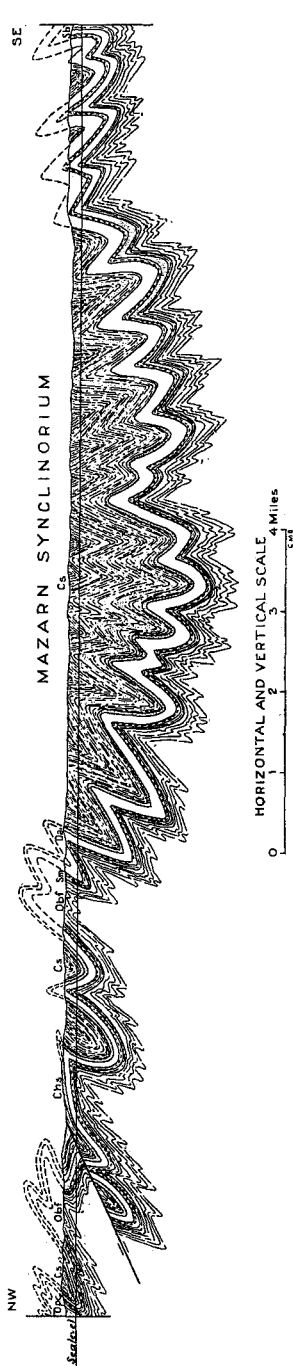


FIGURE 26.—Section across part of the Hot Springs district, showing the overturned folds of the Crystal Mountain and Trap Mountain anticlinoria toward the Mazarn synclinorium.

Cs, Stanley shale; Obf, Hot Springs sandstone; Da, Hot Springs sandstone; Sb, Blaylock sandstone; Opc, Polk Creek shale; Obt, Bigfork chert. (After Furdue and Miser.)

from north to south sees the same beds repeated many times. Although the major structure of the basin is that of a synclinorium, the secondary folds north of the major structural axis are overturned to the south and those south of it toward the north. Most of the beds in the basin therefore dip away from the major structural axis rather than toward it. Although the greater part of the basin is a dissected plain developed on the Stanley formation, Pigeon Roost and Mazarn Ridge stand high above its general surface. The Arkansas novaculite has produced the topographic expression of Pigeon Roost, a prominent anticlinal mountain in T. 4 S., R. 23 W., which rises abruptly out of the Stanley shale and reaches an elevation of 800 to 900 feet above the general surface of the basin. The novaculite does not crop out distinctly at any other place in the Mazarn Basin, but scattered fragments of novaculite in the SE. $\frac{1}{4}$ Sec. 14, T. 4 S., R. 23 W. suggest that the upper beds may reach the surface there also. The Mazarn Ridge parallels Pigeon Roost on the north but is much longer, its total length being about 14 miles. It is formed of resistant Stanley sandstone in an anticlinal fold, which is overturned toward the north.

The general structure of the Mazarn Basin and adjacent

parts of the Trap and Zigzag Mountains is shown in Figure 26, which may be taken as rather typical not only of the synclinoria of the Novaculite Uplift but of the bounding anticlinoria, so far as complexity is concerned.

OUACHITA BASIN

The Ouachita Basin, which is drained entirely by Ouachita River and chiefly by its South Fork, is bounded on the north by the Northern Mountains and on the south by the Crystal Mountains. Although it is well drained, the basin is more rugged than the Saline Basin, but somewhat less rugged than the Caddo Basin.

The rocks exposed at the surface are of the same age as those in the Saline and Caddo Basins, but they are in general somewhat more calcareous, and the shales and sandstones contain more quartz veins. The chief formations exposed are the Womble, Mazarn, and Polk Creek shales, the Blakely sandstone, and the Bigfork chert. The beds in the southern and western parts of the basin are intensely crumpled and folded, but those in its northern part dip gently toward the north and in places are nearly horizontal. The repeated beds of limestone found in the northern part of the basin suggest that the prevailing northern dip may be due to a series of folds that are overturned so far toward the south that they lie essentially flat. On the other hand, the intensity of the folding seems to diminish rather regularly north of the major axis of the Novaculite Uplift, and these low dips may represent flat areas on a local relatively uncomplicated northward sloping monocline.

SALINE BASIN

The Saline Basin, which is drained almost entirely by the Saline River, lies between the Northern Mountains on the north, the Zigzags on the southwest, and the Gulf Coastal Plain on the southeast. The surface features differ markedly from place to place, but the general topography is gently rolling, and much of the land near the larger streams is poorly drained. A few broad-topped hills reach an elevation of 850 feet, and a short anticlinal ridge, capped by Blakely sandstone, 3 miles southeast of Mountain Valley, in the SW. $\frac{1}{4}$ Sec. 26, T. 1 S., R. 19 W. reaches a height of more than 1,080 feet. Much of the land, however, stands between 400 and 600 feet above sea level and some of that near the Saline River less than 300 feet above it.

The surface rocks belong to the formations above the Crystal Mountain sandstone and below the Arkansas novaculite, chiefly the Bigfork chert, Womble shale, and Blakely sandstone. The total section exposed is thin and the folds in the Saline Basin are small. The structural details in this area have not yet been fully worked out;

and the complication of the small folds makes the determination of the structure difficult. The basin, however, lies nearly athwart the main structural axis of the Novaculite Uplift, and its central structural position is shown by the age of the rocks exposed in it.

FOURCHE MOUNTAINS

The Fourche Mountains, as defined by Purdue²⁹ consist of the sandstone ridges lying north of the novaculite area, including Poteau, and Petit Jean mountains. The northern limit of the Fourche Range as here defined coincides with the southern boundary of the Arkansas Valley province, so that Poteau and Petit Jean mountains are excluded from the Fourche Range.

The Fourche Mountains make up an extensive system of ridges, which are the topographic expressions of rather closely folded anticlines and synclines superposed on the north limb of the major Ouachita anticline. The ridges are at least as high as those in the novaculite area but are perhaps somewhat less rugged. The only formations exposed are the Stanley shale, the Jackfork sandstone, and the Atoka formation. The first two of these do not crop out north of Fourche la Pave River. The structural details are still unknown, but the major axes of the folds and the general structural trends are shown in Plate I. There are several overturned folds in the area, but open folding is more common there than in the novaculite area. Many of the anticlines that are not overturned are steeper on their northern than on their southern flanks, but some, such as the Dutch Creek anticline, are essentially symmetrical. The structural features north of T. 2 N. have been described with those in the Arkansas Valley and may be regarded as rather typical of the entire Fourche Range, though the structure becomes increasingly more complex toward the south.

A few test wells have been drilled for oil and gas in the Fourche Mountains, but all have been unsuccessful. Furthermore, there is no reason to believe that commercial deposits of oil or gas will ever be discovered in the region.

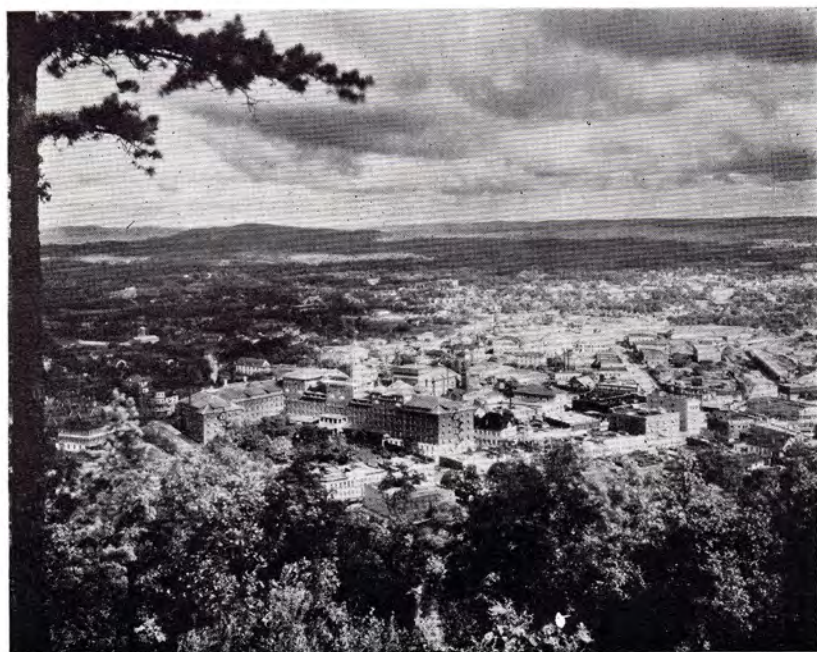
ATHENS PIEDMONT RIDGES

The Athens piedmont area is bounded on the north by the Novaculite Uplift and on the south by the Coastal Plain. It forms a belt 8 to 18 miles wide, which extends from a point near the Ouachita River, in Hot Spring County, westward into Oklahoma. The upland surface of this plateau slopes from an elevation of about 1,100 feet near the novaculite ridges, in northern Howard and Pike counties, to about 400 feet along its southeast border. Although there are few

²⁹ Purdue, A. H., *The slates of Arkansas*: Arkansas Geol. Survey, pp. 26-28, 1909.



A. TYPICAL FOURCHE MOUNTAIN TOPOGRAPHY NEAR MENA



B. PANORAMIC VIEW ACROSS MAZARN BASIN

View southward toward the Trap Mountains from a point above Hot Springs, in the Zigzag Mountains. Courtesy of Hot Springs Chamber of Commerce.

prominent elevations on this piedmont plateau, the surface is intricately dissected by numerous tributary streams that flow eastward or westward and by a few large streams that flow southward. Most of the ridges trend nearly eastward and stand not more than 250 feet above the adjacent valleys. A few ridges, however, rise 500 feet above the general level. The most common type of elevation is a table-land or modified ridge having a long, gentle southern slope and a steep northern face.

Practically all the rocks of the plateau are of Carboniferous age, but at a few places near the Novaculite Uplift novaculite hills rise out of younger beds of sandstone and shale. The other formations that crop out on the plateau are the Stanley shale, found over large areas, chiefly in its northern and central parts; the Jackfork sandstone, exposed mainly in narrow westward-trending bands near the southern part; and the Atoka formation, which is found only in a small area near the Cretaceous border, at the southeast.

The beds generally dip southward, but in places the folds are overturned, and northern dips are not rare. The dips are generally high, inclinations of less than 30 degrees being uncommon. The complex structure causes individual beds to be repeated at the surface many times within short distances. Because of this complexity and of poor exposures, poor roads, poor or incomplete base maps, and the similarity of all the beds involved in the folding, the structural details of the area are incompletely known. A number of the structural axes, however, are indicated on Plate I, *B*, and some of the details of folding are described by Ashley.³⁰ The folds of the Athens plateau represent minor but significant crenulations on the southern limb of the major antiline of the Ouachita Mountains.

Deposits of asphalt in the Trinity formation near Pike, Delight, and Murfreesboro, in Pike County, may have originated in the upturned Carboniferous beds, which lie unconformably beneath the Cretaceous sediments at those places.³¹ The Atoka formation in its more sandy layers, at points just north of the Cretaceous contact, also contains small quantities of asphalt. All the asphalt, however, is a residue left by the evaporation of the more volatile parts of crude petroleum. There is no possibility of obtaining commercial quantities of oil or gas in the Athens plateau. The Carboniferous and older rocks are so highly folded, fractured, and metamorphosed that any gas and much of the oil that they may once have contained escaped long ago, though a part of the oil may remain as an asphaltic residue after the natural distillation.

³⁰ Ashley, G. H., loc. cit.

³¹ Miser, H. D., and Purdue, A. H., Asphalt deposits and oil conditions in southwestern Arkansas; U. S. Geol. Survey Bull. 691, pp. 271-292, 1918.

OIL AND GAS GEOLOGY OF THE PALEOZOIC AREA OF ARKANSAS

FACTS CONSIDERED

The possibility of obtaining oil and gas in the Arkansas Paleozoic area has been considered in other parts of this report, particularly those dealing with the stratigraphy and structure. The petrolific significance of each formation is discussed under the heading "Stratigraphy," and the log of each "wildcat" test well is given in the description of the structural feature on which it was drilled. In addition, general recommendations are made for the exploration of each structural feature described. It is therefore necessary here only to summarize the findings made and to give a brief account of the producing gas fields in the Paleozoic area.

The desirability of making explorations for oil and gas in the area in view of certain fundamental criteria for their occurrence is considered, and the relative potentiality as oil-producing areas of the several physiographic provinces is indicated. The text describing the properties, origin, migration, and accumulation of oil and gas is written for the layman only and is necessarily brief. The geologist is familiar with the voluminous literature on these subjects. The origin of the gas produced in the Arkansas Valley fields, however, is considered.

PROPERTIES OF OIL AND GAS

Oil and gas are mainly mixtures of natural hydrocarbons that are irregularly but widely distributed through the rocks of the earth.

Oil is made up of 81 to 87 per cent of carbon, 10 to 15 per cent of hydrogen, and generally from 1 to 7 per cent of oxygen and nitrogen combined. Most oils contain also small quantities of sulphur and other impurities. The hydrocarbons that form the chief constituents of petroleum include a number of complex series, of which the paraffin series is the most valuable. Each series contains many members, the paraffins, for instance, range from the simple compound methane CH_4 to the complex compound $\text{C}_{35}\text{H}_{72}$. The less complex compounds in this series are gases; the more complex are liquids; and the other members, such as paraffin itself, are solids under ordinary conditions. Other series that are found in most oils are the olefines, benzenes, and naphthenes; and some oils contain acetylenes, naphthalenes, and camphenes.

Most crude oils are opaque by transmitted light and greenish by

reflected light. Certain lighter oils, however, are light yellow, red, or light brown, and some heavy petroleum is essentially black. The oils from different areas have different odors, which range from that of ordinary gasoline to that of hydrogen sulphide. One of the most notable physical properties of oil is its specific gravity, or the relation of its weight to the weight of an equal volume of water. Most oils are lighter than water and ordinarily have specific gravities of from 0.800 to 0.965, that of water being 1. Ordinarily the lighter the oil the more valuable it is. In oil-field practice the gravity of oil is usually expressed not by decimals, but on the Baume scale, in which the gravity of water is 10 degrees. The ordinary decimal expression of the gravity of an oil may be converted into the Baumé scale by dividing 140 by the decimal and subtracting 130. Thus an oil whose specific gravity is 0.845 has a Baumé gravity of about 35.7 degrees. In other words, the higher the Baumé gravity the lighter the oil, and consequently the smaller the figure that expresses its weight in comparison with that of water.

The resistance that an oil offers to its flow is called its viscosity. This property varies nearly directly with the specific gravity, but the temperature also has a very great effect on flow. The lighter the oil ordinarily the easier its flow; and some heavy oils must be heated before they can be pumped.

Natural gas, unlike petroleum, is made up of only the lighter hydrocarbons. Chief among these is methane, or marsh gas (CH_4), but ethane (C_2H_6) is a large constituent of some natural gases. Most gases contain small but variable quantities of carbon dioxide, carbon monoxide, hydrogen sulphide, nitrogen, oxygen, and hydrogen. The gas of the Arkansas Valley is remarkable for its large content of methane.

There are two types of natural gas, "wet" and "dry." "Wet" gas, which contains some of the heavier hydrocarbons, is ordinarily associated with petroleum and is obtained in most oil fields. It is particularly valuable because it contains gasoline, which may be separated from it by condensation. Some of the gas obtained in the northern part of the Arkansas Paleozoic area is "wet." "Dry" gas consists of methane and smaller quantities of ethane and nitrogen. It does not contain condensible quantities of gasoline, and ordinarily it is produced in areas that are rather remote from oil fields. The gas of the Arkansas Valley is of this type.

Natural gas is colorless, and most of it is practically odorless. When mixed with air it is highly explosive. The heating value of natural gas varies within rather wide limits, but in general it is high. "Dry" gas has a lower heating value than "wet," averaging a little less than 1000 B. T. U. per cubic foot. The heating value of "wet" gas is rarely as low as 1000 B. T. U., and that some of it is twice as great.

ORIGIN OF OIL AND GAS

The mode of origin of oil and gas has engaged the attention of scientists for more than a century, but it is not yet surely known. The theory that they are of inorganic origin has been supported mainly by chemists and is based largely upon laboratory experiments. It is possible to form hydrocarbons through inorganic agencies, but the geologist finds that the large quantities of petroleum and natural gas in sedimentary rocks is incompatible with this mode of origin.

Nearly all geologists now believe that oil and gas are of organic origin. They believe that natural hydrocarbons have been formed by the decomposition of organic material that was deposited with sediments. As to whether the organic material consisted of plant or of animal remains, or of both, they are not yet certain; but it is clear that under certain conditions the natural decomposition of remains of both animals and plants, or either, *may* supply the hydrocarbons found in oil and gas. It therefore seems reasonable to suppose that some oils are solely of animal origin, that others were derived from plant remains alone, and that many have originated from a combination of remains of animals and plants. In most areas where oil or gas is found both animal and plant remains were perhaps closely associated, but the gas of the Arkansas Valley was probably never associated with oil and was doubtless formed by the decomposition of plant rather than animal material.

MIGRATION OF OIL AND GAS

In the early stages of their formation both oil and gas are widely disseminated through sediments containing the plant or animal material from which they were derived. They have been gathered together and disseminated by many forces, chief among which are capillary attraction, displacement, gravitation, gas pressure, difference in specific gravity, and the general circulation of water.

Capillarity, which moves a liquid in all directions through small openings in a solid, as kerosene rises in a lamp wick, moves petroleum through the minute pores in rocks. Displacement, an effective cause of the migration of oil and gas, may result from the compaction of the beds in which those materials occur, due to the weight of the overlying rocks. The muds and shales in which oil and gas are assumed largely to originate are much more compacted than the associated sandstones into which the hydrocarbons are driven. The progressive cementation of the pore spaces in these sandstones in turn may cause further migration of the oil and gas and constitute another type of displacement.

Gravitation is rarely an important agent in the migration of oil and gas, and it is effective only where the sands are both porous and

free from water. Gas pressure, however, has probably been a dominant cause of the movement of hydrocarbons. The expansion of the gas equally in all directions as it is formed not only pushes it through the openings in the rock but pushes any other liquids that may lie ahead of it. The difference in the specific gravities of oil, gas, and water is also a cause of the migration of hydrocarbons, for, as the oil and gas are lighter than water they are carried ahead of the water in its movement. The general circulation of water also has contributed to the migration of oil and gas, particularly in the earlier stages of their movement.

ACCUMULATION OF OIL AND GAS

The place of final accumulation of oil and gas after they have been moved depends largely upon the structure of the beds containing them. Oil and gas are likely to move along tilted and porous beds. In the relatively rare dry porous beds the oil moves downward and is concentrated in the synclines. If the beds are saturated with water, as they generally are, the oil and gas are driven upward by the water. This upward migration may continue to the surface, where the oil may emerge as "seeps," or it may be stopped in one or more of several ways. If the reservoir bed is lenticular and the lens is overlain by impervious beds the oil and gas can not move upward; if the reservoir is sealed by a fault or by an intrusive mass, or by asphaltic residue at the surface, these also prevent the escape of the oil and gas. But the most effective obstacle to the continued upward migration of oil and gas is a marked reversal or diminution of the dip of the reservoir bed. In a monocline or an anticline the oil and gas rise to the highest part of the fold; but their farther movement and escape may be prevented by an impervious layer that overlies the reservoir. Under such conditions considerable pressure may be developed and upon drilling on such a structure the oil may be driven upward by the expanding gas to form a "gusher" or flowing well.

EXPLORATION FOR OIL AND GAS

GENERAL CONDITIONS

As certain geologic conditions are essential to the origin, migration, and accumulation of oil and gas, a number of fundamental criteria for their occurrence may be stated. Different geologists have prepared different lists of criteria and have come to regard as essential certain criteria that are of secondary significance to others. The following questions, however, which are essentially those suggested by Clapp,³² may well be asked concerning any area in which exploration for oil or gas is contemplated.

³² Clapp, F. G., Fundamental criteria for oil occurrence: *Am. Assoc. Pet. Geol. Bull.*, vol. 11, No. 7, p. 685.

1. Are there surface indications of oil or gas, such as seeps?
2. Are the rocks of sedimentary origin?
3. Are the rocks that will be encountered by the drill of the same age as those in some producing oil or gas field?
4. Is there a probable or possible source of oil or gas?
5. Are porous beds present?
6. Are the porous beds sufficiently covered by impervious rocks?
7. Are the beds so slightly metamorphosed by heat and pressure that oil and gas, if once present, have not been driven off?
8. Is the structure suitable to the accumulation of oil or gas?
9. Are the hydrostatic conditions favorable to the accumulation of oil and gas?

Although all these criteria are regarded as significant some have greater significance than others. The lack of positive affirmative answers to all the questions, however, need not condemn an area. On the other hand, an unequivocal negative answer to *any one* of the questions except the first may be regarded as unfavorable to the prospect of obtaining oil and gas.

The possibility of obtaining oil and gas in the Arkansas Paleozoic area may now be considered according to these criteria.

SURFACE INDICATIONS IN THE ARKANSAS PALEOZOIC AREA

To the layman "surface indications" are the most convincing evidences of the existence of oil or gas, but to the geologist their absence is not regarded as significant, for they are not found in many producing oil and gas fields. The chief "surface indications" are oil and gas seeps or "springs," rocks impregnated with petroleum or bitumen at their outcrop, and bituminous dikes.

Most of the "surface indications" in the Paleozoic area of Arkansas are found north of the Arkansas River. A number of the Paleozoic rocks of the Ozark plateaus give off the odor of petroleum when freshly fractured, but most of the true seeps are in the post-Boone formations. The Batesville sandstone is at several places somewhat impregnated with bitumen, and oil is reported to be seeping from that sandstone at the base of the Upper Batesville dam, near Batesville.

The Fayetteville formation is at many places petroliferous. Concretions containing a light-green oil of about 40° Baumé gravity are found near Jasper. Septarian limestone concretions found in the Fayetteville shale near Yardell contain either liquid hydrocarbons or their asphaltic residue. Similar concretions are abundant near Kingston, especially in Sec. 15, T. 16 N., R. 24 W. The Wedington sandstone member of the Fayetteville is commonly somewhat bituminous at its outcrops, but actual seepages from it are rare.

The Pitkin limestone, when freshly broken, almost invariably gives off a strong odor of petroleum, and at an outcrop of it along the main road southwest of St. James, the sun's heat, according to W. Z. Miller, brought oily material to its surface. The Hale sandstone is at many places saturated with bituminous material, and there are several seepages from it. There is a slow seep 7 miles southwest of Prairie Grove, along the main road in T. 14 N., R. 32 W., where the sandstone is so greatly saturated with petroleum that a small fragment of it dropped into water produces a "rainbow." Near Floss, in the Cove Creek valley, in T. 13 N., R. 32 W. there is saturated Hale sandstone that at times gives rise to actual seeps, which for 50 years have been known as the "Oil Springs." Near Huntsville there are several seeps in this formation. One is just north of Huntsville, half a mile east of the Eureka Springs highway, where there is an extensive outcrop of asphaltic sand but true seepage only when water conditions are favorable. Another seep is in Sec. 9, T. 16 N., R. 26 W., where a viscous black oil exudes from a bituminous sandstone. Still another seep in the Hale formation is near Deer post office, about 13 miles south of Jasper, where oil oozes slowly from an asphaltic sandstone.

The Bloyd shale yields oil on distillation but no seepages appear to occur in it. The Atoka formation contains beds of asphaltic sand, but few good seeps. In the NE. $\frac{1}{4}$ SW. $\frac{1}{4}$ Sec. 17, T. 16 N., R. 26 W., however, there is a fairly strong seepage of viscous black oil from a dark-brown sandstone near the base of that formation. Near the settlement of Brewer a water spring issuing from the Atoka is said to carry a brownish-green oil that ranges in gravity from 30° to 35° Baumé.

The "surface indications" described are confined to the southern part of the Springfield plateau and the Boston Mountains. Gas seeps, however, have been reported from several places in the Arkansas Valley. One of these, which was visited by the writer, is on the farm of C. J. Pairat, in Sec. 13, T. 6 N., R. 11 W. The gas issues from a series of vents in the bed of a small stream. The gas apparently escapes along a joint plane, for the vents run N. 10° E. The seep is about 20 feet long. No rocks are exposed there, but 100 yards downstream beds of sandy shale of the Atoka formation dip 5° N. and strike 20° W. A number of similar vents were discovered during the flood of 1927, when water stood over many square miles in the valley. Some of these vents were no doubt points of escape of marsh gas, but others were alined for 100 feet or more. Moreover, the direction of alignment, as described by farmers, coincides with the strike of the steeply dipping beds. "Rows of great bubbles" here unquestionably represented gas seepage.

Oil is reported to have been skimmed from water in a well dug a mile southwest of Blue Ball, but the report seems to be questionable. Gasoline noted in water well at Gravelly also caused considerable excitement, but it apparently came from a leaky gasoline tank at a garage near by. In addition to these unverified reports, the only "surface indications" in the Ouachita Mountain province are the asphaltic residues in the Atoka formation on the Athens Piedmont plateau.

A bed in which a seepage occurs may be so inclined that the structurally favorable place for drilling may be far from the seep. All wells drilled near seepages should be located down and not up the dip from them. Furthermore, bituminous sand at any place may indicate the former presence of oil there, but the more volatile matter may have entirely escaped. Finally, the beds in even a highly productive oil and gas area may have been so slightly folded that they were not fractured or fissured, and as the hydrocarbons there have no natural channels of escape they will produce no "surface indications."

SEDIMENTARY ROCKS IN THE ARKANSAS PALEOZOIC AREA

Practically all the Paleozoic rocks of Arkansas except the Hatton tuff lentil of the Stanley formation are sedimentary. This tuff, however, was deposited in water, and its presence does not affect adversely the possibility of obtaining oil and gas in the area or the formation in which it occurs. The Paleozoic rocks are cut at several places by igneous dikes, sills, and plugs of mid-Cretaceous age, which, however, affect adversely the possibility of obtaining oil and gas only in small areas near them.

SIGNIFICANCE OF THE AGE OF THE BEDS IN THE ARKANSAS PALEOZOIC AREA

Large quantities of oil and gas have been produced at many places in North America from Ordovician, Silurian, Devonian, and Carboniferous beds, all of which are exposed also in the Arkansas Paleozoic area. Cambrian beds crop out in a small area in the Novaculite Uplift and are within easy reach of the drill in the Salem and Springfield plateaus and the northern part of the Boston Mountains, but no large quantity of oil or gas has been obtained from them, though they have been tested at many places. Beds of Cambrian age therefore cannot reasonably be expected to yield either oil or gas in Arkansas.

SOURCES OF OIL AND GAS IN THE ARKANSAS PALEOZOIC AREA

Most of the rocks of the Arkansas Ozark plateau contain organic remains. The Ordovician beds, however, particularly the older ones,

contain few such remains. Some of these beds however, have undergone dolomitization, which commonly destroys all evidence of the existence of organisms. The Silurian and Devonian beds exposed in northern Arkansas are in places fossiliferous, but their areal extent is so small that they deserve slight consideration as source rocks. The Mississippian beds, however, are generally crowded with animal fossils, and the Pennsylvanian beds contain the remains of both animals and plants.

The Cambrian, Ordovician, Silurian, and Devonian beds exposed in the Ouachita province contain little organic material. A few fossils have been found in them, and some carbonaceous shales occur, but they cannot be regarded as promising sources of oil or gas. Some of the Carboniferous beds in the Ouachita province, however, are very carbonaceous, and, at most exposures they contain abundant remains of plants. Such remains may evidently be a source of hydrocarbons, as is shown by the gas wells producing from the Atoka formation in the Arkansas Valley and by asphaltic residues in the Carboniferous rocks of the Athens Piedmont plain.

POROSITY OF THE ROCKS OF THE ARKANSAS PALEOZOIC AREA

Most of the rocks through which oil and gas migrate and in which they accumulate and are concentrated into "pools" are porous. The porosity of cavernous limestone and dolomite is due to openings so irregularly spaced that these rocks afford no satisfactory determination of porosity. Most beds of limestone and dolomite, however, are sufficiently fractured or cavernous to serve as reservoirs for oil and gas provided they have an ample cover of impervious beds. The effective porosity of a sandstone may be very different from the actual porosity of samples of it taken at the outcrop. The porosity of such samples may differ widely from place to place and may differ considerably from the porosity of samples of a well core, which indicates more exactly the potentiality of a sandstone as a reservoir for oil and gas. No matter how great the porosity of a sample of a sandstone may be, the effective porosity of the bed yielding it is no greater than that of its least porous parts.

Unfortunately, no detailed studies have been made of the porosity of the beds of sandstone in the Arkansas Paleozoic area as indicated by cuttings obtained from drill cores. The porosity of cuttings from the productive sands in the Kibler-Williams fields, however, is said to be about 18 per cent. Detailed studies of the porosity of samples taken from the outcrops of sandstone in the Paleozoic area are now being made, and in anticipation of the results of this study it is perhaps safe to make the following generalizations.

Most of the sandstones of the Carboniferous formations in the Ar-

kansas Valley and the Ozark plateau are sufficiently porous to permit the easy migration and accumulation of oil and gas. All the sandstones in the Ouachita Mountains are probably somewhat less porous, although in some places they are quartzitic, and in others their pore space appears to be relatively great. The pre-Mississippian sandstones of the Salem and Springfield plateaus are variable in porosity, but they are not notably less porous than the younger sandstones.

The beds of sandstone in the Paleozoic area of Arkansas that may form reservoirs for oil and gas are the sands of the Atoka formation, the Hale sandstone, the Wedington member of the Fayetteville formation, the Batesville sandstone, the Sylamore sandstone, the St. Peter sandstone, and the Kings River member of the Everton formation. As possible limestone reservoirs only certain parts of the Boone formation may be worthy of consideration.

COVER BEDS IN THE ARKANSAS PALEOZOIC AREA

The most effective cover for a porous reservoir consists of thick beds of clay or shale, which ordinarily prevent the escape of oil and gas, but some thick, compact beds of limestone are only slightly less effective. Over much of the Salem plateau beds of the Kings River and St. Peter sandstones are exposed in many stream valleys where they lack sufficient cover to prevent the escape of oil or gas. In the Springfield plateau these beds are exposed in some deep ravines, but at many places they are overlain by thick beds of limestone that are sufficiently compact to be practically impervious. In the same plateau the Sylamore sandstone is at many places covered by the Chattanooga shale, which is an ideal cover rock. The Boone formation, which is the surface rock over large areas, contains cavernous zones that are overlain by compact beds of impervious limestone of the same formation.

In the Boston Mountains the Batesville sandstone is at many places effectively covered by the thick Fayetteville shale, which also prevents the oil and gas in the Wedington sandstone from migrating upward; and the Bloyd shale is at most places ample cover for the Hale sandstone. The sandstones of the Atoka formation are likewise protected by thick beds of clay shale, but in the deeply dissected northern part of the mountains these beds are not everywhere thick enough to prevent the escape of oil and gas. On the Springfield Plateau all these beds of sandstone are without sufficient cover.

In the Arkansas Valley many of the sandstones of the Atoka formation are covered with hundreds of feet of impervious shale, and at most places in the southern part of the Boston Mountains their cover is sufficient. All the older sandstones mentioned are effectively

covered in the Valley province, but the deeper ones lie beyond ordinary drilling depths.

METAMORPHISM IN THE ARKANSAS PALEOZOIC AREA

The rocks in the Arkansas Paleozoic area have undergone different degrees of metamorphism. Those in the Novaculite Uplift are obviously considerably altered, but true metamorphic rock, such as slate, is found at only a few places. The rocks elsewhere have undergone considerable regional deformation, but the internal changes in them seem to be slight. Where the changes are not obvious the degree of metamorphism may be determined by several methods. The most widely used criterion is the carbon ratio of the coal in the area considered. In 1915 David White³³ advanced the theory that the percentage of fixed carbon in pure coal is an accurate index of the degree of metamorphism of the rocks containing the coal, and that the general prospect of obtaining oil in an area where coal occurs may therefore be determined by a study of the carbon ratio of the coal in that area. After studying the locations of Appalachian oil fields in connection with the carbon ratios of the coals in them White concluded that oil in commercial quantities would not be found where the carbon ratios of the coals were higher than 65. Most of the data afforded by other oil fields and coal beds in North America and other continents seemed to justify his conclusion and led him to add that the degree of regional metamorphism in any area determined also the character of the oil it contained.

White's theory has been of considerable value in determining that certain areas where metamorphism is great are unfavorable for the occurrence of oil and gas, but its general validity has been recently questioned by some geologists. Reeves,³⁴ for instance, believes that the geologic agencies that alter carbonaceous deposits are heat and pressure due to depth of burial rather than heat and pressure generated by horizontal thrust. He is also of the opinion that, as incipient alteration of sediments has apparently not determined the extent of our known oil and gas fields, the carbon ratios furnish no reliable information as to the possibility of obtaining oil in any area. Several petroleum geologists, although they doubt the validity of the theory, regard it as a useful empirical generalization.

The carbon ratios in the Arkansas Paleozoic area have already been discussed by the writer,³⁵ who, in 1927, constructed a tentative isocarb map of the area based on the coal analyses then available. These analyses were made by several laboratories, and the coals analyzed

³³ White, David, Some relations in origin between coal and petroleum. Washington Acad. Sci. Jour., vol. 5, pp. 189-212, 1915.

³⁴ Reeves, Frank, Carbon-ratio theory in the light of Hilt's law: Am. Assoc. Petrol. Geol. Bull. Vol. 12, pp. 795-823, 1928.

³⁵ Cronels, Carey, Oil and gas possibilities of the Arkansas Ozarks: Am. Assoc. Petrol. Geol. Bull. Vol. 11, pp. 279-297, 1927.

were obtained from several different formations. The map is therefore not considered accurate in detail, but as the new data available do not help the determination, no attempt has been made to construct a new isocarb map for this report. Plate XLV, however, indicates the carbon ratios in the different parts of the Paleozoic area. Most of the analyses are taken from Bulletins 22, 85, 123, and 193 of the U. S. Bureau of Mines,³⁶ but some analyses of samples collected by H. L. Anderson and the writer were made by the Pittsburgh Testing Laboratories. The coals sampled are of early Pennsylvanian age and most of them were obtained from the Morrow group (Baldwin coal), but samples 16 and 17 were taken from the lower Atoka formation. The analyses are given below:

Sample No.	Location	Moisture	Vol. Mat.	Fixed Carb.	Ash	Carb. Ratio
1.....	Sec. 32, T. 16 N., R. 29 W.	0.54	30.04	61.09	8.33	67.03
2.....	Sec. 21, T. 17 N., R. 29 W.	0.61	26.89	61.57	10.93	69.60
3.....	Sec. 21, T. 17 N., R. 29 W.	3.35	29.14	61.24	6.27	67.75
4.....	Sec. 32, T. 16 N., R. 29 W.	0.59	30.79	61.92	6.70	66.80
5.....	Sec. 10, T. 16 N., R. 30 W.	0.20	25.91	55.73	18.16	68.26
6.....	Sec. 32, T. 16 N., R. 29 W.	7.40	25.98	58.30	8.32	69.17
9.....	Sec. 10, T. 16 N., R. 30 W.	1.20	27.18	66.50	5.12	70.98
10.....	Sec. 25, T. 14 N., R. 31 W.	4.79	22.96	66.35	5.90	74.29
11.....	Sec. 22, T. 13 N., R. 31 W.	0.35	18.17	69.13	12.35	79.20
12.....	Sec. 32, T. 15 N., R. 29 W.	3.07	24.15	65.72	7.06	73.13
13.....	Sec. 1, T. 13 N., R. 32 W.	1.80	23.25	61.82	13.13	72.67
14.....	Sec. 1, T. 13 N., R. 32 W.	6.44	23.58	58.51	11.47	71.27
15.....	Sec. 19, T. 14 N., R. 31 W.	0.59	26.91	61.58	10.92	69.59
16.....	Sec. 21, T. 10 N., R. 29 W.	1.60	20.25	75.39	2.76	78.82
17.....	Sec. 28, T. 17 N., R. 22 W.	0.96	30.20	58.98	9.86	66.14

In addition, the analysis of a sample of coal obtained from the Atoka formation on Weaver Creek, in Sec. 18, T. 12 N., R. 13 W., made by the Tulsa Laboratories for Mr. Samuel Hayes, is given below and is indicated on the map.

Coal from Sec. 18, T. 12 N., R. 13 W. (Atoka formation).

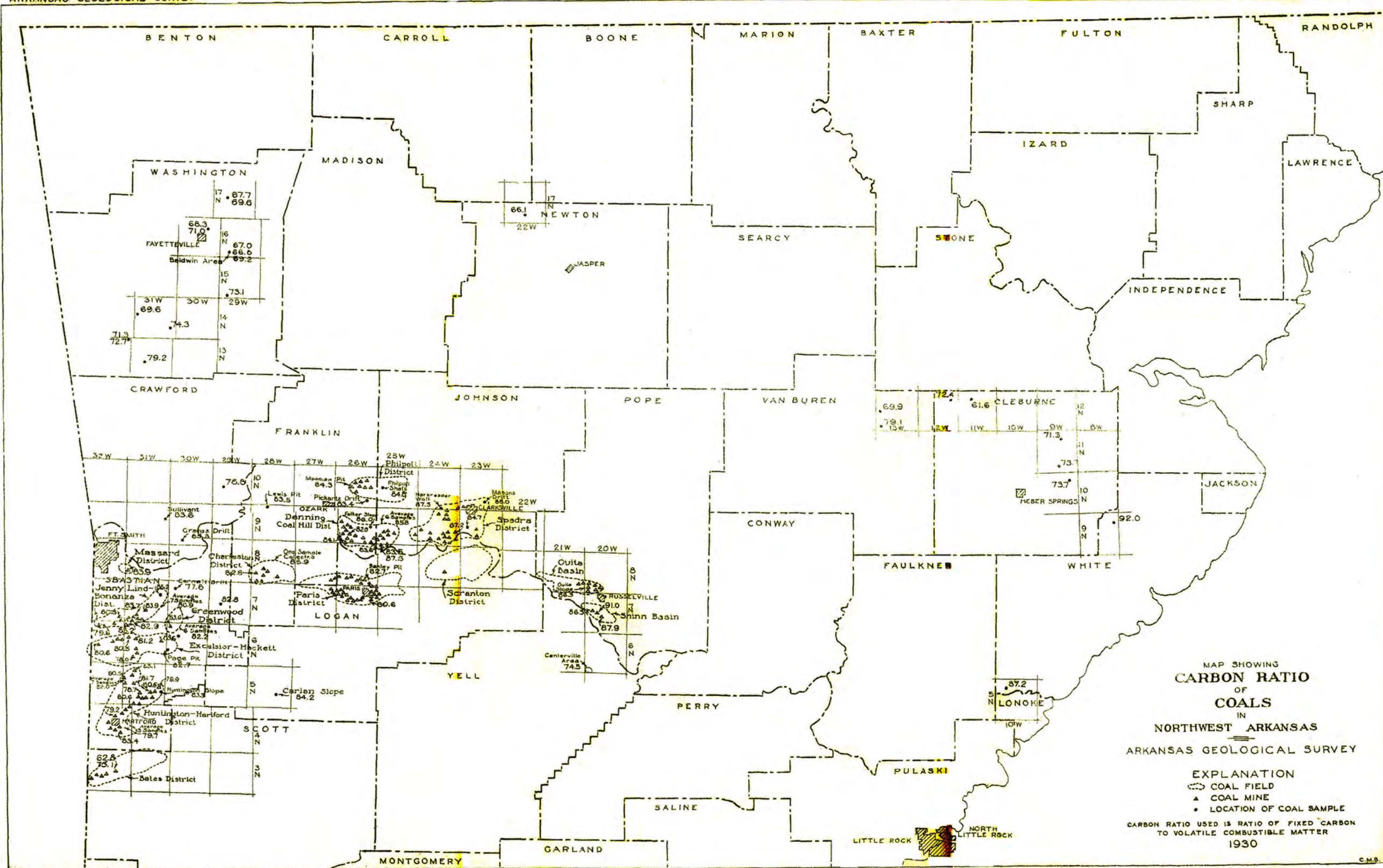
[Sample was free from moisture.]

	Per Cent
Volatile and combustible matter.....	21.36
Fixer carbon.....	49.54
Ash.....	29.10
<i>Correction on pure coal basis</i>	100.00
Volatile and combustible matter.....	30.13
Fixed carbon.....	69.87

Most of the samples of coal collected in the Arkansas Valley for analysis were taken from the Hartshorne coal, but those collected in areas north of Little Rock, south of Dardanelle, near Clinton, north of Mulberry, and near Compton were taken from the lower part of the Atoka formation. The samples obtained in the northwestern part of the State are Baldwin coal.

A study of the map discloses several interesting anomalies. In the Bates district the Hartshorne coal in the Seymour mine is in

³⁶ This information has been brought together in U. S. Bureau of Mines Technical Paper, 416, 1928.



four benches. That of the upper three benches has a carbon ratio of 62.8, but that of the lower bench has a ratio of 73.1. This difference suggests that the composition of the coal rather than either the depth of its burial or horizontal thrust may have aided in determining the carbon ratio. Moreover, the Bates coal shows a much lower ratio than the coals to the north, though it is closer to the area of extreme deformation. This decrease in the carbon ratios toward the south is not local, for the Russellville coals, whose carbon ratios range from 87.9 to 88.9, occur only a few miles north of the Centerville coals, which, in Sec. 31, T. 6 N., R. 20 W., have a carbon ratio of only 74.5. As the Centerville coals are older, however, and have been more deeply buried, it might be supposed that they would have a higher ratio.

The ratios also increase definitely though irregularly from the west toward the east along the Arkansas River Valley. In the Jenny Lind district, near the western border of the State, the ratios range from 77.4 to 83.9, and in the contiguous Bonanza area they range from 79.6 to 81.9. In the Hackett district, south of the Backbone fault, the ratios range only from 81.4 to 82.1, but coal from a shaft sunk at Hackett City has a ratio of 83.2. Most of the coals in the Hartford area have ratios of 79.4 to 80.3, but the coal at Claiborne's pit has a ratio of 83.4. In the Huntington district, where the carbon ratios are not so variable, the range is from 79.9 to 80.4. Near Burma the range is 81.6 to 82.5, and near Greenwood it is 80.9 to 83.6. Further notable irregularities appear in the carbon ratios of coals of the same age that lie near the western part of the Arkansas Valley province in Arkansas. The Watts coal, in Sec. 11, T. 7 N., R. 31 W., has a ratio of 85.2, but the coal from the Carnall drift, in Sec. 6, T. 7 N., R. 30 W., a short distance east, has a ratio of only 77.8. On the other hand, the coal from the Sullivant mine, in Sec. 13, T. 9 N., R. 31 W., which might be expected to have a still lower carbon ratio, has a ratio of 83.6; and coal from the Graves drift, which lies between the Sullivant and Carnall mines, in Sec. 32, T. 9 N., R. 30 W., has a ratio of 85.5. These analyses show that the carbon ratios of the coals in central western Arkansas range from 77.4 to 85.2, and that a variation of 6.5 occurs in the Jenny Lind district alone.

The Altus area, east of the districts already mentioned, yields coals whose ratios range from 83.4 to 85, but the coals in the Denning area range from 80.9 to 84.1. The Coal Hill district, which adjoins the Altus fields on the east, produces coals whose carbon ratios are 83.5 to 87.9, and the coal from Mason's drift, 3 miles northeast of Clarksville, has a ratio of 88. The Spadra field yields coals whose carbon ratios range only from 87.2 to 87.7, but coals from the Paris

area to the south are more variable and have somewhat lower ratios. Most of the coals in the Arkansas Valley lie at the base of the Spadra shale and are known as the Hartshorne coal, but the Paris coals are found in the Paris formation. These coals have been less deeply buried than the Hartshorne coal, and according to Hilt's law they should, other things being equal, have undergone less metamorphism. On the other hand, as the Paris field is closer to the region of severe structural deformation than the Spadra field its coals should logically have higher carbon ratios.

Still farther east, in the Ouita and Russellville areas, the Hartshorne coals have ratios that range from 86.3 to 88.9. The coal in the Atoka formation about 5 miles south of El Paso, in Sec. 8, T. 5 N., R. 10 W., has a ratio of 87.2, and that from the same formation 2 miles east of Pangburn, in Sec. 12, T. 9 N., R. 8 W., has the extremely high ratio of 92, although the rocks in this area are only gently folded.

It is thus evident that the carbon ratios of the coals in the eastern part of the Arkansas Valley are from 5 to 10 per cent higher than those of coals from the vicinity of Fort Smith; and although all the coals analyzed were not obtained at the same horizon, the increase in the ratios of the Hartshorne coal from Fort Smith eastward to Russellville suggests that the further increase toward the east is not due alone to differences in the age and the depth of burial of the coals.

The carbon ratios of the coals analyzed decrease irregularly northward from the Arkansas Valley, though most of the coals there are older than those farther south. The carbon ratios of the Atoka coals near Clinton are notably different. A coal northeast of Clinton, in Sec. 31 (?), T. 12 N., R. 13 W., has a ratio of 79.1, whereas a coal of about the same age only 3 miles north has a carbon ratio of 69.9. A coal in Sec. 11, T. 12 N., R. 12 W., has a carbon ratio of 72.4, but a coal only 4 miles to the east, in a similar stratigraphic position, has a ratio of 61.6. Coals in Sec. 11 (?) T. 10 N., R. 9 W., and in Sec. 34, T. 11 N., R. 9 W. have a carbon ratio of 73.7, and coal collected 5 miles north of the place last indicated have a ratio of 71.3. Coal collected from the Morrow and Atoka formations in northwestern Arkansas show similar but less notable irregularities in the decrease of their carbon ratios northward.

Some of the irregularities noted are no doubt due to differences in the types of samples analyzed, for some samples were taken from the outcrop, others were taken from idle country banks, and still others were taken from new faces in active mines. Not until many samples have been collected from similar places, analyzed in the same laboratory, and compared, with proper allowance for difference in

age, will the meanings of the wide variations in the carbon ratios of the coals in Arkansas be perfectly clear. Until then it is not possible to improve upon the isocarb map prepared by the writer³⁷ several years ago. If differences in carbon ratios do accurately register degrees of regional metamorphism, that map shows that the most intense metamorphism in the Arkansas Paleozoic area was located in the moderately folded beds of the Arkansas Valley province; that the beds in the Ozark plateaus, which resisted the thrust from the south, are least altered; and that the beds in the Ouachita Mountain province (if we may extrapolate), although more metamorphosed than those in the Ozark area, are less altered than those in the Arkansas Valley. As the physical character of the beds of these areas (other than the coal beds) do not seem to sustain these inferences, it appears that the high carbon ratios of the coals of the Arkansas Valley are due to the heat and pressure generated by the great weight of the overlying rocks and to differences in the original composition of the coal.

Whatever may have caused the anomalies in the carbon ratios of the coals in the Arkansas Paleozoic area, it is obvious that so far as carbon ratios alone are concerned, no part of the area for which such ratios are known can be condemned as potential gas territory. In fact, the carbon ratios of coals in or near proven gas territory in the Arkansas Paleozoic area range from 79 to 88, and most of them are higher rather than lower than those of coals in other parts of the State.

STRUCTURE IN THE ARKANSAS PALEOZOIC AREA

The structural features in the Arkansas Paleozoic area are of practically all kinds and sizes, and many of them appear to be favorable to the accumulation of oil or gas. Some of the anticlines are too closely folded to justify their exploration, but as gas has been produced in commercial quantities near Plummerville from a steep-limbed anticline, several other well-defined anticlines may also be productive, and a large number of gentle folds are either productive or untested. An affirmative answer must therefore be given to the question whether the structure in the Arkansas Paleozoic region is favorable to the accumulation of gas and oil.

HYDROSTATIC CONDITIONS IN THE ARKANSAS PALEOZOIC AREA

The beds of sandstone of the Arkansas Paleozoic area commonly carry large quantities of water, and in certain areas there is a minor artesian circulation. A few of the sandstones, however, are notably dry, and among these are some that yield commercial quantities of gas. The gas in such sandstones is found low on the anticline or

³⁷ Croneis, Carey, loc. cit.

concentrated in the synclines, though no field in Arkansas is now producing even principally from a syncline. The chief question in the Arkansas Paleozoic area is therefore not whether artesian circulation has flushed oil or gas from the average anticline, but whether there has been sufficient water to concentrate the oil or gas on structural "highs;" and the occurrence of gas in several anticlines in the Arkansas Valley shows that this question may be answered safely in the affirmative, at least for a large number of localities.

CONCLUSIONS

For large parts of the Arkansas Paleozoic area all the questions regarding the fundamental criteria for the occurrence of oil and gas may be answered in the affirmative, except, possibly, the question regarding metamorphism. The carbon ratios of most of the Paleozoic coals of Arkansas are considered incompatible with the occurrence of oil, and, they are also theoretically too high for the occurrence of gas; yet the Clarksville area, which promises to be the most productive gas field in the Arkansas Valley, produces from sandstone that lies 3,000 feet lower stratigraphically than coals having a carbon ratio of 88. Gas may therefore be found at any place where the fundamental criteria other than carbon ratios are favorable. As oil has not yet been found in commercial quantity anywhere in the Paleozoic area in Arkansas, it is reasonable to assume that in Arkansas, as elsewhere, it will not be found where the carbon ratio is much over 65.

The possibility of obtaining oil and gas in the Arkansas Paleozoic area may be summarized by physiographic divisions (see Pl. III) as follows:

1. The Salem plateau is underlain by rocks that are not probable sources of oil or gas, and the beds of sandstone there that might serve as reservoirs are either without sufficient cover or belong to the Cambrian system, which has not yielded oil or gas elsewhere. For these and other reasons the Salem plateau should not be prospected for oil or gas.

2. The Springfield plateau offers some promise of both oil and gas, particularly in areas near its southern boundary. The carbon ratios in this plateau, in some places at least, indicate that the rocks are not so greatly metamorphosed as to preclude the formation of small oil pools, though if the carbon ratio alone is used as a criterion the entire plateau must be regarded as unpromising. The rocks of this area, however, include potential source beds and suitable reservoir beds, and they are so folded as to be not only favorable to the accumulation of oil and gas but they have sufficient cover to prevent the escape of those products from porous beds.

Drilling in this area, however, should be undertaken only by strong

organizations working under competent scientific advice, and even then only with a full realization of the hazard involved.

3. The Boston Mountains are rather attractive as a potential gas-producing area. Here all the questions regarding the fundamental criteria except the one concerning metamorphism may be answered in the affirmative. The carbon ratios of the coals are very irregular, though most of them are much higher than the arbitrary figure above which the prospect for oil is considered poor. The carbon ratios at some places in the Boston Mountains, however, are about 60, so that, according to the carbon ratio theory, the chances for high gravity oil at such places should be fairly good. The rather high carbon ratios may not affect the possibility of obtaining gas. As the southern part of the area includes more potential producing horizons, with ample cover, that part offers the best chance for the production of gas. Because of the decrease of the carbon ratios northward, however, the northern part of the area is somewhat more favorable to the production of oil. Wells drilled in the Boston Mountains at proper places with respect to the structure have a reasonably good chance of obtaining gas and some chance of obtaining oil.

4. The Arkansas Valley province offers a good opportunity for the commercial production of gas wherever the structural conditions are favorable. The unusually high carbon ratios, however, do not encourage drilling in this province for oil. All parts of the province are regarded as potential gas territory, but the southern border is perhaps somewhat less promising than the other parts.

5. The Fourche Mountains are at most places made up of rocks that are too intricately folded and too highly metamorphosed to be potential oil or gas territory. This statement is not based on carbon ratios. Along the northern border of the mountains, however, and particularly in their northeastern part, small quantities of gas may be obtained from some of the more open anticlines, but exploration there should be undertaken only by strong organizations working under competent scientific advice and fully cognizant of the hazard involved.

6. The Novaculite Uplift offers no possibility for the production of oil or gas and should not be explored for those products.

7. The Athens piedmont plateau is only slightly more favorable as potential oil and gas territory than the Novaculite Uplift. Near its southern border, where the Atoka formation crops out, the chances of obtaining oil and gas are somewhat better than elsewhere in the plateau, but drilling is not recommended.

PRODUCTION OF NATURAL GAS IN THE PALEOZOIC AREA OF ARKANSAS

PRESENT CONDITIONS

There are two developed gas-producing areas in Arkansas. The larger of the two, and at present the more productive, is that in Columbia, Ouachita, and Union counties, in which the gas is derived from beds of late Cretaceous age. Gas is produced from Paleozoic beds only in an area in the western part of the Arkansas Valley, chiefly in Crawford, Johnson, Scott, and Sebastian counties. The gas produced in this area is obtained from the Pennsylvanian Atoka formation, which immediately underlies the productive coal measures.

The Arkansas Valley fields, with which this report is chiefly concerned, were the first to be discovered in Arkansas, and although their production has never been large they have played an important part in the industrial development of central-western Arkansas. The total production from the fields of this area during 1925 averaged about 11,600,000 cubic feet a day. The production may be increased by opening new fields, such as the recently developed Clarksville area. The imperative need of additional production is indicated by the sharp decrease in the production of gas in Arkansas in 1927 as compared with 1926 and by the increase in the demand.

In 1926 Arkansas produced 43,566,000,000 cubic feet of gas, or 3.3 per cent of the total quantity produced in the United States, and consumed 52,630,000,000 cubic feet, or 4 per cent of the total quantity consumed. In 1927 the production had fallen to 30,450,000,000 cubic feet and the consumption to 40,916,000,000 cubic feet. It is in the hope that the discovery of new productive areas in the Arkansas Valley would offset this reduction that this report has been prepared.

In addition to the gas produced from the Atoka formation in the Arkansas Valley small quantities of gas have been obtained from the older Paleozoic rocks of the Ozarks in Arkansas. Although no fields have yet been developed in the area north of the Valley proper, an attempt is now being made to obtain gas for the city of Fayetteville in that area. Most of the gas obtained in the Ozarks has been derived from the Sylamore, Batesville, Wedington, and Hale sandstones and from the Boone formation. Unlike the Arkansas Valley gas, which is "dry," the gas obtained from these older Paleozoic rocks is "wet." The history of development and the possibility of obtaining gas in the Ozark area are discussed elsewhere in this report.

No gas has been obtained in any of the test wells drilled in the Ouachita Mountain province.

GAS OF THE ARKANSAS VALLEY

A tabular summary of the history of development of the natural gas industry in the Arkansas Valley is given in Table 1. Most of the gas has been obtained in the western part of the valley, but some has been obtained as far east as Heber Springs. The entire physiographic province is regarded as potential gas territory, although the chances for the commercial production of gas in its extreme southern and southeastern parts are not so good as in areas farther north. The actively producing fields at present are the Mansfield, Massard Prairie, Kibler, Williams, Alma, and Clarksville. (See accompanying map.) The output of the first two of these, which have been producing for about 25 years, has declined until it is relatively small, but the reserves in the other areas should be sufficient to supply the demand for at least 15 years at the present rate of consumption.

All the gas produced in Arkansas Valley is obtained from beds of sandstone in the Atoka formation, and much of it is probably obtained from beds at nearly the same general horizon. The gas usually occurs in relatively thin, porous beds that lie among thicker beds of sandstone, and it is obtained at as many as four horizons, although most of it is obtained from beds at only two horizons. The initial rock pressure ranged from 220 to 1,180 pounds and was invariably greater for the lower beds than for those that lie higher. The production from the lower beds has also been larger than that from the higher. The initial daily open-flow capacity of some of the wells that tap the deeper beds was as great as 40,000,000 cubic feet, but that of the average well for the district was less than 10,000,000 feet. Drilling has not been difficult, and little troublesome water has been encountered in any of the fields. The average cost of drilling a well in all the fields has been about \$8,000.

The gas obtained is probably essentially dry in all the fields, although reports to the contrary have been circulated concerning the gas from the Clarksville area. A very little oil has been obtained in a few wells, but the gas is not usually associated with oil. Only a few analyses of the gas are available, but they show a rather remarkable uniformity in composition for gases from different fields. The gas is noteworthy for its high content of methane, and in this particular it is similar only to the gas obtained at Caddo, Louisiana, though it resembles slightly some of the Ohio and Indiana gases, which, however, contain more nitrogen. The analyses of typical gases from a number of American gas fields are compared with those from the Arkansas Valley area in Table 2.

The three analyses of Arkansas gas used in the table show fairly well the type of gas obtained in the Valley, although some of the gases from the Williams field contain as much as 4 per cent of ethane

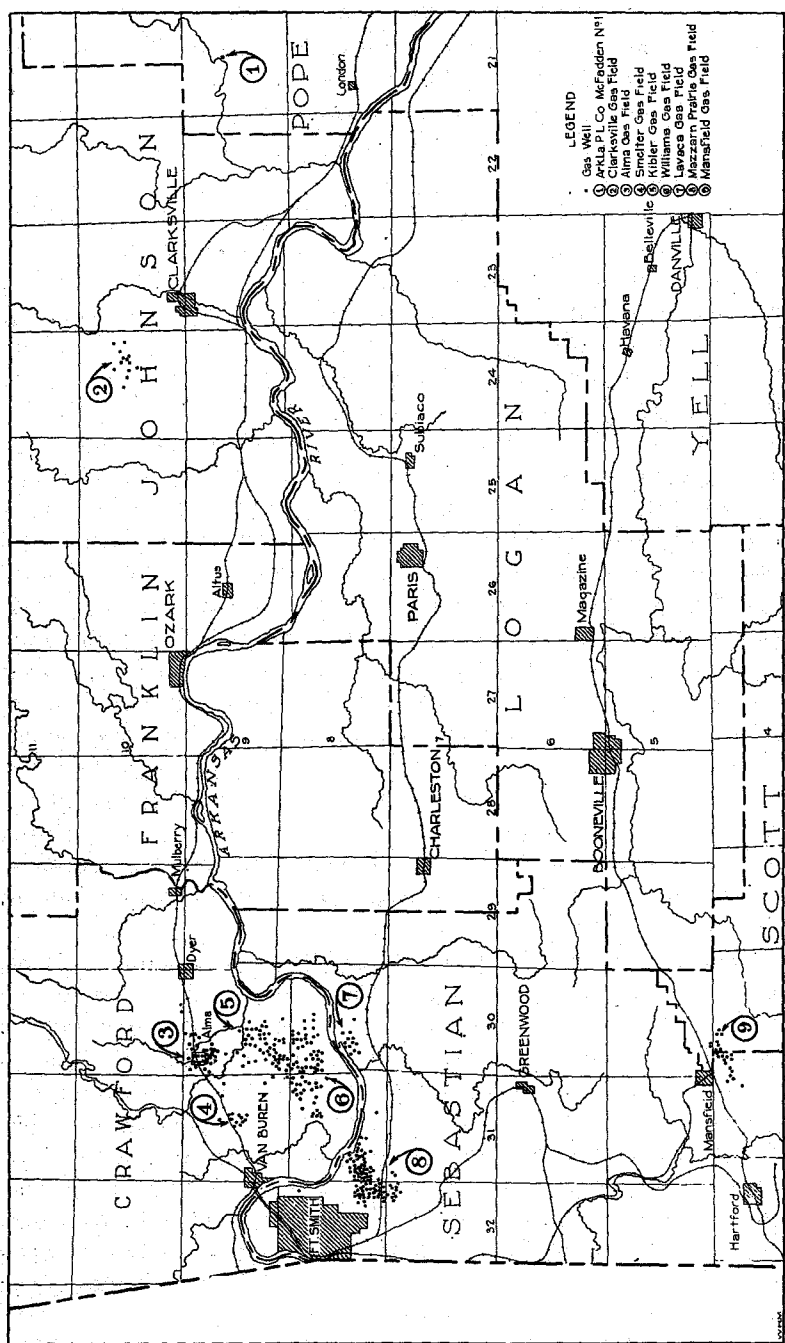


FIGURE 27.—Index map of the gas fields of western Arkansas.

[Scale about 11 miles to the inch.]

TABLE 1.—Development of the natural gas industry in the Arkansas Valley

	Mansfield Field	Alma Field and Extension	Kibler Field	Williams Field	Massard Prairie Field	Indiahoma Ref. Co., Pearson No. 1	CLARKSVILLE FIELD Empire Gas & Fuel Co., Russell No. 1	Empire Gas & Fuel Co., A. M. Qualls No. 1	Plumerville	Scotland	Heber Springs	Jethro
Date of discovery.....	1902	October, 1922	November, 1915	December, 1918	November 5, 1904		March 18, 1926	September 2, 1927	1905	1922	1922	1927
Number of commercially productive sands	4	2	2	2	2	1	3	4	1	1	1	1
Depth to top of producing sand in feet	1st sand, 863 to 1385 2d sand, 1645 to 1725 3d sand, 1750 to 1870 4th sand, 1970 to 2047	1st sand, 1400 to 1936 2d sand, 2400 to 2800	1st sand, 1115 to 1500 2d sand, 1950 to 2400	1st sand, 1315 to 1700 2d sand, 2150 to 2600	1st sand, 1190 to 1402 2d sand, 2100 to 2260	2345	1st sand, 834 2d sand, 2045 3d sand, 2889	1st sand, 929 2d sand, 2288 3d sand, 2853 4th sand, 3012	2582	1625	1370 to 1375	2465
Thickness of sand in feet.....	1st sand, 22 to 60 2d sand, 76 to 142 3d sand, 10 to 30 4th sand, 10 to 101	1st sand, 200 30 feet porous zone 2d sand, 135 36 feet porous zone	1st sand, 200 30 feet porous zone 2d sand, 135 36 feet porous zone	Same as Kibler	1st sand, 40 to 260 2d sand, 75 to 100	20 feet	1st sand, 12 2d sand, 13 3d sand, 3+	1st sand, 4 2d sand, 10 3d sand, 18 4th sand, 31+				10
Initial rock pressure in pounds.....	315 from 1200-foot sand	1st sand, 330 2d sand, 420	1st sand, 220 2d sand, 260	1st sand, 220 2d sand, 265	1st sand, 220 2d sand, 265	520	1,000	1180				
Rock pressure in pounds, April 6, 1928	1st sand, 265	1st sand, 100 2d sand, 175	1st sand, 75 lbs. } 2d sand, 75 lbs. } Average	1st sand, 100 lbs. 2d sand, 100 lbs.	25 to 35							
Open daily flow in cubic feet of largest well.....	5,000,000	1st sand, 25,000,000 2d sand, 42,000,000	1st sand, 3,000,000 2d sand, 21,000,000	1st sand, 14,000,000 2d sand, 24,000,000	4,250,000	6,500,000	11,500,000	15,000,000	?	± 250,000	± 200,000	± 350,000
Present daily flow in cubic feet....	Not known	120,000,000	30,000,000	90,000,000	Not known							
Present daily consumption in cubic feet	400,000	2,900,000	4,000,000	8,000,000 to 10,000,000	1,250,000				None			
Number of present producing wells..	8	1st sand, 6 2d sand, 27	22	44	69	1	1	1				1
Number of dry holes.....	9	8	20	16	1	1	3	1				
Water conditions.....	Surface water to depth of 332 feet; dry below that depth	Water at depth of 2,916 feet	Outer wells being ruined by en- croachment of water	No water	No water below 300 feet	Water between 1234 and 1592 feet		Water between 1206 and 1461 feet				No water reported
Owner or operator of field.....	Mansfield Gas Co.	Industrial Oil & Gas Co. (Thompson Ross Co.)	Industrial Oil & Gas Co. (Thompson Ross Co.)	Industrial Oil & Gas Co. (Thompson Ross Co.)	SW Gen. Gas Co.	Natural Gas & Fuel Co. (Ark. Natural Gas Corp.)	Empire Gas & Fuel Co. (Ark. Natural Gas Corp.)	Empire Gas & Fuel Co. (Ark. Natural Gas Corp.)	J. B. Streeter	Local capital	Heber Springs Oil & Gas Co.	
Use of gas.....	Domestic use at Mansfield Huntington and Mansfield brick plant	Domestic and industrial, at Fort Smith and Van Buren	Domestic and industrial use at Van Buren and Fort Smith	Domestic and industrial use at Van Buren and Fort Smith	Domestic use at Fort Smith				Domestic use in Plumerville for a few months in 1905			
Cost of drilling.....	\$8,000 for 2,000 foot hole	\$8,000 for 2,000-foot hole	\$8,000 (average)	\$8,000 (average)	65c to \$2 per foot							
Area of field in acres.....	— 3,000	± 8,000	± 5,600	± 7,600	± 5,000							
Estimated life of field in years from date of discovery.....	35-40	15-20	25 to 30	20 to 25	30-35		5,000 (est.)			± 5,600	± 1,300	

and as much as 2 per cent of nitrogen. In general, the Arkansas Valley gas is high in methane, low in other hydrocarbons, low in nitrogen, and high in oxygen. This is a combination of characteristics not duplicated in other North American natural gases, and is sufficient to identify it.

TABLE 2.—*Analyses of typical gases from gas fields in the United States*
[Analyses by U. S. Bureau of Mines.]

Source	CH ₄	C ₂ H ₆ ¹	CO ₂	O ₂	H ₂	H ₂ S	N ₂	CO
Massard Prairie, Ark.....	97.96	0.00	0.00	1.55	.....	.....	0.32	.....
Kibler, Ark.....	98.21	0.00	0.08	0.92	.....	.....	0.62	.....
Williams, Ark.....	98.03	0.00	0.33	0.83	.....	.....	0.66	.....
Caddo, La.....	96.50	0.00	1.40	0.00	.....	.....	2.10	.....
Indiana-Ohio ²	93.36	0.28	0.25	0.29	1.76	0.18	3.28	0.53
Augusta, Kans.....	76.48	13.04	0.21	0.00	.....	.....	10.26	.....
Oil City, Pa.....	67.60	31.30	0.00	0.00	.....	.....	1.10	.....
Thurston, Ohio.....	91.20	1.10	0.20	0.30	3.70	.....	2.70	0.80
West Los Angeles, Calif.....	91.00	2.70	1.00	0.01	.....	.....	5.20	.....
Morrison, Okla.....	57.89	16.89	0.40	0.00	.....	.....	24.97	.....
Morgantown, W. Va.....	88.10	8.02	0.24	0.00	.....	.....	3.60	.....
Glasgow, Ky.....	23.60	69.70	2.50	0.00	.....	2.90	1.30	.....
Petrolia, Texas.....	51.30	10.40	0.10	0.00	.....	.....	38.20	.....

¹ Chiefly C₂H₆.

² Average of seven analyses.

ORIGIN OF THE GAS

The gas was formed in part by the distillation of the carbonaceous shales of the Atoka formation by the heat and pressure generated during mountain building. Liquid hydrocarbons, however, were not extensively formed by this process, for the gas is dry and the heavier residual hydrocarbons are not found in the Atoka sandstone where it is exposed. A little high-grade oil has been found in several wells, however, and some oil may have been formed, but practically all of it has been altered to the more stable methane by continued heat and pressure.

The thick beds of carbonaceous shale of the Atoka formation not only provide an amply sufficient source for the gas, but their imperviousness precludes the possibility of notable migration of gas into the Atoka from other sources, except, possibly, by movement along fault lines. The gas originating in the shale migrated to the adjacent beds of sandstone, where the ease of its movement, and therefore the extent of its concentration, has depended largely upon the porosity of the sand.

In the process of alteration of coal from lignite to bituminous and in turn from bituminous to anthracite great quantities of gas are evolved. It is surprising that no more gas is found in sandstones associated with coal, for it is hard to understand by what channels the gas so generated has in most places entirely escaped from the rocks. In the Arkansas Valley area the bituminous coal has been altered to semi-anthracite, but the gas given off during the alteration

is not found in the beds that overlies the coal. Whether any of the gas migrated into the beds of Atoka sandstone below is not known, but in the unfaulted beds in the Valley it could not move downward, because thick beds of impervious shale lie between the beds of coal and sandstone. Some of the gas emanating from the coal may have found access to beds of Atoka sandstone along the major fault lines, but only a few of the faults have sufficient displacement to permit such migration, and none of them except the Backbone fault is close to the producing fields. The upthrown side of the Backbone fault is south of the fault trace, so that sandstones well down in the Atoka were brought into contact with the Hartshorne coal by the movement. The gas given off from that coal may have moved southward in the Atoka formation, but unless it took a very circuitous course it could not have migrated into the Atoka sandstones at points north of the fault. Thus part or all of the gas obtained in the Mansfield field, which lies south of the fault, may have been generated by the alteration of the Hartshorne coal, but the gas in the Alma, Kibler, and Williams fields, which lie north of the fault, could not have been so generated.

Large quantities of methane are formed by the decay of vegetable matter, and undoubtedly methane was generated in great quantities during Atoka time from the abundant macerated plant remains brought into the area of Atoka deposition. Some of the gas may have been entrapped during the process of sedimentation and may have been present as gas in the interstices of the elastic sediments. This mode of origin seems possible because, although the Atoka formation contains large quantities of vegetable material, it was deposited with extreme rapidity, as is shown by both paleontologic and lithologic evidence. The Atoka therefore contained ample material for the generation of the gas, and its rate of deposition was sufficiently rapid to entrap a considerable part of it. Moreover, the composition of the gas is most readily explained by this theory. Part of the gas now forming at the mouth of the Mississippi escapes into the air and part is trapped in the silt accumulating in the delta. A large part of the gas that is entrapped is permanently buried, but some of it comes to the surface again from mud springs. Some gas collected from a spring near Burrwood, Louisiana, by E. W. Shaw³⁸ showed a composition essentially identical with that of the gases in the Kibler and Williams fields, except that it contained more carbon dioxide. Much of the gas in the Atoka formation may have been formed in the same way that the gases at the mouths of the Mississippi are now forming.

³⁸ Shaw, E. W., Gas from mud lumps at the mouths of the Mississippi: U. S. Geol. Survey Bulletin 541, p. 21, 1914.

ACCUMULATION OF THE GAS

No matter how the gas was formed, however, it must at one time have been widely disseminated in small quantities through the sediments. In order to be concentrated into "pools" it must have been transported and collected by some agent. In such transportation one of the most effective agents is water. Driven either by hydraulic pressure or by capillary attraction water moves through porous beds and carries gas along with it or ahead of it. The gas may also move because of the compacting of the beds in which it occurs, and it migrates under its own pressure. When the migrating gas and water (and oil, if any is present) reach a reservoir sufficiently porous they will separate according to their specific gravities, and the gas will occupy the highest part of the structure in which it is entrapped.

It is evident that gas, even under great pressure, would completely dissipate that pressure if it could expand indefinitely in porous beds. Expansion upward in an anticlinal porous reservoir, however, may be prevented by an impervious layer, such as shale, above the porous one; and lateral movement in such a reservoir is also impossible, either because the porous bed is of limited lateral extent or because water occupies lower levels in the same bed. Hence the simplest structure favorable to the accumulation of gas is the anticline, and all the Arkansas Valley gas fields are at least in major part on anticlines.

THE ARKANSAS VALLEY FIELDS

A history of the development of the Arkansas Valley fields and of the wells that may be the nuclei of new areas of production is given in Table 1. The fields are considered in some detail in the following pages, in the order of their discovery. Not much information concerning them is available to the public, but the records in the Twin Cities Pipe Line rate case furnish some facts concerning the Kibler, Williams, and Alma fields. In addition, Mr. Leigh Kelley, of Fort Smith, kindly supplied much information concerning the Mansfield and Massard Prairie fields. Many of the logs of wells in these two fields were not kept accurately and are therefore of no great service in determining subsurface structure. The logs of wells in the Kibler, Williams, and Alma fields have been reported to the State authorities in a very generalized fashion, so that they too are not to be relied upon in detail. The logs of the wells in the Clarksville field, however, are accurate and detailed, but not enough wells have been drilled there to show in detail the subsurface structure.

THE MANSFIELD FIELD

Location.—The Mansfield gas field lies chiefly in Secs. 1 and 2, T. 4 N., R. 31 W., Secs. 5 and 6, T. 4 N., R. 30 W., and Secs. 32

and 33, T. 5 N., R. 30 W. It is partly in Sebastian and partly in Scott County. (See accompanying map, Fig. 27.)

Discovery.—The discovery well of the Mansfield field (the first producing well in Arkansas) was the Duncan No. 2 of the Choctaw Oil and Gas Company. This well, which was drilled on the recommendation of Dr. J. C. Branner, was completed in March, 1902. It had an initial production of 550,000 cubic feet a day, and it is still producing.

Structure.—The field is at present confined to a local dome of the Hartford anticline, whose highest point is in the vicinity of the town of Mansfield, in the W. $\frac{1}{2}$ Sec. 6, T. 4 N., R. 30 W., and the E. $\frac{1}{2}$ Sec. 1, T. 4 N., R. 31 W. The dips near the axis of the anticline range from 3 to 8 degrees, but are generally low. Away from the anticlinal crest the dips become as great as 30 degrees, but they are somewhat lower south of the axis than north of it. The dome is rather sharply defined on the north and south, respectively, by the Sugarloaf and Poteau synclines. The anticline also plunges to the east and west, although the dips in those directions are lower than those at right angles to the axis. The total closure is not less than 750 feet. The accompanying structure map and much of the information regarding the history of the field were made available through the courtesy of Mr. Leigh Kelley of Fort Smith.

History of production.—The Mansfield area has yielded at least 5,000,000,000 cubic feet of gas, although the daily production has never been large and has now fallen to less than 400,000 cubic feet. The largest wells had an initial open-flow capacity of about 5,000,000 cubic feet, but most of the wells were smaller.

The field covers an area of from 2,500 to 3,000 acres and includes eight producing wells and nine dry holes. Most of the abandoned wells, however, had a small initial production, and a few of them yielded gas for several years. A study of the structure map shows that the gas is not distributed regularly through the sandstone, and that wells drilled fairly low on the anticline have been more consistently producers than those drilled nearer the crest. This rather anomalous condition is similar to that in the Alma field, where the larger wells were drilled about 200 feet below the crest of the anticline. Undoubtedly this "spotted" occurrence of the gas is due to differences in the porosity of the sandstone. It is also possible that the sandstone is regularly less pervious toward the axes of this and similar anticlines because during the folding the crests were subjected to more stresses than the limbs. The porosity of the sandstone in the Mansfield field apparently increases toward the southwest, for all the wells in the southwestern part of the field are producers. For this reason that field, although it is old, is perhaps not completely out-

lined, for the outside wells, both on the south and east, are productive. Further drilling on this anticline may therefore be warranted.

Gas is produced chiefly from four sandstones, which lie fairly low in the Atoka formation. The highest is encountered at 863 to 1,385 feet, the next at 1,645 to 1,725 feet, the next at 1,750 to 1,870 feet, and the lowest at 1,970 to 2,047 feet. The highest sand is 22 to 60 feet thick, the next is 76 to 142 feet, the next is 10 to 30, and the lowest is 10 to 101 feet. Some gas has been found at several other

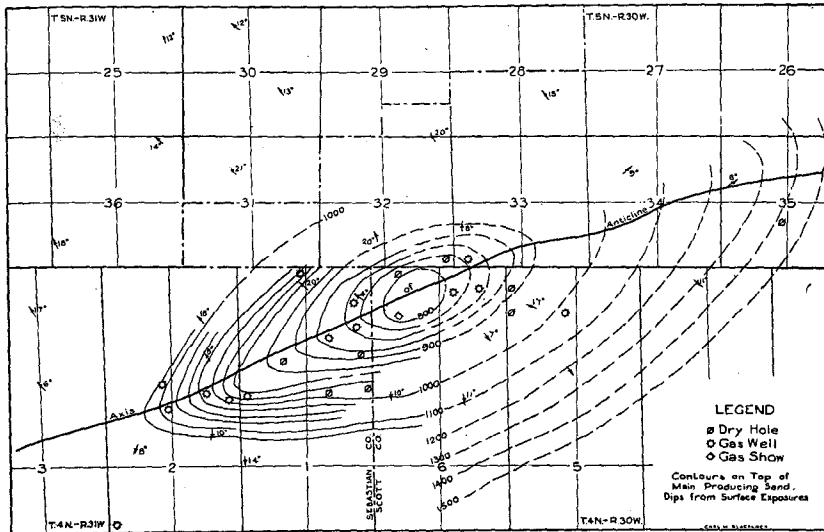


FIGURE 28.—Subsurface structure in the Mansfield gas field.

horizons, particularly at shallower depths than that of the chief producing sand. The rock pressure is in general greater for the lower than for the higher horizons, but a rock pressure of 315 pounds was recorded from the upper or so-called "1,200 foot" sand in the discovery well. This pressure was equalled in only one well producing from the "2,000 foot" sand. The rock pressure has held up unusually well in the Mansfield area, the pressure for the "1200 foot" sand now being nearly three-fourths as great as it was originally.

The first well drilled in the Mansfield area was started on May 23, 1901. Gas was obtained at 197, 648, 930, and 2,090 feet, but the well was abandoned as essentially a failure at 2,382 feet. The second well drilled, the Duncan No. 2, has had a long and interesting history. Completed in March, 1902, with an initial production of 550,000 cubic feet a day at a rock pressure of 220 pounds, it increased its production until, in August, 1903, the tubing was blown out of the hole. The tubing was reset and the rock pressure in October, 1903, was 315 pounds, and by April, 1904, although the well was being continually drained, its daily capacity had risen to 960,000

cubic feet. In March, 1905, the rock pressure had fallen to 305 pounds and the production to 915,000 cubic feet. In May, 1908, the well, after having furnished most of the gas used in Huntington and Mansfield for five years, had decreased in production to 750,000 cubic feet, and its pressure had fallen to 250 pounds. From July 1, 1908, to December 18, 1908, the well was shut off, and the rock pressure on December 18 had risen to 265 pounds. At January 22, 1909, the well

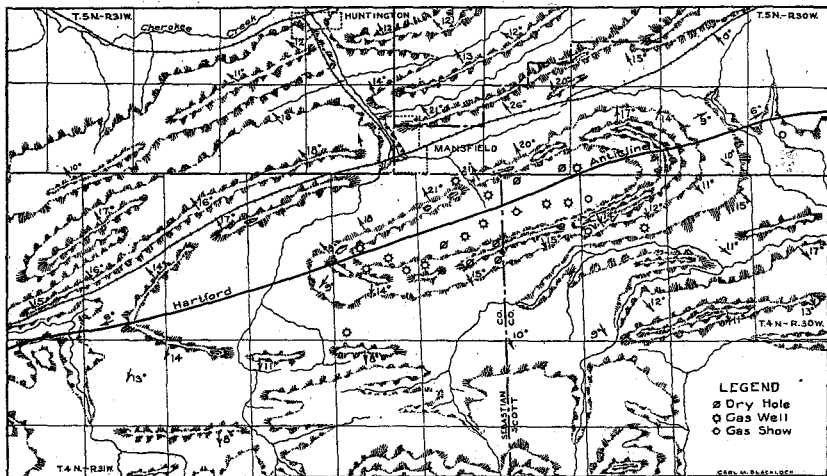


FIGURE 29.—Map showing the relation of the topography to the structure in the Mansfield area.

had a pressure of 276 pounds and was still idle. On September 2, 1909, the pressure had risen to 300 pounds, and the well was turned back into the line and has been producing ever since.

As gas was continually being drained from this well the pressure fell to 237 pounds by March, 1910, but in May, 1911, it had increased to 250 pounds, and in September, 1911, it had decreased to 190 pounds. In March, 1917, the working pressure was 152 pounds, but after the well had been allowed to blow for 5 minutes it rose to 175 pounds. In October, 1919, the well was again furnishing all the gas used, and on account of defective tubing the pressure in the mains varied from 35 to 75 pounds. One year later, after the leaks had been repaired, the pressure had increased to 130 pounds. In June, 1927, the well still had a working pressure of about 100 pounds, although most of the gas produced in the field was being taken from it.

Nearly all the gas produced by this well comes from a depth of 1,125 feet, but some was obtained from a sand at a depth of 863 to 873 feet.

Well No. 3 obtained some gas at depths of 162, 300, and 370 feet

but was abandoned at 813 feet. Well No. 4 was abandoned at 970 feet but obtained gas at depths of 280, 390, 410, 800, and 855 feet.

Well No. 5 struck gas at 885, 967, and 978 feet, but the record of the well and of the time of its completion is lost. When first closed in, however, the rock pressure was only 15 pounds. The well was left open for one year and was then connected to the line with a rock pressure of over 200 pounds. In March, 1905, the pressure had increased to 255 pounds, and the daily production was 245,000 cubic feet. In May, 1908, the pressure had further increased to 295 pounds and the production to 350,000 cubic feet. In December, of the same year the production had risen to 400,000 cubic feet, although the pressure had decreased to 270 pounds. In March, 1910, the working pressure was 200 pounds, but in May, 1911, it had fallen to 110 pounds; and in September, 1911, although the working pressure had risen again to 137 pounds, the well was taken off the line.

Well No. 7 was drilled to 1,450 feet but produced from sands at 1,014 and 1,136 feet. The rock pressure in March, 1905, was 300 pounds and the daily production was about 350,000 cubic feet. The rock pressure steadily declined until, in September, 1911, it had fallen to 160 pounds, and the well was disconnected from the line. The open-flow capacity of the well, however, showed little change.

Well No. 8 also had an initial rock pressure of only 15 pounds, but in 12 hours this had increased to 143 pounds. In March, 1917, it had risen to 152 pounds, and by October, 1919, to 160 pounds. In December, 1922, the pressure had fallen to 90 pounds, but a month later, when the last observations on the well were made, the rock pressure was 112 pounds and the open flow was 413,000 cubic feet, which compared favorably with its capacity five years earlier.

Well No. 9 encountered gas at depths of 1,295, 1,320, 1,330, and 1,425 feet. A flow of 150,000 cubic feet was obtained when the hole was deepened to 1,475 feet, and increased to 1,500,000 cubic feet at 1,743 feet. Additional production from a sand at 2,005 feet raised the daily production to 1,750,000 feet. The initial rock pressure of the higher sand was 165 pounds, but the initial pressure of the lower sand was 240 pounds.

Well No. 12 obtained some gas from 498, 600, 700, 1,025 and 1,152 feet, but the largest quantities were obtained from 1,240, 1,646, 1,740, and 2,047 feet and the respective initial daily output was 950,000, 1,390,000, 250,000, and 2,040,000 cubic feet. The rock pressure of the upper sands was 220 pounds; that of the lower sands was about 315 pounds.

A study of the facts stated shows that the Mansfield area is in several respects unusual. The wells, although small, have been long lived, the rock pressure has declined not only slowly but very

irregularly, and in several wells it has increased for a considerable time after the well was brought in. Most of these peculiarities may be due to variations in the porosity of the sand, which is in general low, and to the gradual establishment of drainage channels in the sands as gas was drawn from the wells. The occurrence of the gas low on the anticline is also of great interest, for it suggests that if the conditions are the same in other anticlines in the Arkansas Valley the initial test wells on such anticlines may profitably be drilled some distance from their crests.

Much of the gas obtained from the Mansfield wells has been used for domestic purposes in Mansfield and Huntington, but most of it has been used as fuel at the Mansfield brick plant.

In view of the present rapid rate of depletion of the field it is estimated that unless new wells are obtained commercial production will cease between 1935 and 1940.

Well records.—In addition to the details of drilling given above, the following logs of typical wells drilled in the Mansfield field are given:

Log of Choctaw Oil Company's Well No. 2

Location not given. Drilling begun February 12, 1902.

	Depth in feet
Soil.....	5
Dark shale.....	5- 858
Cased at 436 (6¼ inch casing)	
Sandy shale.....	858- 863
Gray and brown sand; gas at 863 to 873 feet.....	863- 885
Sandy shale.....	885- 945
Gray sand.....	945- 956
Hard sand.....	956- 997
Shale.....	997-1058
Hard brown shale.....	1058-1084
Hard brown sand.....	1084-1090
Soft sand.....	1090-1095
White hard sand.....	1095-1100
Shale.....	1100-1125
Crevice at 1125 feet (bent bit)	

Quit drilling at 1125 feet in hard, white sand.

The record shows that this well was finished in March, 1902. Packer was set at 860 feet on anchor extending to bottom of hole. Pressure when finished was 220 pounds, which increased and blew out tubing in August, 1903. Tubing was reset, and in October, 1903, pressure was 315 pounds; volume, 960,000 feet.

Log of Choctaw Oil Company's Well No. 3

Drilled on Johnson Lease, Mansfield, Arkansas. Drilling begun March 15, 1902.

	Depth in feet
Soil.....	8
Black shale.....	8- 162
Black close sand.....	162- 171

	Depth in feet
Black shale.....	171- 210
Hard brown sand.....	210- 221
Brown shale.....	221- 300
Light shale.....	300- 370
Black shale.....	370- 795
Sand.....	795- 813

Crooked hole. Abandoned at 813 feet.

Log of Leigh Kelley Well No. 11

Drilled at Mansfield in the southwest corner of Lot 11, N. $\frac{1}{2}$ Sec. 1.

	Depth in feet
Top to shale.....	8
Hard shell.....	8- 90
Shale.....	90- 100
Gray sand.....	100- 405
Shale.....	405- 450
Brown sand.....	450- 940
Shale; gas at 950 feet.....	940- 965
Sand.....	965-1007

Bottom of hole 1130 feet. Gas at 1010 and 1060 to 1100. Trouble with caving after 900 feet. June 12, caving caught tools in bottom of well. They could not be jarred loose. Cut cable June 19, and tried to drill past tools but failed, tried again with whipstock, but hole caved again. Work stopped and well tubed. Pressure 145 pounds.

Log of Choctaw Oil and Gas Company's Well No. 4

Drilled on Zellar lease at Mansfield. Location not given. Commenced drilling on April 8, 1902.

	Depth in feet
Soil.....	6
Dark shale.....	6- 110
Shale.....	110- 800
Sand shells.....	800- 850
Hard brown sand.....	850- 870
Dark sand.....	870- 878
Sandy shale.....	878- 925
Gray sand.....	925- 950
Sand shale.....	950- 969

Abandoned hole at 970 feet, leaving tools at bottom.

Log of Choctaw Oil and Gas Company's Well No. 5

Drilled at Mansfield. Location not given. Commenced drilling May 9th, 1902.

	Depth in feet
Top and dark shale.....	845
Dark brown sand.....	845- 945
Black soft shale.....	945- 953
Hard brown sand.....	953- 958
Gray sand.....	958-1005
Black slate.....	1005-1050

No record of when and at what depth well was completed. The record shows that March 14, 1905, the well had a rock pressure of 255 pounds; volume, 245,000 cubic feet. In December, 1908, pressure of 270 pounds; volume, 400,000 cubic

feet, and that this well was supplying Mansfield and Huntington with gas. Well was still flowing in September, 1911.

Log of Choctaw Oil and Gas Company's Well No. 6

Mansfield. Location not given. Date of drilling not given.

	Depth in feet
Soil.....	10
Light shale.....	10- 320
Dark shale.....	320- 350
Sandy shale.....	350- 650
Light shale.....	650- 800
Hard shell.....	800- 802
Soft shale.....	802- 862
Hard sand.....	862- 868
Soft shale.....	868- 902
Shells.....	902- 930
Soft shale.....	930- 950

Hard, sharp sand at 950 feet to bottom of hole. Crooked hole. Well was abandoned.

Log of Choctaw Oil and Gas Company's Well No. 7

Mansfield. Location not given. Date of commencement not given.

	Depth in feet
Soil.....	4
Hard shale.....	4- 50
Soft shale; cased at 333 feet.....	50- 660
Sandy shale.....	660- 745
Soft shale.....	745- 840
Hard sand and shells; gas at 980 feet.....	840- 980
Shale.....	980- 990
Hard gray sand; gas at 1014 feet.....	990-1014
Hard sand.....	1014-1033
Shale.....	1033-1120
Hard sand; gas at 1136 feet.....	1120-1212
Shale and shells.....	1212-1238
Hard gray sand.....	1238-1248
Shale.....	1248-1249
Hard gray sand.....	1249-1260
Shale and hard shells.....	1260-1278
Shale.....	1278-1344
Hard gray sand.....	1344-1396
Shale.....	1396-1450

Quit drilling at 1450 feet.

March 14th, 1905, rock pressure, 300 pounds. May 8th, 1908, rock pressure 295 pounds, volume 350,000 cubic feet.

Log of Choctaw Oil Company's Well No. 1

Drilled at Mansfield in the S. $\frac{1}{2}$ Lot 9, NW. $\frac{1}{4}$ Sec. 1, T. 4, R. 31 W. Commenced drilling May 23, 1901.

	Depth in feet
Soil.....	2
Sandy shale.....	2- 12
Dark shale.....	14- 187
Water.....	145- 185

	Depth in feet
Black slate.....	185- 195
Little gas at.....	197
Dark slate.....	197- 298
Hard sand.....	298- 342
Sandy shale.....	342- 368
Black slate.....	368- 414
Brown slate.....	414- 435
Dark shale.....	435- 580
Hard sandy shale; gas at 648.....	580- 648
Dark shale.....	648- 910
Hard sand.....	910- 930
Brown sand; gas.....	930- 960
Sandy shale.....	960-1000
Gray sand.....	1000-1075
Dark shale.....	1075-1155
Light gray sand.....	1155-1230
Black slate.....	1230-1237
Light sand.....	1237-1287
Black slate.....	1287-1400
Gray sand.....	1400-1468
Dark sandy slate.....	1468-1520
Hard dark shale.....	1520-1730
Hard brown sand.....	1730-1750
Gray sand.....	1750-1775
Gray coarse sand.....	1775-1800
Dark slate and hard shells.....	1800-2080
Dark tiff-mineral; gas at 2090.....	2080-2100
Sandy shale.....	2100-2223
Dark shale.....	2223-2382

Caving at 2382.

Hole abandoned at 2382 feet; 295 feet of 6¼ inch casing used.

By using the Hartshorne coal horizon as a marker it is possible to reconstruct the pre-erosional aspect of the Hartford anticline at Mansfield. Such a reconstruction brings the coal about 3,000 feet above the present topographic surface of the crest of the anticline. In other words, wells drilled near the top of the anticline were started about 3,000 feet below the top of the Atoka formation. As some of these wells have produced gas from depths of more than 2,000 feet, at least the upper 5,000 feet of the Atoka formation, where the structure is favorable, may be regarded as potential gas-producing strata. It also follows that if both the Mansfield and the Alma field produce from the same horizon, as some have thought, the Atoka formation is several thousand feet thicker at Mansfield than at Alma. In the Alma field the gas is obtained from sands which, it is estimated, lie from 1,800 to 2,800 feet below the Hartshorne sandstone. In the Mansfield area the gas occurs in sands that lie 3,500 to 5,000 feet below the Hartshorne formation. It is possible that the two fields yield gas from the same general horizon, but it is improbable that

any well in the Alma field produces gas from exactly the same bed of sandstone that is productive in the Mansfield area. In fact, the great difficulty involved in correlating the sources of gas in some wells in the same field indicates that the Atoka sedimentation was too variable to permit even moderately long-ranged correlations by lithologic similarity.

A well sunk to a depth of 2,000 feet in the Mansfield area costs, on the average, \$8,000.00. Surface water is encountered to a depth of 332 feet, but the sands are dry at greater depths, and drilling is relatively easy.

THE MASSARD PRAIRIE FIELD

Location.—The Massard Prairie field lies in northern Sebastian County, chiefly in Secs. 25, 26, 35, and 36, T. 8 N., R. 32 W., Secs. 19, 20, 28, 29, 30, and 31, T. 8 N., R. 31 W., and in Sec. 1, T. 7 N., R. 32 W. The field is about 2 miles southeast of the corporation limits of the city of Fort Smith. (See accompanying map, Fig. 27.)

Discovery.—The discovery well of the Massard Prairie field was the Choctaw Oil and Gas Company's No. 10, which was completed on November 5, 1904. This well was connected to the lines on January 7, 1905, and the field has been producing ever since. Although this well was the first to produce gas in this field it was not the first well drilled there. In 1889 Mr. Harry E. Kelley drilled a well to a depth of more than 1,600 feet in the SW. $\frac{1}{4}$ Sec. 1, T. 7 N., R. 32 W. No large quantity of gas was obtained from this well, but some light-green oil was found in a sand at a depth of about 1,600 feet, and on 8 or 10 Monday mornings, after an idle Sunday, the bailer yielded 6 or 8 gallons of this oil from a $5\frac{5}{8}$ -inch hole.

Although this oil was of no commercial value the account of its discovery is of considerable interest, for it is one of the very few authentic records of the occurrence of liquid hydrocarbon in the rocks of the Arkansas Valley. There is evidently no great quantity of oil in the Massard Prairie anticline, however, for the gas produced there is a dry gas, whose chemical composition differs from that of the natural gas commonly found with oil. The fact that oil was actually found, regardless of its quantity, is of scientific interest also, because of the great metamorphism of the rocks about Massard Prairie, where many of the coals have a carbon ratio higher than 83.

Structure.—Most of the Massard Prairie field is on the Massard Prairie anticline, whose axis extends from a point near the Oklahoma boundary, in the SE. $\frac{1}{4}$ Sec. 20, T. 7 N., R. 32 W., northeastward to about the SE. $\frac{1}{4}$ Sec. 26, T. 9 N., R. 30 W. Some of the northwestern part of the field, however, probably lies on the southwest end of the Lane Hill anticline, whose axis south of the Arkansas River is

close to that of the Massard Prairie anticline. The field has not yet been extended north of the Arkansas River.

The Massard Prairie anticline is a low, inconspicuous, essentially symmetrical fold. The dips north of the axis range from 2 to 8 degrees, and those south of it range from 2 to 7 degrees, the average dip on either flank being about 4 degrees. Although the field is old and a large number of wells have been drilled in it, its subsurface structure is not publicly known, but the subsurface features are fairly well indicated by the surface structure.

History and details of production.—The Massard Prairie field, which covers about 5,000 acres, produces gas from two sands in the Atoka formation. The higher sand lies at depths of 1,190 to 1,420 feet and ranges in thickness from 40 to 260 feet. The lower sand is 75 to 100 feet thick and is generally encountered between 2,100 and 2,260 feet. The initial rock pressure of the higher sand was about 220 pounds; that of the lower sand was 265 pounds. These pressures have now declined to 25 to 35 pounds on shut-in wells, and it is therefore necessary to use pressure pumps to supply the mains. The open-flow capacity of the wells has declined much more slowly than the pressure. The discovery well, for instance, in January, 1905, had a pressure of 212 pounds and production of 1,377,000 cubic feet. In January, 1907, the pressure had fallen to 125 pounds but the open flow capacity was essentially unchanged.

The open-flow capacity of the largest wells in the field was slightly more than 4,000,000 cubic feet a day, but the entire production at present from 69 wells is not more than 1,250,000 cubic feet a day. The gas is used for domestic purposes in Fort Smith. This field, although it is no longer very productive, has been of great value in the development of Fort Smith, for from 1905 to 1916 it was that city's sole source of gas, and as it offered cheap fuel to industries, it attracted many manufacturing concerns to the city.

The gas from the Massard Prairie field contains a very high percentage of CH_4 , especially the gas from the deeper sand, which is essentially pure methane. The following analyses of the Massard Prairie gas were made by the United States Bureau of Mines:

Sand at depth of	CO_2	O_2	CH_4	C_2H_6	N_2
1400 feet.....	0.61	0.71	93.72	4.37	0.48
2358 feet.....	0.00	1.55	97.96	0.00	0.32

Well records.—In addition to the details of drilling mentioned above, the following logs of typical wells drilled in the Massard Prairie field are given:

Log of Well No. 38

Drilled in the northeast corner of the NW. $\frac{1}{4}$ SE. $\frac{1}{4}$ Sec. 25, T. 8 N., R. 32 W.
Began drilling October 20, 1910. Finished November 7, 1910=17 days.

	Depth in feet
Top soil.....	5
Shale, dark, soft.....	20
Sand, light.....	30
Shale, soft; water, large flow.....	50
Coal.....	53
Shale, black; caved slightly.....	153
Sand.....	183
Shale, black; well cased at 270 feet.....	280
Sand.....	320
Shale, black.....	550
Sand, hard.....	590
Shale.....	660
Sand.....	700
Shale and sand, black.....	975
Sand, hard; small quantity of gas at 975 feet.....	1025
Shells, hard.....	1100
Shale, black.....	1175
Shells, hard.....	1275
Shale, black.....	1341
Sand; bottom of hole.....	1408

Gas at 1361 feet. Conductor, 8-inch wood; casing, 270 feet, 8 $\frac{1}{4}$ -inch tubing to 506 feet, 3 inches. Packer set in shale at 508 feet. Volume 3,000,000 cubic feet; rock pressure, 125 pounds.

Log of Well No. 19

Name of company not given. Turner Carnall lease, in NW. $\frac{1}{4}$ Sec. 36, T. 8 N., R. 32 W. Massard Prairie Log No. 24. Drilling begun October 31, 1906.

	Depth in feet
Top soil.....	6
Shale.....	6- 608
Sand.....	608- 638
Shale.....	638- 895
Sand.....	895- 997
Shale.....	997-1176
Sand.....	1176-1213
Shale.....	1213-1307
Sand; gas at 1349 feet.....	1307-1383
Shale, gritty.....	1383-1397
Sand.....	1397-1554
Shale.....	1554-1712
Sand.....	1712-1760
Shale.....	1760-2187
Sand.....	2187-2435
Shale, gritty.....	2435-2600

Packer set at 690. Well pressure, 220 pounds; volume, 500,000 cubic feet.

Log of Well No. 31

Name of company not given. Drilled in the southeast corner of the NE. $\frac{1}{4}$ Sec. 1, T. 7 N., R. 32 W., on the Wilkinson lease. Contractor, Ball & Co. Drilling begun February 24, 1910; ended April 20, 1910.

Plenty of water from 60 to 80 feet; cased at 230 feet, in light shale.

	Depth in feet
Shale.....	10- 520
Sandy shale.....	520- 550
Sand light; no gas.....	550- 560
Shale dark.....	560- 900
Sand, light hard; some gas.....	900- 940
Shale.....	940-1290
Sand, hard.....	1290-1355
Shale.....	1355-1490
Sand.....	1490-1535
Shale.....	1535-1870
Sand.....	1870-1910
Shale.....	1910-2000
Sand, dark hard.....	2000-2020
Sand, light.....	2020-2045
Sand; very hard, dark.....	2045-2165
Shale.....	2165-2190
Sand.....	2190-2260
Shale, soft.....	2260-2295
Sand, dark hard.....	2295-2300
Shale, gritty.....	2300-2360
Shale, dark; to bottom of hole.....	2360-2550

Conductor, 181 feet of 10 inch pipe, pulled when closing in. Casing, 230 feet of 8 $\frac{1}{4}$ inch pipe, capped on casing for two days; gas came out around. Casing and well was tubed with 484 feet of 2 inch tubing. Packer set in shale at 485 feet. Volume, 131,000 cubic feet in 900 feet sand. R. P. 185 pounds.

Log of Well No. 36

Name of company not given. Drilled on Hynes lease near the center of NE. $\frac{1}{4}$ SW. $\frac{1}{4}$ Sec. 6, T. 7 N., R. 31 W. Contractors, Ball & Co. Drilling begun July 10, 1910; finished March 1, 1911.

	Depth in feet
Top to.....	10
Black shale; lots of water.....	10- 210
Sandy shale.....	210- 310
Black shale.....	310- 550
Sandy shale.....	550- 600
Black shale.....	600- 700
Sandy shale.....	700- 750
Sand; gas at 870 feet.....	750- 890
Shells.....	890- 990
Black shale.....	990-1090
Sandy shale.....	1090-1110
Sand.....	1110-1170
Hard shells.....	1170-1270
Black shale.....	1270-1300
Sandy shale.....	1300-1500

	Depth in feet
Black shale.....	1500-1550
Sand.....	1550-1700
Shale.....	1700-1710
White sand.....	1710-1800
Black shale.....	1800-1830
Gray sand.....	1830-1910
Black sand.....	1910-1960
Dark sand.....	1960-2110
Black shale.....	2110-2200
Sand and shale.....	2200-2250
Black shale; caved a little.....	2250-2275
Black sandy shale.....	2275-2375
Black shale, gritty.....	2375-2502

Conductor, 8 feet wood pipe; casing to 210 feet, 8¼ inch tubing to 488 feet 2 inch; packer set at 449 feet; wall fastener, 451 feet. Volume, 111,000 cubic feet. Rock pressure 90 pounds.

Log of well of Prospect Oil and Gas Company's No. 1 on J. J. Underwood lease

Drilled in Sec. 29, T. 9 N., R. 29 W. Drilled by Thomas Drilling Co. Begun June 13, 1916. Completed August 26, 1916.

	Depth in feet
Soil.....	7
Hard sand.....	157
Shale, black.....	257
Hard shell.....	262
Black shale.....	265
Shell.....	277
Black shale water at 320 feet.....	327
Hard sandy shale.....	370
Black shale.....	420
Shells, hard lime.....	440
Black shale.....	510
Hard lime shells; two bailers.....	570
Black shale; water at 550 feet with a showing of gas.....	650
Shells.....	700
Black shale.....	790
Hard shell.....	800
Black shale.....	890
Hard shell.....	910
Black shale.....	1000
Sand and shells, 30 thousand feet of gas.....	1100
Hard shells and sand.....	1180
Black shale.....	1300
Shells and sand.....	1350
Black shale.....	1395
Hard shells and shale mixed.....	1475
Black shale.....	1515
Hard limey shells.....	1620
Black shale.....	1750
Hard shell.....	1760
White coarse sand; 500,000 feet of gas.....	1785

	Depth in feet
Black shale.....	1870
Black shells.....	1890
Black shale.....	2030
Hard shells and shale mixed.....	2130
Hard sand, white (Kibler sand).....	2260
Black shale.....	2284
Hard sand, like granite.....	2304
Black shale.....	2364
Hard white shells and shale.....	2425
Sand, white and coarse, filled with salt water to top of hole.....	2450
Plugged and filled with sand pumpings.	

Some of the wells were started in the Spadra formation, some in the Hartshorne sandstone, and a few in the Atoka formation, in which they all terminated. No great amount of water was encountered in any of the wells below 300 feet, and the drilling was relatively easy. The cost of the wells ranged from 65 cents to \$2.00 a foot.

THE KIBLER FIELD

Location.—The Kibler field lies between the Alma and the Williams field, in southern Crawford County, but it is more closely related to the Williams than to the Alma field. Most of it is in Secs. 21, 22, 28, 29, 30, 31, 32 and 33, T. 9 N., R. 30 W., and in Secs. 25 and 36, T. 9 N., R. 31 W., but on the surface it is not sharply separated from the Williams field. (See accompanying map, Fig. 27.)

Structure.—The Kibler field is chiefly on the Lane Hill anticline, but some of the producing wells lie near the axis of the indefinite, shallow syncline that separates the Lane Hill and Massard Prairie anticlines.

The Lane Hill anticline extends from the NE. $\frac{1}{4}$ Sec. 30, T. 8 N., R. 31 W., northeastward to the center of Sec. 23, T. 9 N., R. 30 W. It is asymmetrical in that the dips north of the axis range from 2 to 12 degrees, whereas those south of the crest range from 1 to 3 degrees. The difference between the average dips on the north and south limbs, however, is not great. The subsurface structure of the field has been determined, but the information is not available to the public. It is apparent, however, that the subsurface structure is not a direct reflection of the surface structural conditions.

The wells in the Kibler field encounter the same sands that produce gas in the Williams field, which, however, are there about 200 feet higher. In fact, although no good evidence of a fault is seen at the surface, the subsurface indications are that the Williams and Kibler fields are separated by a fault whose displacement is about 200 feet, the downthrown side being south of its trace, which extends nearly eastward. The Kibler field may be separated from the Alma

field by another fault of the same general type, with the downthrown side north of its trace. If so, the Kibler field has been raised bodily in reference to the other two.

History and development.—The Kibler field was discovered in November, 1915, when a 19,000,000 cubic feet gasser was completed at a location recommended by N. F. Drake. About 40 wells have been drilled in the field, most of which were producers, but about half of them have been abandoned because of encroaching water. In fact, the outer wells of the field are gradually becoming wetter, and the gas reservoir is therefore constantly being reduced in size. The field originally covered about 5,600 acres, but the productive part of it is now less than 4,000 acres. The wells produce from two sands, a shallow sand at 1,115 to 1,500 feet, and a deep sand at 1,950 to 2,400 feet. The shallow sand had an original rock pressure of 220 pounds, and the deep sand a pressure of 260 pounds, but the pressure has now fallen to about 75 pounds for each sand. The largest wells yielding gas from the deep sand produced about 20,000,000 cubic feet a day; the largest in the shallow sand about 3,000,000 cubic feet a day. At present the open-flow capacity of the entire field is about 30,000,000 cubic feet a day, of which about 4,000,000 cubic feet is taken for industrial and domestic use in Van Buren and Fort Smith.

Seepage from the Williams field is probably keeping up both rock pressure and volume in the Kibler field.

Well records.—The logs of most of the Kibler wells filed with the State authorities are too generalized to be of much value in determining the subsurface structure, but some of the more typical logs are given below:

Log of Wildcat Oil Company's Well No. 2

Drilled in the SE. $\frac{1}{4}$ SW. $\frac{1}{4}$ NE. $\frac{1}{4}$ Sec. 28, T. 9 N., R. 30 W., Crawford County Arkansas.

	Depth in feet
Drift.....	1- 17
Slate and shale.....	17- 384
Lime.....	384- 486
Slate.....	486- 550
Broken lime.....	550- 625
Slate.....	625- 680
Lime.....	680- 755
Sand.....	755- 770
Slate.....	770- 830
Lime.....	830- 885
Slate.....	885- 955
Lime.....	955- 970
Broken slate.....	990-1105
Lime.....	1310-1335
Slate.....	1335-1360

	Depth in feet
Sand.....	1360-1380
Hard sand.....	1405-1510
Brake.....	1510-1530
Sand.....	1530-1650
Shale.....	1650-1730
Sand; gas at 1776 feet.....	1730-1805
Slate.....	1805-1900
Shale and slate.....	1900-1970
Slate.....	1970-2012
Sand.....	2012-2075
Slate.....	2075-2200
Sand; cap rock.....	2200
Sand; gas.....	2222
Sand; gas.....	2250
Sand; increase in flow.....	2288
Initial open flow, 11,796,000 feet; bottom.....	2315

Log of Broom Well No. 6

Name of company not given. Drilled in Sec. 28, T. 9 N., R. 30 W., south of Alma. Begun June 25, 1926.

	Depth in feet
Drift.....	20
Slate.....	410
Lime.....	460
Slate.....	760
Lime.....	790
Slate.....	870
Lime.....	950
Slate.....	1060
Lime.....	1090
Slate.....	1155
Lime.....	1200
Slate.....	1405
Lime.....	1535
Sand.....	1780
Slate.....	1835
Sand.....	1910
Slate.....	2000
Sand shell.....	2140
Shale.....	2280
Sand.....	2330
Gas.....	2296

Volume 10,000,000 cubic feet.

Log of Sageley Well No. 4

Name of company not given. Drilled in SW. $\frac{1}{4}$ Sec. 22, T. 9 N., R. 30 W., Crawford County. Begun May 9, 1916.

	Depth in feet
Drift.....	17
Shale.....	91
Sand and water.....	200

	Depth in feet
Slate.....	350
Lime.....	450
Shale.....	700
Sand.....	745
Shale.....	850
Sand.....	925
Slate.....	1040
Hard lime.....	1172
Slate.....	1500
Sand.....	1720
Slate.....	1820
Sand.....	1870
Sand shells.....	2000
Sand.....	2048
Slate.....	2130
Sand.....	2160
Shale.....	2170
Sand.....	2215
Slate.....	2250
Sand.....	2255
Slate.....	2370
Sand.....	2377
Gas.....	2448
Black shale; bottom.....	2505

Volume 1,096,000 cubic feet. Completed, June 16, 1916.

The logs of these wells show a typical succession of Fort Smith sandstone, Spadra shale, and Hartshorne sandstone and the usual alternation of Atoka sandstone and shale mostly not extending below the upper 2,000 feet of the Atoka. The upper productive sand is 200 feet thick and includes a porous zone 30 feet thick; the deeper sand is 135 feet thick and includes a porous zone 36 feet thick.

The records of production to September 1, 1925, of some of the Kibler wells, as given as evidence in the Twin Cities Pipe Line rate case, are given in the accompanying table.

TABLE 3.—*Wells now producing in the Kibler field*
[Production in thousands of feet; pressure in pounds.]

Well	Completed in	Original rock pressure	Rock pressure at end of 1916	Production in 1916	Rock pressure at end of 1917	Production in 1917	Rock pressure at end of 1918	Production in 1918	Rock pressure at end of 1919	Production in 1919	Rock pressure at end of 1920
Cox, J. B.....	1916	265	205	311,345	129	705,332	Unknown	355,899	37	232,161	77
Hanna No. 1.....	1916	250	220	81,888	138	258,960	100	187,838	95	58,111	95
Broom.....	1916	250	195	66,683	135	140,144	115	90,228	70	51,673	70
Cole No. 8.....	1916	230	185		135	318,475	90	145,297	90	51,282	90
Jackson.....	1917	110			110		105	205,070	105	57,100	105
Embry.....	1918	120					115	269,346	115	87,162	115
Edwards.....	1918	140					100	84,147	80	65,184	80
Brown No. 1.....	1918	220					160	94,002	95	173,871	90
Brown No. 2.....	1918	175					175		120	52,504	105
Total.....		1,760				1,422,911		1,431,827		829,078	

	Production in 1920	Rock pressure at end of 1921	Production in 1921	Rock pressure at end of 1922	Production in 1922	Rock pressure at end of 1923	Production in 1923	Rock pressure at end of 1924	Production in 1924	Rock pressure at end of 1925	Total production to Sept. 1, 1925
Cox, J. B.....	98,345	77		77		77	72,000	73	30,628	73	1,805,710
Hanna No. 1.....	31,351	95	8,583	95	21,507	90	51,000	92	35,508	92	734,736
Broom.....	7,000	70		70	15,978	70	71,000	84	7,059	84	449,765
Cole No. 8.....	12,224	90		90	10,000	90	49,000	90		90	537,278
Jackson.....	9,500	105	8,000	105	31,000	105	49,000	92	34,336	92	394,006
Embry.....	99,403	115	39,515	115	47,160	115	49,675	111	61,131	111	653,389
Edwards.....	5,224	80		80	10,000	80	65,000	75	39,410	75	266,965
Brown No. 1.....	63,829	90	10,355	90	6,974	90	16,540	86	23,378	86	388,949
Brown No. 2.....	40,681	105	10,512	105	26,305	105		86	15,217	86	145,249
Total.....	367,567		76,965		168,924		374,215		244,667	789	5,376,060

The nine wells listed above were drilled by the Wild Cat Oil Company, the predecessor of the Industrial Oil and Gas Company, by which they were acquired. Up to September 1, 1925, these wells had yielded 5,376,060,000 cubic feet of gas, and their combined rock pressure had fallen from 1,760 pounds to 789 pounds, a decline of 971 pounds. At this rate of decline, 5,536,000 cubic feet of gas per pound of decline in rock pressure, the nine wells had in September, 1925, a gas reserve of 4,367,904,000 cubic feet.

The rock pressure records of thirteen other Kibler wells, purchased by the Industrial Oil and Gas Company in November, 1923 (individual names unknown), from the end of 1923 to September 1, 1925, are listed below:

Rock pressure at end of 1923	Rock pressure at end of 1924	Production	Rock pressure Sept. 1, 1925
117	122		122
77	71		71
77	76		76
105	101		101
127	119		119
80	78		78
77	73	9,223	73
77	73	16,049	73
100	96		96
65	65		65
77	75	5,686	75
105	97	39,140	97
77	77		77
Total production, 70,098,000 cubic feet.			1,123

By using the 5,536,000 cubic feet of production per pound of decline in pressure, as determined for the nine wells already listed, these thirteen wells, with their combined rock pressure of 1,123 pounds had, on September 1, 1925, a gas reserve of 6,216,928,000 cubic feet. In addition, three Cazort wells, with a combined rock pressure of 352 pounds, had a reserve of 1,948,672,000 cubic feet. Thus the total gas reserves of the 25 producing wells of the Kibler field in September, 1925, as calculated by A. G. Williams and presented as evidence in the rate case, amounted to 12,533,504,000 cubic feet, of which 11,149,504,000 cubic feet were regarded as recoverable.

It is evident that the above method of calculating the gas reserves of the Kibler field may be misleading, for the rate of decline in the rock pressure was not uniform and the open-flow capacity of the wells declined at a slower rate than the pressure. In other words, the reserves as determined by the above calculation are probably too low, though they are doubtless of the right order of magnitude.

Another method of calculating the reserves of the Kibler field is based on the production per pound of decline in rock pressure *after*

the period of flush production as determined from the following data for the nine wells listed above, on which accurate records have been kept:

	1920	1921	1922	1923	1924
Average rock pressure.....	91.9	91.9	91.9	91.3	87.7
Cubic feet of gas produced.....		76,965,000	168,924,000	374,215,000	244,667,000

The total amount of gas produced during the four-year period 1921-1924 inclusive, was 864,774,000 cubic feet, and the average reduction in rock pressure during the same period was 4.2 pounds. In other words, 205,898,000 cubic feet of gas were obtained for each pound lost in average pressure. N. F. Drake, using the above method, assumed that the general average pressure for the field in September, 1925, was not more than 90 pounds and that the lowest pressure at which gas could profitably be taken from the wells is 10 pounds. This assumption gave a reserve pressure of 80 pounds per well at that time. If each pound of pressure yields 205,898,000 cubic feet of gas the volume of gas in reserve would be 16,471,840,000 cubic feet. The quantity of gas sold by the Industrial Oil and Gas Company during the year ending April 30, 1925, was 4,666,767,000 cubic feet, sufficient to exhaust the Kibler field in a little less than four years.

This method of calculating the reserves is somewhat more satisfactory than the first, but it is not absolutely reliable. For example, by this method, as 245,889,000 cubic feet were produced during 1921-1922 and as the rock pressure showed no decrease during those two years, the field should be capable of producing indefinitely. In fact it is almost impossible to calculate the reserves accurately because of the seepage from the Williams field. Even with the present reserve pressure the Kibler field is not particularly efficient under peak load unless pumps are used to supplement the natural pressure.

THE WILLIAMS FIELD

Location.—The Williams field forms the southern part of the Kibler-Williams area, in southern Crawford County. The field lies chiefly in Secs. 4, 5, 6, 7, 8 and 9, T. 8 N., R. 30 W., and in Secs. 1, 10, 12, and 13, T. 8 N., R. 31 W., but on the surface it is not sharply separated from the Kibler field. (See accompanying map, Fig. 27.)

Structure.—Most of the Williams field is on the northeastern part of the Massard Prairie anticline, but some of the wells are on the Lane Hill anticline and others have been drilled on the shallow, ill-defined syncline that separates the two anticlines.

The subsurface structure of the field has been determined, but it is not known to the public. It is known, however, that the subsurface structure is not a direct reflection of the surface structure. The Williams field appears to be separated from the Kibler field by a concealed fault, for the sands in the Williams field lie 200 feet deeper, but the intervals between them and their thickness, as well as their porous zones, are the same, and the initial rock pressures were identical. In addition, the gas from the two fields shows great similarity in chemical composition, as is indicated by the following analyses by the U. S. Bureau of Mines.

Field	Depth of sand in feet	Location	CO ₂	O ₂	CH ₄	C ₂ H ₆	N ₂
Williams.....	2,385		0.32	0.32	93.20	4.31	1.75
Williams.....		Sec. 6, T. 8, R. 30	0.33	0.41	95.30	1.74	2.07
Williams.....			0.33	0.83	98.03	0.00	0.66
Kibler.....		Sec. 29, T. 9, R. 30	0.08	0.92	98.21	0.00	0.62

History of development.—The Williams field was discovered in December, 1918, and reached the peak of its production in 1925. It now covers about 7,600 acres, but as it is gradually being extended it will doubtless prove to be somewhat larger. The gas is produced from two sands in the Atoka formation. The higher sand, which is encountered at 1,315 to 1,700 feet, is 200 feet thick and its productive zone is 30 feet thick. The lower sand is reached at 2,150 to 2,600 feet and is about 135 feet thick. The porous zone in the deeper sand is about 36 feet thick, and the porosity as determined from well cuttings is about 18 per cent. The original rock pressure of the higher sand was 220 pounds and that of the lower sand was 265 pounds, but the pressure of each sand has now diminished to less than 100 pounds. The field is producing from 44 wells, which yield about 8,000,000 cubic feet a day. The gas is used in Fort Smith and Van Buren for domestic and industrial fuel. The present open-flow capacity of the entire field, however, is about 90,000,000 cubic feet a day. The most productive wells drilled to the deeper sand had an initial production of about 24,000,000 cubic feet and were of about the same capacity as those producing from the same horizon in the Kibler field. The larger wells producing from the shallow sand of the Williams area, however, were very much more productive than those producing from the shallow sand in the Kibler field, and a number had an initial production of more than 10,000,000 cubic feet.

The average cost of drilling a well in the Kibler and Williams fields, according to A. G. Williams, is about \$8,000.00. In the Williams field there has been little trouble with water, and drilling has been relatively easy.

Well records.—The logs of most of the wells in the Williams field, as filed with the State authorities, are too much generalized to be of great value in determining the subsurface structure, but several typical logs are given here:

Log of Industrial Oil and Gas Company's J. E. Sullivant well No. 1

Drilled 150 feet north 325 feet west of the center of Sec. 13, T. 9 N., R. 31 W., by A. B. Harper & Co. Data furnished by A. G. Williams, Jr. Drilling begun July 9, 1926, finished, August 28, 1926. Gas formation from 1,530 to 1,670 feet. Total depth 2,500 feet. Dry hole, plugged.

	Depth in feet
Clay.....	12
Gravel.....	20
Shale.....	110
Sand.....	120
Shale.....	275
Sand.....	295
Shale.....	385
Sand.....	485
Shale.....	830
Sand.....	873
Shale.....	1050
Sandy shale.....	1450
Upper sand.....	1670
Sandy shale.....	1872
Hard sand.....	1888
Soft sand.....	1996
Shale.....	2066
Sand.....	2130
Shale.....	2210
Shelly.....	2220
Hard sand.....	2220
Soft sand.....	2265
Broken sand.....	2275
Shale.....	2500

Hole filled from bottom to top with mud-laden fluid.

Log of Industrial Oil and Gas Co., John B. Brown Well No. 1

Drilled in center of SE. $\frac{1}{4}$ of NE. $\frac{1}{4}$ Sec. 10, T. 8 N., R. 31 W., at elevation of 500 feet, by Harper Drilling Company. Data furnished by A. B. Harper. Drilling started July 5, 1929; finished August 15, 1929. Gas formation at depth of 2,496 to 2,518 feet. Total depth, 2,596 feet. Initial production first 24 hours, 1,250,000 cubic feet. Rock pressure, 166 pounds,

	Depth in feet
Soil and gravel.....	37
Shale.....	345
Sand.....	421
Shale.....	760
Sandy shale.....	815
Sand, hard.....	837
Shale.....	908

	Depth in feet
Sand, medium.....	990
Shale and shells.....	1030
Shale.....	1132
Sand.....	1152
Sandy shale.....	1376
Shale.....	1458
Shale and shells.....	1472
Sand.....	1490
Shale.....	1595
Sand.....	1834
Sandy shale.....	1865
Shale.....	1920
Sand.....	1983
Sandy shale.....	2070
Shale.....	2150
Shale and shells.....	2216
Shale.....	2280
Sand, hard.....	2355
Shale.....	2382
Sandy shale.....	2405
Shale, black.....	2420
Sand.....	2584
Shale.....	2596
Total depth.....	2596

Log of G. T. Cazort Well No. 18 in Sec. 7, T. 8 N., R. 30 W. (1,920 feet north and 400 feet east of SE. cor. Sec. 7)

Oil or gas zones: No. 1 from 2,445 to 2,450 feet; No. 2 from 2,455 to 2,465 feet; No. 3 from 2,470 to 2,474 feet; No. 4 from 2,480 to 2,500 feet; No. 5 from 2,505 to 2,515 feet. Important water sand from 130 to 140 feet. Production first 24 hours, 4,600,000 cubic feet. Rock pressure 178 pounds.

	Depth in feet
Grass roots to shale.....	47
Shale.....	314
Sand.....	395
Shale.....	625
Lime.....	715
Sand.....	795
Shale.....	846
Sand.....	908
Shale.....	1060
Sand.....	1208
Shale.....	1410
Sand.....	1452
Shale.....	1546
Sand.....	1820
Shale.....	1890
Sand.....	1989
Shale.....	2110
Sand.....	2140
Broken sand.....	2165

	Depth in feet
Shale.....	2223
Sand.....	2303
Shale.....	2397
Sand.....	2528
Shale.....	2532

Log of G. T. Cazort O. D. Steward Well No. 20

Drilled in Sec. 7, 8 N., 30 W. Drilling begun Sept. 8, 1923; finished Nov. 1, 1923. Initial production, 3,600,000 cubic feet.

	Depth in feet
Grass roots to shale.....	45
Shale.....	740
Sand.....	777
Shale.....	850
Sand.....	893
Shale.....	965
Sand.....	990
Shale.....	1090
Sand.....	1212
Shale.....	1418
Sand.....	1470
Shale.....	1560
Sand.....	1847
Shale.....	1922
Sand.....	1985
Shale.....	2130
Sand.....	2190
Shale.....	2244
Sand.....	2338
Shale.....	2358
Sand.....	2368
Shale.....	2429
Sand.....	2555

Log of Industrial Oil and Gas Company's Lynch Creekmore Well No. 1

Drilled in SW. $\frac{1}{4}$ NE $\frac{1}{4}$ Sec. 10, T. 8 N., R. 31 W., by Harper Drilling Company. Data furnished by A. G. Williams, Jr. Drilling started July 26, 1928; finished September 5, 1928. Gas bearing formations at 2,507 to 2,585 feet. Total depth, 2,585 feet. Initial production, 2,069,280 cubic feet. Rock pressure, 190 pounds.

	Depth in feet
Soil and sand.....	35
Shale.....	375
Sand.....	415
Shale.....	780
Sand.....	838
Shale.....	910
Sand.....	954
Sandy shale.....	970
Shale.....	1222
Sand.....	1239

	Depth in feet
Shale and shells.....	1253
Shale.....	1445
Sand.....	1480
Shale and shells.....	1520
Shale.....	1585
Sand.....	1835
Shale.....	1910
Sand.....	1980
Shale.....	2137
Sand.....	2190
Shale.....	2253
Sand.....	2306
Shale and shells.....	2330
Shale.....	2360
Sand.....	2377
Shale.....	2420
Sand.....	2582
Shale.....	2585
Total depth.....	2585

The logs of the wells in the Williams field are similar in every respect to those in the Kibler field, except that they encounter the producing horizons about 200 feet lower. The surface rocks belong to the Fort Smith formation, below which lie the Spadra shale and Hartshorne sandstone which are penetrated before the drill reaches the Atoka formation, containing the productive sands.

The records of the production of fourteen wells in the Williams field, drilled by the Industrial Oil and Gas Company and exhibited in the Twin Cities Pipe Line rate case, are given here.

TABLE 4.—Records of fourteen wells in the Williams field
[Production in thousands of feet; pressure in pounds.]

[Production in thousands of feet; pressure in pounds.]

Well	Completed in	Original rock pressure	Rock pressure at end of 1919	Production in 1919	Rock pressure at end of 1920	Production in 1920	Rock pressure at end of 1921	Production in 1921
Waddill No. 2	1919	260	250	41,124	210	230,762	183	73,238
J. Moore No. 1	1919	250	250		215	159,289	182	143,029
Vogel No. 1	1919	175	155	104,178	110	13,675	105	58,038
Nance	1919	250	175	179,169	150	223,532	147	15,794
Sanders	1919	205	165	116,091	180	177,422	130	125,046
Ruck	1919	205	165	165,225	140	359,200	140	49,409
Vogel No. 2	1920	240			162	223,567	140	35,187
Moon No. 8	1920	255			255	5,534	246	45,991
Bennett	1920	205			170	74,701	145	99,683
Moon No. 23	1920	245			210	66,769	185	77,731
Harper	1920	245			208	83,666	183	33,393
Halley	1920	270			238	79,572	236	35,187
Moon No. 11	1920	265			265	5,534	258	12,587
Ogden	1921	170					158	
Totals		3,340		605,787		1,703,223		854,313
	Rock pressure at end of 1922	Production in 1922	Rock pressure at end of 1923	Production in 1923	Rock pressure at end of 1924	Production in 1924	Rock pressure to Sept. 1 1925	Total production
Waddill No. 2	145	109,572	145	61,408	138	53,206	115	607,728
J. Moore No. 1	145	79,603	145	72,868	134	101,348	117	679,574
Vogel No. 1	105		105		118		122	117,853
Nance	145	81,577	145	36,261	128	50,308	111	58,523
Sanders	130	49,659	130	10,839	140		106	394,512
Ruck	140	102,686	140	37,376	132	100,786	111	1,024,246
Vogel No. 2	127	27,723	127	10,627	125	9,759	111	339,571
Moon No. 8	234	42,613	277	32,473	203	34,378	222	171,191
Bennett	130	72,646	130	26,805	140	19,786	116	268,378
Moon No. 23	145	40,923	145	18,995	125	3,140	120	229,510
Harper	145	70,944	145	43,411	133	71,340	116	414,074
Halley	170	76,348	167	117,773	145	107,342	132	595,914
Moon No. 11	234	42,613	227	32,472	204	34,378	219	171,791
Ogden	138	55,508	138	4,793	132	11,394	137	91,740
Totals		853,365		506,102		602,167	1,845	5,792,890

The total original rock pressure of these wells was 3,240 pounds, but by September 1, 1925, it had fallen to 1,845 pounds, a loss of 1,395 pounds. Up to September 1, 1925, however, these wells produced 5,792,890,000 cubic feet of gas. Therefore 4,152,000 cubic feet of gas were produced for each pound lost in pressure. According to testimony presented in the rate case by A. G. Williams, which was based on the data given above, the reserves of the fourteen wells in September, 1925, were 7,660,440,000 cubic feet.

In addition to the production above recorded, eighteen wells in the Williams field, purchased in 1923, produced, up to September 1, 1925, 1,807,017,000 cubic feet of gas, and during the same period twelve Cazort wells produced 934,852,000 cubic feet. The total rock pressure for these thirty wells, however, fell from 4,252 to 3,576, a decline of 676 pounds. As the combined production was 2,741,869,000 cubic feet for a decline of 676 pounds of pressure, the yield per pound was 4,056,000 cubic feet, or essentially the same production per pound of decline in pressure for the thirty wells as for the fourteen on which more accurate records were kept. As the thirty wells had a pressure reserve in 1925 of 3,576 pounds, the gas reserves were computed at 14,847,552,000 cubic feet. The addition of this amount to that determined for the fourteen wells gives a total of 22,507,592,000 cubic feet for the entire field, of which 21,580,712,000 cubic feet were estimated to be recoverable.

According to testimony given in the rate case by N. F. Drake, the average rock pressure in the Williams field at the end of the year 1923 was 141.8 pounds. In December, 1924, it had fallen to 134.1 pounds, and it further declined to 122.9 pounds by December, 1925. The total production in 1924 was 1,495,834,000 cubic feet and that for 1925, 2,516,135,000 cubic feet, or a total for the two years of 4,011,969,000 cubic feet. As the decline in the average rock pressure during the same period was 18.9 pounds, the production per pound of decline in average pressure was 212,274,000 cubic feet. Assuming an average rock pressure of 113 pounds and a 10-pound pressure as the lowest at which gas could be produced profitably, the Williams field had a recoverable reserve of 23,986,962,000 cubic feet.

Both of the methods of calculating reserves outlined above give results of the same order of magnitude, but neither is thought to be particularly accurate. Because of the leakage from the Williams to the Kibler field, as well as for other reasons, the reserves of these fields are difficult to calculate accurately, but it is believed that the gas reserves stated above are too low rather than too high. Furthermore, there is reason to believe that the limits of the producing area in the Williams field may eventually be extended a considerable distance to the southwest.

THE ALMA FIELD

Location.—Most of the Alma field is in Secs. 4, 5, 6, 7, 8, and 9, T. 9 N., R. 30 W., in southern Crawford County. A part of it lies within the town of Alma. (See accompanying map, Fig. 27.)

Discovery.—The Alma field was discovered in October, 1922, with the completion of the Lisle No. 1 well, in the so-called "deep" sand, with an initial rock pressure of 420 pounds. Between the date of its completion and September 1, 1925, about 617,437,000 cubic feet of gas were taken from the well.

Structure.—Most of the Alma field is on the Alma anticline, but part of it is on the Alma syncline. The surface features of these structures have been described elsewhere in this report, but their subsurface structure is such that the crest of the Alma anticline moves northward with increase of depth. For this reason wells drilled north of the surface axis of the Alma fold reach the producing horizons at shallower depths than those drilled at or near the surface axis.

The subsurface structure has been determined, but is not known to the public. The structure, however, is well defined and has a closure of between 250 and 350 feet. The wells drilled about 200 feet lower than the crest have been the most productive; most of those drilled high on the anticline have not been good producers.

The Alma field is rather sharply separated from the Kibler field, and although the producing sands in both fields are apparently the same, they are encountered about 300 feet deeper in the Alma field. The Alma field may be separated from the Kibler field by a concealed eastward trending fault whose downthrown side is north of its line of displacement. If so, the Kibler field forms an elevated triangular block between the depressed Alma and Williams fields. The Alma field is also sharply limited on the north by the Mulberry fault, north of which no gas has been obtained.

History of development.—Although the Alma field has been producing for seven years it is still being enlarged. It originally covered only about 1,500 acres, but the recently developed Smelter extension has increased the productive area to about 8,000 acres. The largest well in the Alma field had an initial capacity of 42,000,000 cubic feet, and a number of the wells had a capacity of more than 20,000,000 cubic feet. The large output of the wells has made this field the most productive in the Arkansas Valley areas. The present capacity of the field is about 120,000,000 cubic feet, of which about 3,000,000 cubic feet are taken daily from about 35 producing wells. The rock pressure was originally 330 pounds for the upper sand and 420 pounds for the lower, but these pressures have fallen to about 100 pounds for the upper sand, and 175 pounds for the lower.

The upper sand is encountered at 1,400 to 1,936 feet, and the lower at 2,400 to 2,800 feet. The upper sand is 200 feet thick, and yields gas from a porous zone 30 feet thick. The lower sand is 135 feet thick and contains a porous zone 36 feet thick. The thickness of these sands and their porous zones appear to be indentically the same in the Kibler, Williams, and Alma fields, and the producing horizons in the fields areas are evidently the same, but it is somewhat doubtful whether the sands are really as identical as to thickness and porous zones as the figures would indicate. The difference in the original rock pressure in the Alma and the Kibler-Williams fields is rather notable, and suggests differences not brought out by the figures at hand.

The average cost of drilling a well in the Alma field is about \$8,000.00. Drilling is relatively easy and the only troublesome water is encountered at 2,916 feet, a depth to which most wells do not penetrate.

Well records.—The logs of most of the Alma field wells as filed with the State authorities are too much generalized to be of great value in determining the subsurface structure, but some typical logs are given here.

Log of Industrial Oil and Gas Company's J. T. Jones Well No. 1

Drilled in the NW. $\frac{1}{4}$ of SW. $\frac{1}{4}$ Sec. 4, T. 9 N., R. 30 W., by A. B. Harper Drilling Company. Data furnished by A. G. Williams, Jr. Drilling started April 21, 1926, finished May 23, 1926. Gas-bearing formations from 1,916 to 1,940 and from 2,612 to 2,627 feet. Initial production, 6,000,000 cubic feet. Rock pressure not given.

	Depth in feet
Soil.....	8
Shale.....	200
Sandy shale.....	369
Shale.....	655
Sand.....	695
Shale.....	715
Sand.....	735
Shale.....	918
Sand.....	965
Shale.....	1095
Sand.....	1110
Shale.....	1200
Sand.....	1265
Shale.....	1300
Broken sand.....	1482
Shale.....	1680
Sand.....	1700
Shale.....	1712
Sand.....	1735
Shale.....	1812

	Depth in feet
Top upper sand.....	1812
Break.....	1890
Hard sand.....	1916
Gas pay from 1916 to.....	1940
Hard sand.....	2007
Shale.....	2112
Sand.....	2175
Shale.....	2235
Sand.....	2348
Shale.....	2435
Sand.....	2466
Shale.....	2471
Sand.....	2522
Shale.....	2571
Top of deep sand.....	2586
Good sand.....	2586
Hard sand.....	2595
Show gas.....	2595
Hard sand.....	2612
Gas.....	2627
Hard sand; no gas (bottom).....	2684

Log of Industrial Oil and Gas Company's Well No. 1

Drilled in town of Alma in NW. $\frac{1}{4}$ NW. $\frac{1}{4}$ Sec. 8, T. 9 N., R. 30 W., at elevation of 500 feet. Drilled by Tetley Oil & Gas Company. Data furnished by A. G. Williams, Jr. Drilling begun May 10, 1923, finished June 9, 1923. Gas obtained from formations at 2,540 to 2,603 feet. Initial production, 29,541,000 cubic feet. Rock pressure, 418 pounds.

	Depth in feet
Sand and gravel.....	21
Shale.....	270
Sand.....	290
Shale.....	315
Sand.....	330
Shale.....	660
Sand.....	715
Shale.....	1030
Sand.....	1125
Shale.....	1280
Sand.....	1320
Shale.....	1405
Sand.....	1435
Shale.....	1490
Sand.....	1510
Shale.....	1640
Sand.....	1695
Shale.....	1750
Sand.....	1940
Shale.....	2040
Sand.....	2105
Shale.....	2185

	Depth in feet
Sand.....	2248
Shale.....	2350
Sand.....	2410
Shale.....	2425
Sand.....	2450
Shale.....	2536
Sand, shells.....	2540
Top deep sand.....	2540
First gas.....	2548
Second gas.....	2566
Third gas.....	2576
Big pay.....	2602
Bottom.....	2602

Log of Crow Oil and Gas Company's John Wood Well No. 1

Drilled 660 feet N. 660 feet W. of southeast corner of SW. $\frac{1}{4}$ NW. $\frac{1}{4}$ Sec. 7,
T. 9 N., R. 30 W., Crawford County, Arkansas. Drilling begun March 7, 1923;
finished June 7, 1923.

	Depth in feet
Sand and gravel, soft.....	20
Shale, black.....	260
Sand, gray, hard.....	280
Shale, white.....	640
Sand, black.....	715
Sand, gray.....	750
Shale, black.....	1000
Shelly.....	1050
Sand, gray.....	1096
Shale, brown.....	1212
Shale, broken.....	1260
Sand, brown.....	1340
Shale, black.....	1550
Lime shells.....	1600
Shale, brown.....	1660
Sand.....	1728
Sand, broken.....	1785
Shale, black.....	1865
Hard shells, gray.....	1916
Slate.....	1960
Hard shells, gray.....	1980
Sand, hard.....	2045
Shale, black; cavy hole.....	2145
Hard shells, gray.....	2173
Sand, black.....	2238
Sand, soft.....	2274
Shale, brown.....	2306
Sand, black.....	2336
Shale, brown.....	2508
Sand, black.....	2520
Shale and shells, gray.....	2652
Shale, black.....	2697

	Depth in feet
Sand, black.....	2800
Shale, black.....	2805
Black sand; lost tools and bailer.	

Log of Industrial Oil and Gas Company's George Mausz Well

Drilled in NE. $\frac{1}{4}$ SE. $\frac{1}{4}$ Sec. 5, T. 9 N., R. 30 W., Crawford County, Ark., at elevation of 500 feet, by A. B. Harper Drilling Company. Data furnished by A. G. Williams, Jr. Drilling started May 1, 1926; finished May 31, 1926. Gas from formations at 2,696 to 2,736 feet. Initial production, 18,000,000 cubic feet. Rock pressure not given.

	Depth in feet
Soil.....	8
Gravel.....	12
Shale.....	260
Sand.....	310
Shale.....	325
Sand.....	345
Shale.....	715
Sand.....	814
Shale.....	980
Sand.....	988
Shale.....	1110
Shelly.....	1150
Sand.....	1210
Shelly.....	1320
Shale.....	1390
Sand.....	1430
Shelly.....	1540
Shale.....	1750
Sand.....	1800
Shale.....	1897
Sand.....	2016
Shale.....	2022
Sand.....	2080
Shelly.....	2145
Shale.....	2186
Sand.....	2255
Shale.....	2345
Sand.....	2413
Shale.....	2520
Sand.....	2535
Shale.....	2567
Sand.....	2590
Shale.....	2673
Top of deep sand.....	2673
First gas.....	2696
Second pay gas.....	2716
Total depth.....	2736

Log of Industrial Oil and Gas Company's J. A. Harris Well No. 1

Drilled in SW. $\frac{1}{4}$ NE. $\frac{1}{4}$ Sec. 2, T. 9 N., R. 30 W. Drilling begun March 10, 1927; finished May 28, 1927.

	Depth in feet
Soil and clay.....	25
Shale.....	225
Sand.....	236
Shale.....	465
Sand.....	488
Shale.....	562
Sand.....	572
Shale.....	892
Sand.....	956
Shale.....	975
Sand.....	995
Shale.....	1336
Hard sand.....	1346
Shale.....	1430
Sand.....	1456
Shale.....	1730
Shelly.....	1757
Sand.....	1804
Shale.....	1814
Shale and shelly.....	1828
Sand, hard.....	1850
Shale and shells.....	1880
Shale.....	2030
Shale and shells.....	2100
Shale.....	2160
Sand.....	2202
Shale.....	2208
Sand.....	2350
Shale.....	2460
Sand.....	2530
Shale.....	2605
Sand.....	2690
Shale.....	2748
Sand.....	2772
Shale.....	2784
Sand.....	2848
Shale.....	2850
Shale and shells.....	2979
Sand.....	3062
Shale.....	3072
Sand, black.....	3074
Sand; total depth.....	3077

Log of G. T. Cazort John Rose Well

Drilled in NW. $\frac{1}{4}$ SE. $\frac{1}{4}$ Sec. 4, T. 9 N., R. 30 W., Crawford County, Ark. Drilling begun October 4, 1924, finished November 22, 1924. Gas bearing formations from 1,700 to 1,702, 2,441 to 2,455, and 2,490 to 2,528 feet. Initial production, 25,250,000 cubic feet. Rock pressure, 338 pounds.

	Depth in feet
Grass roots to shale.....	30
Shale.....	158
Sand.....	176
Shale.....	557
Broken sand.....	574
Solid sand.....	590
Shale.....	596
Sand.....	620
Shale.....	933
Sand.....	945
Shale.....	1025
Sand.....	1029
Shale, black.....	1089
Sand.....	1120
Sandy shale.....	1204
Sand.....	1212
Sandy shale.....	1317
Sand.....	1335
Shale.....	1370
Sand.....	1380
Shale, black.....	1515
Sand.....	1542
Shale.....	1554
Sand.....	1557
Shale.....	1565
Sand.....	1577
Shale.....	1646
Sand.....	1648
Shale.....	1659
Sand, hard.....	1736
Sand, broken.....	1744
Sand, hard.....	1854
Shale.....	1948
Sand.....	2011
Shale.....	2087
Sand, hard.....	2150
Sand, broken.....	2165
Sandy shale.....	2238
Sand.....	2250
Shale and shells.....	2275
Sand, hard.....	2291
Shale.....	2310
Sand.....	2319
Shale.....	2400
Sand, broken.....	2415
Sand, solid.....	2523
Shale.....	2528

Log of Industrial Oil and Gas Company's I. L. Cole Well No. 2

Drilled near center of SE. $\frac{1}{4}$ SW. $\frac{1}{4}$ Sec. 5, T. 9 N., R. 30 W., Crawford County, Ark., by Tetley Oil & Gas Co. Data furnished by A. G. Williams, Jr. Drilling started August 2, 1924; finished September 11, 1924. Gas bearing formations from 2,598 to 2,665 feet. Initial production 14,680,000 cubic feet. Rock pressure 315 pounds.

	Depth in feet
Soil and gravel.....	22
Shale.....	260
Sand, water.....	340
Shale.....	680
Sand.....	692
Shale.....	712
Sand.....	740
Shale.....	910
Sand.....	925
Shale.....	1070
Sand.....	1080
Shale.....	1095
Sand.....	1172
Shale.....	1212
Sand.....	1218
Shale.....	1415
Sand.....	1460
Shale.....	1650
Sand.....	1696
Shale.....	1781
Sand.....	1990
Shale.....	2075
Sand.....	2145
Shale.....	2208
Sand.....	2300
Shale.....	2390
Sand.....	2445
Shale.....	2461
Sand.....	2500
Shale.....	2577
Shelly.....	2598
Top deep sand.....	2598
Hard sand.....	2608
First gas.....	2611
Hard sand.....	2619
Second gas.....	2621
Hard sand.....	2649
Big increase at.....	2665

These logs show a remarkable similarity to those of wells in the Williams field, and in their lower parts they are also essentially the same as those of the Kibler field. The surface rocks belong to the Spadra shale; the first heavy sandstone encountered is the Harts-horne sandstone; and the alternating sandstone and shale below the

TABLE 5.—Records of wells sunk to deep sands in the Alma field
[Production in thousands of feet; rock pressure in pounds.]

Well	Completed in	Original rock pressure	Rock pressure at end of 1922	Production in 1922	Rock pressure at end of 1923	Production in 1923	Rock pressure at end of 1924	Production in 1924	Rock pressure Sept. 1, 1925	Production Jan. 1, 1925 to Sept. 1, 1925	Production in thousands of cubic feet to Sept. 1, 1925
A. Byers No. 1	1923	420			350	164,255	255	64,230	230	47,430	275,915
A. Byers No. 3	1923	400			400		255		220	15,544	15,544
Bolling.....	1923	418			305	218,842	230	251,744	230	71,758	542,344
Branch.....	1923	340			400		277	8,305	250		8,305
Coleman.....	1923	418			350	162,333	230	339,030	218	172,070	673,433
Day.....	1923	305			*		238	166,869	231	75,898	242,767
Griffin.....	1923	418			325	117,999	231	244,087	231	79,130	441,216
Hammer.....	1923	304			287	156,302	143	80,658	163	18,801	255,561
Huckaby.....	1923	418			393	24,103	232	81,617	240	26,634	132,354
Lisle.....	1922	420	420	61,000	345	333,497	233	218,053	230	4,887	617,437
Lewers.....	1924	315					255	179,622	232	92,899	272,521
Reed.....	1923	418					221	88,777	232	3,292	99,274
Cole No. 1.....	1924	315					203	48,461	241	5,487	53,948
Cole No. 2.....	1924	315					269		345	98,628	98,628
Totals.....		5,224		61,000		1,184,536	3,272	1,771,453	3,193	712,258	3,729,247
Cazort No. 16	1923										
Cazort No. 17	1923				292				230	16,364	16,364
Cazort No. 18	1923				268				238	45,918	45,918
Totals.....					276				232	31,850	31,850
Totals.....					836				700	94,132	94,132

*Not closed in.

Total original rock pressure, all deep sand wells in pounds..... 6,060
 Total rock pressure Sept. 1, 1925..... 3,893
 Total loss of pressure..... 2,167
 Total production to Sept. 1, 1925..... 3,823,379
 Divided by loss..... 2,167
 =1,764,000 cubic feet produced per pound loss of pressure

Hartshorne consist of sediments of the Atoka formation, from which the gas is derived.

The well records for the Alma deep sand, as presented as evidence in the Twin Cities Pipe Line rate case, are given in Table 5. The total production from deep sand to September 1, 1925, was 3,823,379,000 cubic feet. In producing that quantity of gas, however, the total rock pressure fell from 6,060 pounds to 3,893 pounds, a loss of 2,167 pounds. Hence, 1,764,000 cubic feet were produced for each pound of decline in pressure. Therefore, according to A. G. Williams, the seventeen wells listed had a reserve, in September, 1925, of 6,867,252,000 cubic feet, of which 6,567,372,000 cubic feet were considered recoverable.

N. F. Drake, however, using the pressure decline only after the production had become settled, estimated that the reserves of the Alma deep sand were 32,661,930,000 cubic feet, in his testimony in the rate case.

The records of six wells in the shallow sand are also given here. These form a part of the data on which A. G. Williams made his estimate of the future life of the Alma field, presented in the Twin Cities Pipe Line rate case.

The shallow sand wells had a combined initial rock pressure of 1,772 pounds, which fell to 744 pounds in September, 1925, up to which time 2,426,781,000 cubic feet of gas had been produced. As the total decline in pressure was 1,028 pounds, 2,361,000 cubic feet of gas were produced for each pound of decline. Therefore, according to A. G. Williams, the remaining 744 pounds of pressure indicated a reserve of 1,756,584,000 cubic feet, of which 1,554,924,000 cubic feet were considered recoverable.

According to expert testimony presented by N. F. Drake, however, the reserves recoverable from the Alma shallow sands in September, 1925, were 6,627,789,000 cubic feet. This calculation was based on changes in rock pressure and in production after the production had become settled.

The Cazort wells, drilled east of the Alma field proper, had an original rock pressure of 418 pounds. The drainage from that high-pressure area has served to keep the pressure in the northeastern part of the Alma proper field about 25 pounds higher than that in the rest of the field. The reserves of the extension have not been calculated, but they are undoubtedly great.

The total recoverable reserves of the Kibler-Williams-Alma fields were 45,202,990,000 cubic feet in September, 1925, according to A. G. Williams. This was sufficient to maintain the production for 9.7 years at the rate the gas was then being taken from the fields. The total reserves, according to N. F. Drake, however, were 79,748,521,000

cubic feet and were sufficient to maintain production for 17.3 years. The developments since these estimates were made indicate that the higher figure may be more nearly accurate.

THE CLARKSVILLE FIELD

Location.—The Clarksville field is about 6 miles northwest of Clarksville, chiefly in Secs. 10, 14, 15 and 22, T. 10 N., R. 24 W., but the limits of the field have not yet been definitely defined. (See accompanying map, Fig. 30.)

Discovery.—The Clarksville field is on the Ludwig anticline, whose fitness as a reservoir for gas was pointed out as early as 1916 by N. F. Drake. The first well drilled in the field, however, was not completed until November 31, 1921, when the Indianoma Refining Company's Pearson No. 1 was brought in with a production of 6,500,000 cubic feet of gas at a depth of 2,345 feet.

Structure.—The axis of the Ludwig anticline extends from the NW. $\frac{1}{4}$ Sec. 18, T. 10 N., R. 24 W., slightly south of east to the NE. $\frac{1}{4}$ Sec. 30, T. 10 N., R. 22 W. The anticline is asymmetrical, and in T. 10 N., R. 24 W., is domed. The dips north of the axis range from 2 to 13 degrees and average about 6 degrees. The dips south of the axis range from 2 to 12 degrees, but average considerably less than those on the north limb of the anticline. The anticline is well closed at its west end, but is less definitely closed at its east end and is complicated by minor folds. The closure for the entire Ludwig anticline is not more than 200 feet, but the part of the structure that is now producing gas has a closure of at least 300 feet, and the west end of the anticline forms a pronounced structural nose.

Too few wells have been drilled in the Clarksville field to permit a determination of the subsurface structure, which, however, apparently conforms to the surface structure. A surface-structure map compiled by Charles T. Kirk is presented here through the courtesy of D. W. Johnston of Clarksville. The contours in this map are drawn on the top of a heavy sandstone, which crops out in the field itself.

History of development.—The discovery well of the Clarksville field, the Pearson No. 1, is in the SE. $\frac{1}{4}$ of the NE. $\frac{1}{4}$ of the NE. $\frac{1}{4}$ Sec. 22, T. 10 N., R. 24 W. The gas was obtained from a sand 20 feet thick at a depth of 2,345 feet under an original rock pressure of 520 pounds. The log of the Pearson Well is given below:

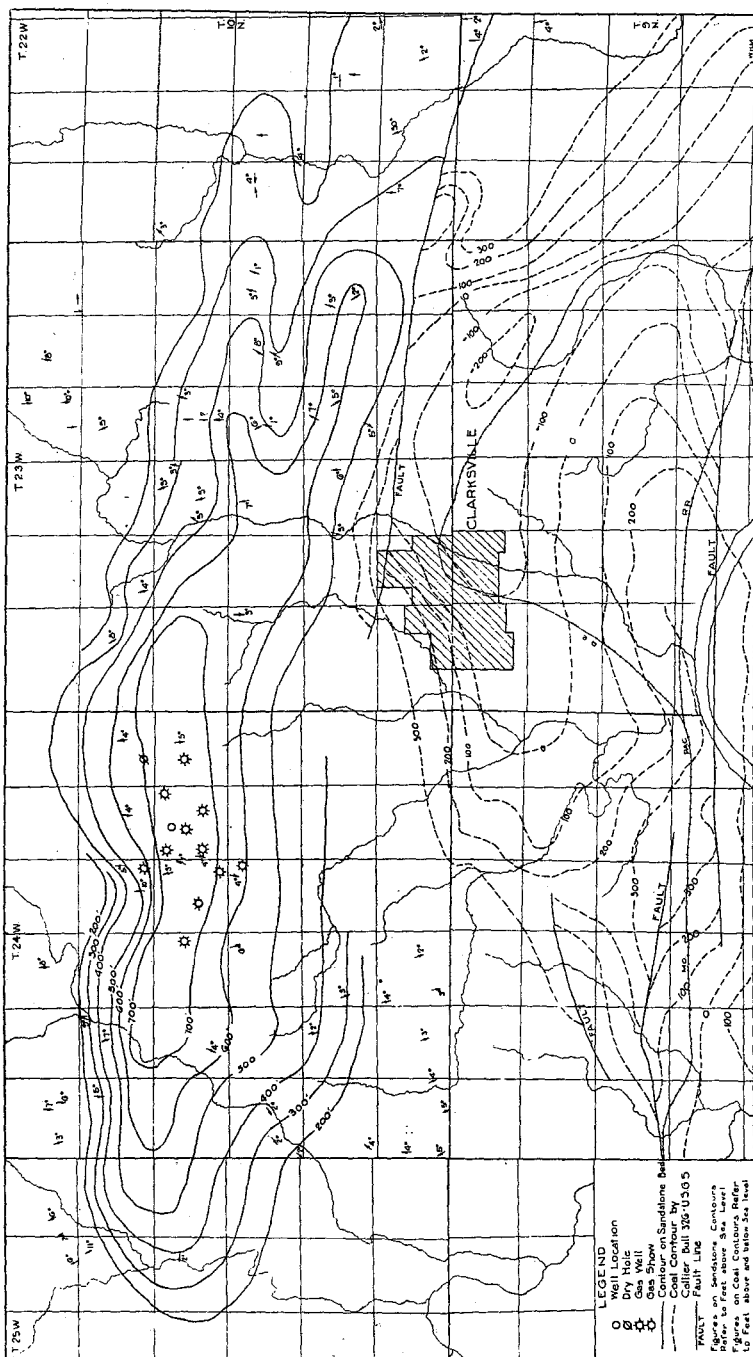


FIGURE 30.—Sketch map showing the structure in the Clarksville area.
[Scale about 2 1/2 miles to the inch.]

Log of Indiahoma Refining Co., Pearson Well No. 1

Drilled in SE. $\frac{1}{4}$ NE. $\frac{1}{4}$ NE. $\frac{1}{4}$ Sec. 22, T. 10 N., R. 24 W., Johnson County, Arkansas. Started drilling June 3, 1921; completed November 31, 1921. Shut down from August 3, 1921 to October 4, 1921. Initial production, 6,500,000 cubic feet.

	Depth in feet
Surface.....	10
Lime.....	120
Slate, black.....	145
Gray lime, water.....	195
Slate, black.....	225
Sandy lime.....	230
Black lime.....	244
Gray lime, 12 inch pipe.....	248
Brown slate.....	395
White lime.....	415
Black slate.....	460
Sandy lime white.....	478
Black slate.....	500
White lime.....	510
Gray lime.....	520
White slate.....	635
Gray lime.....	720
Blue slate.....	820
Gray lime; cased first time.....	940
Slate, blue.....	950
White lime.....	960
Blue slate.....	975
Black lime.....	985
Black slate.....	1020
Black lime.....	1025
Black slate.....	1075
Black lime.....	1085
Blue slate.....	1095
Black lime.....	1110
Black slate.....	1140
White slate.....	1150
Sand; oil and water.....	1234
Slate, dark.....	1240
Black lime.....	1275
Water sand; break at 1307 feet.....	1335
Water sand.....	1592
Slate, black.....	1603
White lime.....	1608
Light lime.....	1620
Blue slate.....	1635
Light lime.....	1648
Slate and shells.....	1730
Sandy lime.....	1885
Black slate.....	1950
Grey sandy lime.....	2020
Slate and shells.....	2120

	Depth in feet
Grey lime.....	2222
Grey sandy lime.....	2235
Black slate.....	2242
Grey sandy lime.....	2255
Black slate.....	2260
White slate.....	2285
Grey lime.....	2305
Dark slate.....	2315
Gray lime.....	2320
Dark slate.....	2325
Light sand; 6,500,000 feet of gas.....	2345

The entire log records an alternating series of beds of sandstone and shale, typical of the Atoka formation, but the sandstone was logged as "lime" and the shale as "slate." It is certain that little or no limestone and no slate was encountered. The oil at 1,234 feet has been variously reported. A small showing of a light greenish oil was evidently obtained at that depth, but the rumor that a 20-barrel well could have been brought in is probably an exaggeration.

The casing has been pulled from the Pearson well, which has now been tubed with 3-inch pipe. The gas obtained at a depth of 2,345 feet is said to yield 1.52 gallons of gasoline per thousand cubic feet, but no analyses of it are available. It has a fetid odor, and a casual field examination indicates that it is dry rather than wet.

The Pearson test well was drilled near the crest of the anticline.

The Indianoma Refining Company's Well No. 2, drilled on the Dennis lease in Sec. 15, T. 10 N., R. 24 W., was abandoned as a dry hole at a depth of 2,590 feet, although structurally it was at least as well located as the Pearson test well. Some gas was obtained at depths of 2,000 and 2,220 feet, and "salt sand" was recorded at 1,178 and 1,330 feet, although it is not known that salt water was actually encountered. The log of the Dennis well is given below.

Indianoma Refining Co., W. C. Dennis Well No. 2

Drilled in Sec. 15, T. 10 N., R. 24 W., Johnson County, Arkansas. Drilling started September 9, 1922; finished December 15, 1922. Total depth, 2,590 feet.

	Depth in feet
Surface.....	8
Rock.....	71
Water sand.....	90
Brown shale.....	212
Brown sand.....	240
Black shale.....	300
Lime.....	315
Black shale.....	357
Sand.....	395
Black shale.....	430

	Depth in feet
Sand.....	440
Shale.....	480
Lime.....	495
Black shale.....	490
Brown sand.....	610
Black shale.....	615
Gray sand.....	651
Black shale.....	665
Black sand.....	695
Black shale.....	796
Brown sand.....	845
Black shale.....	1005
Sandy shale.....	1060
Brown shale; hole full of water.....	1097
Salt sand.....	1178
Lime.....	1198
Black shale.....	1201
Black lime.....	1215
Black slate.....	1223
Lime.....	1226
Salt sand.....	1330
Lime; hole full of water.....	1365
Water sand.....	1394
Gray lime.....	1490
Sand lime.....	1505
Black shale.....	1620
Black lime.....	1635
Black shale.....	1680
Black lime.....	1695
Black shale.....	1715
Sandy shale.....	1757
White sand.....	1792
Brown shale.....	1845
Sandy lime.....	1895
Brown shale.....	1925
Sandy lime.....	1955
Shale.....	1990
Sandy lime.....	2105
Water sand; a little gas at 2000.....	2114
Black shale.....	2137
Black lime.....	2144
Sand.....	2162
Brown shale.....	2167
Lime.....	2184
Shale.....	2188
White gray sand.....	2208
White sand; a little gas at 2220.....	2220
Sandy lime.....	2252
Black shale.....	2312
Lime.....	2316
Sandy shale.....	2450

	Depth in feet
Black lime.....	2455
Shale.....	2510
Lime shell.....	2512
Black shale.....	2590

The Dennis well was said to have been drilled on a fault, but there is little surface evidence of a fault at this place. In the southern part of Secs. 7 and 8, T. 10 N., R. 23 W., however, the beds have evidently been displaced along a line trending somewhat north of east, which if continued southwestward would extend about to the Dennis well.

The information obtained in drilling the Russell and Qualls wells shows that the Dennis well was stopped short of the main producing horizon. The Dennis well was plugged in January, 1923.

The Empire Gas and Fuel Company's Russell No. 1 was completed March 18, 1926, with an initial production variously estimated at from 8,000,000 to 12,000,000 cubic feet and with an initial rock pressure of about 1,000 pounds. Most of the gas was obtained from a sand at 2,889 feet, but gas was found also at 843, 1,111, 2,045, and 2,632 feet. The log of the Russell No. 1 is given below.

Log of Empire Gas and Fuel Co., Russell No. 1

Drilled in Sec. 14, T. 10 N., R. 24 W., Johnson County, Arkansas. Drilling begun November 9, 1925; completed March 18, 1926.

	Depth in feet
Surface.....	50
Black shale.....	70
Slate, dark.....	100
Black shale.....	130
Lime.....	155
Hard lime.....	165
Lime.....	171
Slate.....	186
Shale.....	218
Black shale.....	224
Lime.....	234
Shale.....	250
Black shale.....	290
Black shale.....	334
Lime.....	349
Black shale.....	364
Sandy lime.....	384
Lime, sandy.....	416
Lime.....	448
Shale.....	460
Lime.....	473
Lime.....	498
shells.....	515
Lime.....	523

	Depth in feet
Lime, hard.....	537
Sandy shale.....	549
Sandy shale.....	589
Black shale.....	595
Shelly lime.....	607
Light slate.....	623
Hard lime.....	629
Lime.....	659
Lime.....	667
Slate.....	709
Black shale.....	759
Lime, hard.....	774
Slate.....	799
Lime.....	819
Lime.....	834
Sand gas.....	839
Sand gas.....	846
Black shale.....	867
Black shale.....	879
Black shelly.....	892
Shale and shell.....	920
Lime.....	940
Lime; shells.....	946
Slate.....	976
Black shale.....	1021
Slate.....	1027
Lime.....	1046
Shale and shells.....	1086
Slate.....	1106
Sand gas.....	1111
Sand.....	1125
Sand, hard.....	1131
Sand, hard.....	1146
Lime, hard.....	1159
Lime.....	1165
Hard lime.....	1168
Lime, hard.....	1179
Lime.....	1185
Black slate.....	1190
Lime.....	1201
Lime.....	1205
Sand.....	1211
Sand, hard.....	1220
Water sand.....	1236
Water sand.....	1262
Water sand.....	1287
Water sand.....	1297
Brown sand.....	1303
Brown sand.....	1306
Lime.....	1315
Lime.....	1322

	Depth in feet
Lime.....	1337
Sandy lime.....	1360
Sand.....	1375
Sand.....	1383
Lime.....	1393
Sand.....	1397
Sand.....	1405
Sand.....	1415
Sand.....	1426
Sand.....	1438
Lime.....	1450
Lime.....	1460
Lime.....	1470
Lime.....	1490
Sand.....	1499
Broken lime.....	1572
Black shale.....	1580
Broken lime.....	1615
Shale.....	1638
Broken lime.....	1670
Black shale.....	1707
Lime.....	1842
Shale.....	1854
Black shale.....	1909
Broken lime.....	2000
Shale.....	2015
Shells and shale; gas.....	2045
Black sand.....	2048
Sand.....	2058
Sandy shale.....	2083
Shells and shale.....	2108
Sandy shale.....	2121
Sandy lime.....	2136
Lime.....	2216
Black lime.....	2228
Shale.....	2233
Lime.....	2250
Shale.....	2260
Lime.....	2300
Black shale.....	2341
Hard sand.....	2361
Hard lime.....	2399
Black lime.....	2416
Lime.....	2423
Shale.....	2431
Black shale.....	2436
Black lime.....	2440
Shale.....	2466
Broken lime.....	2497
Shale.....	2522
Lime.....	2527

	Depth in feet
Shale.....	2535
Shale.....	2550
Black shale.....	2564
Lime.....	2570
Black shale.....	2615
Lime, sandy; gas at 2632-36.....	2641
Broken lime.....	2730
Lime.....	2780
Black shale.....	2783
Lime.....	2805
Black shale.....	2828
Lime.....	2852
Broken lime.....	2860
Lime.....	2874
Sand.....	2875
Broken lime.....	2887
Lime.....	2889
Gas sand.....	2892

Initial production about 8,000,000 feet, according to H. T. Beckwith of Tulsa, Oklahoma.

In this log, as in all the logs of wells in the Clarksville area, some of the sandstones are reported as "limes," but very little true limestone and no slate was encountered. The alternation of sandstone and shale is typical of the Atoka formation. The Russell well was drilled slightly north of the axis of the Ludwig anticline.

Another productive well drilled in the Clarksville area is the Empire Gas and Fuel Company's Qualls well No. 1, which was completed September 2, 1927, with an initial production of at least 15,000,000 cubic feet and a rock pressure of 1,180 pounds. This is not only one of the largest of the Arkansas Valley wells in its initial production, but the rock pressure was higher than that recorded for any earlier well and was sufficient to blow the drilling tools out of the hole when the gas sand was encountered. Some of the later wells in the Clarksville field, however, had still greater initial rock pressure. The log of the Qualls well is given here.

Log of Empire Gas & Fuel Co., A. M. Qualls Well No. 1

Drilled 660 feet S. 660 feet E. of the northwest corner of Sec. 14, T. 10 N., R. 24 W., Johnson County, Arkansas, by C. B. Harding. Data furnished by C. B. Harding. Drilling started November 10, 1926; completed September 2, 1927. Gas formations from 929 to 933, 2,288 to 2,298, 2,853 to 2,871, and 3,012 to 3,043 feet. Initial production, 15,000,000; cubic feet; rock pressure 1,180 pounds.

	Depth in feet
Sandy shale, black, soft.....	60
Lime, black, medium.....	88
Shale, black, soft.....	153
Lime, black, hard.....	173
Shale, black, soft.....	213

	Depth in feet
Lime, black, hard.....	256
Shale, black, soft.....	295
Lime, black, hard.....	305
Shale, black, soft.....	313
Lime, hard.....	321
Shale, soft.....	332
Sand, black, medium.....	346
Shale, black, soft.....	384
Lime, black, hard.....	400
Sand, grey, hard.....	410
Lime, black, hard.....	456
Sand, black, hard.....	466
Sandy lime, black, hard.....	500
Shale, black, soft.....	545
Lime, black, hard.....	571
Shale, black, soft.....	596
Sand, black, hard.....	602
Lime, black, hard.....	610
Shale, black, soft.....	645
Lime, black, medium.....	650
Shale, black, soft.....	688
Sandy lime, grey, hard.....	709
Sandy shale, black, soft.....	721
Lime, sandy, black, hard.....	767
Shale, black, soft.....	802
Lime, grey, hard.....	814
Shale, black, soft.....	877
Lime, black, soft.....	833
Shale, black, soft.....	909
Lime, gray, hard.....	932
Sandy, black, medium.....	965
Sandy slate, black, soft.....	1042
Lime, black, hard.....	1052
Shale, black, soft.....	1131
Water sand, grey, medium.....	1206
Lime, black, hard.....	1300
Water sand, white, medium.....	1420
Sandy lime, black, hard.....	1452
Water sand, white, soft.....	1461
Sand, hard.....	1469
Sand, gray, hard.....	1509
Sand, hard.....	1531
Sandy shale, black, hard.....	1539
Sandy lime, black, hard.....	1574
Sandy shale, black, hard.....	1585
Sandy lime, black, hard.....	1590
Sandy lime, black, medium.....	1599
Sandy shale, black.....	1604
Sandy lime, black, hard.....	1612
Sandy shale, black, medium.....	1675
Lime, black, hard.....	1685

	Depth in feet
Lime, gray, hard.....	1736
Sandy shale, black, medium.....	1750
Lime, black, hard.....	1766
Sandy shale, black, soft.....	1843
Lime, black, hard.....	1851
Lime, gray, hard.....	1898
Broken lime, black, medium.....	1943
Lime, black, hard.....	1947
Broken lime, black, medium.....	1961
Shale, black, soft.....	1983
Lime, black, hard.....	2001
Sandy shale, black, medium.....	2006
Sandy lime, black, hard.....	2072
Sandy shale, black, hard.....	2086
Sandy lime, black, medium.....	2093
Shale, black, soft.....	2117
Lime, black, hard.....	2125
Lime, gray, hard.....	2130
Lime, light gray, hard.....	2135
Sandy lime, gray, hard.....	2150
Shale, black, soft.....	2157
Sandy lime, gray.....	2164
Shale, black, soft.....	2190
Sandy lime, hard.....	2206
Sandy, gray, hard.....	2224
Broken lime, black, soft.....	2237
Shale, black, soft.....	2280
Lime, black, hard.....	2288
Gas sand, gray, soft.....	2304
Lime, black, hard.....	2310
Sand, black, hard.....	2333
Lime, black, hard.....	2369
Sandy shale, black.....	2384
Sand lime, black, medium.....	2400
Broken lime, black, soft.....	2414
Shale, black, soft.....	2517
Sand, black, hard.....	2540
Sandy lime, black, hard.....	2556
Sand, gray, hard.....	2571
Shale, black, soft.....	2580
Sandy lime, black, medium.....	2586
Shale, black, soft.....	2637
Lime, black, medium.....	2641
Shale, black, soft.....	2650
Lime, black, hard.....	2654
Black shale, soft.....	2695
Sandy lime, brown, hard.....	2710
Shale, black, soft.....	2759
Lime, black, hard.....	2765
Shale, black.....	2777
Sandy lime, gray.....	2795

	Depth in feet
Sand, gray, hard.....	2820
Lime, black, hard.....	2826
Shale, black, medium.....	2853
Gas sand, gray, medium.....	2871
Shale, black, soft.....	2905
Sandy shale, black.....	2919
Lime, black.....	2929
Shale, black, soft.....	2932
Sandy shale, black.....	2936
Shale, sandy, black.....	3011
Lime, hard.....	3012
Sand.....	3014
Sand, soft.....	3043

Gas was obtained from sands at four different horizons, as indicated by the log, but the largest quantity came from the deepest sand. The gas produced from the Qualls and Russell wells was apparently obtained from the same sand, but the Qualls well was drilled somewhat lower on the anticline.

In addition to the wells listed, the following wells have been drilled in the Clarksville area proper.

Arkansas-Louisiana Pipe Line Co., J. H. McPherson No. 1, southeast corner of the SE. $\frac{1}{4}$ SE. $\frac{1}{4}$ Sec. 10, T. 10 N., R. 24 W.

Arkansas Natural Gas Corp., J. I. Bynum No. 1, southeast corner of the SE. $\frac{1}{4}$ NW. $\frac{1}{4}$ Sec. 13, T. 10 N., R. 24 W.

Arkansas Natural Gas Corp., W. C. Hudson No. 1, 660 feet north and 660 feet west of center Sec. 14, T. 10 N., R. 24 W.

Arkansas Natural Gas Corp., J. G. Houston No. 1, 660 feet north and 825 feet west of the southeast corner of Sec. 15, T. 10 N., R. 24 W.

Arkansas Natural Gas Corp., M. F. Kirwin No. 1, 660 feet north and 660 feet west of the southeast corner of the E. $\frac{1}{2}$ NE. $\frac{1}{4}$ Sec. 16, T. 10 N., R. 24 W.

Arkansas Natural Gas Corp., W. T. Self No. 1, 735 feet south and 735 feet east of the northwest corner of the NW. $\frac{1}{4}$ SW. $\frac{1}{4}$ Sec. 14, T. 10 N., R. 24 W.

Arkansas Natural Gas Corp., O. L. Hudson No. 1, 300 feet south and 660 feet west of the northeast corner of the NW. $\frac{1}{4}$ SE. $\frac{1}{4}$ Sec. 14, T. 10 N., R. 24 W.

Arkansas Louisiana Pipe Line Co., J. I. Bynum No. 2, 696 feet north and 610 feet west of the southeast corner of the SE. $\frac{1}{4}$ SW. $\frac{1}{4}$ Sec. 12, T. 10 N., R. 24 W. (Still drilling September 3, 1929.)

The logs of these wells are given below.

Log of Arkansas-Louisiana Pipe Line Co., J. H. McPherson No. 1

Drilled 660 feet north 760 feet west southeast corner SE. $\frac{1}{4}$ SE. $\frac{1}{4}$ Sec. 10, T. 10 N., R. 24 W., Johnson County, Arkansas. Total depth, 3,452 feet. Initial production 15,000,000 cubic feet. Rock pressure, 550 pounds.

	Depth in feet
Shale.....	0- 15
Shale.....	15- 120
Shale.....	120- 130
Hard sand.....	130- 160
Shale.....	160- 275

	Depth in feet
Hard sand.....	275- 320
Shale.....	320- 470
Sand.....	470- 480
Shale.....	480- 605
Sand.....	605- 630
Shale.....	630- 645
Sand.....	645- 665
Shale.....	665- 715
Sand.....	715- 722
Shale.....	722- 745
Hard white sand.....	745- 755
Hard sand.....	755- 815
Shale.....	815- 850
Hard sand.....	850- 868
Sandy shale.....	868- 885
Shale.....	885- 970
Sand.....	970- 977
Hard sand.....	977-1047
Shale and shells.....	1047-1090
Broken sand.....	1090-1100
Shale.....	1100-1198
Broken sand.....	1198-1240
Shale.....	1240-1285
Water sand.....	1285-1305
Hard sand.....	1305-1410
Sand.....	1410-1475
Hard sand.....	1475-1525
Sand.....	1525-1550
Hard sand.....	1550-1590
Sand.....	1590-1610
Hard sand.....	1610-1640
Broken sand.....	1640-1670
Hard sand.....	1670-1705
Sand.....	1705-1710
Sandy shale.....	1710-1750
Sand.....	1750-1795
Sandy shale.....	1795-1800
Broken sand.....	1800-1835
Sandy shale.....	1835-1850
Hard sand.....	1850-1975
Sandy shale.....	1975-2055
Hard sand.....	2055-2100
Sand.....	2100-2285
Hard sand.....	2285-2320
Sand.....	2320-2330
Shale.....	2330-2350
Sand.....	2350-2375
Shale.....	2375-2390
Sand.....	2390-2400
Shale.....	2400-2420
Sand gas at 2430 feet.....	2420-2430

	Depth in feet
Gas sand.....	2430-2450
Sand.....	2450-2460
Hard sand.....	2460-2475
Sandy shale.....	2475-2525
Sand.....	2525-2560
Hard sand.....	2560-2575
Broken sand.....	2575-2680
Shale.....	2680-2715
Sand.....	2715-2755
Broken sand.....	2755-2865
Hard dark sand.....	2865-2910
Hard sand.....	2910-2930
Shelly.....	2930-2975
Sandy shale and shells.....	2975-2990
Sand.....	2990-3045
Broken sand.....	3045-3118
Gas sand.....	3118-3125
Sand.....	3125-3250
Shale.....	3250-3298
Sand.....	3298-3315
Hard sand, more gas.....	3315-3345
Gas sand, more gas.....	3345-3367
Sand.....	3367-3385
Shale (Steel line measure).....	3385-3422
Lime, dark hard.....	3422-3452

Log of Arkansas Natural Gas Corporation, J. I. Bynum Well No. 1

Drilled 570 feet north and 740 feet west of the southeast corner SE. $\frac{1}{4}$ NW. $\frac{1}{4}$ Sec. 13, T. 10 N., R. 24 W., Johnson County Ark. Total depth, 3,126 feet. Initial production, 7,194,000 cubic feet. Rock pressure, 1,250 pounds.

	Depth in feet
Shale.....	0- 60
Hard sand.....	60- 70
Broken sand.....	70- 80
Shale.....	80 101
Shale.....	101- 105
Shale.....	105- 155
Brown sand.....	155- 165
Shale.....	165- 238
Shale.....	238- 251
White lime.....	251- 265
Broken sand.....	265- 320
Shale.....	320- 395
White lime.....	395- 455
Shale.....	455- 468
White lime.....	468- 490
Shale.....	490- 558
Hard sand.....	558- 604
Black shale.....	604- 660
Sand.....	660- 680
Shale and shells.....	680- 749

	Depth in feet
Hard sand.....	749- 797
Shale.....	797- 808
Sand.....	808- 813
Black shale.....	813- 840
Shells and shale.....	840- 880
Shale.....	880- 965
Sand.....	965- 990
Shale.....	990-1050
Hard sand.....	1050-1134
White sand.....	1134-1140
Water sand.....	1140-1200
Water sand.....	1200-1230
Gray sand.....	1230-1240
Hard lime.....	1240-1265
Hard lime.....	1265-1277
Sand.....	1277-1288
Sand.....	1288-1290
Hard lime.....	1290-1306
Hard lime.....	1306-1317
Hard lime.....	1317-1326
Hard lime.....	1326-1340
Hard lime.....	1340-1353
Hard lime.....	1353-1360
Gray sand.....	1360-1367
Gray sand.....	1367-1380
Black lime.....	1380-1383
Black lime.....	1383-1400
Hard black lime.....	1400-1419
Black lime.....	1419-1420
Black lime.....	1420-1438
Black lime.....	1438-1444
Broken lime.....	1444-1473
Hard lime.....	1473-1480
Hard lime.....	1480-1485
Hard lime.....	1485-1497
Black shale.....	1497-1505
Black shale.....	1505-1524
Broken lime.....	1524-1540
Medium lime.....	1540-1545
Broken lime.....	1545-1562
Broken lime.....	1562-1600
Broken lime.....	1600-1645
Shale.....	1645-1655
Shale.....	1655-1659
White lime.....	1659-1694
White lime.....	1694-1703
Lime.....	1703-1732
White lime.....	1732-1765
White lime.....	1765-1777
Black shale.....	1777-1861
Lime.....	1861-1862

	Depth in feet
Lime.....	1862-1890
Lime.....	1890-1910
Broken lime.....	1910-1950
Broken lime.....	1950-1972
Shale.....	1972-1990
Broken gas sand.....	1990-1998
Sandy shale.....	1998-2010
Hard lime.....	2010-2081
Hard lime.....	2081-2120
Hard lime.....	2120-2184
Shale and shells.....	2184-2194
Hard lime.....	2194-2207
Shale.....	2207-2228
Broken sand.....	2228-2258
Shale.....	2258-2312
Black lime.....	2312-2372
Broken lime.....	2372-2425
Broken lime.....	2425-2455
Shale.....	2455-2480
Light lime.....	2480-2496
Shale.....	2496-2523
Hard lime.....	2523-2534
Broken lime.....	2534-2566
Sandy lime.....	2566-2580
Hard lime.....	2580-2610
Broken lime; gas.....	2610-2675
Broken sandy lime.....	2675-2710
Broken sandy lime.....	2710-2715
Shale.....	2715-2740
Hard sand.....	2740-2782
Sand, very hard.....	2782-2808
Broken lime.....	2808-2832
Gray sand.....	2832-2910
Broken lime.....	2910-2935
Black broken lime.....	2935-2960
Hard sand.....	2960-2980
Hard sand.....	2980-2990
Sand.....	2990-2996
Hard sand.....	2996-3010
Broken sand.....	3010-3015
Hard lime.....	3015-3020
Shale.....	3020-3035
Sandy shale.....	3035-3044
Hard lime.....	3044-3060
Shale.....	3060-3080
Shale.....	3080-3105
Sand; gas at 3110 feet.....	3105-3112
Gas sand.....	3112-3120
Gas sand.....	3120-3126

Log of Arkansas Natural Gas Corp., W. C. Hudson Well No. 1

Drilled 660 feet north and 660 feet west of center, Sec. 14, T. 10 N., R. 24 W.
Johnson County, Arkansas. Initial production, 10,000,000 cubic feet.

	Depth in feet
Shelly lime.....	0- 5
Shelly lime.....	5- 15
Dark shale.....	15- 25
Dark shale.....	25- 50
Dark shelly lime.....	50- 125
Hard lime.....	125- 130
Hard sand.....	130- 137
Sand.....	137- 150
Hard sand.....	150- 160
Shelly lime.....	160- 280
Lime.....	280- 290
Lime.....	290- 310
Hard sand.....	310- 360
Hard lime.....	360- 372
Black shale.....	372- 376
Black lime.....	376- 385
Shale and lime shells.....	385- 440
Hard sand and lime.....	440- 470
Sand and lime shells.....	470- 510
Black shale.....	510- 520
Gray shale.....	520- 577
Hard lime.....	577- 580
Hard sand.....	580- 585
Hard sand.....	585- 600
Shale.....	600- 603
Hard sand.....	603- 615
Hard sand.....	615- 635
Shale.....	635- 655
Dark shale.....	655- 720
Shale.....	720- 772
Hard lime.....	772- 778
Hard lime.....	778- 780
Hard sand.....	780- 790
Hard sand.....	790- 797
Hard sand.....	797- 805
Hard black lime.....	805- 835
Hard lime.....	835- 850
Lime.....	850- 875
Broken lime.....	875- 905
Lime and sandy shale.....	905- 950
Sandy lime.....	950- 960
Shale.....	960- 985
Hard sand.....	985- 995
Sand.....	995-1008
Hard sand.....	1008-1014
Hard shale.....	1014-1066
Hard black lime.....	1066-1072
Gas sand.....	1072-1085

Log of Arkansas Natural Gas Corporation J. G. Houston Well No. 1

Drilled 660 feet north and 825 feet west of the southeast corner Sec. 15, T. 10 N., R. 24 W., Johnson County Arkansas. Initial production, 1,500,000 cubic feet. Rock pressure, 690 pounds.

	Depth in feet
Lime.....	0- 15
Shale.....	15- 25
Shale.....	25- 50
Shale.....	50- 75
Water sand.....	75- 80
Black shale.....	80- 135
Gray lime.....	135- 150
Sandy lime.....	150- 176
Shelly lime.....	176- 180
Black shale.....	180- 190
Black shale.....	190- 225
Lime.....	225- 235
Shale.....	235- 240
Shale.....	240- 255
Shelly lime.....	255- 258
Lime, shells and shale.....	258- 315
Gray lime.....	315- 360
Gray lime.....	360- 410
Dark shale.....	410- 468
Hard sharp lime.....	468- 480
Hard sharp lime.....	480- 525
Hard sharp lime.....	525- 540
Dark shale.....	540- 580
Dark shale.....	580- 600
Hard sand.....	600- 625
Hard sand.....	625- 660
Hard sand.....	660- 680
Dark shale.....	680- 735
Sandy shale, lime and shells.....	735- 750
Shale and lime shells.....	750- 795
Shale.....	795- 810
Hard lime.....	810- 825
Hard sandy lime.....	825- 851
Salt water; sand.....	851- 880
Black lime.....	880- 890
Black shale.....	890- 897
Shale and lime shells.....	897- 943
Shale and lime shells.....	943- 970
Lime.....	970- 980
Shale.....	980- 990
Shale.....	990-1052
Lime.....	1052-1054
Shelly lime.....	1054-1070
Gray shale.....	1070-1096
Shale.....	1096-1130
Salt water sand.....	1130-1135
Sand.....	1135-1150

	Depth in feet
Sand.....	1150-1175
Hard sand.....	1175-1185
Hard sharp lime.....	1185-1210
Black shale.....	1210-1216
Hard lime.....	1216-1220
Shale.....	1220-1225
Shale.....	1225-1229
Water sand.....	1229-1310
Hard sand.....	1310-1335
Sandy lime.....	1335-1357
Sandy lime.....	1357-1370
White sand.....	1370-1380
White sand.....	1380-1405
Hard sand.....	1405-1424
Hard sandy lime.....	1424-1450
Hard gray sand.....	1450-1470
Dark lime.....	1470-1475
Shale.....	1475-1480
Hard sandy lime.....	1480-1494
Hard dark lime.....	1494-1510
Dark shale.....	1510-1515
Shelly lime.....	1515-1525
Dark lime.....	1525-1535
Shale.....	1535-1550
Shale.....	1550-1555
Dark lime.....	1555-1572
Shale.....	1572-1580
Shale, lime shells.....	1580-1600
Shale.....	1600-1615
Lime.....	1615-1620
Shale and lime shells.....	1620-1650
Sandy shale.....	1650-1695
Shale and lime shells.....	1695-1730
Hard sand.....	1730-1750
Hard sand.....	1750-1780
Hard sand.....	1780-1790
Hard gray sand.....	1790-1804
Hard gray sand.....	1804-1835
Hard gray sand.....	1835-1857
Dark shale.....	1857-1895
Black shale.....	1895-1935
Hard gray sand.....	1935-2015
Hard, broken shale and shells.....	2015-2025
Hard sand.....	2025-2028
Hard gray sand.....	2028-2130
Hard sand.....	2130-2135
Shale and hard shells.....	2135-2160
Hard gray sand.....	2160-2165
Hard gray sand.....	2165-2185
Shale, broken.....	2185-2190
Hard gray sand.....	2190-2196

	Depth in feet
Hard gray sand.....	2196-2205
Shale.....	2205-2220
Hard gray sand.....	2220-2225
Sand; gas showing.....	2225-2235
Gas sand.....	2235-2245
Shale.....	2245-2250
Hard gray sand.....	2250-2255
Shale.....	2255-2265
Hard shells.....	2265-2270
Shale and shells.....	2270-2310
Black shale and shells.....	2310-2338
Hard sand.....	2338-2342
Hard gray sand.....	2342-2357
Dark shale.....	2357-2361
Hard sand.....	2361-2366
Shale and shells.....	2366-2410
Black hard shale.....	2410-2440
Total depth.....	

Log of Arkansas Natural Gas Corporation, M. F. Kirwin Well No. 1

Drilled 660 feet north and 660 feet west of the southeast corner of E. ½ NE. ¼ Sec. 16, T. 10 N., R. 24 W., Johnson County, Arkansas. Initial production 4,200,000 cubic feet. Rock pressure, 1,275 pounds. Gas formation from 2,260 to 2,270; from 2,765 to 2,780; from 3,350 to 3,361.

	Depth in feet
Soil.....	0- 6
Shale.....	6- 15
Shale.....	15- 55
Shale.....	55- 120
Shale.....	120- 150
Hard sand.....	150- 155
Broken sand.....	155- 180
Hard sand.....	180- 205
Shale.....	205- 216
Shale.....	216- 235
Shale.....	235- 260
Shale.....	260- 300
Shale.....	300- 320
Hard sand.....	320- 345
Sand.....	345- 364
Sand.....	364- 375
Shale.....	375- 475
Soft shale, brown.....	475- 620
Brown shale.....	620- 665
Hard brown sand.....	665- 680
Brown sand.....	680- 700
Brown shale.....	700- 716
Sand.....	716- 730
Shale.....	730- 790
Shale.....	790- 805
Sand.....	805- 815

	Depth in feet
Sand.....	815- 824
Broken sand.....	824- 850
Broken sand.....	850- 875
Blue shale.....	875- 905
Hard brown sand.....	905- 915
Hard brown sand.....	915- 935
Shale.....	935- 945
Broken sand.....	945-1015
Shale.....	1015-1032
Brown sand.....	1032-1070
Brown sand.....	1070-1150
Sandy shale.....	1150-1190
Sandy shale.....	1190-1220
Shale.....	1220-1260
Sandy shale.....	1260-1330
Water sand.....	1330-1420
Dark blue shale and lime shell.....	1420-1425
Blue shale.....	1425-1435
Lime shells.....	1435-1437
Lime shells.....	1437-1445
White water sand.....	1445-1530
White sand.....	1530-1555
Gray sand.....	1555-1562
Shale.....	1562-1570
Dark gray sand.....	1570-1604
Gray sand.....	1604-1618
Gray lime.....	1618-1628
Hard white sand.....	1628-1635
White sand.....	1635-1650
Blue sand.....	1650-1675
Blue sand.....	1675-1705
Blue sand.....	1705-1720
Shale.....	1720-1730
Green sand.....	1730-1815
Broken sand.....	1815-1910
Soft mud.....	1910-1920
Sand.....	1920-1975
Hard blue lime.....	1975-1985
Blue lime, hard, sandy.....	1985-2000
Hard sand.....	2000-2035
Broken sand and shale.....	2035-2070
Black shale.....	2070-2120
Black shale.....	2120-2140
Black lime shells.....	2140-2152
Sandy lime.....	2152-2175
Hard lime.....	2175-2188
Lime.....	2188-2202
Black lime.....	2202-2208
Broken sand.....	2208-2230
Broken sand.....	2230-2260
Gray sand and black shale, little gas.....	2260-2270

	Depth in feet
Sand.....	2270-2292
Black shale.....	2292-2330
Shells and blue shale.....	2330-2335
Blue shale.....	2335-2340
Sand.....	2340-2375
Lime and sand.....	2375-2390
Hard lime.....	2390-2435
Lime.....	2435-2455
Broken sand.....	2455-2520
Broken sand.....	2520-2560
Sand.....	2560-2620
Sand.....	2620-2660
Little gas and salt water.....	2660-2680
Sandy shale.....	2680-2725
Black shale and lots of water.....	2725-2748
Shale.....	2748-2752
Shale.....	2752-2760
Hard sand.....	2760-2765
Hard sand, little gas.....	2765-2780
Hard sand.....	2780-2805
Hard sand.....	2805-2855
Broken sand.....	2855-2920
Hard white sand.....	2920-2970
Sandy shale.....	2970-2995
Black lime.....	2995-3007
Black lime.....	3007-3028
Black lime.....	3028-3060
Shale.....	3060-3062
Sand.....	3062-3105
Shale.....	3105-3140
Black lime and sandy shale.....	3140-3160
Black sandy shale.....	3160-3195
Black lime.....	3195-3205
Water.....	3205-3208
Hard black sand.....	3208-3215
Black sand.....	3215-3225
Sand.....	3225-3300
Sandy shale.....	3300-3350
Gas sand.....	3350-3355
Gas sand.....	3355-3361

Log of Arkansas Natural Gas Corp., W. T. Self Well No. 1

Drilled 735 feet south and 735 feet east of the northwest corner of the NW. $\frac{1}{4}$ SW. $\frac{1}{4}$ Sec. 14, T. 10 N., R. 24 W., Johnson County, Arkansas. Initial production 12,000,000 cubic feet. Rock pressure, 345 pounds.

	Depth in feet
Shale.....	0- 40
Black shale.....	40- 80
Black shale.....	80- 120
20 feet lime.....	120- 140
Lime.....	140- 168

	Depth in feet
Shale.....	168- 170
Shale.....	170- 215
Black shale.....	215- 240
Blue shale.....	240- 280
Shale.....	280- 300
Shale.....	300- 330
Sandy shale.....	330- 410
Hard sand.....	410- 420
Hard sand.....	420- 430
Hard sand.....	430- 440
Shale.....	440- 530
Sand.....	530- 600
Sand.....	600- 640
Shale.....	640- 645
Sand.....	645- 660
Sand.....	660- 680
Light shale.....	680- 710
Sandy shale.....	710- 770
Salt water sand.....	770- 800
Sand.....	800- 860
Broken sand.....	860- 930
Sandy shale.....	930- 960
Sand and blue shale.....	960-1000
Blue shale.....	1000-1050
Gas sand.....	1050-1068
Gas.....	1068-1075

Log of Arkansas Natural Gas Corporation O. L. Hudson Well No. 1

Drilled 300 feet south and 660 feet west northeast corner NW. $\frac{1}{4}$ SE. $\frac{1}{4}$ Sec. 14, T. 10 N., R. 24 W., Johnson County, Arkansas. Total depth, 2,796 feet. Initial production, 7,000,000 cubic feet. Rock pressure, 1,050 pounds.

	Depth in feet
Lime.....	0- 45
Lime.....	45- 50
Lime.....	50- 60
Hard sand.....	60- 75
Hard sand.....	75- 90
Black shale.....	90- 170
Black shale.....	170- 220
Shale and lime.....	220- 238
Blue shale.....	238- 265
Shale.....	265- 310
Shale.....	310- 350
Shale.....	350- 378
Sand.....	378- 404
Shale.....	404- 445
Broken sand.....	445- 465
Shale.....	465- 515
Sand.....	515- 520
Sand.....	520- 575
Shale.....	575- 665

	Depth in feet
Sandy shale.....	665- 725
Hard sand.....	725- 730
Sand.....	730- 745
Hard sand.....	745- 775
Sandy shale.....	775- 850
Sandy shale.....	850- 860
Black shale.....	860- 935
Shale and shells.....	935- 985
Hard sand.....	985-1015
Hard sand.....	1015-1025
Hard sand.....	1025-1030
Hard sand.....	1030-1035
Hard sand.....	1035-1042
Hard sand.....	1042-1065
Hard sand.....	1065-1075
Hard sand.....	1075-1095
Water sand.....	1095-1140
Water sand.....	1140-1190
Hard sand.....	1190-1225
Sand.....	1225-1245
Water sand.....	1245-1275
Hard sand.....	1275-1290
Hard sand.....	1290-1300
Hard sand.....	1300-1315
Hard sand.....	1315-1328
Lime.....	1328-1345
Hard sand.....	1345-1360
Dark sand.....	1360-1372
Dark sand.....	1372-1375
Broken sand.....	1375-1420
Broken sand.....	1420-1425
Hard sand.....	1425-1446
Hard sand.....	1446-1460
Broken sand.....	1460-1520
Broken sand.....	1520-1560
Sandy shale and shells.....	1560-1610
Hard sand.....	1610-1645
Sand.....	1645-1675
Sand.....	1675-1715
Sand.....	1715-1730
Shale.....	1730-1810
Sand.....	1810-1815
Sand.....	1815-1835
Sand.....	1835-1850
Broken sand.....	1850-1920
Broken sand.....	1920-1935
Black lime.....	1935-1945
Sand; light show of gas at 1,945 feet.....	1945-1960
Sand.....	1960-2015
Sand.....	2015-2030
Sand.....	2030-2080

	Depth in feet
Soft sand.....	2080-2100
Shale.....	2100-2140
Sand.....	2140-2165
Shale.....	2165-2185
Shale.....	2185-2210
Gas sand.....	2210-2230
Sand.....	2230-2250
Sand.....	2250-2255
Sand.....	2255-2304
Sand.....	2304-2315
Shale.....	2315-2335
Sand.....	2335-2375
Shale.....	2375-2380
Broken sand.....	2380-2450
Shale.....	2450-2475
Shale.....	2475-2480
Hard sand.....	2480-2510
Hard sand; gas.....	2510-2525
Sand.....	2525-2530
Shale.....	2530-2590
Broken sand.....	2590-2655
Broken sand.....	2655-2705
Hard sand.....	2705-2735
Hard sand.....	2735-2775
Gas sand.....	2775-2780
Hard sand.....	2780-2785
Gas sand.....	2785-2792
Hard white lime.....	2792-2976

Log of Arkansas-Louisiana Pipe Line Co., J. I. Bynum Well No. 2

Drilled 696 feet north and 610 feet west southeast corner SE. $\frac{1}{4}$ SW. $\frac{1}{4}$
 Sec. 12, T. 10 N., R. 24 W. Total depth, 3,125 feet.

	Depth in feet
Hard, gray sand.....	0- 40
Hard, dark shale.....	40- 65
Water sand.....	65- 70
Dark shale.....	70- 100
Hard, gray sand.....	100- 110
Hard, dark shale.....	110- 210
Hard, gray sand.....	210- 220
Brown shale.....	220- 237
Dark shale.....	237- 250
Hard, gray sand.....	250- 260
Dark shale.....	260- 275
Hard, gray sand.....	275- 290
Dark, hard shale.....	290- 345
Hard, gray sand.....	345- 365
Hard, dark shale.....	365- 385 $\frac{1}{2}$
Hard, gray sand.....	385 $\frac{1}{2}$ - 395
Hard, gray sand.....	395- 415
Gray shale.....	415- 515

	Depth in feet
Hard, gray sand.....	515- 546
Dark shale.....	546- 600
Hard, gray sand.....	600- 615
Dark shale.....	615- 700
Gray sand.....	700- 705
Dark shale.....	705- 710
Hard, gray sand.....	710- 730
Sandy shale.....	730- 745
Hard, gray sand.....	745- 750
Dark shale.....	750- 780
Shell.....	780- 785
Dark shale.....	785- 800
Dark shale and shells.....	800- 839
Dark shale.....	839- 880
Hard sand.....	880- 890
Dark shale.....	890-1003
Water sand.....	1003-1020
Hard, gray sand.....	1020-1038
Dark sandy shale.....	1038-1050
Gray sand.....	1050-1055
Blue slate.....	1055-1062
Light sand.....	1062-1068
Gray sand; drilling wet hole, full of salt water.....	1068-1105
Salt water sand.....	1105-1190
Hard, gray sand; showing of gas at 1,200-1,204 feet.....	1190-1218
Hard sand.....	1218-1225
Water sand.....	1225-1250
Hard sand.....	1250-1270
Hard, white sand.....	1270-1293
Hard, gray sand.....	1293-1300
Hard, light sand.....	1300-1316
Hard, gray sand.....	1316-1345
Blue shale and hard shells.....	1345-1355
Hard sand.....	1355-1357
Gray sand.....	1357-1367
Shale and hard shells.....	1367-1376
Gray sand.....	1376-1385
Hard sand or lime.....	1385-1392
Hard gray sand.....	1392-1404
Broken sand and shale.....	1404-1417
Hard gray sand.....	1417-1422
Blue shale.....	1422-1430
Shale and shells.....	1430-1442
Hard gray sand; little gas showing at 1,442-1,444 feet.....	1442-1470
Dark shale and shells.....	1470-1480
Dark shale.....	1480-1500
Shale.....	1500-1505
Hard gray sand.....	1505-1514
Hard sand and lime.....	1514-1518
Gray sand and shells.....	1518-1533
Shale and shells.....	1533-1550

	Depth in feet
Dark shale.....	1550-1566
Gray shale.....	1566-1575
Shale and shells.....	1575-1615
Dark shale.....	1615-1640
Gray sand or lime.....	1640-1650
Hard gray sand.....	1650-1725
Gray sand, shale brakes.....	1725-1750
Hard shells and shale.....	1750-1775
Dark shale.....	1775-1835
Hard, gray sand.....	1835-1845
Shale and shells.....	1845-1855
Hard, gray sand.....	1855-1862
Gray broken sand.....	1862-1915
Sandy shale and shells.....	1915-1950
Dark shale and hard shells.....	1950-1985
Hard, gray, broken sand.....	1985-2090
Dark shale brakes.....	2090-2095
Gray sand.....	2095-2110
Shale and hard shells.....	2110-2124
Hard, gray sand.....	2124-2150
Soft black slate.....	2150-2155
Hard, gray sand.....	2155-2158
Hard shells and shale.....	2158-2200
Hard shell.....	2200-2202
Hard gray sand.....	2202-2211
Shale and shells.....	2211-2270
Black shale.....	2270-2285
Hard, gray sand.....	2285-2337
Gray sand, shale breaks.....	2337-2365
Gray sand and shells.....	2365-2425
Dark shale.....	2425-2450
Hard, gray sand.....	2450-2460
Shale and shells.....	2460-2495
Very hard shells.....	2495-2497
Correct depth, steel line measurement.....	2528
Gray shale.....	2528-2555
Gray shale and shells.....	2555-2570
Hard, gray sand.....	2570-2685
Gray sand, shale breaks.....	2685-2720
Gray sand.....	2720-2725
Soft, dark slate.....	2725-2745
Hard shell.....	2745-2750
Shale and shells.....	2750-2785
Hard, gray sand.....	2785-2833
Gas sand.....	2833-2835
Gray sand.....	2835-2856
Gray to light sand.....	2856-2885
Gray sand.....	2885-2940
Dark shale.....	2940-2945
Dark slate and shell.....	2945-2965
Gray sand; hole making 1½ bailers of water per hour.....	2965-2979

	Depth in feet
Hard shell.....	2979-2985
Hard gray sand.....	2985-3043
Dark shale and shells.....	3043-3085
Gray shale.....	3085-3100
Hard shell.....	3100-3103
Broken sand.....	3103-3110
Hard shell.....	3110-3112
Sand; hole full salt water. Little gas from 3103-3110 feet.....	3112-3115
Soft sand.....	3115-3120
Hard sand.....	3120-3125

This well was temporarily abandoned, but is now being deepened and this may be considered as a partial log.

This completes the list of wells drilled in the Clarksville area proper, but the Piney Oil and Gas Company also drilled a well on the southeastern flank of the Ludwig anticline, in the SW. $\frac{1}{4}$ of the SW. $\frac{1}{4}$ Sec. 25, T. 10 N., R. 23 W. This well was abandoned as a failure at 3,001 feet, but a showing of gas was obtained at 2,283 feet, and showings of oil were reported in sands at 2,864 feet and 2,950 feet. The showing of oil at 2,950 is locally reported to have been sufficient to bring in a 20 barrel well. This report has not been verified, but some light green oil of 38° gravity was found at the depth of 2,950 feet. The log of the Piney Oil and Gas Company's well is given below.

Log of Piney Oil and Gas Company's W. Gray Well No. 1

Drilled in the SW. $\frac{1}{2}$ Sec. 25, T. 10 N., R. 23 W., in Johnson County, Arkansas.

	Depth in feet
Soil.....	5
Blue, gravel.....	10
Black lime.....	12
Blue gravel.....	14
Lime, black.....	24
White sand.....	38
Coal, black.....	40
Sand, gray.....	155
Slate.....	320
Sand, black.....	340
Slate, black.....	450
Sand, black.....	480
Slate, black.....	530
Sand, black.....	550
Slate, black.....	580
Sand, black.....	630
Sand, white.....	655
Sand, black.....	675
Slate, black.....	730
Sand, black.....	780

	Depth in feet
Slate, black.....	800
Sand, shells, black.....	860
Shale, brown.....	900
Sand, white.....	970
Slate, black.....	1060
Sand, shells.....	1120
Slate.....	1275
Sand, white.....	1322
Slate, black.....	1514
Sand, shells, black.....	1605
Sand.....	1630
Slate.....	1690
Sand.....	1715
Slate and shells.....	1775
Sand, shells, dark.....	1800
Slate, shells, dark.....	1890
Slate, dark.....	1910
Granite (Driller's interpretation).....	1920
Sand, dark.....	1940
Slate and shells.....	1975
Slate.....	2030
Sand, hard.....	2050
Slate.....	2118
Sand, hard.....	2148
Slate and shells.....	2170
Sand.....	2200
Slate and shells; gas show at 2,283 feet.....	2210
Hard sand.....	2260
Sand; water.....	2330
Hard slate.....	2332
White sand.....	2565
Black sand.....	2695
Slate.....	2855
Gray sand.....	2990
Sand; show of oil.....	2864
Sand; show of oil.....	2950
Black slate.....	
Black sand.....	
Black sand.....	3001

The Clarksville field has not yet been outlined, but the initial production and rock pressure of the wells already drilled indicate that it will be the most productive field in the Arkansas Valley. The gas is used for domestic and commercial purposes in Clarksville, Russellville, Morrilton, and Conway.

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