Oklahoma Geological Survey

BULLETIN 32

Geology of the Southern Ouachita Mountains of Oklahoma

PART I

Stratigraphy, Structure, and Physiographic History

BY C. W. HONESS, NORMAN, OKLA.

APRIL, 1923

WARDEN COMPANY, OKLAHOMA CITY

OKLAHOMA GEOLOGICAL SURVEY

Governor J. C. Walton, State Superintendent M. A. Nash,
President Stratton D. Brooks, Commission
C. W. Shannon, Director

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SCIENTIFIC STAFF.

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PART I.

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CONTENTS

ILLUSTRATIONS.

GEOLOGY OF THE SOUTHERN OUACHITA MOUNTAINS OF OKLAHOMA

PART I

STRATIGRAPHY, STRUCTURE, AND PHYSIOGRAPHIC HISTORY

PREFACE

This report has for its object the fulfillment, in part, of the demand coming from the general public for information pertaining to the natural resources of the Ouachita Mountain region of Oklahoma. Hundreds of letters have been received at the offices of the Oklahoma Geological Survey during recent years, from individuals both within the State and outside the State inquiring about the mineral resources, soils, and timber of this great region. Numerous requests have come for special investigations in various parts of the mountains to determine the importance of certain mineral deposits or to report upon agricultural tracts. This information has been freely given in so far as it has been available, and prospective buyers of property have been assisted in every way possible to learn the truth about the mineral and agricultural values of these lands. Nevertheless, as earnest as have been these appeals from the public and as desirous as have been the Survey officials to please and give reliable information concerning the Ouachita Mountain region, it has been impossible to do as much as the Survey could have wished, since up to the present time almost nothing has been written on the region.

The present report therefore, although dealing with only a portion of the region, is designed primarily to relieve the present situation and to provide a means whereby the public may know the general geological conditions of a portion, at least, of the Ouachita Mountains, and what they have to offer in the way of natural resources.

On account of the more purely scientific treatment of the chapters dealing with the stratigraphy, structure, and physiographic history, these subjects have been combined with this brief introduction to form Part I. The chapters covering the geography, and economic geology, treated less technically, and of more general and immediate use perhaps, is issued as Part II.

INTRODUCTION

During the summer and fall of the year 1916 the writer, assisted in the first part of the field season by C. R. Longwell and M. S. McMurtrey and in the latter half of the year by E. S. Perry, mapped, in all its details, the northern limit of the Trinity sand formation from the 96th Meridian, 6 miles east of Atoka, in Atoka County, Okla., eastward to the state of Arkansas, 95 miles distant. The Trinity sand formation constitutes the basal Comanchean deposit of the Gulf Costal Plains in this region and it overlies unconformably the truncated edges of the Paleozoic formations of the Ouachita Mountains. It was, therefore, the Paleozoic-Mesozoic line of unconformity, in other words, which was thus traced. The results of these labors were presented briefly at the 2nd meeting of the Southwestern Association of Petroleum Geologists* held in Tulsa, Okla., in February, 1917, and the map was published later, but without comment or description in Bulletin No. 19 part II, Oklahoma Geological Survey, maps pp. 36 and 326.

It was not the original purpose of the Survey to make a study of the Paleozoic rocks in connection with this work referred to, but to map the Paleozoic-Mesozoic contact merely and, if time permitted, to study the Trinity. Nevertheless, while on the ground, the character and inclination of the strata composing the older sediments were carefully noted all along the unconformity from Atoka to Ultima Thule and the axes of the principal folds located, with the result that the Paleozoics became more and more of absorbing interest as the work progressed and came finally to occupy the writer's chief attention.

A great many rock specimens were collected from both the Paleozoic and Mesozoic formations throughout the extent of the field operations of that first year and several of the most unusual of these were sent to Dr. C. P. Berkey of Columbia University for microscopic examination. Those submitted to him were all from the Paleozoics east of Little River and were as follows:

No. 229, Womble schistose sandstone; Location NW. ¼, NW. ¼, sec. 33 (100 paces south of section corner) T. 5 S., R. 23 E.

No. 246, Basal division Arkansas novaculite; Location 200 paces NW. of center sec. 2, T. 6 S., R. 24 E. (at the dam on Yashoo Creek.)

No. 207, Basal division Arkansas novaculite; Location NW. ¼, sec. 28, T. 5 S., R. 22 E.

No. 209, Basal division Arkansas novaculite; Location NW. ¼, NW. ¼, sec. 28, T. 5 S., R. 22 E.

*Bull. Southwestern Association of Petroleum Geologists, Vol. I, p. 14.

No. 203, Chloritic fragmental from near the base of the Stanley shale containing segments of crinoid stems and a pyrite cube; Location SE. ¼, SE. ¼, sec. 24, T. 5 S., R. 21 E.

No. 198, Chloritic fragmental from near the base of the Stanley shale. Location NE. ¼ NE. ¼ sec. 30 T. 5 S. R. 22 E.

No. 286, Cone-in-cone from the middle portion of the Stanley. Location SE. ¼, NW. ¼, sec. 3, T. 6 S., R. 26 E.

No. 1-B, Jackfork sandstone. Sec. 22, T. 3 S., R. 13 E.

In due time these were sectioned, briefly examined and some of them reported on by Dr. Berkey in a letter to me under date of June 26, 1917 as follows:

I have had the thin sections of your set of Ouachita rocks for sometime, but have neglected to send them on. It is a splendid set and the specimens have a great many peculiarities. On the whole, some of them are very unusual and not as easy to interpret as one might expect.

I have no doubt myself but that some of them are tuffs, especially No. 198. It shows original fragmental habit and a material a part of which was originally glassy. No. 209 is more unusual, but I believe it has the same history. The dynamic modifications that belong to subsequent geological happenings have modified them so much that almost all of their original character is destroyed. No. 207 is another peculiar one of rather uncertain original habit. No. 203 is a fragmental of very complex composition, chiefly of crystalline fragments, and the curious thing about it being the large amount of little modified feldspar, also the rather slight evidence of complex subsequent dynamic history.

It was thus at this time and through the mapping of the northern limit of the Trinity sand in southeastern Oklahoma that the writer first gained an interest in the geology of the Ouachita Mountains.

TIME EMPLOYED

Opportunity was not granted during the field season of 1916, during the mapping of the Cretaceous-Paleozoic contact in the southeast, for any detailed work in the Paleozoic area proper, and it was not until the middle of June of the following summer that the mapping was actually begun. The work was started on the eastern side of the area and continued until Dec. 4, 1917, when bad weather brought the field season of that year to a close. An area of about 450 square miles was mapped after the manner described in later paragraphs.

In the Spring of 1918 the task was resumed by the author, who worked entirely alone for nearly two months, from April 4th to May 30th, when an accidental camp fire destroyed most of the equipment and one month's notes. Other interruptions followed immediately, and it was not until Aug. 12, that the work could be continued. With an assistant and new equipment rapid progress was again made, until illness took first one of us and then the other. It was Oct. 1st and with the exception of a few days work during the latter part of November nothing more was accomplished in 1918. Seven whole townships in the central part of the area had been mapped during this season.

In the final year, spring and summer of 1919, the work was started early in March (March 4) and good progress made throughout the season, taking into consideration the conditions under which work had to be accomplished. The season was concluded Aug. 19, 1919, and 390 square miles were mapped. More country to the north and west might with profit have been covered, but in so far as the structure and sedimentation are concerned, no new facts could be learned and none of the country in any direction beyond the confines of the present area as mapped would have any bearing on the solution of the problems of the area in hand. The area is a unit structurally in other words, and is complete.

In the three seasons of 1917, 1918, and 1919, about 1,000 square miles of country, embracing most of the northern half of McCurtain County and adjacent portions of LeFlore and Pushmataha counties were thus mapped in detail. This is practically the area included within the Lukfata quadrangle lying west of and adjacent to the DeQueen quadrangle of Arkansas and Oklahoma (fig. 1) and covers, geologically, all of the pre-Mississippian rocks in this part of the State as well as large areas of the Stanley and Jackfork formations. It holds within its borders, that is, the great Choctaw anticlinorium and related structures of the southern Ouachitas, whose history is the subject of the present report.*

METHODS OF WORK

The field work upon which this report is based was done entirely on foot by the author, accompanied the greater part of the time by someone acting as compassman.

The Government land corners—section corners and quarter corners**—have been made the basis of all locations in this work.

The entire country was surveyed and sectioned in 1896-1898 by the U. S. Geological Survey and the work is not so old but that practically every section corner and quarter corner can be found and

*The Geological map of this area was exhibited at the Boston meeting of the Geol. Soc. Amer., Dec. 1919, and at the meeting of the Geol. Section of the Amer. Mus. Nat. Hist., Jan. 19, 1920.

**Quarter corners are often incorrectly called "half section corners" and quarter lines "half section lines." Though the use of such expressions is not the least confusing, the terms "quarter corner" and "quarter line" will be used throughout this report.

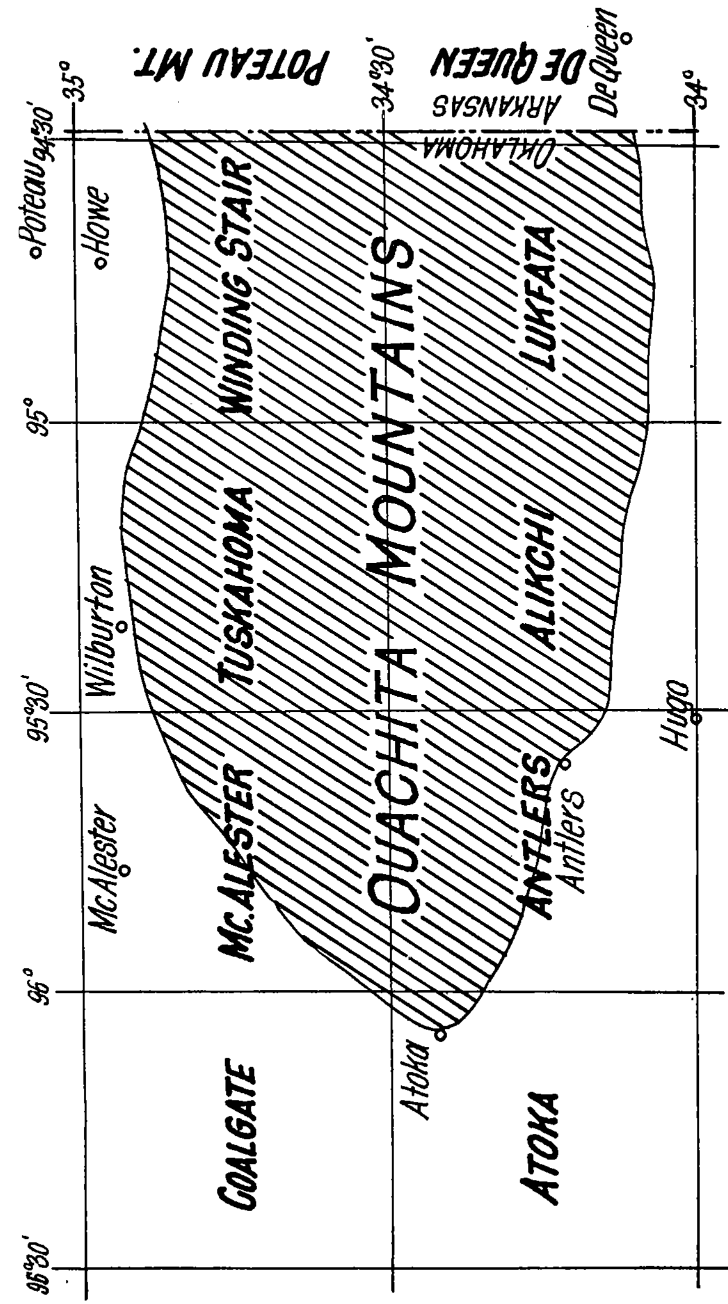


Figure 1—Table Showing Location of Topographic Atlas Sheets of the United States Geological Survey Covering the Ouachita Mountain Area in Oklahoma

the blazed lines can all be followed without difficulty. While there are topographic maps of the region, these are found to be erroneous in some places. The accuracy of the sectioning of the country, however, is beyond criticism, and the work has been checked time and time again by the compass work done in connection with the geologic mapping. It is believed, therefore, that the geologic map accompanying this report, based mainly on the land survey, represents the facts in their true relationship.

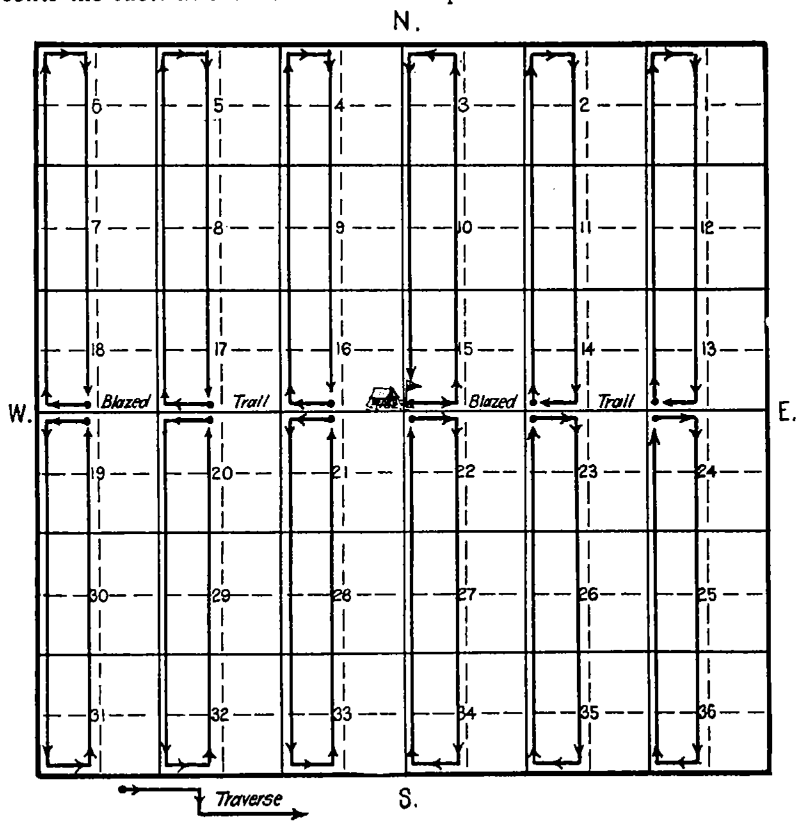


Figure 2—Diagram of township showing field tactics.

As the principal folds and other structures in the region were known by reconnaissance to strike generally east-west, it was decided at the outset to traverse across the region in north-south direction directly across the structure and formations. Traverses were made north and south on the section lines and quarter lines and on the center east-west section line of each township. The center east-

west section line was used as a "Blazed trail" leading to and from the camp ordinarily. A single camp in a township located as near the center as could be conveniently placed was found sufficient in nearly all cases. From such a camp it was convenient to run either north or south three miles to the township line and back in a day. In this way 12 days were required to complete the field work of a single township, a rate of 3 square miles per day; and in following this plan a traverse line passed along one side of every 40 acres in the township and along two sides of many of them. The foregoing diagram (fig. 2) illustrates the method of work.

ACKNOWLEDGMENTS

The writer wishes at this time to make acknowledgments to Drs. J. F. Kemp, D. W. Johnson, and J. J. Galloway, Professors in the Department of Geology, Columbia University, and to Dr. I. H. Ogolvie, Associate Professor of Geology in Barnard College for critically reading and correcting the original manuscript. To Mr. R. J. Colony of the Geological Department of Columbia University who checked over most of the thin sections of the rocks prepared for miscroscopic study acknowledgements are also due.

The writer is under obligations to Messrs. C. W. Shannon, Frank Gahrtz, and A. C. Shead and to Miss Lucile Carson and others of his colleagues of the Oklahoma Geological Survey, for criticism and assistance in several ways. Mr. Shannon has made valuable suggestions concerning the publication of the report and through his kindness the writer has been allowed practically his full time and every available resource for the pursuance of this study; all the maps, diagrams and sections appear in their printed form as drafted by Mr. Gahrtz to whom my special thanks are due; and Mr. A. C. Shead has made several chemical tests of minerals and has made two complete analyses of rocks.

Finally, but by no means of least importance, is the aid given me in the field. Thus I am under obligations to Messrs. John F. Butler and S. M. Dendy, who acted as student assistants during the summer months of 1917 and to Mr. J. H. Sanders of Wickes, Ark., who did admirable work as assistant in the fall of 1917 and summer and fall of 1918; also to Mr. Rolfe Engleman who assisted during a brief period in the fall of 1918; and to Mr. H. R. Durall who worked through the 5½ long months of the difficult season of 1919.

REVIEW OF LITERATURE

PREVIOUS WORK

Aside from the topographic map, embracing portions of the Lukfata, DeQueen, Winding Stair, and Alikchi quadrangles of the Topographic Atlas of the United States, made by the United States Geological Survey during the years 1896 to 1898 and partially revised in 1908 to 1911, there has been no work done in the area with which this report has to deal. The early explorers: John Sibly*, Thomas Nuttall**, L. Bringier***, G. W. Featherstonhaugh ****, G. Engleman*****, and others of this period, made their way up the Arkansas and Red rivers, wrote brief descriptions of the formations and topography along these routes, and most of them managed to penetrate into the hills as far west as Hot Springs and Magnet Cove, Arkansas. Nuttall went back into Indian Territory by way of the Fourche Maline and Kiamichi rivers to Fort Towson and returned by way of the Seven Devils and Kiamichi Mountains, but he did not see what is now northern McCurtain County.

Later, D. D. Owen, the first Director of the Arkansas Geological Survey,† Justin Straszer,†† and other Government engineers, also James P. Henry,††† C. H. Hitchcock†††† and others, made contributions to the general geology of the Ouachitas of the Arkansas Territory.

*Dr. Hunter and Wm. Dunbar; Observations: Message from the President of the United States Communicating Discoveries made in exploring the Missouri, Red and Washita Rivers by Capts. Lewis and Clark, Dr. Shelby and Mr. Dunbar with statistical account of the country adjacent, 178 pp. Plate. Washington, 1806.

**Nuttall, Thos., A Journal of Travels into the Arkansas Territory during the year 1819 with Occasional Observations on the Manners of the Aborigines XII, 296 pp., map, 5 plates, Phila. 1821.

***Bringier, L., Notes on the Geology, Mineralogy, Topography, Productions and Aboriginal Inhabitants of the Region around the Mississippi and its Confluent Waters, Amer. Jour. Sci., Vol. 3, pp 15 to 46, 1821.

****Featherstonhaugh, G. W., Rept. of an examination made in 1834 of the Elevated Country between the Missouri and Red Rivers, 97 pp., Washington, 1835—23rd Cong. 2nd session, House Ex. Doc. No. 115—; Reviewed Amer. Jour. Sci. Vol. 28, p. 379, 1835.

*****Engleman, G., Remarks on the Geology of the Region between Little Rock and Hot Springs, Ark., Amer. Assn. Adv. Sci. Proc. Vol 5, pp. 199-201, 1851.

†Owen, D. D., Second Report of a Geological Reconnaissance of the Middle and Southern Counties of Arkansas for 1859 and 60 p. 13 to 153, Philadelphia, 1860.

††Straszer, J.; Report, Observations on the Ouachita, White, Little Red, Little Missouri, and Petit Jean Rivers, U. S. Army; Chief of Engineers, Report for 1871, pp. 338-374, Washington, 1871.

†††Henry, J. P., Resources of the State of Arkansas, 134, pp, Little Rock, 1872; in three editions.

††††Hitchcock, C. H.; Geological Map of the United States, Amer. Inst. Min. Eng. Trans. Vol. 15, pp. 465-488, Map 17x27 inches, 1887.

From 1887 forward to the present time the various members of the Arkansas Geological Survey under the directorship of J. C. Branner (1887-1893), A. H. Purdue (1907-1909) and N. F. Drake (1912-), assisted in recent years by the U. S. Geological Survey, have pretty well mapped the eastern half of the Ouachitas. Some of the men most active in this work besides Branner, Purdue, and Drake were T. B. Comstock, R. A. F. Penrose, L. S. Griswold, A. A. Steel, and H. D. Miser. References to their works are too numerous to mention here, but may be had from the Bibliography of the Geology of Arkansas by J. C. Branner and from the list of publications of the Arkansas Geological Survey.

In Oklahoma, J. A. Taff of the United States Geological Survey is the only person who has done any work in the Ouachita Mountains. Through his labors* the structure and age of the rocks in the northern part and extreme west end of the range have become known in a general way, but nothing has ever been published covering the 1,000 square miles of country in the south central part of the Ouachita Mountains in Oklahoma which is the region dealt with in the present report. It was not until 1911, when H. D. Miser and L. C. Snider made a 10-day trip into McCurtain County to look for igneous rocks that Ordovician and Siluro-Devonian strata were known to exist in this region, and since the results of their brief reconnaissance were not published the entire Ouachita region west of the Oklahoma-Arkansas state line sometimes, even now, appears on maps as Undifferentiated Carboniferous. The latest and best geologic map in existence today of the western half of the Ouachitas is the progress geological map prepared by the Oklahoma Geological Survey in 1917** which shows three areas of combined Cambrian, Ordovician, Silurian, and Devonian rocks, viz.: 1, a small area at the west end of the range, at Stringtown; 2. the Potato Hills region near Talihina; and 3, a generalized outline of the area in northern McCurtain County the whole remaining area being unclassified Carboniferous.

THE NAME "OUACHITA MOUNTAINS"

The region now generally known as the Ouachita Mountains or Ouachitas of southeastern Oklahoma and west-central Arkansas was originally called by Darby on page 138 of his Emigrants Guide to the Western and Southwestern States and Territories, published in 1818, the "Masserne Mountains" and by Thomas Nuttall on pages 109, 121, 146, etc of his book, "A Journal of Travels into the Arkansas Territory during the year 1819," the "Massern Ranges." It was in

*Taff J. A.; Atoka and Tishmingo Folios, Nos. 79 and 98 of the U. S. Geological Survey 1902 and 1903 respectively and numerous other papers by him.

**Petroleum and Natural Gas; Okla. Geol. Surv. Bull. 19 part II, Plate 1, 1917.

1888 that the mountains came to be known as the Ouachitas for it was then that J. C. Branner introduced the phrase, "Ouachita Mountain System,"* to apply to this range of mountains or to a part of it. R. T. Hill, two years later,** followed Darby and Nuttall in speaking of these mountains and used the phrase "Ouachita System of Arkansas and Indian Territory" to include the Massern Ranges, the Arbuckle Hills, and the Wichita Mountains. Then, J. A. Taff, following Branner, first in his report on the McAlester-Lehigh Coal Field, Indian Territory, p. 431, 19th Ann. Rept., U. S. Geol. Surv., 1897-98, Part III, and later in all his other reports and his folios used the term Ouachitas as essentially equivalent to Massern Ranges. Taff's works have formed the sources of all information concerning the Oklahoma end of these mountains since their publication and practically every one referring to these mountains since, both in Oklahoma and in Arkansas, has used Branner's definition as accepted and modified by Taff.

In 1909 A. H. Purdue in a footnote on page 26 of his Slates of Arkansas says in this connection:

> The term Ouachita System was first applied in the Reports of the Geological Survey of Arkansas, 1888, Vol. II, p. 10; and 1890, Vol. III, p. 190 to those east-west ridges that contain the novaculites or Arkansas whetstone rocks. But in late years, the term has been extended to include the important group of mountains to the north and Ouachita Range is here used [restricting the term to the novaculite ridges] in the sense of the original term "Ouachita System."

adding in the main body of his report on slates, page 26, that "no name has yet been adopted for the aggregate of the several high mountain ridges constituting the northern part," and proposes that these high ridges to the north be "designated the Fourche Range, that being the name applied to one of the highest mountains of the area, as well as to another ridge of lesser importance." Purdue's recommendations however, have not been followed nor have Hill's. The term Ouachita Mountains or Ouachitas as now used by everyone is essentially a substitution for the Massern Ranges of Darby and Nuttall.

Recognizing this fact and realizing that the names "Washita" and "Ouachita" are pronounced so nearly alike and are continually being confounded one with the other and both with "Wichita" the writer sent out a circular letter to some 25 or 30 prominent geologists throughout the country recommending the revival of the name "Massern Ranges." Special emphasis was laid upon the fact that

*Ann. Rept. Ark. Geol. Survey, 1888, Vol. 1, p. 59.

**Hill, R. T., Geography and Geology of the Black and Grand Prairies, 21st Ann. Report, U. S. Geol. Survey, Vol. 7, 1900, p. 37.

the chief objection to the present usage is that the Ouachita Mountains of **southeastern** Oklahoma and west-central Arkansas are often confounded with the Wichita Mountains or Wichitas of **southwestern** Oklahoma.

A number of voluminous letters were received with arguments *pro* and *con* the change of name and the writer wishes to acknowledge his indebtedness and express his gratitude to those who replied so fully and energetically. He would like to include here all the discussion which took place, but for lack of room this will not be attempted. Without mentioning any names it may be said that the opinions were about equally divided. The writer is unmoved in his own opinion that the name should be changed back to Massern Ranges or Massern Mountains, but for lack of a substantial majority favoring this view he has followed the current usage in the present report.

In the earliest reports upon the Arkansas Country the words Ouachita and Washita are used interchangeably for the river by that name and they are mis-spelled very often in diverse ways. From his reading the writer was led to believe that all three words, "Ouachita," "Washita," and "Wichita" originated from the same root and originally had the same meaning and reference and that doubtless two of the three words have come about from the mis-pronounciation and mis-spelling of the original—whatever it was. The word "Massern" is likewise spelled in many ways. Writing to Dr. J. B. Thoburn of the Oklahoma Historical Society for enlightenment on these points the following was received:

> And now, in reply to your question as to the origin, derivation, signification, and possible identity of the names Ouachita, Washita, and Wichita: (1) Ouachita is the French rendering of the native name of a small tribe of Indians of the Caddoan linguistic family, appearing in various forms in the writings of Tonti (1690), Iberville (1700), Penicault (1712), LaHarpe (1719), and DuPratz (1774). This tribe or band seems to have been merged with the Natchitoches (to whose people they were doubtless closely related) shortly after the French occupancy even as the latter were subsequently absorbed by the Caddoes. Their original habitat was on the river which still bears their name, in Northern Louisiana:
>
> (2) The name Washita is directly derived from that of Ouachita and the pronunciation of the two is practically identical. For some reason which has never been explained, the French voyageurs and traders who paddled up Red River from the French settlement at Natchitoches, in Louisiana, to trade with the Indians of the Upper Red River country, always referred to the tributary which enters Red River from the north at a point near the center of the southern border of Oklahoma as the "Faux Ouachita," which literally translated, means "False Washita." It was still designated as the Faux Ouachita during the early part of the last century and, with the name Anglicized, was

called the False Washita thereafter until about the time of the Civil War, since which time the prefix has not been used, the river being merely called the Washita. It is to be regretted that there should be such an identity between this Oklahoma river and the stream in Arkansas and Louisiana, in the matter of name, for the Oklahoma stream certainly seems possessed of sufficient distinction to warrant a name of its own; its Caddo name, by the way, was Bahachachaha;

(3) The origin of the name Wichita, as applied to an Indian Tribe, a range of mountains in Oklahoma, a river in Texas and a city and a county in Kansas, is open more or less to conjecture, as the name does not seem to appear in its present form until well along toward the middle of the last century. When I first discussed this matter with Doctor Gould, something over a dozen years ago, I was inclined to accept his surmise that it was in fact a derivative of Ouachita and Washita but subsequent investigation and research led me to a different conclusion. In considering this matter it is well to bear in mind that the French and Spanish languages do not employ the use of the letter "w" and, as a consequence, the same word which would naturally be rendered with a "w" in English, might begin with "ju" in Spanish or "ou" in French. Probably no tribe of Indians in the United States has had more appelations than have the Wichita Indians, though it is quite possible that some, if not most, of these may have been merely those of particular sub-tribes or bands, for the present Wichita tribe is the remnant of a once powerful confederacy of closely related tribes and bands. Among the names by which they seem to have been known by the Spaniards of Texas and New Mexico are the following: Jumanos, Tejas, Teyas, Ahijaos, Taovayases, and Taguayachi; among the French names for the same people were: Toayas (LaHarpe, 1719), Taouayaches (Robin, 1802-06), Ouicita (La Harpe, 1719), Panis Noirs (Bruyere, 1742), Panis Piques (Perrin du Lac, 1805) and Les Quichaatcha ou les courtes Jambes, which is to say, "the Quichaatcha, or short legs" De L'-Isle, 1700). American names for the same people have included Towiaches, Tawehash, Pawnee Piquas, Pawnee Picts, Tattooed Pawnees, Black Pawnees, Wichataw and Wichita. Most of the foregoing names have been subject to so many variations that they form but a small fraction of the whole number. It is my conclusion that the origin of the present Wichita must be sought in "les Quichaatcha" of DeL'Isle's map in 1700, or in LaHarpe's "Ouisita" in 1719, rather than as a derivative of Ouachita or Washita.

I know nothing of the name, Massern, though I had seen it in Nuttall's journal. Presumably, it is of French origin, as were most of the geographic names of that region, a century since."

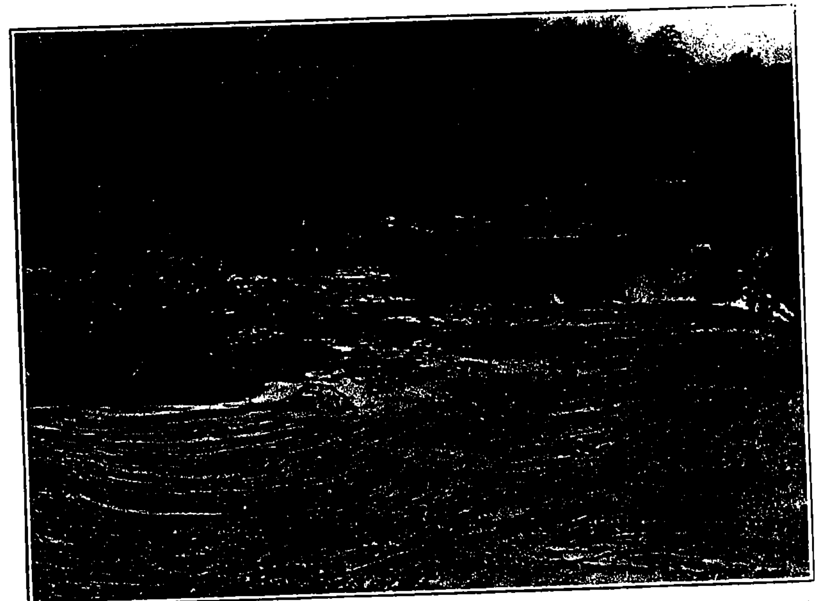
STRATIGRAPHY

COLLIER SHALES AND LIMESTONES

GENERAL DESCRIPTION AND CORRELATION

The oldest formation which comes to the surface in the area under consideration is a mass of much contorted and metamorphosed, graphitic, black shales, capped by thin bedded, undulating limestones which, if the correlation be correct, is the Collier shale. This formation, especially the non-calcareous portion, is with difficulty distinguished from the Mazarn shale and other graphitic, black shales in the region, and the area of outcrop of the Collier is, therefore, more or less imperfectly known. At a point about three-fourths of a mile north of Glover post office (in sec. 33, T. 5 S., R. 23 E.), how-

PLATE III.



COLLIER SHALE OUTCROPPING IN GLOVER CREEK NEAR THE W. ¼. COR. SEC. 27, T. 5 S., R. 23 E., OKLAHOMA.
Note hard sandstone layers dipping 20° West and striking due North through the twisted crumpled, metamorphosed shales.

ever, and north-northeast for a distance of five miles some shales and limestones appear in a position immediately beneath the unmistakable basal conglomerate of the Crystal Mountain sandstone. This conglomerate is a very characteristic bed of rock, occurring above the Collier limestones and shales in Arkansas where the type section of Collier occurs and this relationship serves to identify the shales and limestones north of Glover, Okla., as Collier. It is the exposures of this locality only that will be described definitely under this name, although, as will be pointed out presently, the limestones and associated shales in the Lukfata Creek country and east are probably also Collier and have been so mapped.

The best of the outcroppings of the Collier shale proper are to be found in the creek bottom of Glover Creek, (about 500 paces east of the center of sec. 28, T. 5 S., R. 23 E.) and east, down stream, nearly half a mile to the acute bend in the stream. In this locality the westerly and older part of the outcroppings are blue-

PLATE IV.

THIN BEDDED COLLIER LIMESTONES OUTCROPPING IN A BRANCH OF LUKFATA CREEK, 300 PACES SOUTH OF THE NW. COR., SEC. 9, T. 5 S. R. 24 E.

black slates and soft unctuous shales, cut by thin stringers and veins of milky quartz; farther east these give way to thin limestones interbedded with soft shales and local developments of limestone-sandstone conglomerates; in the bluff formed at the acute bend in the creek and constituting the youngest and most easterly exposures in this particular section are some 25 or 30 feet of thin bedded limestones lying practically horizontal and overlaid by the Crystal Mountain sandstone. The limestones in the bluff extend down to water level, but what their structural relationship is to the interbedded

limestones, shales, and conglomerates 175 paces to the west is obscured beneath a deep hole of water and alluvial deposits in the bend. Owing to the lithological similarity of the limestones in the two places and to the succession it is assumed, however, that these rocks all belong to one continuous series.

In thin section under the miscroscope the shales are seen to consist of a finely divided aggregate of a dense, black, opaque substance resembling graphite. The particles of this aggregate are variable in size ranging from the finest "dust" to particles 0.3 mm. across, but all have irregular ragged edges, and bear other evidence of having been torn apart from each other by a crushing and shearing movement.

Quartz occurs in veinlets occupying the shear zones where the little crystals have oriented themselves with the c-axis parallel to the direction of the movement. Quartz is also disseminated throughout the mass to such an extent that the original must have been a fine, black mud or silt.

The conglomerates are irregular in thickness and may be only local in their development. There are two or three of them, the maximum thickness of the most important one being only four feet, and this bed is very irregular, thinning in one place to a few inches. They are fairly resistant layers and form rapids in the creek. The boulders of which the conglomerates are made consist of limestone, sandstone, and black chert, but for the most part they are of limestones, and range in size from coarse gravel to cobbles 8 inches in diameter. The matrix is a very siliceous mixture and weathers to a harsh, jagged surface.

The limestones at the top of the section are dense fine-grained limestones of dark, bluish gray color, in beds about one inch in thickness and gently crumpled. There are no shales interbedded with the top-most 25 or 30 feet of limestone and there is very little variation in any of the characters of the rock.

That the series has been subjected to very severe regional metamorphism is evident from the condition of the limestone-sandstone conglomerates, the pebbles in which are noticably striated and sheared, and both pebbles and matrix alike are cut by quartz and carbonate veins. The shales have suffered pronounced twisting and crushing, not only as shown by miscroscopic examination, but as revealed by the sandy more resistant layers, whose presence indicates the complexity of these contortions. The resistant layers in the shales are usually slickensided also. All the softer materials are rendered schistose or slaty by compression, and the planes of schistosity in these slates, on an average in this locality dip about 25° due west.

Bunches and stringers of quartz, carbonate, and crystalline kaolinite are extremely abundant locally in the shales. The quartz veinlets frequently form a closely set mesh of intersecting ridges on the surface of some of the weathered materials.

THICKNESS

A complete section of the Collier shales and limestones is not obtainable for study. As in Arkansas so in Oklahoma only the upper portion of the formation is exposed and this is so badly mashed that it cannot be measured. It is estimated that the exposed portion attains a thickness of at least 200 feet.

SHALES AND LIMESTONES OF UNCERTAIN AGE AND RELATIONSHIP

(Probably Also Collier and so Mapped)

GENERAL DESCRIPTION AND CORRELATION

Black, graphitic slates, soft, unctuous shales, and thin limestones, similar to if not identical with those just described as Collier, outcrop to the east over a wide area. They are exposed extensively along Lukfata, Yashoo, and East Cedar creeks; in the valley of Mountain Fork River below Hochatown; and are continuous from Lukfata creek westward across the divide to the Collier shale outcroppings on Glover Creek (sec. 28, T. 5 S., R. 23 E.)

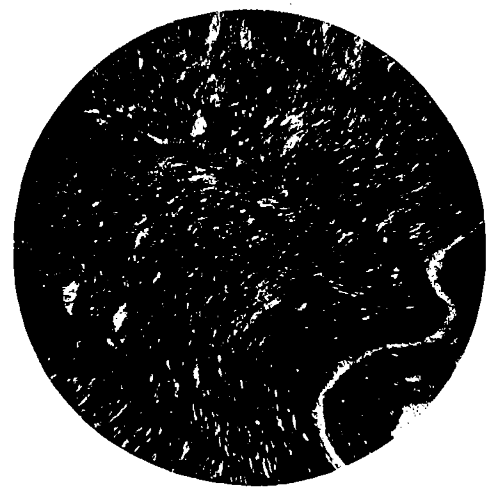
Shales of a somewhat different character outcrop farther north on Glover Creek in an isolated northeast-southwest belt across the central part of T. 5 S., R. 23 E. and again in the southeast corner of the same township, but these two areas are probably Mazarn shale and will subsequently be referred to under that name.

Those shales and related materials along Lukfata and Yashoo creeks and north and east along East Cedar Creek and Mountain Fork River are associated with, but bear an unknown relationship to the Crystal Mountain sandstone. The Crystal Mountain sandstone is so massive and so generally void of bedding that it is impossible to determine the dip or any structural feature of it, and the shales in question are so profoundly metamorphosed and generally covered with dèbris that **their** structure is likewise obscured. The weathered condition of both sandstones and shales also adds to the difficulty of determining their relationship. Judging, however, from the distribution of the outcroppings of the determinable Crystal Mountain sandstone, and from the fact that this formation always occupies high ground it seems not unreasonable to conclude that the Crystal Mountain sandstone is younger than the shales on its border and that these shales also must be Collier.

That those shales which outcrop down Lukfata Creek may all be Collier shales is indicated further by the fact that their outcroppings are areally connected with the undoubted Collier shales and thin limestones on Glover Creek, and by the fact also that the limestones are exposed at numerous points along Lukfata Creek and around the northern border of the most westernly outcroppings of

PLATE V.

A. Photomicrograph of sheared, graphitic Collier shale showing original fragments, (black) torn asunder by, and saturated in the intruded quartz (white). Crossed nicols X 20.



B. Photomicrograph of crumpled, metamorphosed Collier shale showing the characteristic shredded appearance of the chloritic-sericitic-quartzitic mass and the development of shear folds (specimen 855). Plain light X 40.

the Crystal Mountain sandstone, in close proximity to the Crystal Mountain sandstone. (The Collier limestones on Glover Creek lie immediately beneath the Crystal Mountain sandstone.)

These same shales appear to be continuous east and northeast also, where few limestones were noted. So far as the limestones are concerned it is possible that they pinch out in that direction or are wanting because of erosion prior to the deposition of the overlying Crystal Mountain sandstone; or they might be concealed from view by float. From the vicinity of Hochatown, (sec. 21, T.. 4 S., R. 25 E.) south and southwest for eight miles or more (to sec. 24, T. 5 S., R. 24 E.) these shales lie in contact with a series of schistose sandstones and shales called in this report the Womble equivalent, i. e. sandstones and shales assumed to be equivalent in age to the Womble shale of Arkansas. This means that the writer has been unable to identify the Crystal Mountain sandstone, Mazarn shale or Blakely sandstone on the eastern side of this central mass of shales and that the shales in question may be: (1) wholly Collier in age, or (2) represent shaly phases of the unidentified formations.

If the former case is true the formations which appear to be absent are doubtless wanting because of non-deposition or erosion prior to Womble time and not through faulting, for the contact is too crooked to be a fault line. If the second case be true the change in sedimentation took place rapidly from west to east—sandstones giving place to shales within a space of two miles in the case of the Crystal Mountain sandstone.

These unidentified, presumably Collier shales farther north likewise lie adjacent to the Womble schistose sandstones all the way from sec. 22, T. 5 S., R. 23 E. northeast for 15 miles, to Hochatown. Fault breccias have, however, been noted along this line in two or three places and a fault has been assumed here to account for the missing formations, but with some hesitancy it should be added.

It appears, taking everything into consideration, that the Crystal Mountain sandstone thins to the northeast and pinches out west of Hochatown as do also the overlying Mazarn shale and Blakely sandstone formations, thus allowing the Womble sandstones above to come in contact with the Collier shale below. One point in favor of such an hypothesis is the fact that the conglomerate which occurs at the base of the Crystal Mountain sandstone (in sec. 27, T. 5 S., R. 23 E.) on Glover Creek, is 14 feet thick at that place and carries blocks and boulders 8 inches in diameter, while east of Lukfata Creek it was not found at all, except a six inch bed of conglomerate made up of one inch pebbles found 1½ miles west of Hochatown which may possibly be an equivalent horizon. The maps have been constructed with this view in mind at any rate and if at some future time these shales are found to be other than Collier in whole or in part a change can be made.

In the southern part of T. 5 S., R. 24 E., redeposited Cretaceous gravels and alluvial soils, washed against the Bigfork chert hills to the south in recent times, completely cover the shales and a part of the Crystal Mountain sandstone. Consequently it has not been possible to map this particular strip, as indicated on the maps.

The Collier shale as mapped (see Plate I) should therefore be regarded as doubtful Collier, with the exception of that portion which lies in secs. 27 and 28 of T. 5 S., R. 23 E. In this region the thin limestones and graphitic shales positively underlie the massive conglomerate occurring at the base of the Crystal Mountain sandstone and they must, therefore, be Collier in age at this place.

THICKNESS

Nothing is known of the thickness of the shales of doubtful age and relationship excepting that in case they be Collier they are at least 200 feet thick.

BOULDERS IN THE SHALES

At the mouth of East Cedar Creek (SE. cor. sec. 20 T. 4 S., R. 25 E.) in the creek bottom and northwest, also southeast, for 250 paces in either direction, are some excellent exposures of the slates and shales (Collier?) with boulders and gravel intermingled at intervals, cemented in the abundant shale matrix. Pebbles from one inch to six inches are most abundant, but occasionally one sees a boulder 2 feet in length. In all cases these are scattered through the shale as solitary pebbles or boulders and are not in beds. The majority of them, moreover, are lenticular and have pinched off, striated and frayed out ends, indicating that they have, actually, been pinched or pulled to pieces in some way. In the same locality certain of the thin, siliceous bands, up to 1 inch in thickness, occurring in the shales have been drawn out by the shearing processes which accompanied the folding of the region, so that irregular cracks and crevices an inch wide in some instances separate these siliceous bands into little blocks, which never have been cemented by vein materials. The shales on either side of the siliceous bands preserve a marked flow structure indicating movement of the shaly matters around the broken layers.

The occurrence of large and small boulders scattered thinly in an abundant shale matrix is difficult to explain unless they happen to be fashioned by the folding and shearing of resistant bands in the shales in which manner it is believed they were formed as indicated by the character of the boulders and by the nature of the broken resistant layers found in the shales.

QUARTZ-ORTHOCLASE PEGMATITES

Of special interest in connection with the shales of doubtful age is the milky white quartz which has been precipitated or injected into cracks and fissures as veins and bunches in the shales in amounts almost unbelievable in places. Three miles southwest of Hochatown may be found several of the largest of the quartz veins (see map) which strike east-northeast across country more or less continuously for several miles forming in some sections mountain ridges. Large chunks and boulders of the loose rock cover the ground over wide areas elsewhere so that the whole country side in reality shines with the quartz.

The quartz seems to occur most often as lenticular veins of large size and as bunches whose dimensions are always to be measured in feet rather than in inches. It is milky white and usually massive, but often contains vugs of clear crystals. Orthoclase occurs in minor amounts with the quartz and locally here and there and very rarely one sees small oxidized cubes of pyrite. On account of the extraordinary large sizes of these veins coupled with the more or less general appearance of orthoclase associated with the quartz it seems that their origin must be connected with hydrothermal action if they are not actually in part at least, igneous pegmatites. In any case they are regarded as having had an igneous source. (See also pp. 48 and 64, and Plate I).

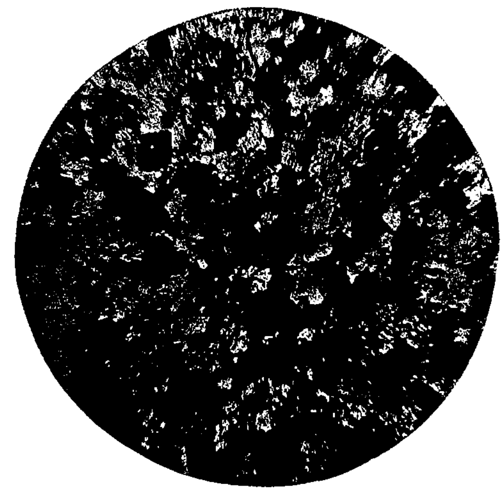
Emerson in his study of the geology of Massachusetts and Rhode Island noted silicic differentiates of granite* similar to the quartz-orthoclase pegmatites here described. Some of these he was able to trace into true granite on the one hand and into quartz-diorite on the other showing that the quartz "is a member of the unaltered plutonic series and cannot be called a vein quartz, a quartzite, or a greisen," thus he names the rock northfieldite from the mass in Northfield that forms Crag Mountain. The writer has not been able to trace the quartz masses in the Ouachita Mountains into granitic or other igneous rocks, but their resemblance to the northfieldite of Emerson is apparently very marked.

MICROSCOPIC PETROGRAPHY OF THE SHALES

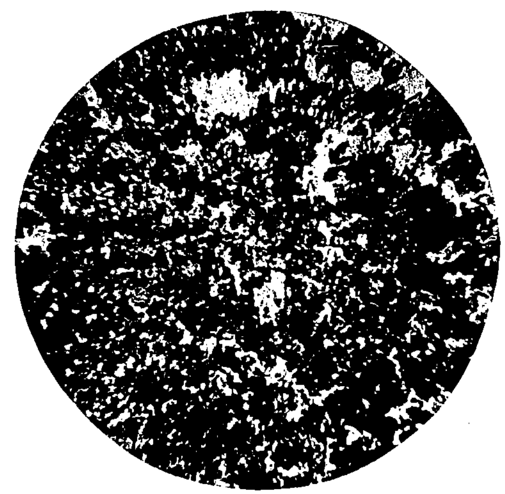
When examined beneath the microscope the slates and shales of doubtful age and relationship (Collier?) reveal a variety of interesting structures. These are chiefly the effects of shearing, re-organization and silicification. Some of the black, graphitic slates are noted to have been torn to bits and the ragged irregularly shaped fragments caught up and saturated with introduced quartz which has come into the rock in bands resembling the lit-par-lit type of injection. Other portions of the shales seem to have been originally siliceous muds and these have become sheared in such manner as to drag the quartz particles out into long ravelings and shreads so fine and so uniformly intermingled with the other constituents of the

*Emerson, B. K., Geology of Massachusetts and Rhode Island, U. S. Geol. Survey Bull. 597, pp. 167 and 250, 1917.

PLATE VI.



A. Photomicrograph of carbonated, siliceous Collier shale from the East Cedar Creek locality (specimen 1055). The carbonate has replaced the original rock and has since weathered in part to limonite (black in photo). Plain light X 40.



B. Photomicrograph of Collier replacement limestone, originally quartzite (specimen 844), showing 50 percent carbonate (dark gray with high relief) and 50 percent original quartz sand and quartz cement (white with low relief). Plain light X 15.

rock that although it may contain 50 per cent of quartz, it will not scratch steel, but quickly and effectively polishes it.

One specimen collected is a hard, dense, firmly, thickly bedded slate, whose bedding planes have been crumpled into an even series of little folds the length of which is less than half an inch and whose height is about one-quarter inch. The rock splits nearly at right angles to the bedding. In thin section, normal to the bedding, the structure of this slate is beautifully shown. The rock is made up of wavy fibres or shreds whose undulation extends parallel with or forms the crumpled bedding planes. These shreds are very fine and when resolved into their component parts are observed to be made up of tiny orientated crystals and grains of quartz, intimately mingled with rutile needles and sericite, and maintaining, even under the highest power of the microscope, a characteristic shreaded appearance. The extinction of the sericite takes place in bands or belts at right angles to the bedding, i. e. parallel with the direction in which the rock splits, the cleavage planes occurring at the places where these belts of extinction join abruptly or where the orientation of the particles changes suddenly. The splitting planes are accentuated or actually made in most cases by shearing. The shearing planes, under the microscope, are small normal faults, so to speak, which occur on the flanks of the little folds. (Plate V-B).

The contents of this slate appear to be wholly indigenous. The present mineral composition is due to a reorganization of the original shaly materials, brought about by lateral pressure under load.

Mention should be made also of an unusually graphitic phase of the shale (found 600 paces east of the N. ¼ cor. sec 30, T. 5 S., R. 23 E.) In the hand specimen the material resembles an almost pure shining black graphite. It is thick bedded, soft, soils the fingers and marks readily on paper. Upon close examination, however, portions of it are gritty and under the miscroscope some quartz is observed, occurring chiefly as small concretionary or rounded bunches with radiate structure, but also in thin veinlets. Other impurities occur, as chlorite and kaolinite, but all told they will not, it is estimated, amount to 20 per cent. The graphitic matter itself is in rounded grains of minute, but uniform size, visible only with the highest power of the miscroscope. It is not known what could have been the origin of the graphite, but it is obviously not of commercial grade.

In some of the shales there are present hosts of rutile needles which may represent as much as 1 per cent of titanium oxide. Anamorphic chlorite and tourmaline also occur.

All of the argillaceous, metamorphosed shales throughout the region are intersected by numerous veins of a silvery white mineral which resembles talc, but which upon partial analysis proves to be

kaolinite. The veins range in thickness from microscopic size up to one half inch and the majority of them are irregular. Pyrite and ferruginous carbonates are noticed occasionally replacing portions of the shales.

MICROSCOPIC PETROGRAPHY OF THE LIMESTONES

All the limestones appear more or less siliceous, and show replacement effects—the carbonate replacing quartz. The quartz in some specimens, as extreme cases, is coarse, granitic gravel, associated with which are bits of feldspar; in others it occurs as rounded millimeter grains of sand associated with minor amounts of plagioclase, derived it is thought, judging from its strained and sheared condition and from its old and dirty-looking appearance, as a sediment from an ancient gneiss. In most instances, on the other hand, the quartz is a kind of cryptocrystalline chert of very fine texture, and in some cases it appears to be genuine chert. In one specimen the quartz grains have suffered enlargment, and both the old and the new quartz have been replaced by carbonate indicating that the original rock was a quartzite containing some feldspathic material (these matters being visible still) and that it had been largely replaced by the carbonate. Some of the purer limestones contain enough quartz so related to the carbonate as to indicate that all of the latter amounting to 95 per cent of the rock mass in some specimens and 80 per cent at least of the whole formation is replacement carbonate. Certain layers however, seem to be made up of chert and limestone pebbles, seen best in the hand specimen, so that there must be at least some original carbonate in the rock. There is very little chlorite, sericite, or other re-organized argillaceous or aluminous matter present.

The replacement carbonate is clear, well crystallized, irridescent, and twinned. It occurs in irregular interlocking grains, but also in well formed rhombohedra and sometimes, (due to shearing) as long, slender, interfingering slivers or sphenodial pieces. Although clear in thin sections, it is often black in the hand specimen, due to included carbonaceous matter, but it weathers light-bluish gray. In thin sections the well formed rhombohedra are noted to weather invariably to limonite indicating that a part of the carbonate at least is siderite or at any rate ferruginous carbonate, probably hydrothermal and magmatic in origin.

In some specimens quartz veins were introduced subsequent to the replacement of the quartzites and cherts by carbonate, and after that shearing and granulation took place with an introduction of more carbonate as a final end stage of the process, which partially replaced and filled in around the broken quartz vein. In other sheared and metamorphosed specimens finely crystalline quartz was noted to be filling the interiors of carbonate veins as an end stage effect.

A few remains of fossils have been found in the limestones, most important of which are the branching nodose siliceous (possibly silicified) algae shown in figure 3.

These appear to be quite abundant in certain specimens as may be noted by dissolving chips of the limestone in hydrochloric acid. There are about 78 nodes per millimeter in these algous chains. A single instance of doubtful sponge spicules (possibly radiolarian remains) was discovered, and one specimen revealed a structure which suggested a rambling, coarse bryozoan colony, but none of these last mentioned structures are sufficiently preserved to render even a phyletic determination possible.

RESUME AND CONCLUSIONS

By way of recapitulation of the facts of the areal geology, it may be said of this whole slaty and calcareous mass herein mapped and regarded as Collier: (1) that the extreme western exposures only are positively known to be pre-Crystal Mountain in age; (2) that the outcroppings to the east in the basin of the upper Lukfata Creek (in the western part of T. 5 S., R. 24 E.) are so distributed in their relationship to the Crystal Mountain sandstone and are so similar in their lithological characters to the slates and limestones of unquestionable correlation that there is scarcely any doubt whatever that these also are Collier; (3) that owing to the absence or poor development of the limestones farther east and northeast (west and southwest of Hochatown) so far as observation has been possible, and owing to the scarcity of outcroppings in this quarter, there is much doubt as to the position in the stratigraphic column of the beds composing the eastern-most exposures; but they have been nevertheless, tentatively referred to the Collier and so mapped; and (4) that the shales and other soft materials in the south-central part of T. 5 S., R. 24 E. are so completely covered with alluvium and gravel that the character and age of the beds in this quarter, as well as their structural relationship to the outcropping formations to the north and to the south are wholly unknown and have not been mapped. On the map this particular area has been indicated as "Covered with alluvium and gravel.'

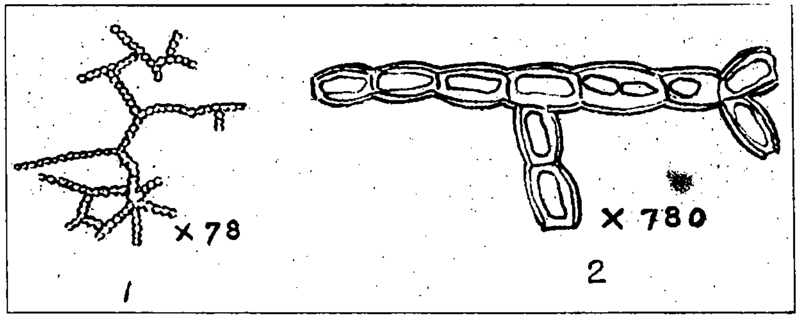


FIGURE 3—SILICEOUS (SILICIFIED?) ALGAE.

The chief facts brought out by the microscopic and other detailed studies of the shales are: (1) the development of metamorphic minerals such as crystalline kaolinite, chlorite, epidote, graphitic "dust" etc. due to a reorganization of the materials ,and the development of flow structure and slaty clevage—the usual effects of shearing; (2) the development of boulders and pebbles in the slates, brought into existence by intense crumpling and shearing of the siliceous bands or layers in the original shale; (3) the discovery of plagioclase fragments and grains of tourmaline pointing to an igneous region for a source of some of the matter; (4) the discovery of oolitic structures and of doubtful forminiferal remains (possibly replaced or carbonated quartz grains) in some of the calcareaus portions; (5) the replacement of quartz and argillaceous matter by carbonate (siderite) and pyrite both undoubtedly introduced substances.

The miscropic examination of the limestones occurring in the valley of Lukfata Creek reveals certain facts more or less of significance as follows: (1) the presence of granitic gravel and arkosic fragments cemented in the carbonate matrix, in certain layers in the limestones, indicating the presence of an igneous region at some not distant locality during Collier times; (2) the occurrence of chert and limestone pebbles in certain horizons telling of the existence also at this time of a cherty limestone area as the source of a portion of the Collier gravel. These materials indicate moreover, relatively shallow water conditions during the time of deposition of at least part of the formation; (3) the presence in nearly all of the limestones examined of from 5 per cent to 30 per cent of finely granulated quartz and quartz sand also indicating shallow water conditions; (4) the remarkable dearth, in many horizons total absence, of argillaceous matter; (5) the discovery of siliceous algae in the limestones and of other fossils of doubtful character giving unforunately no information as to the age of the rock in which they occur; (6) the thoroughly recrystallized and metamorphised condition of the limestones; the enlargement of quartz grains by the addition of silica; the etching and replacement of quartz grains and especially of the chert by carbonate (in part siderite), all of which facts speak for regional metamorphism of a rather severe type and a hydrothermal magmatic source, by replacement for the limestones; and (7) the almost total absence of ore minerals in either the limestones or the veins in the limestones, showing their economic value to be zero in so far as metal is concerned.

CRYSTAL MOUNTAIN SANDSTONE

GENERAL DESCRIPTION AND CORRELATION

BASAL CONGLOMERATE

Disconformably (?) overlying the thin-bedded limestones of the upper part of the Collier shale formation, 1½ miles north of Glover post office (in the SW. ¼, sec. 27, T. 5 S., R.. 23 E., and traceable northeast to the SE. cor. sec. 13, also south into sec 33) is a coarse, massive conglomerate 14 feet thick, forming a distinct cliff where undercut by Glover Creek. This conglomerate constitutes the basal portion of the Crystal Mountain sandstone. It contains pebbles of quartz, coarse and fine sandstone, limestone, angular pieces of black chert, bits of micaceous shale and slate, chips of quartzite, and much quartz sand. The largest pieces of chert and limestone exceed 8 inches in greatest diameter, but the majority of the pebbles average from 1 to 2 inches in diameter. The cherty materials predominate and surprisingly enough angular chert and limestone blocks are about as abundant as rounded materials. Except that the larger pieces appear to lie nearest the bottom, there is no bedding and the material is only very roughly assorted. Flat pebbles assume an inclined position as well as a horizontal one and are intermingled with the angular fragments.

In hand specimen the matrix is a fine grained, dense, siliceous limestone or calcareous sandstone, the exact character of it depending on the locality and particular place in the formation from which the sample is taken. Certain places in the formation approach quartzite while other parts contain very little of the quartz. The exact nature of the matrix as revealed by the microscope will be considered later. As the heavier blocks of chert and other rocks are more numerous near the bottom so the matrix, in proportion to included fragments, increases toward the top. The entire ledge of conglomerate is cut by numerous thin veinlets of quartz, which intersect included fragments and matrix alike. These occur in parallel series for the most part and there may be as many as a dozen or more of them in a single hand specimen. There are also present small irregular concretionary growths of chert and tiny vugs of quartz. Numerous slight displacements in the rock indicate that the formation has been under heavy strain.

This conglomerate weathers by jointing into large, rectangular blocks and these in favorable places roll down as talus at the base of the cliff. Exfoliation takes place also, attacking material of cliff and talus alike and both these processes very effectively slice the conglomerate into slabs, two to six inches thick, chopping the contained boulders and other fragments square off, as they are held firmly by the matrix Slabs 2 inches thick by several fee.t in length and breadth may thus be caused to peal off and these, like thin sec-

tions prepared for microscopic study, will contain cross sections of the boulders and pebbles. The calcareous portions of the rock are then etched out through the agencies of rain and atmosphere leaving the chert and other hard fragments and pebbles in relief and forming an unusually rough and jagged surface. The chert always has sharp cutting edges and acute projecting points, which upon long exposure retain their cutting edges. The sand grains are harsh and rough and the cementing material in the sandstone pebbles also weathers away leaving the sand grains of the pebbles with their hard particles projecting as a cluster of grains. The result is the roughest, harshest, most jagged surface imaginable. Much of the angularity of the pebbles in the conglomerate, on first sight a most striking fact, may be accounted for by the processes of jointing and exfoliation.

OVERLYING SANDSTONES

In the region of the exposures of this conglomerate-breccia just described and superseding it in rapid transition are coarse, massive, dark grey sandstones, some of which appear to be veritable quartzites; others have a carbonate cement and these upon weathering become porous and spongy and through long exposure are recognized as coarse, brown friable sandstones. The sandstones constitute the major portion of the formation and cover, in all, about 18 square miles of country in the central part of the uplift. East of Lukfata Creek, and especially to the north and northeast the Crystal Mountain sandstone is more quartzitic, and on this account more resistant and lighter in color. It is also finer grained in this direction. Interbedded with the sandstones of the types mentioned may occur certain argillaceous horizons or other rarer types of sandstones.

The outcroppings everywhere consist mainly of boulders and weathered, jointed blocks, more or less in place, on the slopes and tops of broadly rounded ridges and hills. Rarely does one encounter solid rock actually unmoved and when he does, it yields no trace, usually, of the bedding or other means of ascertaining the structure.

Many of the boulders which weather from this formation and which lie about on the outcroppings result from exfoliation of joint-blocks, but some of them are water worn boulders of Cretaceous or Tertiary age. These may be 6 to 10 inches in diameter and may cover the ground completely on the south slopes of the hills, in some quarters (as in the NW. ¼, sec. 24, T. 5 S., R. 23 E., and in the NW. ¼, sec. 3, T. 5 S., R. 24 E.) They are usually lacking or few in number on the northern slopes, due presumably to more active erosion on these slopes, which are prevailingly steeper. Altogether perhaps 4 or 5 square miles of the Crystal Mountain sandstone area are covered with the water worn boulders derived from this sandstone in Mesozoic or Cenozoic times. Coarse brown sand washes down the slopes and into the valleys where it covers the shales rendering the contact of the sandstone with the shale always uncertain as has before been intimated.

The formation contains no fossils; it is unstratified or massive in structure for the most part; and the sand grains are spherically rounded and of rather uniform, 0.3 to 0.6 mm. size.

THICKNESS

On account of the massive character of the formation and poor exposures the thickness of the upper sandstones could not be calculated, but it is estimated that these must be at least 500 feet thick.

QUARTZ—ORTHOCLASE PEGMATITES

Quartz-orthoclase veins are a common feature of the Crystal Mountain sandstone. They vary in thickness from 1 to 4 inches and where weathering has gone on for some time the veins stand in relief upon the brown, spongy, porous blocks and boulders of sandstone often 2 to 6 inches or more in height and are very attractive. This is especially true of the outcroppings west of Lukfata Creek, where the carbonate content of the rock is highest and disintegration most rapid. Quartz crystals which occur in this formation in Arkansas and which gave the name "Crystal Mountain" to the formation do not occur in the Oklahoma exposures to any noticeable extent and none whatever of large size have been found.

Of unusual interest are the large amounts of orthoclase associated with the quartz in the veins in Oklahoma in some places. Ordinarily only about 5 per cent to 10 per cent of the veins is feldspar, but it often reaches 15 per cent to 25 per cent. Without making any special effort to find orthoclase this material was noted in 20 different localities in the Crystal Mountain sandstone and it appears to be generally present throughout the full extent of the outcroppings (see map). A careful search for orthoclase doubtless would reveal its presence in every quarter section if not actually in most of the veins in this formation.

In hand specimens the two minerals ordinarily occur in parallel intergrowths, the crystals of both quartz and orthoclase being elongated in a direction normal to the walls of the vein, but in the larger masses, veins exceeding 2 inches across, the distribution of the minerals is apt to be more irregular. Vugs and irregular open spaces are common especially in the larger veins. These cavities are often lined with well formed crystals, though never large so far as observed. In one specimen a two inch filling consisting of orthoclase and quartz is characterized by borders rich in orthoclase, but whose middle is chiefly quartz. Whether this is the rule among the thicker veins or not is not known, but in this particular case it would seem that the uprising solutions were initially more alkaline than

later. The thinner veins, not showing this differentiation were probably completely filled before a change in the solution occurred.

In thin section, under the microscope, neither of the minerals shows any unusual features. Large cleavage plates of orthoclase may contain specks of quartz and contrarywise, particles of orthoclase may project into the quartz crystals. The orthoclase is not given to twinning.

MICROSCOPIC PETROGRAPHY

BASAL CONGLOMERATE

The microscopic petrography of the basal conglomerate may best be discussed under four headings: (1) limestone pebbles; (2) chert pebbles; (3) matrix; and (4) veins. The descriptions are taken from typical specimens from the cliff on Glover Creek above referred to.

(1) **Limestone pebbles:** The limestone pebbles of the conglomerate are observed in thin sections to be thoroughly recrystallized and to consist of distinct rhombohedra of carbonate set apart by interstitial graphite and quartz. The rhombohedra have an average diameter of nearly a millimeter and are particles of the original dirty material, which have been enlarged by the addition of new, clear, transparent carbonate, filling out the original grain in most instances to a complete rhombohedron. The interstitial graphite seems to be residual from the recrystallization process; the quartz, on the other hand, is regularly marginal on the carbonate grains and in some instances fills fissures and is believed to be introduced. The quartz ranges from coarse to fine grained and is typical of vein material, but it in no case encroaches on the carbonate grains.

(2) **Chert pebbles:** The chert pebbles seem to be, in the main, of a rather complex nature, having had a previous history. They are black, more or less uniform in appearance to the unaided eye, but when examined miroscopically are seen to include rounded grains of quartz and rounded grains of other materials all reorganized into a more or less uniform whole. The quartz grains, which are present in the chert to the extent of perhaps 25 per cent of the cherty mass, retain their original form and, except that some of them have a granular (etched) border, appear not to have changed at all. Of the other grains in the chert pebbles, and these are the most numerous, nothing of their original character remains except their form. Most of them are oval or elongated, smoothly rounded and have a diameter of 0.3 mm. They appear in plain polarized light as hazy patches and under crossed nicols as an aggregate chiefly of quartz but with chlorite and other minerals also present.

The quartz grains and the "hazy" grains are scattered through and bound together by an aggregate of fine but uneven grained quartz of the variety known as chert proper. The pebbles of black chert in other words contain: (1) rounded quartz grains whose borders grade imperceptibly into the chert matrix, and (2) hazy rounded grains, reorganized and now consisting almost wholly of quartz (chert) chlorite and minor amounts of other minerals, all cemented in a cherty matrix.

Carbonate rhombohedra of all sizes, especially those of microscopic size, are abundant within the chert pebbles, but they are nearly all confined to a zone about 5 mm. broad near the borders of the pebbles, a fact which would seem to indicate a definite time for and a limiting force to the replacement action, but how long the time or how great the force could scarcely be calculated.

(3) **Matrix:** The matrix of the conglomerate holding the limestone, chert and other pebbles is composed of quartz and carbonate. The quartz is in the form of rounded detrital grains, a large proportion of which are almost spherical. Their borders, once smoothed by erosion, are now jagged and irregular—made so by the projecting points of rhombohedra of carbonate which have been introduced into the rock and have replaced a part of the quartz. The original size and shape of the quartz grains can be learned by observing the line between the old, dirty matrix (now carbonated) and the clear carbonate of the partially replaced grains. The loss on the periphery of the grains, due to replacement amounts to about .10 mm. The quartz grains are fractured, most of them in two directions, and have inclusions of rutile and apatite indicating that the quartz came from a granitic area that had been under strain. A large piece of biotite was noted in and completely surrounded by one quartz grain.

The carbonate of the matrix like that of the limestone pebbles occurs in the form of rhomohedra of megascopic size. Many of the rhombohedra, as noted above, have grown at the expense of the quartz. The limestone is dirty with argillaceous matter and other impurities, but the iron which comes out upon weathering is observed to be coming from the well formed rhombohedra which must therefore be ferruginous.

(4) **Veins:** The quartz veins which cut the conglomerate contain a few crystals of clear carbonate (enlargements of limestone fragments of the wall rock) along the outside of the vein. These project from the walls .1 mm. (slide 1012). Either the carbonate was the initial fissure-filling material or the quartz vein has been replaced on its borders by carbonate. That the latter case is not impossible is attested by the fact that the quartz grains of the same rock have been attacked and replaced by the carbonate on their borders. It has already been mentioned that carbonate fills the centers of some veins and that quartz fills the centers of others as an end stage of the precipitation.

PLATE VII.

A. Photomicrograph of crystal mountain sandstone conglomerate pebbles, showing original limestone fragments (black or dark gray) enlarged to perfect rhombohedra by the addition of new carbonate (light gray) with a border of quartz (white) added later. Plain light X 15.

B. Photomicrograph of Crystal Mountain sandstone (quartzite) showing enlargement of quartz grains (white and light gray), by the deposition of silica around the original sand grain in crystallographic continuity in the usual manner, and subsequently partially replaced by carbonate (dark gray). Crossed nicols X 40.

UPPER SANDSTONES

The sandstones overlying the basal conglomerate and embracing the greater part of the formation when examined under the microscope in thin sections are observed to be essentially fine to medium grained quartzites which have been partially replaced by carbonate. The coarse grained sandstones are composed of grains, averaging .4 to .6 mm. in cross section which are, in the majority of cases, remarkably and uniformly rounded. Most of the grains are small oblate spheroids, but some are almost perfect spheres. In general these are simple, clear, crystalline particles, but some of them are crossed by minute parallel fractures; and a few are complex, consisting of two or more particles of interlocking granitic quartz. The original particles of quartz of the finer grained sandstones, on the contrary, are angular and have diameters which range around .1 mm. In some specimens observed there is a peculiar commingling of these two distinct types of grains without intermediate kinds, suggesting, because of their marked dissimilarity of character, a dual source and origin of the materials. In addition to the quartz there is some detrital zircon, but the sandstones are not feldspathic. Inclusions of rutile, apatite, and zircon are noted frequently in the grains of quartz.

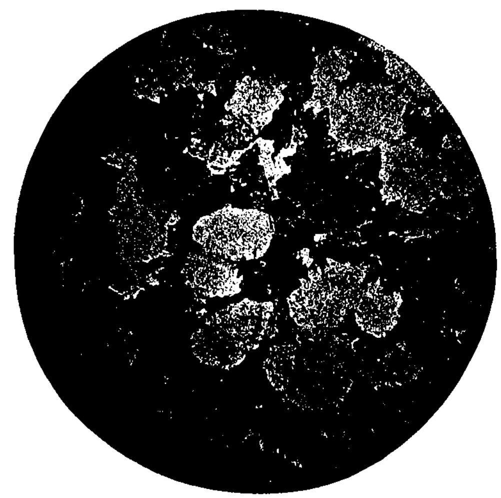
The cementing material is silica, which in some specimens has attached itself to the original grains in crystallographic continuity in the usual manner.

In other cases it is a finely granulated material resembling chert, and this seems to have reacted with the original grains in such a way as to produce a most unusually firm interlocking of crystalline particles whose surfaces actually grasp and hold each other with interfingering prominences.

Replacement carbonate occurs in all the specimens of Crystal Mountain sandstone thus far examined, and judging from the manner of weathering of the formation it should be found throughout the full extent of the outroppings. It occurs in places to the extent of 50 per cent of the rock, but usually less abundantly and sometimes very sparingly. In the coarser grained varieties it is largely interstitial replacing all of the cement and portions of the original grains. In the fine grained materials the replacement is more general. The carbonate in any case, however, is finely crystallized in interlocking grains and as rhombohedra averaging .3 mm. in cross section. Many of the rhombohedra have cloudy interiors representing original argillaceous or graphitic matters, no doubt, which are portions of the original binding materials, but which were left by the selective replacement process to be incorporated in the new cement (carbonate). The outsides of the carbonate grains are clear and

PLATE VIII.

A. Photomicrograph of Crystal Mountain sandstone (quartzite) showing large quartz grains, (light gray) etched and partially replaced by rhombohedra of carbonate (dark gray.) Crossed nicols X 40.



B. Photomicrograph of carbonated Crystal Mountain sandstone. Note crystal boundaries of carbonate rhombohedra projecting into the quartz grains showing replacement. Plain light X 15.

transparent, especially that portion which has replaced original grains of quartz.

In partially altered specimens of the sandstones abundant limonite is observed to be altering from the carbonate, which must, therefore, be ferruginous carbonate, possibly calcite—siderite isomorphous intergrowths if not actually siderite. The majority of the sandstones in the hand specimens are, therefore, quite brown; the rock in the field appears decidedly ferruginous, yet, originally the deposit appears to have been a pretty clean sand.

Quartz veins of millimeter thickness or less are noticed in the thin sections. These are as firmly cemented to the wall rock as the sand grains are to each other, and are thus virtually and practically an inseparable part of the quartzite. The veins have a tabular structure which is revealed in the thin section as irregularly parallel interlocking, elongated grains, having a length equal to the width of the vein (comb structure). The veins contain an occasional rhombohedron of carbonate, replacing the quartz indicating that the date of veining preceded that of the introduction of the carbonate and was probably contemporaneous with the process of silicification, which converted the sandstones into quartzites. In the limestone pebbles of the basal conglomerate it has just been pointed out that the quartz is interstitial and later than the added, new carbonate. The facts indicate, therefore, a protracted period for the introduction of quartz beginning early and lasting late, but with a more limited period for the replacement action by carbonate.

RESUME AND CONCLUSIONS

The principal facts with regard to the Crystal Mountain sandstone are: (1) the heterogeneity and local development of the conglomerate at the base whose general character and distribution would indicate short transportation and rapid deposition of this part of the formation. (2) Evidences of strain and fracture, and inclusions of rutile, biotite, apatite, and zircon in the sand grains of the upper sandstones indicating a granitic or gneissic source for the sand and judging from the fineness of grain and absence of felspathic material, a distant and ancient source. (3) The spherical roundness and uniform size of much of the sand which combined with the massive structure in the formation, absence of fossils, and other characters indicates that possibly a portion of the upper part of the formation might be eolian in origin, (4) the absence of the basal conglomerate and the finer grain of the sandstones in the northern and eastern exposures of the formation pointing to a southerly source for the materials, (5) the enlargement of quartz grains and the presence generally of a siliceous cement which locally incorporates limonitic, chloritic and carbonaceous matters indicating original partial consolidation by ferruginous matters, but later consolidated through

the process of silicification to a quartzite, (6) the replacement of quartz by introduced carbonate in appreciable amounts in the southern exposures, but scarcely at all farther north, representing probably hydrothermal and gaseous magmatic emanations and finally (7) the pronounced development of quartz-orthoclase veins throughout the full extent of the outcroppings which can scarcely be other than aqueo-igneous in origin.

MAZARN SHALE

GENERAL DESCRIPTION

There are two areas of shale herein regarded and described as Mazarn: (1) a narrow, northeast-southwest belt extending across the central part of T. 5 S., R. 23 E., and (2) a roughly circular

PLATE IX.

VIEW LOOKING NORTHWEST UP GLOVER CREEK, WHERE IT UNDERCUTS A BANK OF MAZARN SHALE CAPPED BY BLAKELY SANDSTONE, 700 PACES NORTH AND 300 PACES EAST OF THE SW. COR., SEC 15, T. 5 S., R. 23 E.

The alluvial flats within the bend to the east are under cultivation. Bigfork chert hills in the far distance.

patch outcropping in the southeast corner of the same township and range. The rocks of the first mentioned area are best exposed in the bluff overlooking Glover Creek in secs. 15 and 16 where a close examination was made of them and specimens taken.

The shales in this bluff are dark bluish gray to black in color and are soft and unctious in some places, but where perfectly fresh they are tough and firm under the hammer and often slaty, splitting into thin leaves and splintering when broken. On account of the slaty cleavages developed the bedding is not discernable, but the strike presumably is northeast, parallel with the schistosity and with the strike of the overlying sandstones. As a result of the shearing processes certain hard, dark, siliceous materials in one zone noted have become brecciated and the sharp jagged fragments can be found scattered through a thickness of several feet of the shales. Shattered pebbles of sandstone occur also in some horizons, where the shale appears to have been under such pressure as to have flowed around them. Thin, shining veins of crystalline kaolinite occur in the softer, blue, even-grained, clay shales; gash veins of milky quartz are present, also blanket veins, but none of these are numerous, nor extensive.

Brushy glades and water-oak flats are common topographic features of the shale areas in this quarter.

The second area of what is believed to be the Mazarn shales, is found in the southeast corner of T. 5 S., R. 23 E. where they apparently form a shallow syncline and are partially overlaid by the Blakely sandstone. The formation consists of hard, blue shales, weathered usually to a buff color and cut by milky quartz veins. Everywhere these shales have undergone a shearing movement and the schistosity is almost horizontal, but in places it dips 10° or more north.

The topography of this area is undulating. The creeks are in flat valleys bordered by narrow flood plains. The higher ground is invariably covered with Cretaceous gravel or fresh vein quartz derived from the veins in the shales. There is an abundance of brush and small timber as usual.

THICKNESS

No actual measurements have been made of the Mazarn shale on account of the poorly exposed and greatly metamorphosed condition of the formation, but judging from the great mass of the shales in the bluff mentioned above (secs. 15 and 16) it is estimated that there might be 1,000 feet.

MICROSCOPIC PETROGRAPHY

The most prominent features of the metamorphosed shales of the Mazarn, as brought out by an examination of them in thin section under the microscope, are the disrupted and silicified condition of the graphitic ones and the sheared and schistose character of the siliceous ones. There seems to be a quantity of carbonaceous or graphitic matter present in the formation which has been torn by shearing movements into ragged fragments and these, divided and subdivided into the minutest microscopic bits imaginable, have been surrounded with intruded silica. The siliceous shales, originally silts of extremely fine grain, have also been sheared, but the most important change in them has been the development of large amounts of sericite and a marked orientation of the argillaceous matters. The quartz also has been drawn out into streaks.

One of the siliceous bands in the Mazarn shale formation has been found to contain ragged and irregular grains of detrital plagiolase in size up to 0.1 mm. The appearance of the mineral grains in this instance indicates that hydrothermal action has played an important role in the metamorphism, for the grains of both quartz and feldspar are frayed out at the ends and welded together with chlorite. Silicification has also taken place.

Innumerable veinlets of quartz and crystalline kaolinite occur in all the thin sections examined. These are very minute in most instances and have the habit of pinching out at one or both ends and

PLATE X.

Photomicrograph of quartz veins in black, graphitic Mazarn shale. Plain light x 15.

beginning again a little to one side. These are also minutely crumpled and sometimes bifurcate and intersect to form a most complex network of very fine mesh.

Small rhombohedra of replacement carbonate occur in the siliceous portions of the shale. These are altering to limonite indicating their ferruginous character.

RESUME AND CONCLUSIONS

The most noticeable fact brought out by the study of thin sections of the Mazarn shale is that of profound metamorphism which has brought about (1) the development of schistosity and slaty cleavages in the shales; (2) a reorganization of the old mineral compounds and the formation of new minerals, and (3) the presence of small amounts of carbonate (siderite) in the shales indicating that the carbonated solutions which "mineralized" the Collier shale and the Crystal Mountain sandstone below were unusually penetrative.

It does not seem worth while to venture an opinion or explanation regarding the source of the Mazarn shales or their probable extent. It is entirely possible that these shales once extended in outcrop farther north. Doubtless they did and have been eroded from the hill tops along the divides now occupied by the Crystal Mountain sandstone.

BLAKELY SANDSTONE

GENERAL DESCRIPTION

Capping the Mazarn shale at the top of the cliff in sec. 16, T. 5 S., 23 E. is a hard sandstone coming on suddenly and without transition. The bottom layers are dark smoky gray and extremely hard. Thin veins of milky quartz and smoky quartz cut them vertically to the bedding and the sandstone seems saturated with silica so that the rock virtually is a quartzite. The basal beds of this quartzite are in layers six inches to two feet in thickness and are fairly evenly bedded. These materials, however, give way to coarse grayish-green sandstones very quickly and pass upward into the red sandstone grits (red through surface oxidation) which are regarded as being equivalent to the Womble shales of Arkansas, since they occupy a similar stratigraphic position beneath the easily recognizable Bigfork Chert.

The appearance of the smoky quartzite above the Mazarn shale is very sudden, but the passage from the quartzite layers to the schistose sandstone above is gradual and transitional. Some shales can be found among the sandstones higher in the series, but they appear to be interbedded with the sandstones and no great amount of the shales occurs. Apparently then, the Womble **shale** of Arkansas, as a shale, is wanting in this locality and the same is true of the entire region under discussion. The red (green when fresh) schistose sandstones which occupy the whole interval between the Blakely sandstone below and the Bigfork chert above take their place and doubtless constitute the western equivalent of the Womble **shales.** It is possible, however, that this sandstone, with its few shales, filling the entire gap from the Mazarn shale mass below to the Bigfork chert above is all Blakely, but the dark quartzitic layers at the bottom with their intersecting veinlets of milky and smoky quartz do not occur anywhere else at the bottom of the red schistose sandstones except in T. 5 S., R. 23 E. They are easily recognized and unique in all their characters. In this volume the bottom beds only, which have a thickness of about 10 to 15 feet will be designated, Blakely. The red schistose sandstones above will be called the Womble equivalent.

At no place excepting in the bluff overlooking Glover Creek are there good exposures of the Blakely. Elsewhere these rocks come to the surface as projecting ledges in the small creek valleys or form low, rounded ridges, covered with their weathered fragments and other materials.

The Blakely weathers rusty and bronze colored and being quartzite and carrying smoky vein quartz it is readily recognized as long as a piece of it can be found. These weathered materials, more or less in place, may be seen to good advantage in the south central part of sec. 16 and in the N. ½, sec. 30.

It should be added that the beds are everywhere tilted at such high angles, the crumpling and metamorphism of the entire series so great (and not only is this true of the Blakely itself but of the shales below and of the schistose sandstones above), and the exposures so few and so widely separated, that it is impossible to indicate the true structure of this locality. An attempt however, has been made (see map) which seems as good as can be done at the present time.

The other area of Blakely sandstone, (in sec. 25, T. 5 S., R. 23 E.) is confined to about one square mile in extent and is synclinal in structure. It is here a fine grained, thin bedded, compact, ripple marked sandstone, grayish green in color, hard and resistant, but more weathered than the exposures farther north and not so well exposed as the region is pretty well sprinkled over with gravel. The sandstones are not bronze colored in this quarter and for that reason there is some doubt about the correlation with the beds to the north. It is possible that the basal 10 to 15 feet of bronze quartzite occurring in the central portion of the township and known in this report as the Blakely sandstone is wanting in sec. 25 and what has been mapped as Blakely in this section is the transition, really, to the Womble sandstones. At least these rocks are neither Mazarn shales, or Womble schistose sandstones, as known elsewhere in this region.

MICROSCOPIC PETROGRAPHY

The essential features of the Blakely sandstone as learned by microscopic examination are: the rounded character of the sand grains; the unusually large amount of binding material present; the welding of the sand grains by a reorganization of the original cement; and the peculiar character of the smoky quartz "veins." The sand grains are well rounded, some of them almost spherical and of uniform size, .4 to .6 millimeters in diameter. They are clear crystalline grains ordinarily, but like the grains of the Crystal Mountain sandstone they are apt to be crowded with rutile needles. What few fractures there are in them can be traced usually from one sand grain into the next indicating that the stresses causing them were initiated subsequent to deposition. Rounded grains of zircon associated with grains of leucoxene and rutile were noted abundantly in certain horizons in this rock.

The cementing material is very dark and almost opaque in places, but much of it is of a greenish hue and fibrous, rendered so by the formation of shreds of chlorite during the period of metamorphism. The striking feature of this rock is the orientation of these chlorite shreds normal to the surfaces of the quartz grains on all sides as though the latter had been little magnets, figuratively speaking, and had drawn the chlorite to them. Since the chlorite invades the quartz grains it is assumed that the quartz was essential to the formation of the mineral chlorite. In many instances the result is practically a "fusion" of the sand grains; in all cases there is present nothing other than a reaction rim, resulting, it is believed, through hydro-thermal processes.

The veins of smoky quartz which are very numerous in the Blakely are shown in thin sections, not as single fissure fillings, but as fracture zones charged with a black opaque substance resembling graphite. These tiny fractures which together make up the zone are the smallest imaginable and pass from one sand grain into the adjacent and on to the next, etc., without causing the slightest displacement. The black specks of the substance making up the "vein" in fact appear only as minute inclusions in the quartz grains massed together in rows more or less parallel, but often intersecting and passing out of one grain into the next. So fine are these rows that the zone actually is not brecciated. These little rows of specks (fractures) combined make up what appears to the naked eye, a vein. The veins may be 2 mm. or more wide by several cm. long and they are usually straight. The black, opaque substance (graphite, or whatever it is) in the veins must have been at the time of its injection powerfully penetrating. The occurrence suggests heated gases as its means of travel and is in accord with the other facts noted in this rock. There are also milky quartz veins present, but these are true fissure fillings, entirely different from the smoky quartz veins.

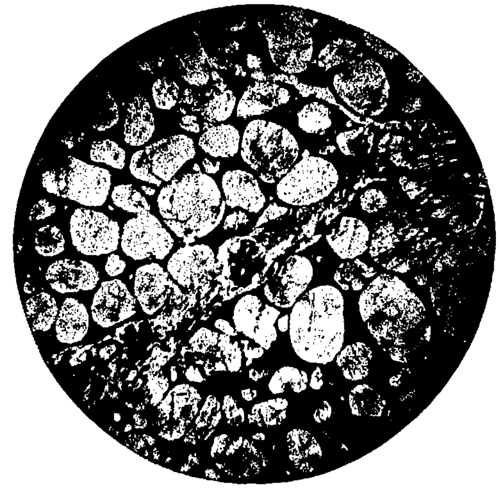
Replacement carbonate occurs commonly in its usual rhombohedral form. This is altering to hematite, but the good form of the carbonate crystals and their failure to show any movement whatever indicates the relatively late date of their introduction—subsequent to the shearing and other hydro-thermal effects.

RESUME AND CONCLUSIONS

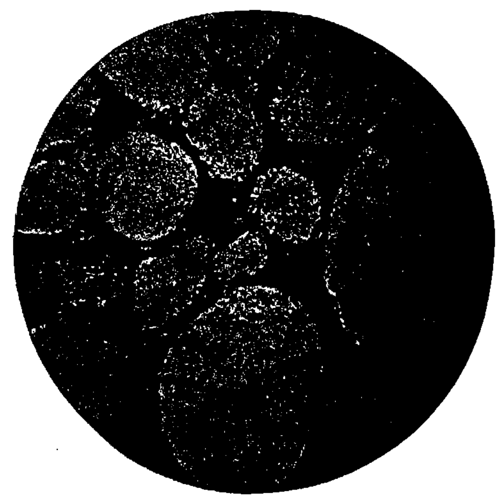
The limited distribution of the lithologic unit herein called the Blakely sandstone is the most important fact about this formation. If it occurs farther east it has not been discovered.

Since the contact with the Mazarn shale below is sharp and the upper limit of the Blakely indistinct the most logical conclusion it

PLATE XI.



A. Photomicrograph of penetration vein of smoky quartz in Blakely sandstone. The introduced graphitic (?) matter penetrates the quartz grains, passing from one grain into the adjacent grains. Plain light x 15.



B. Photomicrograph of Blakely sandstone showing rounded character of the quartz grains, which are knitted together with shreds of chlorite, normal to the surfaces of the grains (slide 1105). Plain light x 42.

seems, would be that the Blakely-Womble series represents a new, but not altogether sudden, inrush of sands into a sea which had been hitherto chiefly a quiet and muddy body of water. The absence of the Blakely to the north and east of the Glover Creek locality would indicate a southwesterly source for these deposits. The failure of any great amount of shale to appear in the Womble schistose sandstone area of Oklahoma would point in the same direction, for the Womble **shale** occurs northeast in Arkansas.

That hydro-thermal processes have been responsible for most of the metamorphism of the Blakely sandstone is indicated by the peculiar nature of the veins of smoky quartz which seem to have required a high heat for their formation, that is to say the apaque graphitic (?) dust included in the quartz seems to have been powerfully penetrating. The present condition of the quartz grains which have chlorite-quartz reaction rims, moreover, is one which is not brought about at ordinary temperatures.

The siderite, doubtless, was a magmatic emanation and that it came into the rock subsequent to the development of the schistose structure and later than the other hydro-thermal effects is attested by the facts of its good crystalline form, and failure to show shearing effects or fracture itself.

WOMBLE SCHISTOSE SANDSTONE

GENERAL DESCRIPTION

Interbedded between the shales and slates of uncertain age and relationship below, and the Bigfork chert above, in the vicinity of Hochatown, west and south; and between the Blakely sandstone below, and the Bigfork chert above, in the Glover Creek country, (in T. 5 S., R. 23 E.) is to be found a mass of green (invariably weathered red) schistose, micaceous, fine grained sandstones and grits. These outcrop in general in a zigzag belt one fourth mile to two miles in breadth from a point 5 miles west of Glover Creek, (sec. 26, T. 5 S., R. 22 E.) in a northeasterly direction to Mountain Fork River, west of Hochatown, thence southeast for 4 miles, back west 6 miles, and south and west paralleling the Bigfork Chert hills, but finally disappearing beneath alluvium, creek rubble and gravel, in unknown relationship to its associated formations in the vicinity of Lukfata Creek (in sec. 32, T. 5 S., R. 24 E.)

Exposures of these rocks are usually described in the notebooks as "red sandstone grits," "schistose red sandstones," "soft micaceous green sandstones" or "green schistose sandstones," but there is a great variety of color depending on the degree and character of the weathering; and they may be resistant in places or soft and shaley in others, depending on the relative amounts of sand and argillaceous matter present. Again these rocks may be massive and the schistosity not apparent when they would be described as "soft red sandstones," "argillaceous, compact, brown sandstones" or "soft spongy massive sandstones and grits." The massive varieties sometimes weather by jointing into blocks, but ordinarily the outcroppings of these sandstones are thin, jagged, and irregular, projecting ledges, the schistosity in which causes them to weather into acutely sphenoidal slabs with rough edges. In general the more massive or heavier bedded materials lie east of Mountain Fork River and in the upper part of the formation, while the schistosity appears to be more noticeable and most severe in the westerly exposures west of Glover Creek, and in the lower part of the formation. The sandstones are everywhere more or less argillaceous and they are fine to medium grained.

Extensive outcroppings of the Womble red and green sandstones and grits, etc. are exceedingly rare and no complete section of these rocks has been observed, but anyone wishing to see typical exposures will find them throughout sections 8, 9, and 10, T. 5 S., R. 23 E.; along the southern half of the west section line of sec. 17, of the same township; in the NW. ¼, sec. 27, T. 4 S., R. 24 E., or in the northern half of sec. 23, T. 4 S., R. 24 E. Of the more massive beds perhaps the best exposures appear south of the center of sec. 26, T. 4 S., R. 25 E. and in that general region.

Owing to the soft, non-resistant character of these sandstones one usually sees only the characteristic float. Close to the Paleozoic-Cretaceous contact, from which region the Cretaceous gravels and sands have only recently been eroded and where the local relief is ordinarily less than 15 feet, this is eminently true. Moreover, the country is generally denuded of its forests, burned over, and much of it grown up with briers and brush, making it difficult to mark with precision the limits of the Womble, and impossible to measure its thickness. These conditions extend even into the most northerly exposures where one might hope for at least one fair section, but in vain.

It has been stated that the rocks of the Womble equivalent weather invariably red. So generally is this true that in but two or three places was the fresh unaltered rock with its green color observed. In mapping the formation, therefore, these loose and weathered materials were, perforce, the chief and only guides in most localities. However, the slabs and blocks of the sandstone which one ordinarily sees have not, it is believed, as a rule slumped very far from their positions.

Southeast of Hochatown (in section 26 and also to the south in secs. 34, 35, and 36, T. 4 S., R. 25 E.) occurs what appears to be a lenticle of black, cherty limestone (see map). The black chert predominates decidedly over the calcareous portions and the thickness of the lenticle is approximately 30 feet. There are about 100 feet of Womble spongy brown sandstone intervening between the lenticle of black chert and black limestone and the bottom of the Bigfork chert formation. Inasmuch as the bedding is thicker in the Womble of this region than westward and the sediments apparently transitional to the Bigfork chert, it occurs to me that probably the sea was deeper and more quiet in this part than west and that one should look here rather than westward for the complete and uninterrupted section. Above, and well toward the top of the overlying Bigfork chert there are ledges and horizons of cherty and gritty limestones which weather to pink porous grits very similar to the typical spongy brown Womble sandstones of this region. These would seem to indicate that the two formations are quite conformable.

THICKNESS AND CORRELATION

In west central Arkansas according to Miser* the Womble shale

> Consists of black graphitic shale with thin beds of sandstone near the base and beds of limestone near the top. The shale near the base is composed of black and green layers that split at an angle with the bedding and thus show ribboned cleavage surfaces. Graptolites of Lower Ordovician age are numerous. Thickness 1,000 feet.

In Oklahoma shales are extremely subordinate in the Womble and only in one locality was limestone observed. Sandstones and grits make up almost the whole of this interval and probably represent conditions shoreward of the Womble shales of Arkansas and if so a source of the sediments of these times to the south and southwest.

As to the thickness of the grits and sandstones of the Womble in Oklahoma no accurate information can be given at the present time, since no place has been seen where it is possible either to measure or to calculate the thickness. However, there is no reason to assume a lesser thickness in Oklahoma than has been found in Arkansas.

QUARTZ VEINS

An interesting feature of the Womble sandstones is the peculiar distribution of the quartz veins in this rock which reveals an apparent resistance to fissuring. In the underlying shales especially, quartz is most ubiquitous, occurring in extended massive veins and bunches or stringers of smaller dimensions everywhere. The veins in the Womble sandstones are noticeably fewer in number and more irregular. One remarkable occurrence was located 450 paces south of the W. ¼ cor. sec. 8, T. 5 S., R. 23 E. where a solid mass of milky vein quartz, irregularly dome shaped and ragged in form

*Miser, H. D., Bul. 660-C p. 67, U. S. G. S. Manganese Deposits of the Caddo Gap and DeQueen Quadrangles, Arkansas.

rises above the surrounding sandstone slope several feet in height. It resembles a great quartz boulder some 20 to 30 feet in diameter sitting out on the hillside, but upon examination was found to be projecting from the ground, and appeared to have a somewhat broader base pinching out however, in ellipitcal cross section resembling in miniature a volcanic pipe or plug more than anything else. (See plate XII).

Quartz occurring in a similar way on a much larger scale, but in lesser relief was noted also at the N. ¼ cor. sec. 18, T. 5 S., R. 25 E. Here a solid mass of milky vein quartz forms a rounded, rocky, jagged knoll 200 paces long, north-south, by 100 paces wide

PLATE XII.

MASSIVE CRYSTALLINE MILKY QUARTZ IN THE WOMBLE SANDSTONE ONE-FOURTH MILE NORTH OF THE SE. COR., SEC. 7, T. 5 S., R. 23 E.

and terminates on all sides abruptly by sandstones of the Womble formation. Again the occurrence is just a huge mass of solid quartz projecting from the ground and one wonders if the deposit is not perhaps a spring deposit precipitated in the form of a pipe by rising thermal solutions. Lenticular, short, stubby veins and bunches of lesser dimensions, as well as huge, extensive masses of quartz occur in the shales of the older formations, but none was seen that was not clearly a vein or some modified form of one.

Other occurrences, as follows, will show that when vein quartz does occur it does so prominently, as though the solutions carrying quartz had broken through from below in definite zones or crevasses. This habit of occurrence is particularly well shown in sec 10, T. 5 S., R. 23 E. at the S. ¼ cor. of which may be found a small amount of vein quartz associated with the schistose sandstones, but north of which place, for nearly half a mile, no vein quartz whatever—absolutely none—is seen; but in the exact center of the section coming apparently from an east-west vein the ground is literally covered with vein quartz. North of the center again there is no vein quartz whatever in the sandstones.

Likewise in the region immediately west in sec. 9 a marked absence of the quartz is noted and throughout the N. ½, sec. 23, T. 4 S., R. 24 E., there is no vein quartz in the Womble sandstones, while there are ridges of it in the southern part of the same section in the rotten shales of the older formations.

In other places vein quartz was noted locally in big chunks only —chunks a foot or two lying about on the surface—as in the center of sec 6, T. 5 S., R. 25 E.

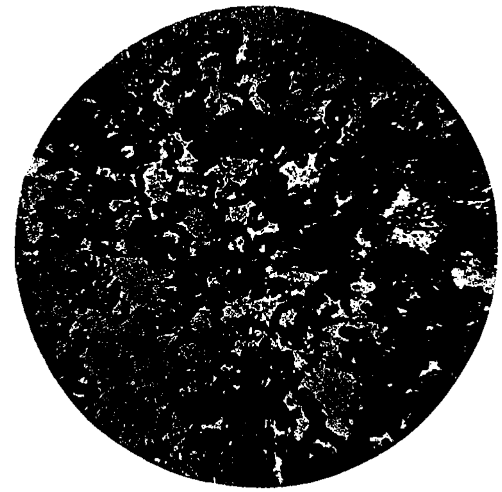
Quartz containing vermicular chlorite (sp. 1038) was found 150 paces south of the center of sec. 8, T. 5 S., R. 23 E. The specimen is a fragment of a geode and the quartz is green and pseudomorphous after some mineral which crystallized in cubes. In thin section the green color is observed to be vermicular chlorite.

At a point 200 paces north of the S. ¼ cor. sec. 25, T. 5 S., R. 23 E. a segregated mass of crystallized chlorite several inches long was found in a quartz vein. It is beautifully crystallized and much of it is vermicular, as determined by microscopic examination, and included in the quartz. For other occurrences of the quartz see pp. 39 and 48, and Plate I.

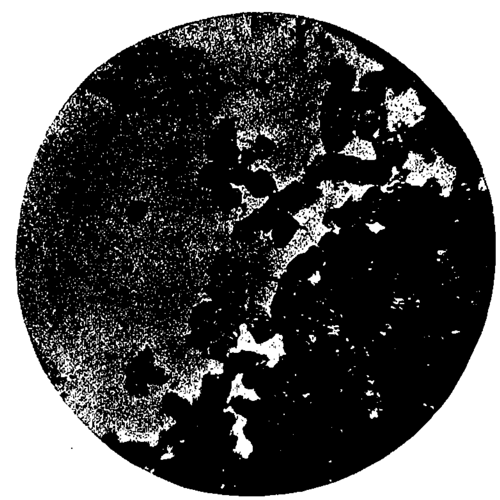
MICROSCOPIC PETROGRAPHY

The great bulk of the materials herein called the Womble are dirty, greenish or red fine-grained, argillaceous, schistose sandstones which, when examined microscopically in thin section, are observed to consist of minute irregular grains of quartz and minor amounts of acid plagioclase cemented in a highly reorganized and schistose siliceous matrix. The quartz grains are usually gritty and heterogeneous in size up to 1. mm. Some of them are crowded full of rutile needles many of which are large enough to reflect beautiful colors. Bubble inclusions are also present in great numbers in some grains presenting the remarkable phenomenon of moving bubbles of gas on the surface of the liquid enclosed. The feldspars are fresh and aside from their irregular outlines are not unusual. The majority of them are acid plagioclases. An occasional grain of zircon and some of

PLATE XIII.



A. Photomicrograph of vermicular chlorite in crystal quartz (vein material). Plain light x 50. Specimen 1038.

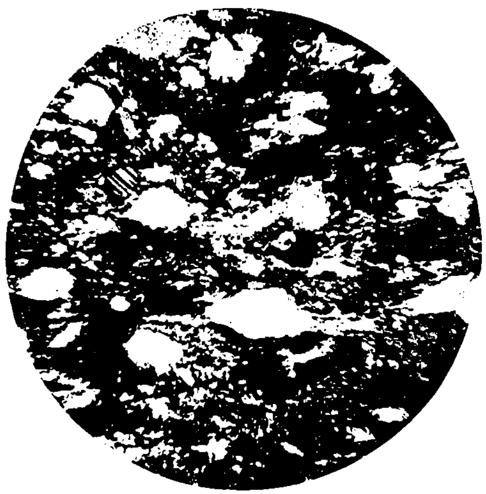


B. Photomicrograph of vermicular chlorite in crystal quartz (vein material), Plain light x 40.

tourmaline are noticed in some slides; one specimen contained three or four rounded, detrital grains of vesuvianite.

The matrix is a mixture of metamorphosed, chiefly anamorphic, products of which chlorite, sericite, and finely recrystallized and granular quartz are the most abundant. Interstitially, in streaks and undulating bands is the ubiquitous limonite and dirty yellowish to black organic matter. The processes of hydrothermal action and of metamorphism generally have knitted the quartz grains together with chlorite shreds which stand normal to the surface of the quartz grains, as described above in the description of the Blakely sandstone, but not to such a marked degree. Chlorite is the most abundant cementing material in all parts of the Womble and it is to this

PLATE XIV.



Photomicrograph of Womble schistose sandstone, showing the dragged out ends of the quartz grains (white) and the development of sericite and chlorite (light gray) on the borders—the usual hydrothermal effects observed in this sandstone. A single detrital grain of tourmaline is present near the center and one of plagioclase. Locally the rock is replaced by ferruginous carbonate, not showing in this section. Crossed nicols x 40.

mineral that is due the greenish gray cast of the fresh material. Hydrothermal action is responsible also for the frayed out ends of the quartz grains and for the ragged character of the feldspar grains. This factor, assisted by shearing, has given these sandstones a remarkable schistose structure causing them to split across the bedding as stated in the beginning.

Subsequent to the hydrothermal shearing action which frayed out the quartz and developed the chlorite, carbonate was introduced as a result of later hydrothermal action. The carbonate, which appears to be siderite, occurs as small, well formed rhombohedra. These have etched their way into quartz, feldspar and the materials of the matrix regardless of the composition of the particles attacked. Their sharp points, definite boundaries and good form are the criteria by which the writer judges that the carbonate crystals have not been sheared, hence have been introduced subsequent to the reorganization of the rock and after the schistose structure had developed.

As characteristic of the massive spongy, brown varieties of sandstones occurring typically in the upper part of the Womble and chiefly to the east of Mountain Fork River south of Hochatown the following description is given: In the weathered hand specimen the rock is red to brown in color, harsh, and gritty to the feel, light and porous, and is essentially a very fine grained grit. In thin section quartz is observed to be the chief constituent and it is present not as rounded grains, but as sharp angular particles most of which have ragged, irregular and indefinite outlines due to enlargment of the original grain and subsequent etching by carbonate. The sizes range from submicroscopic specks to fragments 0.6 mm. across. Some of these contain inclusions of rutile. Besides quartz there are grains of plagioclase feldspars and leucoxenized grains of rutile. As there is not a great deal of chlorite and only a little sericite present it appears that argillaceous matter was not abundant in the original sediment and that the quartz added to the rounded grains was the chief cementing material. The porosity of the sandstone is due entirely to the alteration of a rhombohedral mineral undoubtedly siderite, which was subsequently introduced in amount estimated at from 15 per cent to 20 per cent of the rock and which has replaced the quartz to that extent. The alteration of the siderite rhombohedra is complete in this particular specimen and the red and brown discoloration is due altogether to the decomposition of this mineral to limonite. The sediment originally seems to have been a pretty clean fine sand.

RESUME AND CONCLUSIONS

The most important facts of the lithology of the Womble sandstones are: (1) the wide and rather uniform distribution of the sediments indicating wide spread submergence, and a new and abundant source of sand and mud brought about, doubtless, by a rise of land somewhere; (2) the uniform character of the materials and the absence of conglomerates indicating a comparatively distant source; (3) the presence of much argillaceous material in most of the sandstones indicating a very muddy sea at the time; (4) the development of metamorphic minerals such as chlorite, kaolinite, sericite, graphite, quartz, epidote, and of a pronounced schistosity causing the sandstones to split across the bedding; (5) the replacement of quartz grains, and especially chert by carbonate, pointing probably to a period of magmatic hydrothermal action. The smoky quartz, chlorite-quartz reaction rims, and bubble inclusions in some of the quartz grains may possibly mean the same, coming either contemporaneously with, or subsequent to the folding, but prior to the introduction of the carbonate (largely siderite.)

BIGFORK CHERT

GENERAL DESCRIPTION

One of the most resistant formations in the geologic section of this region and one which is easily recognized, also, is the Bigfork

PLATE XV.

BIGFORK CHERT HILLS IN HALF MOON BEND OF MOUNTAIN FORK RIVER (SECS. 26 TO 28, T. 3 S., R. 25 E.) VIEW LOOKING NORTHEAST.

chert. It consists, as will be shown presently in detail, chiefly of hard, black chert, which has accumulated in beds 4 inches to 2 feet in thickness, but there are present also some coal-black shales and a number of heavy ledges of black cherty limestone. Preceded, as it is, by the soft, schistose sandstones of the Womble formation and succeeded by the Polk Creek shales and slates, also soft and easily eroded, it is a ridge maker. More than any formation, heretofore considered, therefore it is typically a key-rock, whose delineation bespeaks accurately the structure of the country. The Arkansas Novaculite, higher in the section is a more accurate guide even than the

PLATE XVI.

A VIEW LOOKING EAST DOWN THE STRIKE OF THE INVERTED BIGFORK CHERT EXPOSURES IN THE SW. ¼, SEC. 27, T. 3 S., R. 25 E.

This is the succession which has been measured and described in detail in this report. From these exposures also were collected specimens 898 to 921 inclusive, characteristic of the formation. The two heavy ledges in the lower left hand corner are each about two feet thick.

Bigfork in this respect, but all the formations below or older than the Bigfork are quite deficient, in one way or another for this purpose. It is timely, therefore, that a resistant formation appear. By reference to the map the Bigfork formation will be seen to outcrop in a practically continuous series of Vs, Ms, and Ws, hitched together by a few long sweeps, the zig-zag line featuring thus all the important folds of the central part of the uplift.

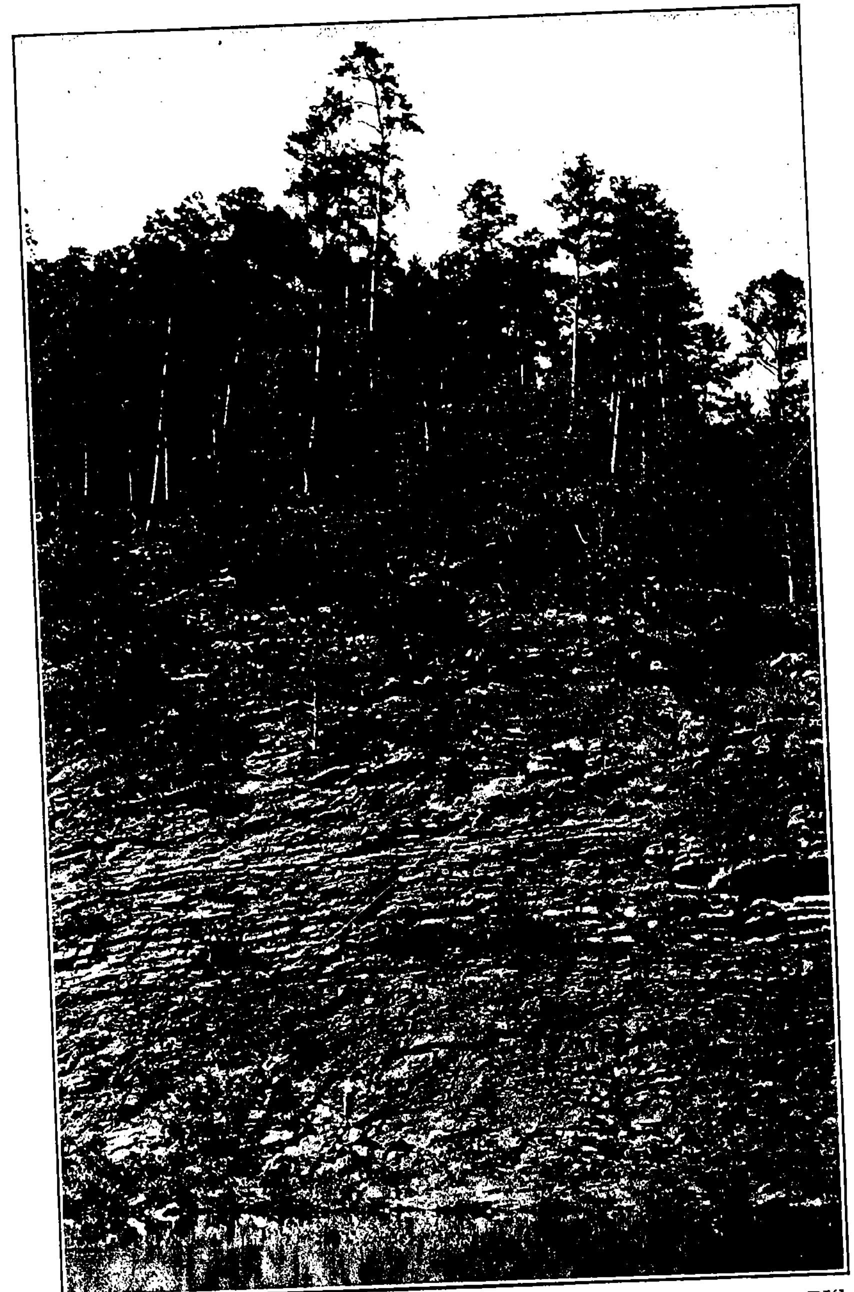
The slopes of the Bigfork chert ridges and rounded hills are characterized in general, by great quantities of small loose blocks and rectangular pieces of chert, which usually cover the ground.

PLATE XVII.

BIGFORK CHERT FORMING A RAPIDS IN MOUNTAIN FORK RIVER ONE-FOURTH MILE NORTH OF THE CENTER OF SEC. 16, T. 4 S., R. 25 E. STRATA STRIKE E-W AND DIP 35° NORTH.

Where steep sided gullies have formed on the mountain sides, such slopes are often extremely rough and dangerous, especially the talus slope (as versus the dip slope) where jagged ledges tilted at high angles project through the cover of loose rock forming; sometimes, short abrupt precipices. Small outcroppings, of the harder or thicker beds occur quite frequently on the steeper slopes and exposures are often seen in the creek bottoms, but so readily does the chert fracture and joint, and at the same time, resist decay that great thicknesses of the Bigfork chert are exposed to view in but few places.

PLATE XVIII.



A VIEW LOOKING NORTH AT A ONE HUNDRED FOOT CLIFF OF BIG-FORK CHERT AT THE RIVER'S EDGE IN THE SW ¼. SEC. 27, T. 3 S., R. 25 E.

The strata strike N. 85° E., dip 55° N., and are inverted.

In the southern part of the area where the Trinity sand (Comanchean) has only recently been removed from the underlying Paleozoics, the region has a very low relief, characterized by low rounded chert hills, which by a stretch of the imagination, even now, bears semblance of having been only recently subdued by the ocean. Over much of this country quartz gravel, mingled with, and loosely cemented to subangular blocks of chert may still be found on the hills. In the area of outcrop of the Bigfork chert these materials are inextricably mingled in various proportions with the float more recently derived from the rock in situ, making it difficult in some cases to tell which was one time Trinity and which is merely float derived more recently from the Bigfork. Loose materials of one kind or another are practically always under foot, solid rock, one might say, never. Consequently, in the region within 2 miles of the northern limit of the Trinity sand, float was largely relied upon to determine the contacts of formations. Boulder shoals and alluvial flats overgrown with brush are features of the creek bottoms.

Of the more important partial sections of Bigfork chert accessible for study might be mentioned a cliff on the east bank of Glover Creek 5 miles north of Glover postoffice (in the NE. ¼, sec. 9, T. 5 S., R. 23 E.); a bluff now being undercut by Mountain Fork River, 3 miles south of Hochatown (in the SW. ¼, sec. 33, T. 4 S., R. 25 E.); and two precipitous prominences around the bends of Mountain Fork 4 miles north of Hochatown (secs. 27 and 29, T. 3 S., R. 25 E.) The exposures in Sec. 27, T. 3 S., R. 25 E., are beyond question the best of them all, but the strata here are inverted and dip 53° north. (See Plate XVI). A thorough study was made of the Bigfork chert at this place and representative specimens collected. Following is the detailed description of the beds. The horizons are numbered in order from top downward stratigraphically, but from water level to mountain top in the field.

Partial section, Bigfork chert (upper part), SE. ¼, sec. 27, T. 3 S., R. 25 E.:

Top. (Stratigraphically)	*Thickness Feet*	*Inches*
1. Massive ledges of black chert with cherty shale partings and some massive ledges of dark limestone with chert concretions; outcropping in river bottom and not well exposed; series is transitional to Polk Creek shales; strike is N. 85 W. and the dip 53° N. Calculated thickness	130	
2. Gnarled thick massive ledges of black chert, calculated thickness	47	
3. Massive dull, coal-black chert with small stringers milky quartz—a single heavy bed, gnarled and twisted	7	
4. Coal-black hard brittle chert, distinctly bedded in undulating layers		4
5. Coal-black, hard, brittle chert with crystalline black cherty limestone layers in beds 2 inches to 8 inches thick undulating; thin quartz veins	3	9
6. Cherty black limestone, massive bed with calcite veins	2	4
7. Thin bedded black chert, wavy, irregular; contains quartz calcite and pyrite in thin blanket veins	2	
8. Cherty black massive limestone with thin calcite and quartz veins bedded at top 2 inches to 6 inches	3	3
9. Chert, slightly calcareous in one inch beds, even, fine grained		6
10. Coal Black Chert		3
11. Cherty, hard, black shale, cutting edges		5
12. Irregularly bedded black chert layer, average thickness		3
13. Black cherty shale, thin cherty layers included	-	8
14. Pearly gray, calcareous massive chert, rather soft, irregularly bedded, carries carbonate veins		8
15. Irregularly bedded coal black chert in thin layers partly shaly	2	9
16. Fine-grained pearly gray massive bed limestone; cherty at top with 1 inch bedding	2	2
17. Coal black brittle Chert in beds 1 inch to 4 inches with quartz veins interbedded	3	7
18. Fine-grained pearly gray crystalline limestone indistinctly bedded calcite veining	1	1
19. Dull, sooty, coal black chert in wavy beds 1 inch to 6 inches	1	7
20. Pearly gray finely crystalline cherty limestone, undulating bed	2	
21. Dull coal black hard Cherty layers, undulating and unevenly bedded		4
22. Pearly gray fine grained crystalline limestone grading laterly into black chert		6
23. Shaly thin bedded dull black chert, with small milky quartz veins		8
24. Hard, brittle black chert in two beds of 2 inches and 10 inches	1	
25. Pearly gray to lavender crystalline limestone harsh to the feel, few calcite veins perpendicular to the bedding	1	
26. Thin bedded coal black chert in beds 1 inch to 3 inch	3	9
27. Finely crystalline light gray limestone as above, wavy		8
28. Unevenly bedded, hard undulating chert in beds 1 inch to 12 inches thickness	1	10

29.	Pyritiferous fine-grained crystalline gray limestone, cherty at top		11
30.	Shaly chert		6
31.	Siliceous (cherty) light gray limestone, harsh to the feel, calcite veined, more cherty at top	1	2
32.	Harsh black chert, fine quartz veins, undulating bedding 1 inch to 6 inches	1	6
33.	Hard, harsh, light gray, fine-grained crystalline limestone	1	2
34.	Dull sooty, coal black, medium hard, thin bedded (1 to 4 inches chert	3	2
35.	Crystalline, light gray, fine grained, limestone cherty at bottom, all calcite-quartz veined		11
36.	Coal black, dull, sooty chert in thin beds shaly at top; calcareous parting below	1	6
37.	Limestone layer, single bed vertically veined, thin calcite-quartz veins	1	2
38.	Thin-bedded, sooty, coal black chert, vertically jointed, undulating in beds 1 inch to 2 inches including a blanket vein of milky quartz which bifurcates, thins and thickens	1	2
39.	Sooty black chert as above		9
40.	Calcareous chert and cherty limestone thinly and unevenly bedded	1	6
41.	Hard, brittle, black chert, thin, fine quartz veins		5
42.	Soft light gray limestone, cherty in thin lenses, calcite and quartz veined	3	
43.	Massive light gray limestone bed containing black chert nodules and calcite and quartz veins	3	
44.	Coal black undulating hard chert in layers up to 4 inches	3	6
45.	Dark limestone grading above and below into chert, undulating, calcite veins vertical		8
46.	Black chert band grading into limestone below		4
47.	Sooty, black, cherty shale		2
48.	Sooty, black chert, undulating beds 4 inches to 8 inches	1	
49.	Distinctly crystalline fine-grained limestone, cherty in thin lenses, calcite and quartz veined	1	4
50.	Slightly calcareous chert		6
51.	Thin bedded undulating chert layers as above, calcareous in patches	3	
52.	Calcareous layer, undulating and unevenly bedded with blanket vein of quartz at bottom		5
53.	Black chert in beds 6 inches to 8 inches, shaly partings and calcite veined	2	5

54.	Massive limestone ledge, cherty concretions at top and bottom	1	4
55.	Sooty, coal black chert and flint, undulating bedding in layers 1 inch to 8 inches and with cherty shale partings; calcareous concretions 2½ feet by 6 inches and quartz veins	5	9
56.	Gray finely crystalline massive limestone bed, few calcite veins.		8
57.	Stony cherty limestone, hackly fracture		6
58.	Black chert layer		10
59.	Thin bedded black chert 2 inch bedding, undulating	3	
60.	Uudulating black chert layer, few calcite veins		6
61.	Massive, coarsely crystalline light gray speckled limestone with chert nodules and quartz-calcite veins grading laterally into a predominance of chert in thin lenses and bands	1	10
62.	Resistant nodular mass of black chert with thin leaves of limestone all through it. Chert predominates and is partly in beds and partly concretionary	7	4
63.	Limestone layer		10
64.	Thinly bedded black chert layers, shaly to 2 inches		9
65.	Limestone ledge, massive, heavy bedded, small chert nodules in upper part and cherty at base, calcite and quartz gash veins	2	4
66.	Thin bedded black chert, hard brittle, undulating in beds 1 inch to 4 inches	3	6
67.	Resistant hard black chert ledge		9
68.	Two blanket veins of quartz		2
69.	Black chert ledge calcareous at base	1	
70.	Thinly bedded 1 inch cherty limestone and calcareous chert	2	4
71.	Hard, resistant, black chert layer calcareous below locally	1	3
72.	Sheared shaly chert		6
73.	Undulating layer dark limestone		3
74.	Cherty shales and chert layer at top		7
75.	Resistant black chert calcareous locally at base	1	5
76.	Undulating thin bedded (under 2 inches) black chert	1	
77.	Hard black chert ledge		6
78.	Heavy ledge finely crystalline light gray limestone containing nodules and cherty layers at top	2	5
79.	Undulating band of black chert average thickness		3
80.	Undulating band of light gray limestone		5
81.	Undulating unevenly thin bedded, black sooty chert		11

82.. Undulating unevenly thick bedded, black sooty chert, shaly parting below		8
83. Undulating unevenly bedded ledge of black chert with local calcareous band.	1	10
84. Mass of black chert in undulating layers with irregular beds of limestone full of chert nodules near the middle averaging 1 foot	8	
85. Heavy ledge of fine-grained gray limestone finely crystalline, few large chert nodules, undulating	2	
86. Hard brittle black chert ledge, shaly at top	2	1
87. Hard brittle black chert ledge shaly at top	1	2
88. Hard brittle black chert ledge shaly at top	1	2
89. Resistant cherty limestone	1	
90. Undulating, unevenly bedded chert		4
91. Fine-grained, crystalline, gritty siliceous limestone, few chert nodules		9
92. Undulating, heavy bedded black chert in beds 2 inches to 10 inches locally containing a calcareous band	3	6
93. Cherty coal black shales becoming calcareous at top, merging into limestone	2	
94. Limestone layer, shaly at bottom becomes cherty laterally	2	5
95. Hard black chert, undulating, 2 shaly partings	2	3
96. Cherty coal black shale		5
97. Hard black chert		9
98. Resistant black chert sheared in beds 6 inches to 8 inches forming a resistant shoulder on the mountain side	5	
99. Hard, finely crystallized light gray, siliceous limestone containing cherty concretions.	2	6
100. Hard finely crystalline light gray siliceous limestone containing cherty concretions to the extent of 50% of the mass, heavy bedded massive ledges	30	
101. Heavy bedded black chert in layers 1 foot or more thick	4	
102. Heavy bedded calcareous ledges with chert concretions	10	6
103. Calcareous cherty layers and siliceous cherty limestone in undulating beds a foot thick or more with cherty, shaly partings. Calcareous bands are distinctly separated from the cherty layers generally, uniformly interbedded, no concretions or veins.	12	9
104. Black chert layer "vesicular" structure		1
105. Hard black chert in 2 inch layers		6
106. Hard black chert layer	1	
107. Banded black chert layer		4

108. Calcareous banded black chert in layers 1 inch to 4 inches		9
109. Coal black chert with calcareus blotches (replacement effects?)		3
110. Hard resistant black chert layer	2	4
111. Hard resistant black chert layers under one foot thickness, over all	3	5
112. Shale parting		2
113. Hard resistant black chert layer	1	1
114. Hard resistant black chert layer calcareous at bottom locally	1	4
115. Shaly calcareous layers	4	
116. Hard black chert layer undulating		5
117. Hard black chert layer undulating		5
Section discontinued because of poor and interrupted exposures, but judging from the float cherty limestones and black chert alternate to form a considerable added thickness.		
Total measured portion:	416	9

The succession is a rather uniform series of black cherts and cherty black limestones and is uniformly bedded when viewed at large. If other formations were not also exposed in the locality it would be impossible to tell from the lithology of the formation itself which might be the top and which the bottom of the series.

A large number of specimens was collected from this cliff as characteristic and representative of the Bigfork chert and most of these have been studied microscopically. The principal facts brought out by this study are given in the resume following.

THICKNESS

Because of the float-covered condition of the Bigfork exposures generally no complete section of the formation was measured; and on account of the complicated folding which seems likewise to be very general in the Bigfork no trustworthy calculation of its thickness could be made. It is estimated however that there are about 800 feet of the cherts. Nothing is known of the relative thickness in different localities.

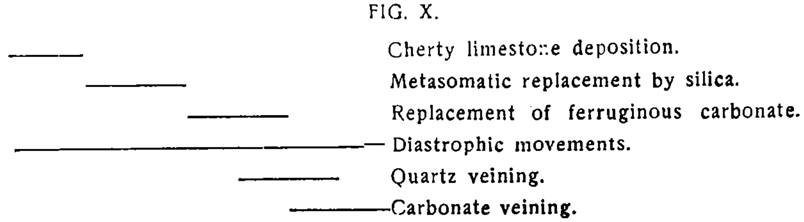
RESUME AND CONCLUSIONS

The essential facts of the sedimentation of the Bigfork chert formation are: (1) the wide spread distribution and so far as known the uniform character of the formation over the entire region speaking for conditions of deposition of more than local significance; (2) the presence of crinoid stems and abundant fragmental remains of brachiopods and other animals in the cherty limestones indicating the marine origin of the formation; and (3) the transitional character of the beds at the bottom into the Womble equivalent and of the beds at the top into the Polk Creek shale pointing to conformable contact with the underlying and overlying formations.

The principal facts brought out by the microscopic study of the hand specimens collected from the measured section of the cherts are as follows: (1) Metasomatic replacement of fossil fragments (carbonates) by cherty, fine grained silica in some horizons or places, but not in others indicating that much of the chert is secondary and that limestone originally was more abundant in the Bigfork formation than now. (2) Ferruginous-carbonate (siderite) replacing chert in large or small amounts in some cases observed, and not at all in others, indicating an uneven introduction of the carbonate, which came in, doubtless, as a hydro-thermal magmatic emanation. (3) A precipitation of secondary, fibrous quartz in front, or to the rear of the siderite rhombohedra indicating movement subsequent to the introduction of at least a part of the siderite. (4) The presence of quartz-carbonate veins in which quartz appears adjacent to the walls and the carbonate in the middle, showing that the latter was deposited subsequent to the quartz in the veins. (5) The occurrence of pyrite cubes and of tiny spherical bodies of quartz which are probably normal growths of these minerals subsequent to the period of sedimentation and mean nothing in particular. (6) The development of chlorite and other reorganization products resulting from the diastrophic movements. (7) The development of shear-zones and crush-zones in the cherts and of marked schistosity in some of the more argillaceous horizons resulting also from diastrophic movements. Quartz and carbonate have occupied crevices and cracks pretty generally wherever formed.

The paragenesis of the Bigfork chert would therefore be represented about as given in the diagram. (Fig. x).

FIG. X.



POLK CREEK SHALE

GENERAL DESCRIPTION

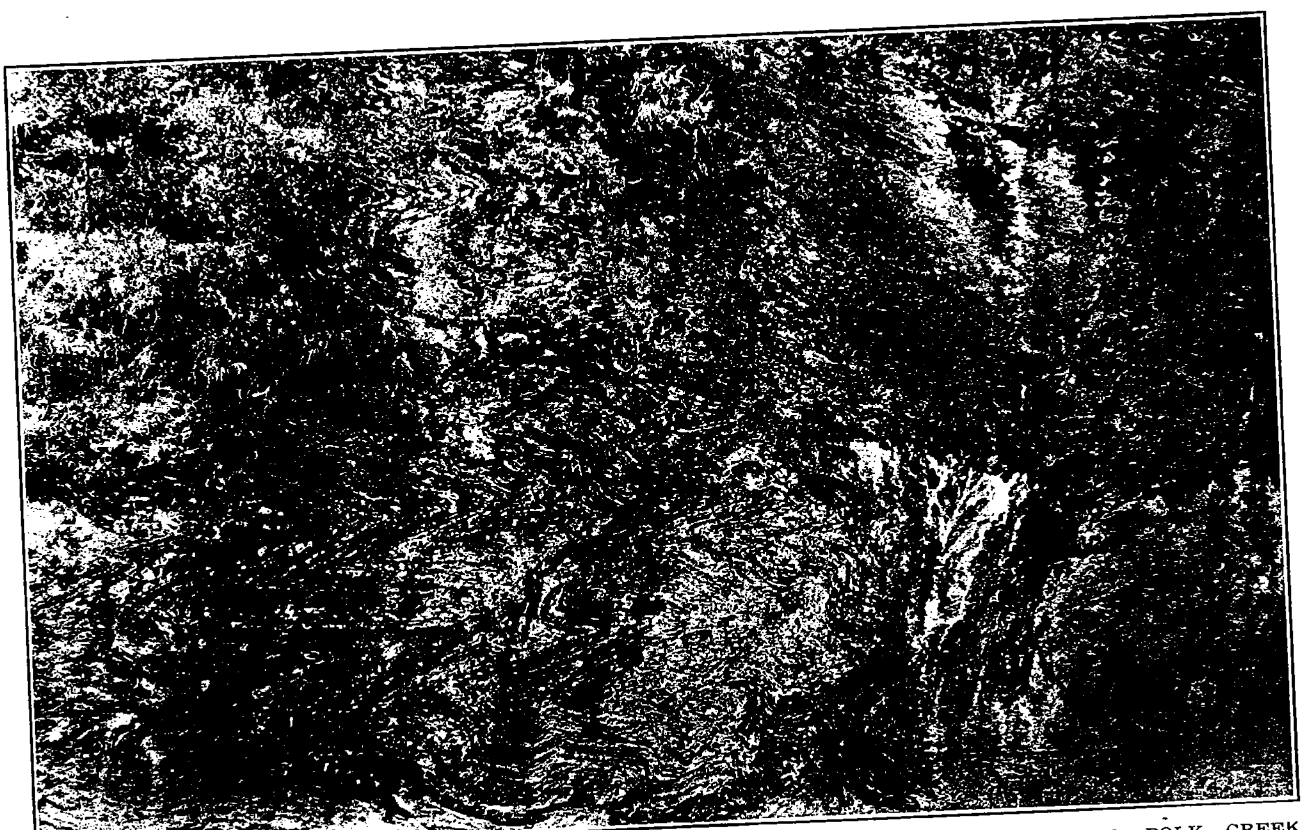
The Polk Creek shale is a coal-black, graphitic, firmly indurated, but soft slate and shale, which hugs the upper side of the Bigfork chert and follows it in all its crooks and turns throughout the region. It is conformable with the Bigfork and is in reality only a shaly and final stage of that formation for in its lower portion it carries cherty layers and is transitional.

Owing to its non-resistant character and its failure to have accumulated in great thickness it is exposed to view only under the most favorable circumstances. As a rule a steep sided V-shaped valley, one side covered with Bigfork chert float and the other with Blaylock sandstone float, marks the horizon of this formation as it strikes through the mountains. It is almost never seen in outcrop and even the float from it, always weathering light bluish gray in color, is often entirely missing, being covered by the talus of the more resistant formations.

Of the few exposures available for close examination the best are to be found around the outside of Beaver Bend of Mountain Fork River and up the small creeks which enter the river from the west and south at this point (in the SW. ¼, sec. 9, and SE. ¼ sec. 8, T. 5 S., R. 25 E.) The dip of the rocks in this general region is low and although the Polk Creek is sheared, and contorted and the thickness not determinable, yet the character of the strata can be studied at length over a considerable acreage and the transitions to the Bigfork on the one side and to the Blaylock on the other observed. The transitional series of fine shale and thin sandstones and the sediments marking the initial deposits of the Blaylock sandstone appear in a partially covered, precipitous slope overlooking the river in sec. 8 and can be studied here in detail as nowhere else, but unfortunately no time has, as yet, been given to a special study of this section. The river swinging against the bank immediately south in this locality has cut a vertical cliff several hundred feet in length exposing long stretches of the Polk Creek, but on account of deep water and the precipitousness of the cliff these particular exposures are inaccessible. Photographs were taken of them, however, and they are here reproduced to show the contortions common to this shale even where the folding is not of the most severe type.

Excellent exposures occur also in the bend of Mountain Fork River 4 miles north of Hochatown (in sec. 27, T. 3 S., R. 25 E.) adjacent to the Bigfork chert outcroppings occurring at that same place. One may stand on the opposite bank and look at these as he can the cliffs just menioned in Beaver Bend, but they are inaccessible for detailed study, and indeed such observations would not be worth the pains if they were, on account of the twisted, and many

A VIEW LOOKING WEST AT A VERTICAL CLIFF OF CRUMPLED POLK CREEK SHALE APPEARING ON THE WEST BANK OF BEAVER BEND OF MOUNTAIN FORK RIVER IN THE SE ¼, Sec. 8, T. 5 S., R. 25 E.
The principal fold is standing on edge, so to speak, and becomes double at the south end. The jointing is vertical. Large blocks of the shale have fallen out in places.



A VIEW LOOKING WEST ACROSS MOUNTAIN FORK RIVER AT A VERTICL WALL OF CRUMPLED POLK CREEK SHALE, 200 PACES WEST OF THE E ¼ COR., SEC. 8, T. 5 S., R. 25 E.
The white stains on the cliff are of aluminum sulphate.

times overturned condition of these rocks. The photographs are characteristic views of the Polk Creek as here exposed and serve the purpose better than pages of description.

There are some very good, but partially covered exposures of the Polk Creek shales on the hillsides in the SW. ¼, sec. 12, and in the center of sec. 5, T. 4 S., R. 25 E. Black shales and slates appear as float or as small outcroppings in the bottoms of flat bottomed creeks, on saddles of mountains or occasionally on hillsides in a few places elsewhere in the region, but as very small and imperfect exposures only. The formation in most places has been recognized and mapped chiefly by its characteristic light blue colored float.

Typical of the slopes formed by outcropping Polk Creek is that found 4 miles southeast of Hochatown (¼ mile north of the center of sec. 1, T. 5 S., R. 25 E.) where an inverted section of chert, slate and shale forms a slippery talus on the south side of the 400 foot ridge in that region. The mountain side is thinly strewn with the bits of slate which slide down a 45° slope. A thin covering of dark clay soil has accumulated in favorable places and holds small trees and brush while here and there a chert ledge protrudes its jagged profile and looses occasional angular sharp edged blocks, which roll to the foot of the cliff. If it were not for the thin covering of brush and small trees the slope would be very hazardous either of ascent or descent.

THICKNESS

It has not been possible to ascertain the exact thickness of the deposits, but Miser* in describing the Polk Creek shale of the Caddo Gap and DeQueen Quadrangles of Arkansas states that the thickness ranges from 0 to 175 feet. In Oklahoma the writer judges there were from 100 to 200 feet of these shales, but these figures represent merely an estimate and not a calculation.

GRAPTOLITES IN THE SHALES

At the NW. cor. of sec. 2, T. 5 S., R. 23 E. black shales and slates of the Polk Creek formation yielded great numbers of graptolites in several outcroppings, but they are poorly preserved and all that were seen were unidentifiable. Graptolites were observed in the Polk Creek, also at a point 250 paces north of the S. ¼ cor., sec. 26, T. 4 S., R. 23 E. and again 500 paces south of the center of sec. 6, T. 4 S., R. 26 E., along Otter Creek.

MICROSCOPIC PETROGRAPHY

The great bulk of the Polk Creek shale is graphitic or carbonaceous shale containing varying amounts of siliceous and argillaceous matters. When examined microscopically the majority of the thin

*Miser, H. D., Bull 660-C U. S. G. S., P. 67.

PLATE XXI.

LOOKING N. 65° E. TOWARD A 150 FOOT BLUFF OF SHARPLY AND COMPLEXLY FOLDED POLK CREEK SHALE, FORMING THE EAST BANK OF THE RIVER, ONE-FOURTH MILE NORTH OF THE S. ¼ COR., SEC. 27, T. 3 S., R. 25 E. The Bigfork Chert lies on top of this mass to the north (left in picture) and a portion of the Blaylock sandstone lies beneath it to the south (right, not showing in picture), the entire series dipping north at an angle of about 40°; Note the details of the structure in the cliff.

PLATE XXII.

LOOKING EAST AT THE SOUTHERN END OF THE POLK CREEK SHALE BLUFF, 350 PACES EAST AND 150 PACES NORTH OF THE S. ¼, SEC. 27, T. 3 S., R. 25 E.

The cliff is vertical, in places overhanging, and rises out of deep water. Note the details of the structure.

sections reveal a mass of tiny shreds, flakes and grains of the finest sizes, more or less uniformly distributed, but not always regularly oriented through the abundant graphitic matrix. The tiny shreds and flakes are often too small to identify or interpret, but quartz, sericite, and chlorite are usually definitely present and sometimes epidote. The quartz occurs most often as fine indefinite grains with "hazy" borders as though portions of it had been dissolved by hydro-thermal processes and the remainder sheared and dragged out into long stringers. Sometimes the quartz is present in the form of fine grit embedded in the graphite. Microscopic veinlets of quartz, as introduced matter, also abound.

Of special interest is the thin conglomerate layer occurring locally near the top of the Polk Creek shale (300 paces south and 100 paces east of the W. ¼ cor., sec. 35, T. 3 S., R. 25 E.; also 500 paces south of the N. ¼ cor., sec 6, T. 4 S., R. 26 E.) It is composed of black chert, limestone pebbles, and granite gravel up to ¼ inch in diameter, roughly assorted and mingled with a considerable amount, estimated at 10 per cent of slaty-shaly matrix. When examined microscopically the granitic fragments are found to be complex rounded grains and associated with them, besides chert and limestone, are rounded pieces of basalt. The rock is heavily carbonated with replacement siderite, which is altering to an abundant limonite. Pyrite is also present in well formed cubes although very sparingly. There is no definite indication in the two or three specimens studied that the particular layer here described, is a volcanic breccia, but a further study of it might prove it to be such, for it resembles very closely the thin agglomerate to be described as occurring at the top of the basal division of the Arkansas novaculite.

RESUME AND CONCLUSIONS

The chief fact with regard to the sedimentation of the Polk Creek shale is that of its deposition in relatively deep, but shallowing seas of wide extent, conformably upon the preceding, and deeper water deposit—the Bigfork chert. The deposit seems to have been a black mud much of which was organic in origin. Some of the shales are argillaceous, others are siliceous, but these matters are no more abundant, it appears in many instances, than the organic content of the rock. The conglomerate layer discovered near the top of the formation at two points might be taken to indicate a coming change of conditions at the close of the Polk Creek sedimentation, but so gradually do the sandy sediments of the Blaylock come on that the transition is made, it is believed, without a break.

BLAYLOCK SANDSTONE

GENERAL DESCRIPTION

The Blaylock sandstone, on account of its thickness and consequent broad and extensive outcroppings, covering many square miles of country, is geologically of considerable importance, and stamps a large portion of the area with a characteristic hilly topography.

The areal distribution of this formation can best be had by referring to the map accompanying this report, whence it will be seen to form a complicated series of zigzags having long pointed projections and re-entrants depicting truthfully the character of the larger structural features of the region. In general there are two areas of outcroppings: a large one zigzagging back and forth about the main axis of the Choctaw anticlinorium and a smaller area farther north forming the central mass of the Cross Mountains anticlinorium.

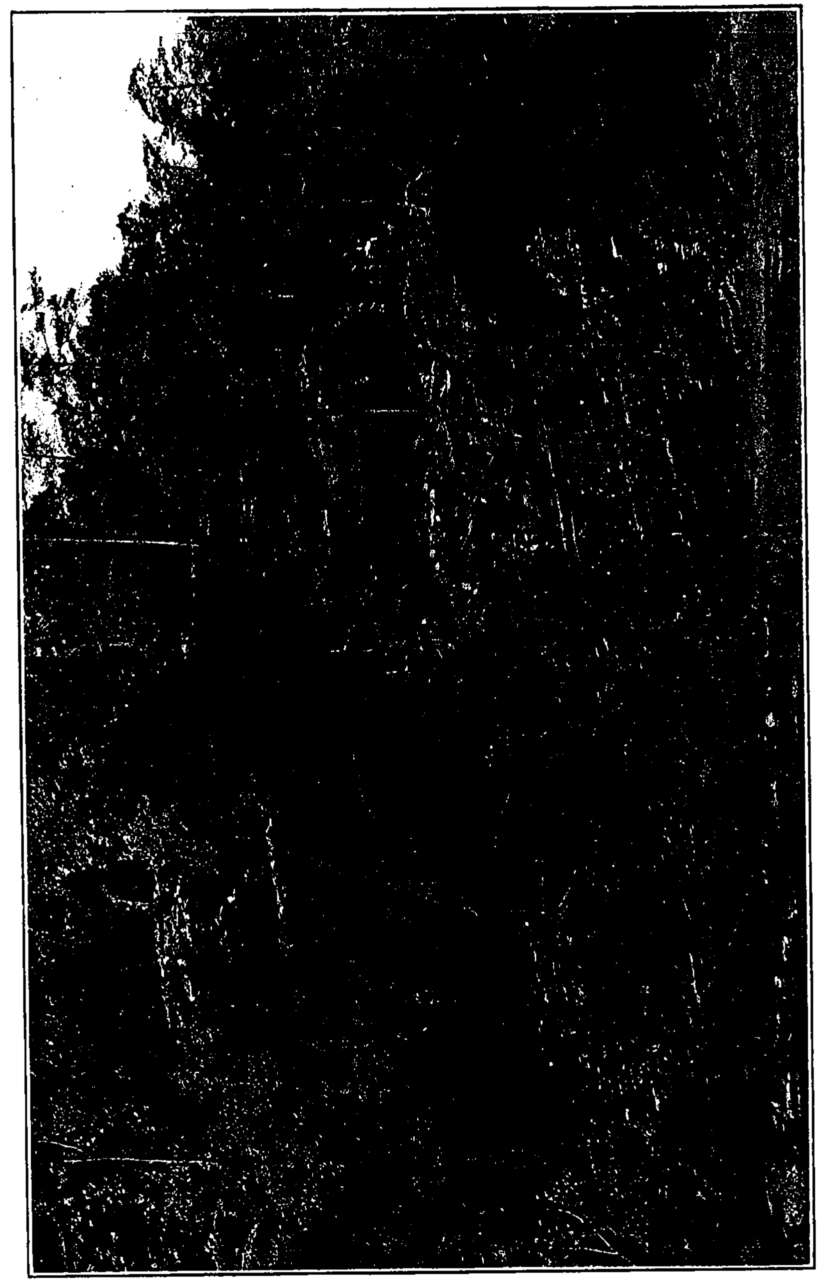
The strata comprising this formation are thin bedded, fine-grained, greenish gray, hard sandstones and inter-bedded shaly sandstones and dark shales, all of which, upon exposure, weather to a decidedly red color. Moreover, in practically all parts of the field the sandstones seem to be characteristically veined with veins of smoky quartz, which have a width usually of 2 to 3 mm.

The bedding and the character of the sediments of the lower part of the formation can best be observed as pointed out above, in Beaver Bend of Mountain Fork River, (SE. ¼, sec 8, T. 5 S., R. 25 E.) where the river in swinging against the bank has cleared away the fallen debris leaving the steep slope and cliff exposed. The lower most beds, at this place, are dark, carbonaceous, fine, sandy silts intimately interbedded with argillaceous materials of the type composing the black Polk Creek shales below, but grading upward into thin sandstones and sandy shales of dark chocolate brown color above and passing finally, still higher in the series, into sandstones proper. The thickness of the transition beds is about 100 feet. This transition may be seen also at a point one mile east of Hochatown in a partially covered slope on the north side of the road (in the NW. ¼, sec. 23, T. 4 S., R. 25 E.), but not so satisfactorily. A little farther east, however, in a ravine which connects with the creek, the middle portion is exposed in good shape, and advantage has been taken of this fact and the section measured as follows:

Blaylock Sandstone, NW ¼ Sec. 23, T. 4 S., R. 25 E.

Top		Thickness *Feet*	*Inches*
39.	Top of Blaylock not well exposed; apparently very shaly. Thickness as calculated from the following data: Diff. elev. 40 feet; hor. dist. 73 feet; direction, normal to strike of strata; dip of rock 28° NE.	69	1
38.	Sandstones and shales, not well exposed. Thickness as calculated from the following data: Diff. elev. 96 feet; hor. dist. 250 feet; direction, normal to strike of strata; dip of rock 28° NE.	202	1

PLATE XXIII.



BUZZARDS ROOST. THIN BEDDED, HARD, GREENISH GRAY, FINE-GRAINED SANDSTONES OF THE BLAYLOCK FORMATION STRIKING N. 35° W., AND DIPPING 15° NE.
Location, south bank of Mountain Fork River, about 200 paces east of the S. ¼ cor. sec. 4, T. 5 S. R. 25 E.

		Feet	Inches
37.	Same as above; data: Diff elev. 5 feet; hor. dist. 60 feet; direction normal to strike; dip 24° N. E. Calculated thickness	32	6
36.	Same as above; data: Diff. elev. 0; hor. dist. 52 feet; direction normal to strike; dip 20° N. E.; Calculated thickness	17	9
35.	Same as above; data: Diff. elev. 22 feet, 6 inches; hor. dist. 65 feet; direction of line, normal to strike; dip of beds, 23° N. E. Calculated thickness	45	11
34.	Green, fine grained hard sandstone	2	3
33.	Thin bedded green fine-grained hard sandstones, shaly at top	2	
32.	Thin bedded, green fine grained hard sandstones, undulating below	3	3
31.	Thin bedded shaly sandstone		4
30.	Greenish gray hard sandstone layer parting in middle	1	6
29.	Greenish gray hard sandstones in layers 4 inches to one foot without shaly partings	6	8
28.	Greenish gray fine grained sandstone (sp. 1041)		7
27.	Greenish gray sandy shale and shaly sandstone		10
26.	Greenish gray fine-grained thin bedded sandstone (sp. 1042)	3	
25.	Hard evenly bedded, fine-grained, greenish gray sandstone in beds 2 inches to ten inches over all	19	5
24.	Hard, fine-grained, greenish gray quartzitic sandstone		6
23.	Hard, thin bedded, shaly sandstone, over all	1	
22.	Hard fine-grained, greenish gray sandstone	3	
21.	Dark gray sandy shale		[illegible]
20.	Shaly greenish gray sandstone	1	4
19.	Hard, fine-grained gray sandstone	2	4
18.	Greenish gray clay shale (sp. 1043)		8
17.	Hard greenish gray fine-grained sandstone ledge (sp. 1044)	2	7
16.	Hard, greenish gray fine-grained sandstone ledge	1	3
15.	Shaly sandstones	1	6
14.	Heavy bedded fine-grained greenish gray hard sandstones	4	11
13.	Fine grained greenish gray quartzitic sandstone layer		10
12.	Fine grained greenish gray sandstones, unevenly bedded		0
11.	Sandy shales and shaly fine grained sandstones	1	4
10.	Hard, greenish gray, fine-grained sandstones, splintery and weathering with cutting edges	1	9
9.	Greenish gray, hard, fine-grained sandstone	9	8
8.	Hard, fine-grained, thin bedded, wave marked sandstone striking N. 35° W., dipping 22° NE.	4	8

		Feet	Inches
7.	Thin bedded, hard, greenish gray, fine-grained sandstones with thin quartz veins	1	7
6.	Greenish gray, fine-grained, hard sandstones, thickly bedded	1	9
5.	Green, hard, thin bedded quartzitic sandstone	5	7
4.	Thin, evenly bedded, greenish gray, fine-grained sandstones	10	2
3.	Covered, probably shaly sandstones	3	
2.	Hard, greenish gray, thick bedded sandstones with peculiar markings "worm trails," at top, forming the final exposures at bottom of gully. Strike of the beds at this point N. 35° W., and the dip 18° NE.	5	2
1.	The bottom of the section is covered with the exception of certain hard sandstone layers projecting from the mountain side. The thickness of this portion was calculated from the following data: Direction of the line connecting the bottom of the Blaylock with item No. 2 above, N. 85° E; difference in elevation of the ends of this line, 0; length of line as measured by tape, 1,250 feet; strike of bedding N. 25° W.; dip of rocks 18° NE. Calculated thickness	331	5
	Total thickness	804′	5″

Near the mouth of Cedar Creek (in the SE. ¼, sec. 29, T. 4 S., R. 23 E.) Cedar Creek is undercutting a bluff, locally known as "Alum Bluffs," in which are exposed about 100 feet of the uppermost portion of the Blaylock sandstone, all of the Missouri Mountain slate and all except the upper division of the Arkansas novaculite. That portion of the section here exposed which has to do with the upper part of the Blaylock follows:

Upper Part Of Blaylock Sandstone, SE. ¼ sec. 29, T. 4S. R. 23E.

Top		*Thickness* *Feet*	*Inches*
100.	Soft, sandy to argillaceous blue shale weathering back in cliff (initial sedimentation of the Missouri Mountain shale)	1	2
99.	Hard gray sandstone, siliceous shale parting in middle		10
98.	Hard, thin-bedded, sandy shale, gray in color becoming argillaceous at top	2	
97.	Prominently ripple marked gray sandstone		2
96.	Hard, drab clay shale		8
95.	Quartzitic ripple marked, unevenly bedded sandstone "worm trails" (sp. 977)		2
94.	Hard, drab clay shale	1	10
93.	Hard sandstone		4
92.	Hard slaty layer		3

91.	Hard sandstone bed		4
90.	Siliceous shale, cutting edges		3
89.	Resistant light gray quartzitic sandstones		4
88.	Soft shaly sandstone, unevenly bedded, sheared and schistose		10
87.	Greenish gray, soft, fine-grained sandstone		5
86.	Black to blue thick bedded clay shale		3
85.	Hard sandstone layer, slightly ripple marked		3
84.	Siliceous silver gray shale, sheared and schistose		4
83.	Thin, evenly bedded, ripple marked sandstone, shaly at top		5
82.	Shale, slightly siliceous		7
81.	Hard, light gray sandstone, shaly at top		5
80.	Drab colored slightly siliceous shale		2
79.	Light green quartzitic sandstone		2
78.	Sheared siliceous shale		4
77.	Light greenish gray quartzitic sandstone		5
76.	Argillaceous shale parting		3
75.	Ripple marked, fine-grained sandstone		3
74.	Light greenish gray, siliceous, ripple marked shale		10
73.	Hard sandstone, layer undulating at top—thrust faulted from the south		4
72.	Sheared, siliceous, hard shale		11
71.	Light greenish gray, resistant, gritty sandstone, not quartzitic		5
70.	Somewhat siliceous, hard, tough, slaty, drab colored shale	2	10
69.	Light greenish gray sandstone, gritty at bottom		9
68.	Tough, hard, dark gray shale		7
67.	Greenish gray, hard, quartzitic, thin bedded sandstone in beds under 1 inch	1	
66.	Hard, light blue clay shale evenly and thinly bedded	1	4
65.	Undulating blue quartzite layer		4
64.	Hard, slightly siliceous shale, protrudes in bluff with cutting edges	2	
63.	Hard, fine-grained, dark blue quartzite, two undulating partings dividing it into thirds	1	6
62.	Soft, thickbedded, blue to black argillaceous shales	1	7
61.	Hard, dark blue sandstone in layers 1 to 4 inches, smoky vein quartz—over all	1	7
60.	Dark blue, fine-grained quartzitic sandstone	1	4
59.	Dark gray to blue, tough argillaceous shale	1	
58.	Gray, siliceous, hard, massive, shaly sandstone		7
57.	Dark gray quartzite (sp. 968)		10
56.	Soft, blue, argillaceous shale		3

55.	Hard resistant blue quartzite layer		8
54.	Argillaceous blue shale		6
53.	Schistose, ripple marked sandstone	1	
52.	Resistant, fine-grained greenish gray quartzite		4
51.	Gray, shaly, schistose sandstone		9
50.	Gray sandstone, shaly at top		9
49.	Shaly, siliceous, schistose, ripple marked sandstone	5	
48.	Light gray, evenly bedded, fine-grained sandstone in beds 2 feet to 6 inches	4	4
47.	Slaty, hard, blue to dark gray shale, partially covered	2	
46.	Massive, light gray sandstone, undulating parting in the middle	2	7
45.	Light bluish gray, soft, slightly siliceous shale		4
44.	Fine-grained, greenish gray quartzite ledge		4
43.	Hard, blue, slaty shale		10
42.	Grayish green, resistant, unevenly and poorly bedded (sp. 967)	3	8
41.	Hard, dark gray to blue clay shale, soft and thick bedded		10
40.	Unevenly, thinly bedded, hard, gray sandstone, jointed, few quartz veins	1	8
39.	Hard, drab colored, slightly siliceous shale		5
38.	Hard, gray, fine-grained sandstone, poorly but evenly bedded	5	9
37.	Soft, siliceous shale		2
36.	Fine-grained, light gray, quartzitic sandstone, shaly at top		5
35.	Argillaceous, thick bedded, blue shale, crushed in the middle	1	3
34.	Light gray, ripple marked sandstone		3
33.	Dark gray, quartzitic sandstone		7
32.	Argillaceous shale		10
31.	Very fine-grained quartzitic sandstone with smoky and milky vein quartz		3
30.	Hard, fine-grained, ripple marked, siliceous shale		9
29.	Grayish green, hard quartzitic sandstone with numerous quartz veins	1	3
28.	Clay shale parting		3
27.	Hard, greenish gray quartzitic sandstone		10
26.	Sheared quartzitic sandstone zone		4
25.	Dark blue clay shale, siliceous in upper part	2	
24.	Dark gray, hard quartzitic sandstone, fine and even grained and tightly and evenly bedded	1	2
23.	Hard blue slightly siliceous shale	2	4

22.	Hard, light gray quartzitic sandstone, shale parting in middle		11
21.	Hard, light gray quartzitic sandstone, shale parting in middle	1	4
20.	Hard, light gray shale, sheared		2
19.	Dark gray quartzitic sandstone with numerous thin quartz veins	2	
18.	Hard blue clay shale sheared	2	2
17.	Hard, fine grained, greenish gray quartzitic sandstone		6
16.	Hard, blue argillaceous shale, breaks with cutting edge		3
15.	Greenish gray quartzitic even and fine grained distinctly bedded sandstone		6
14.	Greenish gray, fine grained evenly bedded quartzitic sandstone		11
13.	Slightly siliceous clay shale parting		2
12.	Resistant, hard, greenish gray sandstone, ledge, with quartz veins, and a 4 inch siliceous shale at bottom	1	8
11.	Dark gray quartzite ledge with a few thin quartz veins		8
10.	Hard blue clay shale slightly siliceous		6
9.	Massive, greenish gray, resistant quartzite ledge, few thin quartz veins	1	1
8.	Thin bedded, dark blue, hard, tough, jointed argillaceous shales		9
7.	Tough siliceous, sericitic drab colored, thick bedded shale		3
6.	Very thin bedded, hard, tough, jointed, dark argillaceous shale	2	
5.	Dark grey quartzitic, fine-grained sandstone, evenly bedded and splitting into three beds	2	2
4.	Blue argillaceous shale, crushed in upper 4 inches		11
3.	Resistant, hard, green sandstone ledge, jointed vertically N. 15 W. and N. 80 E. with few thin quartz veins along the joints	3	
2.	Hard, tough, siliceous, sericitic shale, blue in color at top, drab below	1	
1.	Resistant, hard green quartzitic sandstone	1	8
	Total (partial section)	91	5

As shown by these sections the bottom of the series is very shaly, the central mass as exposed east of Hochatown is 90 per cent at least, fine grained sandstone, the remainder shale, while the uppermost 91 feet, outcropping at Alum Bluffs is about 40 per cent shale and 60 per cent fine-grained sandstone. There is a notable absence of coarse grained material and there is no other evidence of a change of conditions during this period of sedimentation. It should be recalled however, that a gravel bed containing bits of chert and slate and limestone gravel up to ¼ inch in size was found

in the transition beds at the top of the Polk Creek in the southeastern part of T. 3 S., R. 25 E. and similar material, containing in addition some granitic quartz gravel was noted 3 miles to the southeast.

THICKNESS

The total thickness of the Blaylock sandstone east of Hochatown is 804 feet, but as this is the only section measured in its entirety it is not known whether there is a greater or lesser thickness elsewhere. In the southern part of sec. 19, T. 3 S., R. 25 E. and east for 6 miles there lies in normal sequence between the Polk Creek shales beneath and the Missouri Mountain shales above, a belt of the Blaylock sandstones which seems narrower than usual for a complete cross section of these rocks. The general average dip of strata in this strip is 45° north and the average distance across the outcroppings normal to the strike is about 400 paces. The calculated thickness, therefore, is about 670 feet. While not an accurate method of measuring because of variations in the dip of the rocks and because of the possibilities of faulting, etc., the calculation shows that the formation is 135 feet thinner here than 5 miles farther south at Hochatown.

The Blaylock sandstone of Arkansas is described by Miser* as "fine-grained light gray to dark gray or green, compact, hard, sandstone and buff to dark shale. Thickness 0 to 1,500 feet."

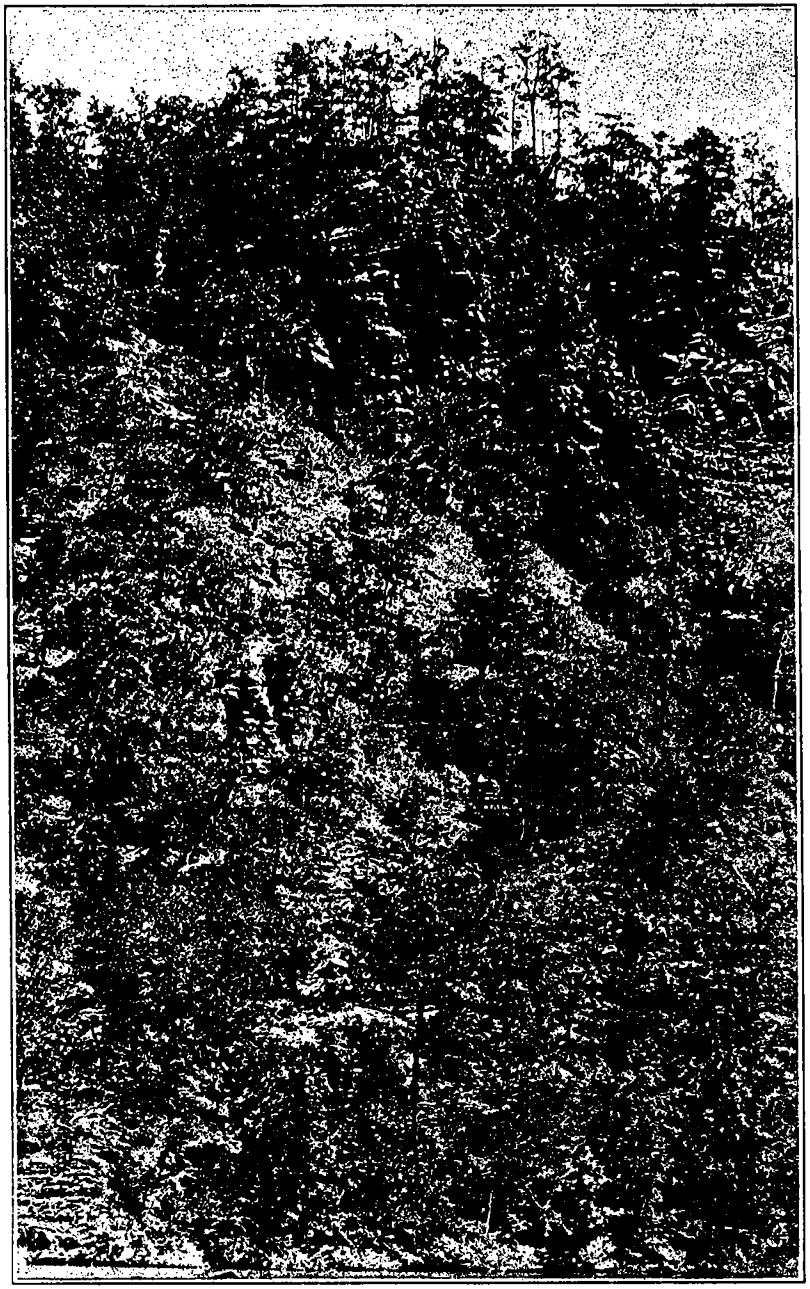
MICROSCOPIC PETROGRAPHY

A large number of specimens of the Blaylock sandstone have been collected from widely separated localities throughout the region and thin sections have been prepared of a great many of these in order to determine their essential characteristics. In general the sandstones are composed of gritty particles .01 to .2 mm. in cross section bound together by a cementing material which is now largely chlorite. The grains are chiefly of quartz, some of which are rutile bearing, but fragments of plagioclase, grains of zircon tourmaline, garnet, and leucoxene are also present in minor amounts. Plagioclases, zircon, and tourmaline appear in almost every specimen examined.

The cementing material (chlorite) in most specimens is fairly abundant and it encroaches on the borders of the grains of quartz and feldspar and occurs as flakes in the grains. As in the case of the Blakely and Womble anamorphic cements, so in the Blaylock, quartz seems to have been required in the formation of the chlorite and the grains of sand in the sandstone were called upon to furnish it. This accounts for the ragged, irregular outlines of the quartz and feldspar grains, which are firmly knit together by the granular

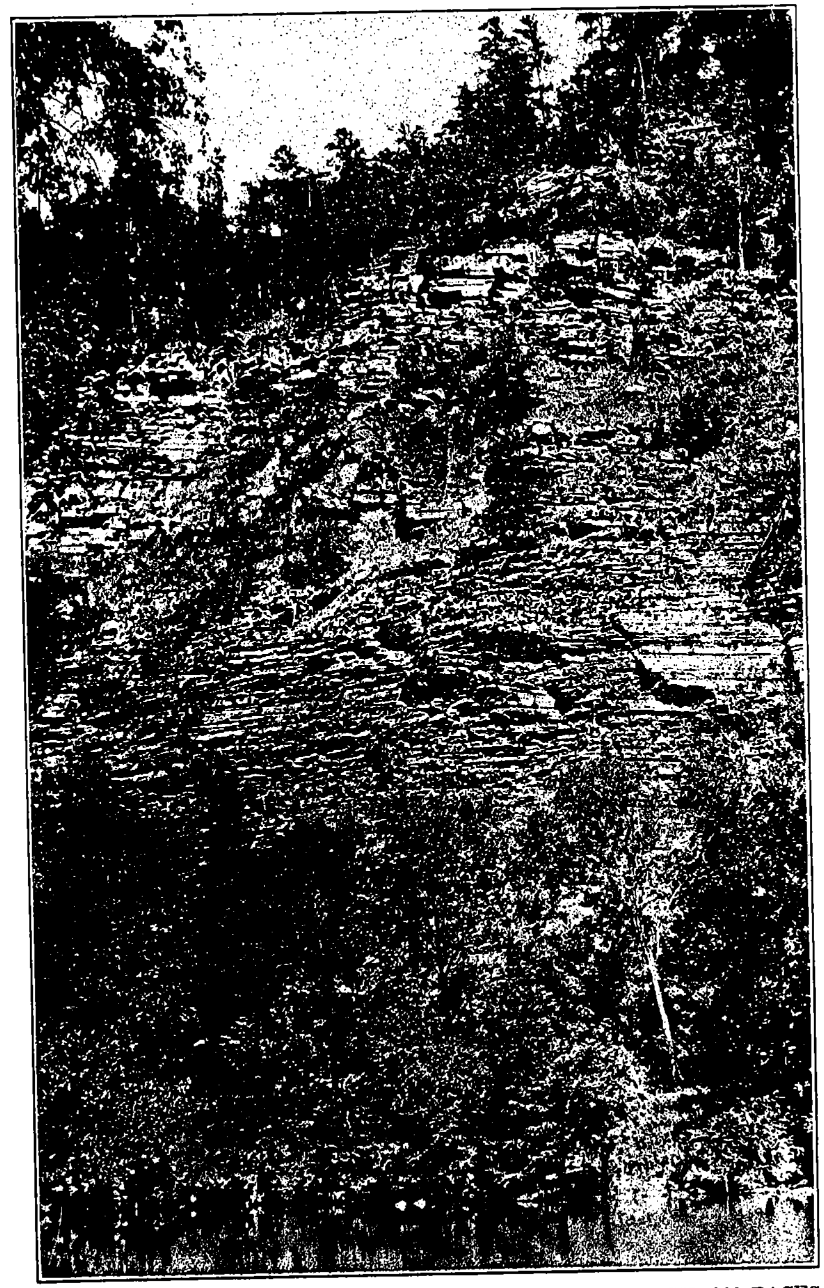
*Miser, H. .D., Bull. 660-C, U. S. G. S., p. 66.

PLATE XXIV.



BLAYLOCK SANDSTONE BLUFF ABOUT 125 FEET HIGH, 500 PACES EAST AND 400 PACES SOUTH OF THE CENTER OF SEC. 34, T. 3 S., R. 25 E., ON THE NORTH BANK OF MOUNTAIN FORK RIVER VIEW LOOKING E-NE.

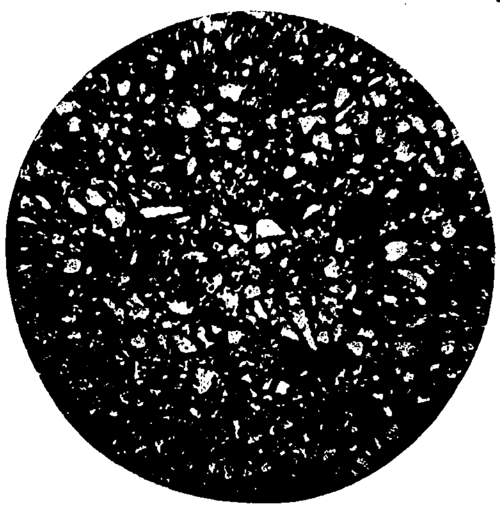
PLATE XXV.



BLAYLOCK SANDSTONE BLUFF MORE THAN 100 FEET HIGH; 300 PACES SOUTH AND 100 PACES EAST OF CENTER SEC. 34 T. 3 S., R. 25 E. NORTH BANK MOUNTAIN FORK RIVER; VIEW LOOKING NORTH.

flaky aggregate of chlorite. There is practically no limonite, epidote, or other coloring matter present in the fresh Blaylock. The materials are essentially tourmaline bearing slightly feldspathic, chlorite-quartz sandstones of which chlorite often forms as much as 10 per cent of the whole and is the cause of the greenish color of the rock when observed in the hand specimen. In a few instances observed the quartz grains have been enlarged by the addition of silica in the usual way to form quartzites. In one case the original argillaceous constituents have been reorganized for the most part to chlorite, and this is present now as flakes and grains disseminated through the added quartz.

PLATE XXVI.



Photomicrograph of characteristic Blaylock sandstone (slide 1041) showing gritty quartz (white) detrital tourmaline, zircon, and other mineral grains (not distinguishable in photograph) cemented in flaky chlorite. Plain light x 42.

The quartz veins which cut the sandstone are of two types: 1. true fissure fillings and 2. zones of penetration. The larger veins are of the first class and consist of clear, interlocking quartz grains, but the smaller veins, like those described as occurring in the Blakely sandstone, consist in thickly set lines and rows of injected inclusions in the original quartz grain. These lines of inclusions pass from one sand grain to the next, they are opaque and black, and to the unaided eye appear as true veins. The rock is thickly set with these intersecting zones of penetration. As remarked above the penetration must have taken place under conditions of extremely high pressure and temperature.

The sandstones are not ordinarily schistose; replacement carbonate occurs only sparingly, in most specimens not at all; the quartz veins are never large nor numerous.

PALEONTOLOGY

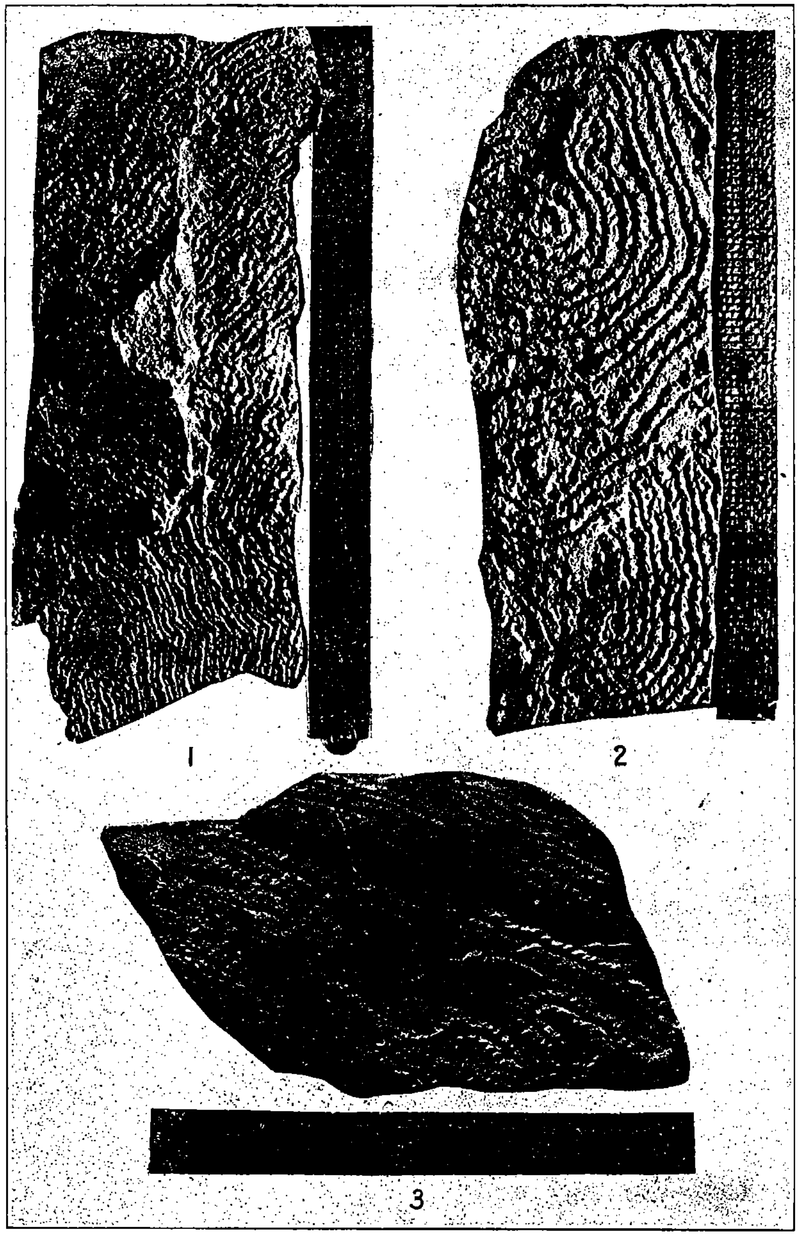
Fossils in the Blaylock sandstone are not abundant. In fact those of value in correlation and in a desirable state of preservation seem very rare. In Arkansas, at the south base of Blaylock Mountain, seven species of graptolites have been found, by means of which E. O. Ulrich was able to assign the Blaylock sandstone to the Silurian System.* No mention is made of any other finds in that State.

In Oklahoma no graptolites have been discovered in the Blaylock, nor have any fossils which might be considered important, been found. Some annelid remains, a seaweed or two, and other marks or trails were the only evidences of life appearing in this formation in this State and these are very unsatisfactorily preserved. It should be remarked, however, that on account of poor exposures, and for other reasons noted above, no special examination has been made of the basal beds and not all of the upper middle portion has been carefully searched. Possibly with patience some of the shales may be made to yield valuable returns.

The only fossils found which occur at all commonly in the Blaylock sandstone is an assemblage of markings which, for want of a more appropriate term, I have designated as "worm trails," although since they never cross each other, it seems that worms never could have made them. These have been located in the section at Hochatown (cf. ante. measured section, item 2) in a hard greenish gray thick bedded sandstone, 331 feet above the bottom of the formation, and loose slabs with these markings on them are commonly seen all over the area. Specimens 894 and 895 from a point 250 paces south of the W. ¼ cor., sec. 32, T. 3 S., R. 25 E. (Plate XXVII, figs. 1 and 2) are characteristic patterns of these trails. They consist essentially of an extended mass of much attenuated undulatory double or parallel lines which, united, terminate in blunt rounded ends. The individual lines are about 5mm. apart, which is also the distance of the parallel pairs from each other, and strangely enough these lines never seem to cross each other. They are frequently arranged in wavy rows, but more often in concentric rings or in flat spirals, and so uniformly distributed are these markings over the surface of the rock and so well connected together that the mass of lines looks more like some pattern of wall paper than anything else. In some cases there is preserved along each side of the lines a regular series of tiny impressions and elevations alternating, which resemble a fine fringe and

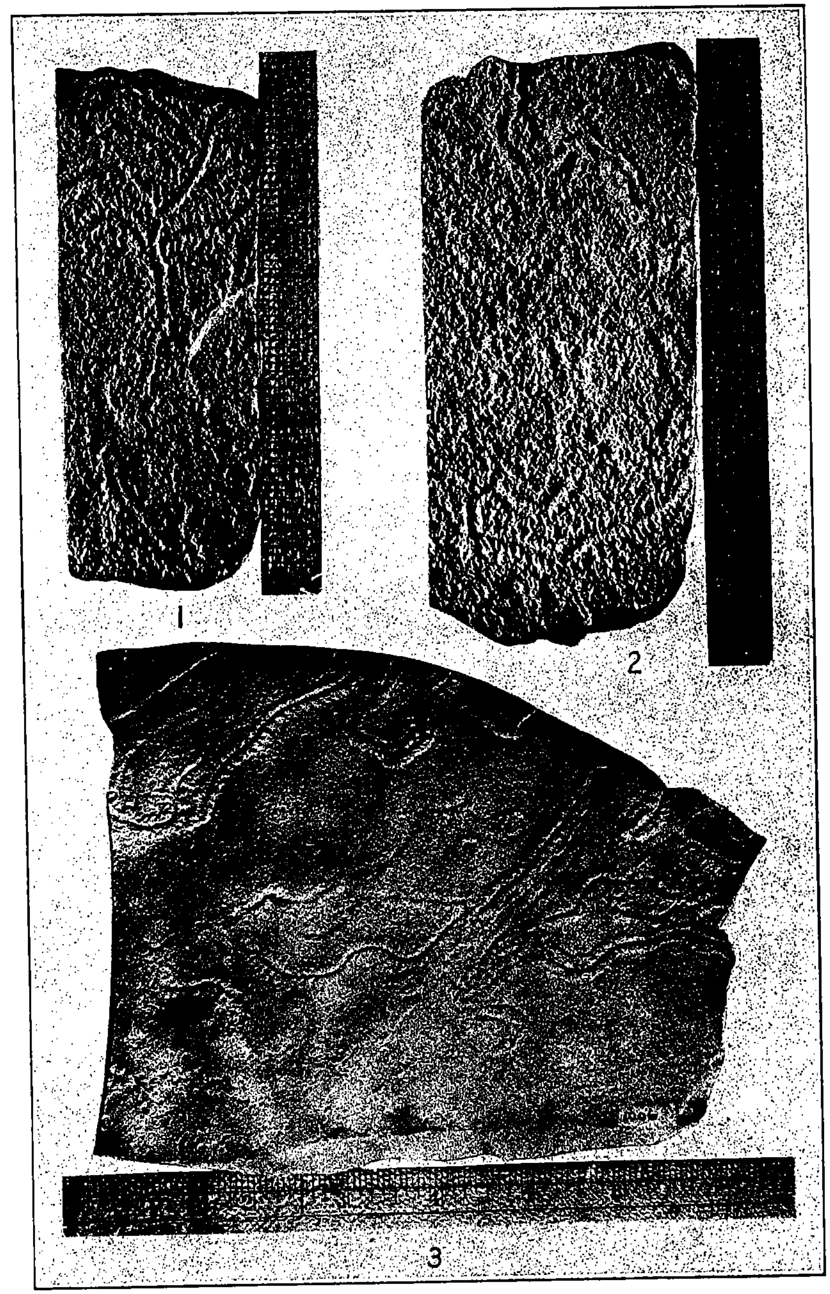
*Miser, H. D., U. S. G. S. Bull. 660-C p. 66.

PLATE XXVII.



BLAYLOCK SANDSTONE "ANNELID TRAILS" THE SCALE IS IN INCHES.

PLATE XXVIII.



BLAYLOCK SANDSTONE "ANNELID TRAILS" THE SCALE IS IN INCHES.

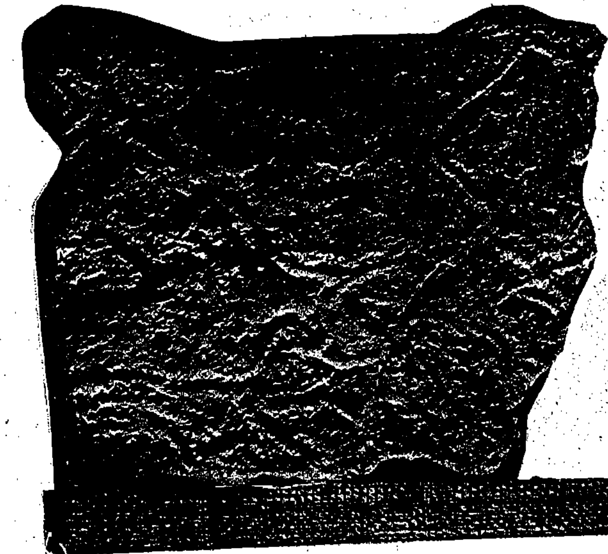
which might be taken for legs similar to those of a small centipede, but whether this fossil be animal or plant or just a track or trail is not known.

Somewhat similar to this type of marking, but less frequently observed, is a more irregular single growth represented by specimen 1005 from 400 paces south of the W ¼ cor., sec. 1, T. 4S., R. 24E., (Plate XXVII, fig. 3) and specimens 880, 881 and 1006 from 125 paces west of the northeast cor., sec. 20, T. 5 S., R. 25 E. (Plate XXVIII, figs. 1, 2, and 3.) This fossil is apparently the remains of an animal with a long, fleshy, wormlike body, with circular cross-section and uniform diameter of about 2 mm., to which were attached either side, as with the centipedes, a large number of legs. These legs number about 6 per centimeter, are set at an oblique angle of about 70° to 80° and span 8 mm. in the best preserved specimens. The length of these annelids is not known, as no complete individuals have been secured, but fragments of their serpentinous bodies, 6 inches (15 cm.) long, are in the collection. In the horizons where they are found they seem to be quite numerous, that is, there may be individuals or fragments of them every few inches at least, and in some instances they lie across one another. In a fragment of sandstone collected near the W ¼ cor., sec. 33, T. 3S., R. 24E., are several individuals of what appears to be this same annelid and in this case also they lie across one another. (Plate XXIX, fig. 1).

At a point 300 paces south of the N. ¼ cor., sec. 26, T. 3S., R. 24E., was found a rambling, branching growth of what appears to have been a fucoid or some other plant. (specimen 1004, Plate XXIX, fig. 2). The fossil is an internal cast and is slightly eroded, hence although now practically smooth, nothing is known positively of the surface ornamentation, if it had any ornamentation. The thickness of the stem of the weed is ver' uniform and is about 5 mm. It is the only specimen found of what appears to be a plant of some kind.

RESUME AND CONCLUSIONS

The more important facts with regard to the Blaylock sandstone formation are: (1) The shaly and transitional character of the basal portion and also of the upper part of the series, indicating continuous and uninterrupted deposition from the Polk Creek shale below to the Missouri Mountain slate above. (2) The fineness of grain of all the sandstones pointing to a distant source for the sediments and long transportation. (3) The presence generally of plagioclases, zircon, rutile, ilmenite, tourmaline, and locally of other igneous minerals, as sand grains in the sandstones, indicating that an igneous region was the distant, but direct source of these sands and muds. (4) The abundance of chlorite representing from 1 per cent to 10 per cent or more of clay in the original sandstones and up to



1

2

(1) ANNELIDS FROM BLAYLOCK SANDSTONE.
(2) FUCOIDS FROM BLAYLOCK SANDSTONE. THE SCALE IS IN INCHES.

100 per cent in the shales speaking for a muddy sea and doubtless fairly deep waters throughout Blaylock time, but muddier at the beginning and at the close than midway, it would seem. (5) An apparent uniform and even distribution of the sands and muds over the region as exposed, showing no variation laterally and apparently very little or no differences in thickness so far as could be learned—facts which would result from a protracted period of accumulation. (6) The presence of fucoids, annelids and in Arkansas of graptolites suggesting quiet waters at least during a part of the time, the graptolites of Arkansas as cited above pointing to the Silurian age of these deposits. (7) The fundamentally changed condition of the sandstones and shales due to the processes of metamorphism which have made it difficult to ascertain in many instances which are original, which anamorphic and which if any are the introduced minerals. (8) The peculiar character of the smoky quartz veins, the so-called zones of penetration, which indicate extraordinary conditions involving high temperatures and great pressure indicative of pneumatolitic action.

MISSOURI MOUNTAIN SLATE

GENERAL DESCRIPTION

The Missouri Mountain slate strictly speaking comes more nearly to filling the requirements of a typical slate than any other formation in the region under consideration, but like other deposits of a similar character it is a slate and it is not a slate depending upon the locality and upon the horizon in the formation. There are in the series certain beds which locally have the properties of slate scientifically speaking, and such material may have quite a general distribution within certain limits, but in many places where the Missouri Mountain is exposed it is, to be strictly accurate, a metamorphosed shale and like the Collier, Mazarn, Polk Creek, and other metamorphosed shales of this region, it is not always sufficiently indurated nor of the right composition to properly come under the classification of slate. It fails to fill the requirements in these instances more especially, it seems, because of the mineralogy of the rock rather than as a result of insufficient pressure, for in many of the shales the orientation of the mineral particles is remarkably uniform, yet the rock when struck with the hammer will have a dull deadening sound not at all characteristic of a true slate. From a microscopic study of some of these materials it would appear that there is too much chlorite and not enough quartz and sericite to make them tough, sonorous and resistant to decay. The abundance of chlorite renders them soft and friable in spite of anything and subject to relatively easy decomposition, for the iron of the chlorite readily oxidizes to limonite on exposure.

There are sandy shales, thin sandstones and one or two carbonated bands of pyroclastic material as well as slates and metamorphosed shales in the Missouri Mountain. As a unit one would be inclined to look upon the formation essentially as a hard compact argillaceous to sandy metamorphosed shale, greenish gray to drab in color, but which, locally in certain horizons, becomes a slate, and which upon long exposure to the weather may turn pink, red or buff. With the above facts in mind it would seem that the formation should best be styled a shale rather than a slate, nevertheless, in as much as there are slates in the series it appears not inappropriate to apply the term slate to the whole, thus preserving the usage as established in Arkansas. It should be added, however, that it would be just as appropriate to speak of parts of the Collier, Mazarn, Polk Creek and Stanley shales likewise as slates which in fact they are, provided all that is required is that their mineral particles have a marked parallelism and that the rocks split into thin leaves across the bedding.

THICKNESS

The Missouri Mountain slate has a thickness of about 60 feet, possibly in places as much as 100 feet, but it is not resistant and occurring as it does just beneath the heavy ledges of the hard, brittle Arkansas novaculite, fresh exposures are very unusual and in numerous places nothing whatever was seen of the Missouri Mountain slate in passing over the novaculite ridges. The characteristic float was observed pretty generally over the region, however, and it is believed that the formation is nowhere absent from the section. Whether observed or not, therefore, it has been mapped in its proper position just beneath the base of the Arkansas novaculite.

TYPICAL EXPOSURES

Partial sections of the weathered slates appear in some of the creek valleys and at the heads of gullies, but of all the miles of outcroppings over this region one place only was found where the formation was exposed in situ from top to bottom in good shape and could be studied in detail. This section is at Alum Bluffs, near the mouth of Cedar Creek, referred to earlier in this report. The description lit-par-lit is as follows:

Missouri Mountain Slate
SE. 1/4, Sec. 29, T. 4 S., R. 23 E.

	Thickness Feet	Thickness Inches
Top		
35. White novaculite (Arkansas novaculite)		
34. Blue to black argillaceous slaty shale	3	6
33. Porous thin siliceous or cherty layers, very brittle		1
32. Light to drab slaty shale, entirely argillaceous, schistose dark blue to black at top	5	

31.	Blue resistant siliceous limestone, red at base, containing pyroclastic material (Sp. 970 to 973 incl. & sp. 975)		2
30.	Soft argillaceaus blue to black shale		9
29.	Resistant calcareous ledge containing pyroclastic material and cut by quartz veins (sp. 974)		9
28.	Drab greenish gray hard slaty shale partially covered	6	
27.	Hard sandstone layer parting in middle upper half schistose		1
26.	Hard drab schistose shale or slate	1	5
25.	Hard greenish gray sandstone layer whose horizontal bedding forms an angle of 7° with the schistosity in the adjacent shales		2
24.	Hard drab schistose shale		10
23.	Ripple marked, cross bedded, hard, greenish-gray sandstone		1
22.	Hard drab slaty shale		4
21.	Thin even bedded sandstone layer		2
20.	Hard drab shale		2
19.	Hard greenish gray quartzitic sandstone layer		1
18.	Hard drab shale, slightly siliceous at top		11
17.	Siliceous evenly bedded shaly greenish gray sandstone		1
16.	Hard drab shale		6
15.	Greenish gray hard quartzitic gritty sandstone		1
14.	Fine grained greenish gray hard sandy shale		3
13.	Thin bedded granular sandstone		1
12.	Drab, slightly siliceous hard shale, same as item 9	9	6
11.	Fine grained sandstone layer cutting across schistosity at an angle of 7°.		1
10.	Same as item 9 but blue in color, not so hard, finer grained	5	6
9.	Hard, drab to light greenish gray slate, uniformly thin bedded and slightly siliceous but exceedingly fine-grained, hackly fracture, sheared in certain zones and jointed. Same is hard, harsh, and breaks with cutting edges rarely with blunt edges; weathers rusty brown (sp. 969) a half inch of sandstone 7½ feet from the bottom schistose	18	6
8.	Medium grained shaly sandstone, schistose		10
7.	Sandy slaty shale, sheared, and breaking with cutting edges	1	10
6.	Thin even bed of sandstone		1
5.	Hard drab slaty shale, schistosity dips 20° N., bedding dips 15° N.		5
4.	Fine grained hard sandstone layer		2
3.	Hard drab shale with cutting edges, slaty and sheared	3	4

2.	Light gray evenly and thinly bedded sandstone, almost shaly		4
1.	Soft, sandy to argillaceous blue shale weathering back in the bluff	1	2
	Hard gray sandstone with siliceous shale parting in the middle (Blaylock)		
	Total thickness	63	3

At the W. ¼ cor., sec. 17, T. 4S., R. 24E., Cedar Creek has cleared away the debris from the bank where the Missouri Mountain comes to the surface. The formation is here freshly exposed and the character of the rocks were noted as green, hard slates, and metamorphosed sandy shales, but the strata are doubled back upon themselves at this place and not all exposed—hence could not be measured.

A very good section of the Missouri Mountain slates occurs at the W. ¼ cor., sec. 10 T. 5 S., R. 25 E., along the south bank of Mountain Fork River and south for ¼ mile up a small shallow creek valley. The rocks dip only 15° at this place and they have not been overturned, as a result of which the beds here are not much metamorphosed. The rocks are not weathered and are steel blue to drab in color, and although exposed fairly well and the thickness quite easily determinable this section has not been gone over with the care which it deserves, nor has it been measured. It was neglected because of its remoteness from camp at the time.

In practically all other places the Missouri Mountain is covered with Arkansas novaculite float, or appears in small isolated exposures scarcely worthy of mention. In general considerable float may be observed about the ends of the novaculite synclines or around the ends of the Blaylock sandstone anticlines, but this is not always true.

AGE

No determinable fossils of any kind whatsoever have been discovered in the Missouri Mountain slate, so far as known to the writer, either in Arkansas or Oklahoma, but the formation has been referred to the Silurian system on lithological grounds and stratigraphic relationship.

MICROSCOPIC PETROGRAPHY

The Missouri Mountain slate when examined in thin section under the miscroscope is a uniformly oriented mass of shreds, flakes and small grains, chief among which are flakes of chlorite, much sericite and a quantity of finely granular quartz. A great deal of the very finest of the material cannot be determined and should probably be referred to as clay-slate needles. The slates weather red or brown with the liberation of much limonite from the chlorite.

Of special interest are the two narrow bands of crystalline limestone occurring about 10 feet from the top of the formation (items 29 and 31 of the measured section). In the hand specimen this material is dark gray in color, massive, effervesces freely in cold acid and weathers dark. It contains, and indeed seems originally to have been made up in large part of very small fragments of shells, for on the weathered surfaces bits of crinoid stems, pieces of brachiopod shells, and myriads of minute globular perforated sacks and a few serpula-like tests appear *en masse*. In thin section under the microscope the fragments of fossils are clearly in evidence. There is also much ferruginous carbonate and quartz. The fossil fragments are of quartz for the most part and appear to have been silicified and later to have been partially replaced by the ferruginous carbo-

PLATE XXX.

Photomicrograph of carbonated, pyroclostic fragmental material from near the top of the Missouri Mountain slate. Note bogen structure of largest fragment. Crossed nicols x 15.

nate, which has crystallized in the form of well-defined rhombohedra. Several of the specimens from these thin limestone layers were found to contain igneous material also. One such fragment is a piece of rock which has a granitoid texture, a massive structure and which consists wholly of interlocking plagioclases. A second piece is triangular in outline, consists of plagioclases and quartz, and has been partly replaced by carbonate. In still another instance the feldspars are associated with quartz together with altered biotite in a patch whose texture is finely granitoid and whose mineralogy would suggest a piece of granite. The quartz grains contain inclusions of apatite. Several pieces of porpryritic material are visible in the

thin section, and a number of the fragments have a characteristic bogen structure which indicates clearly their pyroclastic origin. It appears, therefore, that volcanic ash falling in water at the close of Missouri Mountain time entrapped and buried the animal life resident in the sea at the particular time and place of the ash fall and that later the deposit was silicified and still later, replaced by ferruginous carbonate. It should be repeated that only a few inches of this material was encountered in the whole section of Missouri Mountain slate.

RESUME AND CONCLUSIONS

The chief facts brought out by the study of the Missouri Mountain slate are: (1) The transitional character of the bottom beds indicating continuous deposition and a conformable contact with the Blaylock sandstone. (2) The predominance of shales and the total absence of coarse or medium grained rocks, also the even fine bedding of these materials lacking cross-bedding and ripple marks pointing to deep water conditions of deposition and possibly a widening of the sea during this time. (3) The unexpected and sudden appearance of a limestone in the series carrying fragments of fossils and fragments of volcanic ash, the former giving, unfortunately, little or no information, but the latter meaning that a region of igneous activity was not far distant. (4) The development of slates and other metamorphic rocks giving evidence of the character of the regional metamorphism which the rocks of the region have undergone.

ARKANSAS NOVACULITE

GENERAL DESCRIPTION

The Arkansas novaculite comes to the surface in a long line of narrow exposures woven together in a tightly compressed series of V's, M's and W's, in a manner similar to some of the other formations herein described. The narrowness of the exposures and the distribution of the outcroppings are due to the highly tilted and folded condition of the beds and, owing to the superior resistance of the formation to weathering, this rock is preeminently the most important ridge maker of the region. On account of the brittleness of the novaculite and because of the jointing which readily takes place in it the slopes leading to the ridges are invariably covered with large and small angular blocks. The tops of the ridges are sometimes also covered with loose material, but ordinarily not. Bare rough ledges present themselves, usually as low, ragged or rounded masses along the crest of the ridges and sometimes, locally, walls of the novaculite several feet high occur. The formation is wide spread and the ridges formed by it appear in 18 of the 30 townships dealt with in this report.

The Arkansas novaculite, a variety of which is sometimes called the Ouachita stone or "Washita" stone, is widely known from the region of outcrop in Arkansas both to science and in commerce. It has been described fully and admirably from every point of view in the monograph by Griswold* and more recently, but briefly by Miser,** with the result that the writer feels he has little to add in the way of description. After a careful reading of these reports it is very evident to him that there is practically no difference between the formation as exposed in that State and as exposed in Oklahoma. He can do no better therefore under the circumstances than refer his readers to the two volumes just cited for the details of the lithol-

PLATE XXXI.

ARKANSAS NOVACULITE RIDGES. VIEW LOOKING N-NW, FROM A RIDGE IN SEC. 10, T. 4 S., 26 E.

ogy, thickness and other facts pertaining to these beds. By way of a general description Miser says in part: (op. cit.)

In the Caddo Gap and DeQueen quadrangles and many other parts of the Ouachita Mountains the formation consists of three lithologic divisions—a lower one, made up almost entirely of massive white novaculite; a middle

*Griswold, L. S. Whitstones and the Novaculites of Arkansas, Ann. Rept. 1890, Vol. III, Ark. Geol. Survey.

**Miser, H. D., Manganese Deposits of the Caddo Gap and DeQueen Quadrangles, Arkansas. U. S. Geol. Survey Bull. 660-C.

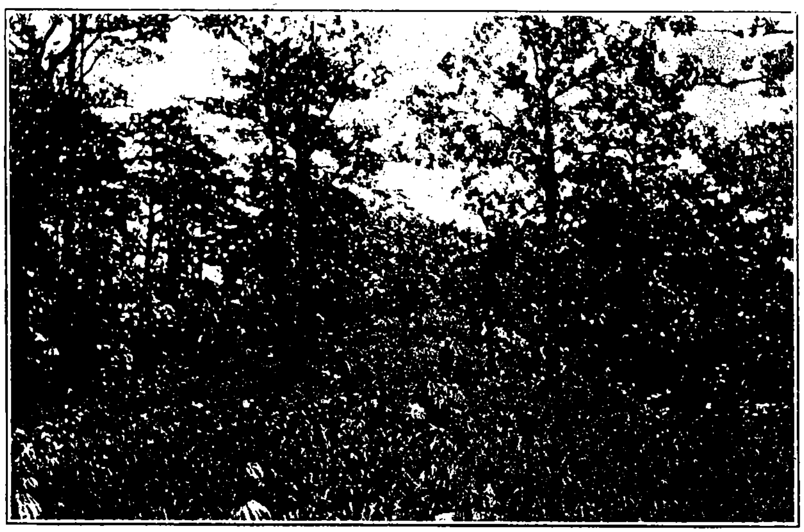
PLATE XXXII.

OUTCROPPING LEDGES OF THE LOWER DIVISION OF THE ARKANSAS NOVACULITE (INVERTED) AS SEEN IN AN ARTIFICIAL CUT AT THE BLUE HOLE ON YANUBBE CREEK, 300 PACES SOUTH OF THE W. ¼ COR., SEC. 31, T. 5 S., R. 25 E.

one, consisting mainly of thin layers of dense dark-colored novaculite interbedded with shale; and an upper one consisting chiefly of massive, highly calcareous novaculite. Manganese is found at the top of the lower division and in the upper division. These divisions vary in thickness and character from place to place.

The lower division is commonly from 150 to 300 feet thick, though at some places the thickness is greater. It is made up almost wholly of typical novaculite, whose white color and massiveness make it the most conspicuous part of the formation. In fact it is this part that usually occupies the crest of the ridges. The beds are from 2 to 10 feet thick and are commonly even bedded, though in places some of the novaculite occurs in thin lenses and

PLATE XXXIII.



VIEW LOOKING EAST DOWN A RIDGE FORMED BY THE BASAL DIVISION OF THE ARKANSAS NOVACULITE.
It shows the characteristic profile of all the mountain tops composed of this rock. Location 650 paces south of NE. Cor., Sec. 11, T. 4 S., R. 24 E.

nodules. Some of the exposed bedding planes show large, uneven ripple marks. At a number of places beds of red, buff, and less commonly, black and green shale, reaching 15 feet in thickness, are interbedded with the basal layers of this division of the formation.

The massive novaculite is usually dense, gritty, fine-grained, homogeneous, highly siliceous, translucent on thin edges, and white with a bluish tint, but where unweathered it is bluish gray. It has an uneven to conchoidal fracture and a waxy luster like that of chalcedony. Though the bulk of the rock is white, much of it varies in shades of red, gray, green, yellow and

brown, and in many places it is black. These shades are produced by iron and manganese oxides and possibly in some places by carbonaceous matter. The darker colors are prevalent in the lower 50 to 75 feet. In parts, especially near the base, the rock shows a fine parallel lamination, and much of it contains a few cavities that are oval in cross section and half an inch in their longest dimension, besides others of less size and of irregular shape. The rock contains a little calcite, but exposures of the calcareous stone are not common. Joints are numerous and run in all directions, but the most prominent joints are normal to the bedding. Many of them are filled by white quartz veins which are usually so thin as to be inconspicuous. Slickensides along both joints and bedding planes are common.

The middle part of the formation consists chiefly of interbedded novaculite and shale. The novaculite is similar to that in the lower massive part of the formation, except that the common color is dark gray to black and that the beds are much thinner, usually between one inch and six inches thick. Moreover, some thin layers are argillaceous and have a fairly good cleavage, resembling in these respects a highly siliceous shale. The whole division is cut by many joints, some of whose faces are so smooth they look as if they had been polished. A conglomerate at the base of this division was observed at a number of places. It consists of small rounded and subangular pebbles of novaculite in a sandy and dense flinty matrix. The shale ordinarily observed is black, weathering to a buff or brown color, but some of it is red. It is in beds from a fraction of an inch to 70 feet, thick. As a rule it is a fissile argillaceous shale, but at some places it has been hardened to slate. Much of it strongly resembles the lower part of the Stanley shale.

The upper part of the formation ranges from about 20 to 125 feet in thickness and is thickest along the southernmost exposures. It consists chiefly of massive, highly calcareous light gray to bluish-black novaculite which is so resistant that at some places where it and the accompanying beds are not overturned it produces low ridges or knobs on the slopes of the higher ridges. Some thin beds of ordinary dense, chalcedonic novaculite like that so characteristic of the middle and lower parts of the formation are also included. Fine lamination parallel with the bedding is common. On weathering, the more calcareous rock loses its calcium carbonate, becomes white or cream colored and porous and soft enough to receive impressions from the hammer without breaking, and shows a great many oval and irregular-shaped cavities like those in the basal division of the formation. Some of these cavities are due simply to the removal of calcium carbonate through solution, but others appear to have a different origin and may be casts of poorly preserved shells. Although some dense, hard, novaculite is present at most, if not all, places where this division of the formation is exposed, it becomes less calcareous and more siliceous toward the north, and at some localities it consists entirely of novaculite like that in the basal division of the formation.

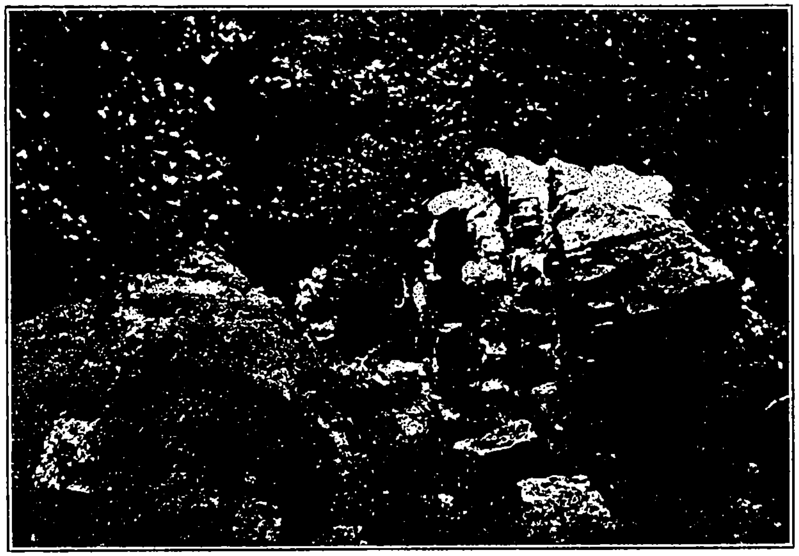
In the above quotation, Miser refers repeatedly to the novaculite as being calcareous in places and at certain horizons. The writer has not positively found calcium carbonate in the novaculite. The mineral referred to here is doubtless manganese carbonate or rhodocrosite, which is abundant in the upper division of the formation in Oklahoma. Otherwise, Miser's description might well have been written from observations taken altogether in McCurtain County, Oklahoma. In general there is nothing more to be said with regard to the lithology, excepting some facts pertaining to the thickness, concerning which in Arkansas, Miser reports as follows:

THICKNESS

The Arkansas novaculite is thickest in its southermost outcrops where the thickness at many, if not at most places, is about 900 feet. The greatest known thickness 950 feet, was measured one mile west of Hanna Mountain. At Caddo Gap the formation is about 890 feet thick. It thins toward the north and along the northern border of the area is about 250 to 300 feet thick. This thinning finds expression in the lower elevation of the ridges toward the north. In the Cross Mountains on the west side of the DeQueen quadrangle, the formation is 540 feet thick.

In Oklahoma the formation becomes thin toward the west as

PLATE XXXIV.



VERTICAL LEDGES OF THE LOWER DIVISION OF THE ARKANSAS NOVACULITE PROJECTING ALONG THE CREST OF ONE OF THE RIDGES OF THE CROSS MOUNTAINS.
Location 400 paces south of the NW. cor., sec. 26, T. 2 S., R. 24 E.

PLATE XXXV.

A CRUMPLED, JOINTED, INVERTED MASS OF THE MIDDLE DIVISION OF THE ARKANSAS NOVACULITE FORMATION AS SEEN IN AN ARTIFICIAL CUT AT THE "BLUE HOLE" IN YANUBBE CREEK, 300 PACES SOUTH OF THE W. 1/4 COR. SEC. 31, T. 5 S., R. 25 E.

well as toward the north and nowhere attains a thickness of more than about 600 feet.

AGE

Concerning the fossil content and age of the novaculite, Miser continues:

The only remains of animals thus far found in the formation consist of numerous conodonts in a minutely pebbled novaculite conglomerate and of conodonts and small linguloids and sporangites in associated shale, which have been obtained from the middle division of the formation at Caddo Gap. Upon them E. O. Ulrich bases the opinion that the middle and upper divisions of the formation are to be correlated with the Woodford chert in the Arbuckle Mountains in southern Oklahoma and with the Chattanooga shale. He assigns these two formations to the Mississippian series of the carboniferous and accordingly regards the middle and upper divisions of the Arkansas Novaculite

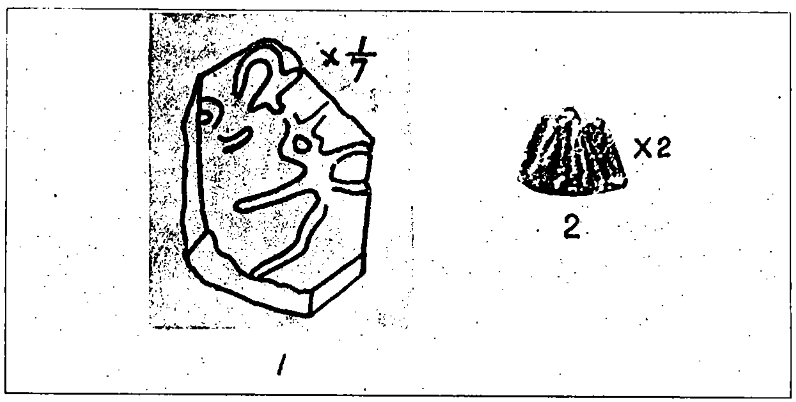


Figure 4—1 Fucoids (?) from the middle division of the Arkansas novaculite from a point 250 paces north of the SW. cor., sec. 21, T. 3 S., R. 26 E.
2 **Leptocoelia flabellites,** brachial Valve (X2) from the top of the basal division of the Arkansas Novaculite.

as belonging to that series, but the United States Geological Survey tentatively places these two divisions of the novaculite in the Upper Devonian. The lower division is separated from the middle one by an unconformity of at least local extent and by its lithologic character and stratigraphic relations, is correlated with the Camden chert of western Tennessee, which is known by its fossils to be of lower Oriskony (Lower Devonian) age.

Carl O. Dunbar* says of this correlation that:

This type of rock (novaculite) occurs at so many horizons, however,

*Stratigraphy and Correlation of the Devonian of Western Tennessee, Bull. 21, p. 82, Tenn., Geol. Survey.

in the southern part of the United States that the correlation of the Camden chert with the Arkansas novaculite can only be tentative until fossils are found in the latter.

The writer was fortunate enough to find a single specimen of *Leptocoelia flabellites** at the top of the lower division of the novaculite formation on Bog Springs Mountain (150 paces north of the S. ¼ cor. sec. 5, T. 3 S., R. 27 E., Okla) This species is a characteristic Devonian form and proves beyond any question the Oriskany or Onandoga (Devonian) age of the lower division.

No determinable fossils have been found in the middle and upper divisions of the Arkansas novaculite in Oklahoma, hence no opinion regarding the age of this part of the formation will be given at the present time.

DETAILED SECTIONS

So readily does the novaculite joint and fracture to blocks and bits to form a talus that, although the ridges of this material stand out prominently, one seldom sees a complete section exposed. One may observe individual ledges projecting on every mountain, but whole sections of the formation very rarely. The basal di'sion is exposed in its entirity in the Alum Bluffs section, which follows. This is the only section of the lower division which has been measured:

Basal Division of the Arkansas Novaculite
SE. ¼ sec, 29, T. 4S., R. 23 E.
Oklahoma

Top		Thickness Feet	Thickness Inches
29.	Black paper shales and black cherts sheared across the bedding (2nd division Arkansas novaculite.)		
28.	Massive ledge of smoky gray novaculite in beds 1 foot to 4 feet thick	15	
27.	Massive ledge of smoky gray novaculite with undulating surfaces above and below	15	
26.	Massive ledge of smoky gray novaculite with undulating surfaces above and below	5	
25.	Massive ledge of smoky gray novaculite with undulating surface at top	3	
24.	Drab to gray hard clay shale		4
23.	Nodular unevenly bedded novaculite		10
22.	Cherty nodular dark gray shale		6
21.	Massive smoky-gray ledge of novaculite	2	
20.	Hard blue gray stony slate	1	
19.	Massive, smoky gray, novaculite ledge with shale partings above and below	4	4

*Identified by Dr. C. Schuchert.

		Feet	Inches
18.	Massive smoky gray novaculite ledge with undulating surfaces	2	3
17.	Hard drab slaty to cherty shale with hackley fracture and cutting edges. Stony in appearance and uniformly evenly bedded. (It is harder than the Missouri Mountain slate.)	9	
16.	Unevenly bedded mass of smoky blue to gray novaculite	2	
15.	Blue gray, cherty shale		6
14.	Hard gray novaculite layer, undulating surfaces above and below with smoky veinlets		6
13.	Massive white to yellow novaculite somewhat nodular throughout and undulating	5	
12.	Undulating cherty shale band		3
11.	Yellow novaculite stained at bottom with oxide of manganese		7
10.	Hard cherty shale with cutting edges, undulating throughout		4
9.	Novaculite with two undulating shale partings	1	
8.	Hard cherty shale		4
7.	Undulating mass of novaculite in thin bands 1 inch to 4 inches thick	1	2
6.	Mass of shattered novaculite	4	6
5.	Massive ledge of novaculite, fractured and with uneven surfaces	1	
4.	Nodular shaly sandstone and sandy shale (calcareous) cherty in places containing peculiar cone-in-cone cherty concretions (sp. 976) over all	4	2
3.	Gray gritty sandstone layer unevenly bedded, undulating above and below		4
2.	Hard, thin, slaty, sandy shale, breaking with cutting edges	5	
1.	White novaculite layer, pinching and swelling and may be lenticular		4
	Blue to black, argillaceous slaty shale 3 feet, 6 inches (top of Missouri Mountain slate.)		
	Total	85	3

The second and third divisions of the Arkansas novaculites occur also at this place, but they form the dip slope back of the cliff, the strata dipping 15° N, and are not well exposed. The second division consists of interbedded black cherts and black slates. The cherts are in layers from 1 to 6 inches thick and are cut by innumerable intersecting, thin, smoky quartz veins. The slates are thoroughly interbedded from top to bottom and the whole mass weathers dark bluish gray. The thickness of the second division is estimated to be about equal to that of the basal division. The upper or third

division of the novaculite appears only in its weathered condition as a cream-colored, soft, spongy, porous mass whose thickness apparently does not exceed 25 or 30 feet, making the total thickness of the novaculite in the extreme western part of the area (in T. 4 S., R. 23 E.) to be about 200 feet, only.

A good section of the second and third divisions of the novaculite formation together with the basal beds of the overlying Stanley was obtained at the road crossing on Flat Rock Branch in the SE. ¼, sec. 17, T. 3 S., R. 26 E.

The succession as here measured is as follows:

(From Stanley Shale of Oklahoma, American Journal of Science, Vol. L., pp. 68-69, Table.)

Basal Beds of Stanley

Top		*Thickness Feet*	*Inches*
1.	Dark thin fissile shale weathering greenish to bronze, one or two thin quartzitic layers	6	3
2.	Light gray quartzite heavy bedded and cut with veins of milky quartz	3	6
3.	Light gray quartzite thin even quartz veins		8
4.	Thin-bedded fissile blue slaty shale—evenly finely bedded now and then a harder quartzitic layer under two inches thickness	29	
5.	Thin-bedded fissile blue slaty shales uniformly and thin bedded, jointed; one inch layers quartzite occur not infrequently and are extremely hard and tough and of blue-gray color	32	
6.	Blue flinty layer		3
7.	Hard even bedded drab slaty shale		11
8.	Hard blue flint layer		1
9.	Drab hard shale		3
10.	Blue-gray flint layer		2
	Hard even bedded drab clay shales	1	2
11.	Uniformly bedded banded white flint, banded only at the bottom; top massive gray flint	1	6
	Upper Division Arkansas Novaculite		
12.	Concretionary resistant gray harsh novaculite weathers porous, white and gritty	26	
13.	Black flint	1	
14.	Bluish gray harsh novaculite with red tinge weathers lavender and finally to a cream-colored porous chert	11	
15.	Resistant blue quartzite, flinty film ½ inch thick	2	
16.	Blue-white translucent flint		6
17.	Concretionary massive schistose cream-colored porous chert (novaculite) weathers almost white	3	

Middle Division Arkansas Novaculite

18.	Stony black chert (novaculite)	1	
19.	Coal-black shale, weathers to a brown clay shale, fissile hard, thin bedded	9	
20.	Coal-black shale and black flint (novaculite) thin bedded and concretionary	15	
21.	Thin-bedded (chiefly under 1 inch) black flints, few shales in bottom; vein quartz in upper 2 feet	12	
22.	Partially covered coal-black brittle slaty, flinty shale	16	
23..	Coal-black, brittle, slaty shale and flint, seamed by minute quartz veins intricately intersecting	8	9
24.	Blue-black flints (novaculite) in layers 2 to 6 inches	9	
25.	Hard black flint and shaly seams in beds not over 2 inches	4	
26.	Hard black novaculite ledge		6
27.	Covered, probably black slaty shale	4	
28.	Hard black novaculite ledge		4
29.	Coal-black, hard, slaty shale	1	4
30.	Black flinty layer		3
31.	Shaly flinty layers, coal-black, up to 1 inch in thickness	2	
32.	Coal-black slaty shales and thin flinty layers		7
33.	Black pyritiferous flint		3
34.	Black slaty shale and a few 1 inch layers of black flint	3	
35.	Lenticle of thin-bedded shale pinching out		3
36.	Black even-bedded cherty layer		3
37.	Concretionary black flint undulating surfaces	2	3
38.	Thin, slaty black flints undulating		3
39.	A local agglomerate layer, thickness 6 inches occurs at this horizon but was not found at this place.		

Basal Division Arkansas Novaculite

The bottom 65 feet of the basal beds of the Stanley as here shown are regarded by Dr. Schuchert* as belonging in point of time or age to the upper division of the Arkansas novaculite, thus making the heavy ledge of light gray quartzite the bottom of the Stanley. The writer has taken the position that the lithology of the beds in question more closely resembles the superjacent than the subjacent strata and has, accordingly, excluded these basal 65 feet from the novaculite series. This is a difficult line to draw and as indicated by Dr. Ulrich in Dr. Miser's report above referred to, the middle and upper divisions of the novaculite may be Mississippian rather than Devonian. The age of the Stanley has not definitely been fixed either as will be pointed out later. The agglomerate which occurs locally between the lower and middle divisions of the novaculite, although not found in either of the localities where the above sections were measured, does occur on Pine Mountain (in the center of the SW. ¼, sec. 15, T. 3 S., R. 26 E.) and to the south (in the center of the NW. ¼, sec. 20, T. 3 S., R. 27 E.) and at other places in the general locality. It has not been found, however, at any point in Oklahoma beyond the confines of those two townships, although mention should be made of the fact that its presence could easily be overlooked on account of its thickness, which ordinarily does not exceed six inches.

*Personal correspondence.

MICROSCOPIC PETROGRAPHY

The novaculites of Arkansas have been examined a number of times by various authors, professors, and students in an effort to learn, if possible, the origin and other facts about this unusual rock. The results of the early investigators together with references are briefly recorded and discussed in Griswold's monograph (loc. cit., chap. IX) and the conclusions of the more important later workers are stated by F. W. Clark in his bulletin (Data of Geochemistry, Bull. 616, p. 542). A review of the opinions of the various authors regarding the origin of the novaculite reveals the fact that there is a wide range of ideas on the subject. Griswold (loc. cit. pp. 189-192) for example regards the novaculite as a siliceous sedimentary mud or silt of extremely fine grain. F. Rutley (Quart. Jour. Geol. Soc. Vol. 50, 1894, p. 386) thinks that it is a siliceous replacement of limestone or dolomite. Comstock and others would explain it as a chemical precipitate analogous to siliceous sinter; and J. C. Branner (Ann. Rept. Geol. Survey, Ark. 1888, Vol. I, p. 49, foot-note) thinks it was produced by the metamorphism of chert.

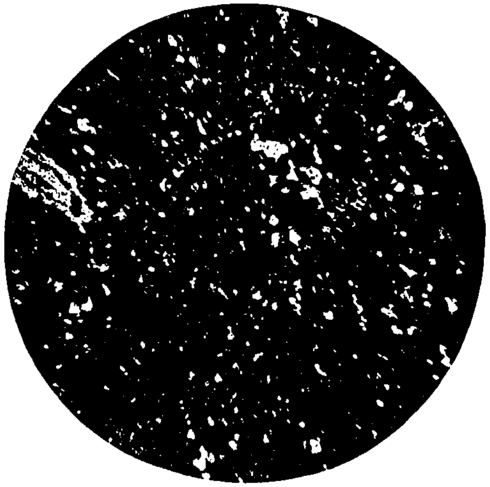
The writer has made a study of a large number of specimens and has examined upwards of 50 thin sections with the microscope in an effort to learn any new facts which might present themselves. Some of these observations are recorded below and the writer's conclusions will be found appended thereto.

BASAL DIVISION

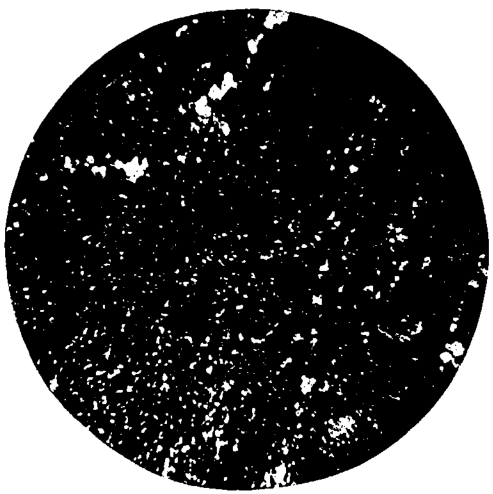
The westernmost exposures of the novaculite in the area under consideration appear in the valley of Cypress Creek (in sec. 29, T. 5 S., R. 22 E.) In this locality the basal division has a very different aspect than anywhere else in the entire region and on that account, and because of conclusions deduceable therefrom bearing on the origin of the novaculite, the exposures at this place deserve first attention. The noticeable and unusual features about the novaculite in this locality are its schistose and augen structures and the fact of its having in it pink and white mottled flaky, and angular particles, which are undoubted volcanic ash fragments.

In hand specimen most of the material from the Cypress Creek locality is a bluish white to pink mottled chert having a tendency toward an augen structure in which the augen are fresh semitrans-

PLATE XXXVI.



A. Photomicrograph of typical pseudo-granular Arkansas novaculite from the basal division of the formation. The large white fleck is a piece of original muscovite. Crossed nicols x 154.



B. Photomicrograph of typical pseudo-granular massive novavulite from the lower division of the formation showing tiny veinlets of quartz (white). Crossed nicols x 40.

lucent novaculite lenses averaging ¼ inch in length surrounded or partially surrounded by a thin film of soft, ochery, powdered chert. The rock splits irregularly because of the schostose and augen structures, along the uneven parting planes leaving on the surface a limonitic, harsh, cherty powder.

Microscopically this material appears as an extremely fine aggregate of minute interlocking bits of quartz intersected by seams or tiny veinlets of granular quartz and streaks of limonitic and sericitic matter. Under high power, all of the little "grains," so called, of the main mass of rock show wavy extinction, the polarizing colors of one fragment grading into those of another so gradually and

PLATE XXXVII.

Photomicrograph of the ashy tuff from the lower division of the Arkansas novaculite (Cypress Creek locality) showing devitrified and silicified vesicular ash in large flecks embedded in typical novaculite. Plain light x 15.

imperceptibly that one cannot be sure that these are individual grains at all, but rather a silicified and thoroughly reorganized mass that has the appearance only of being granular. The dark lines which one might take to be divisions between grains are in many instances merely lines of extinction which migrate across the "grain" upon rotation of the stage between crossed nicols. What appear to be grains with sharp points and concave edges, therefore, are not grains, for their size and shape change upon rotating the stage.

One might conceive of solidified gelatinous silica with a varying internal structure, each individual speck of which, averaging .01 mm. in diameter, would give a wavy extinction, but, since volcanic ash occurs as will be shown presently, is not this silica devitrified and silicified ash! There are clear pieces of quartz, up to .4 mm. in diameter which have uniform optical properties and irregular rounded outlines. These appear to be original grains of silt but they are not abundant, nor even common, in the rock.

Embedded in this siliceous cherty matrix in large quantities in this locality are pink and yellowish flakes of siliceous matter, which under the microscope are observed to be angular, oddly and variously shaped fragments often with sharp points and bounded by convex or concave lines. Their sizes range from 2 to 10 mm. or more, but average about 5 mm. so that their form or outline is clearly visible to the unaided eye. What the original character of the flakes was cannot in all cases be determined, but that they differ in composition is certain, for they range in color from blue-gray through yellow to pink and some are spotted. Many of them are streaked or foliated resembling flow structure; some are most certainly vesicular; while others are more or less uniformly massive. The tiny acicular crystals and the flow structure in these fragments have a definite orientation for each fragment, which is not the same for all fragments throughout the rock mass; nor is the orientation of particles always parallel with the long way of the particular fragment, showing that the structure was developed prior to deposition and is not due to shearing stresses. Some of the tiny shreds and crystals in the flakes are highly polarizing and are probably sericite; others are green in color and should be chlorite. These sericitic and chloritic matters also abound in the matrix indicating that the matrix may consist also of flecks of the same kind of materials as the large scales, but so fine and so completely reorganized that they cannot now be recorganized as fragments (ash).

The presence of a few spherically rounded grains of quartz in some of the specimens examined is of importance also. These are single, homogeneous, grains which have not been etched or changed in any way and whose excellent preservation would argue against an original siliceous sand as the genesis of the novaculite, for if a few rounded quartz grains can be preserved so should all the quartz sand. It is therefore argued that the bulk of the material is not sand or silt. The material seems to be essentially a silicified ashy tuff with a certain amount of silt and sand admixed, indicating that the ash content did not fall directly where it now lies, but was transported thither immediately afterward and was then co-mingled with minor amounts of silt and sand, and interbedded with shales (see measured sections).

The novaculite from localities other than the Cypress Creek locality contains none of the scaly and flaky matters identifiable as volcanic ash fragments, at least none that are readily identified as

such, and it is not schistose nor highly colored. The great bulk of the novaculite in the area under consideration in this report is a white or gray, dense, massive, brittle, semi-translucent material comparable in every detail to the novaculite of Arkansas. It should be stated, however, that where the forces of deformation have been most active (and it is difficult to find a place where such forces have not been intense), the novaculite has suffered recrystallization, and like marble, has become actually granular, but not coarsely granular. In all such materials the original structures have been destroyed. In studying the novaculite microscopically, therefore, recrystallized material should not be counted upon as yielding any reliable information. Most of the typical novaculite is recrystallized. Thus it is possible that the tuffaceous nature of the great bulk of the deposit has been lost through silicification, devitrification, and metamorphism generally. However, the novaculite in the Cypress Creek locality has suffered intense crumpling and has undergone apparently the same history as the novaculite to eastward. Perhaps the Cypress Creek locality lay nearest the source of the ash and it was the coarse material only that withstood the metamorphism and escaped complete destruction.

In thin section under the microscope any of the novaculite (lower division) east of the Cypress Creek locality, when not recrystallized, appears as a dense pseudo-granular chert with some chlorite, limonite, sericite, and other similar matters as tiny shreds scattered through the mass. The "grains" of quartz are of that character which causes them to have a wavy extinction and to change in size and shape upon rotating the slide between crossed nicols as in the matrix of the ashy tuffs in the valley of Cypress Creek (SW. ¼, sec. 29, T. 5 S., R. 22 E.) The tiny shreds of chlorite and sericite occur sometimes in bunches and streaks as though they had been derived from bits of slate and shale or from volcanic ash fragments. In all such instances the distribution would indicate that angular fragments of some kind originally played a part in the make-up of the rock. The particles of ash if such they were, are now wholly reorganized and richly silicified and can not be seen at all except faintly in reflected light in thin sections beneath the microscope.

In some specimens there is a kind of microscopic augen structure present, seen best in plain polorized light and which by a stretch of the imagination might be called vesicular structure, but what the origin of it is cannot be ascertained for certain. One specimen (No. 212 from a point 350 paces south of the center of sec. 9, T. 4 S., R. 26 E.) is a very dark and unusual variety of the novaculite, which contains a considerable amount of black manganese compounds, thoroughly absorbed by the silica. Under the microscope in thin section the cherty matrix appears, as in other specimens, finely pseudo-granular and highly siliceous with a little chlorite and sericite distributed through the mass, but it contains, in addition, manganese as veinlets and grains, but chiefly as an impregnation, which, as the finest dust imaginable, permeates through large portions of the rock. There are slender rods (crystals), arcs of circles (vesicles) and other markings outlined by the manganese dust indicating that these might be fragments of an igneous rock, but there are detrital grains of zircon and tourmaline also present. Another specimen (No. 629) from the dam on Yashoo Creek (near the center of sec. 2, T. 6 S., R. 24 E.) is one of the clear, translucent variety of the dark gray novaculites which happens to be relatively coarse grained, the "grain" being .02 mm. in cross section or three times as large as the "grains" one ordinarily sees in novaculite. Shreds and flakes of sericite and chlorite are very common and there are a few pieces of what appear to be tuffaceous matters now wholly reorganized and silicified. All these substances are grouped into wavy or undulating lenticular bunches and bands which have a common orientation and give to the rock a faint schistose structure. There is not however, a sufficient amount of these materials (sericite, chlorite, etc.) to have any marked effect upon the fracture of the novaculite, which is conchoidal.

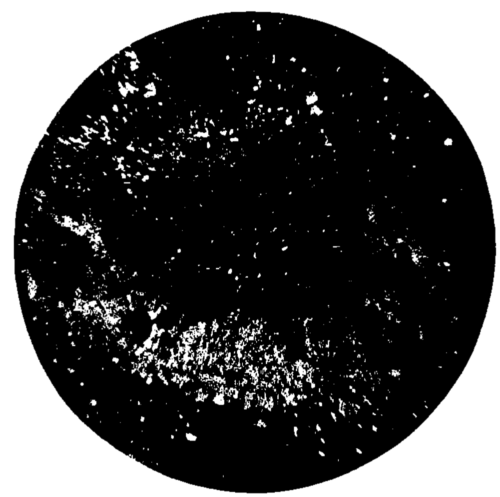
It is only in the Cypress Creek locality (sec. 29, T. 5 S., R. 22 E.), therefore, that unquestionable volcanic ash is found in the Arkansas novaculite (lower division), but the ill-defined structures in the mass of the material **elsewhere,** although of questionable origin, yet being contemporaneous and otherwise closely related to the ash deposits in the valley of Cypress Creek may be ash also. At the same time the writer sees no objection to the theory of chemical precipitation for the origin of this portion of the novaculite—even if it has volcanic ash, sand, and silt mingled with it and is interbedded with shales. Indeed the chemical composition of the novaculite, which carries 99 per cent of silica, would seem to definitely disprove the volcanic ash theory for the origin of the true novaculites. The writer is assuming that the analyses as published by the Arkansas Geological Survey in Griswold's monograph above referred to are correct. My own microscopic studies certainly would indicate that typical novaculite consists of about that much silica.

NOVACULITE AGGLOMERATE
(Volcanic Breccia)

At the top of the lower division of the Arkansas novaculite there occurs locally an agglomerate layer which has a thickness not exceeding 10 inches and ordinarily not more than 4 inches. In the hand specimens this material is seen to be made up chiefly of subangular to rounded pieces of black chert rounded quartz grains, and weathered fragments of feldspar all less than ¼ inch in cross sec-

PLATE XXXVIII.

A. Photomicrograph of Arkansas novaculite agglomerate occuring at top of basal division of the formation showing quartz, and feldspar crystals (white and light gray respectively) and basalt fragments (black) in a cherty matrix (mottled). Plain light x 15.



B. Photomicrograph of Arkansas novaculite agglomerate material showing large crystal of zonal orthoclase (light and gray) including large apatite crystals (dark) the whole embedded in a siliceous, cherty matrix (speckled). Crossed nicols x 40.

tion ,and the whole firmly cemented in a cherty matrix. It is a very tough and hard layer of rock, which breaks with an uneven fracture and has a dull black color specked with yellowish white, the white specks marking the position of feldspar grains. The top of the bed is finer of grain, lighter colored and more sandy than the lower portions.

Under the microscope in thin section the texture and structure are decidedly those of a medium to coarse grained breccia made up for the most part of igneous and metamorphic rock fragments, but containing also minor amounts of sedimentary materials, all cemented in a highly siliceous binding material resembling black chert.

The lithic fragments are present in great variety. In the few thin sections which have been prepared it is possible to recognize angular bits of black chert, pieces of sandstone and quartzite, rounded sand grains, fragments of granite with abundant albite, zonal orthoclase containing large apatite inclusions, micrographic granite, scoriacious and porphyritic basalts, vesicular ash or glass with beautiful bogen structure and fragmented quartz, besides numerous other grains of doubtful character. The fragments are most hetrogeneously co-mingled except that at the top of the layer the quartz sand grains are abundant; elsewhere scarcely present at all.

The cementing material as above stated is essentially a chert, highly discolored with a finely divided, black, opaque substance, possibly manganese compounds, but there are also minor amounts of chalcedony present filling certain irregular cavities. Quartz veins and tiny concretions of granular and chalcedonic quartz occur sparingly and finally, replacing the original fragments, cementing material, and the veins, there occurs quite commonly a ferruginous carbonate, altering to limonite. The feldspars have altered slightly to kaolin and sericite.

The general petrography of this layer of rock as outlined above, coupled with the nature of its occurrence in the stratigraphic succession (as a thin layer, occurring locally, and without transition to the finer materials above and below) seem to indicate beyond controversy that this particular horizon is a volcanic breccia or agglomerate. The volcanic ash in the novaculite in the Cypress Creek locality, though of a different character, is probably a contemporaneous fall.

MIDDLE DIVISION

A study of a large number of specimens from the middle division of the Arkansas novaculite, representing every phase of this part of the formation that it was possible to sample reveals no volcanic ash. The middle division of the Arkansas novaculite is more nearly a series of black cherts and carbonaceous metamorphosed shales. It bears a close resemblance lithologically to the Woodford

chert of the Arbuckle Mountains region, indicating, so far as lithology may be considered as a factor in correlation, that possibly these two formations may be synchronous, as Ulrich has pointed out.*

The materials are all richly carbonaceous and more or less argillaceous. They are also silicified and seamed with countless tiny intersecting veinlets of quartz—so much so in fact that in many instances the rock is fattened with silica to the extent of 25 per cent and the cherts, thus shattered and veined, become micro-breccias.

There is very little sand or silt associated with these black shales and cherts. What there is of these materials is confiined to

PLATE XXXIX

Photomicrograph of fractured and quartz-veined, dark gray chert from the middle division of the Arkansas novaculite. Crossed nicols x 15.

certain thin horizons. The great bulk of the mass was originally an impalpably fine black mud apparently.

One specimen (No. 1064, from a point ¼ mile north of the SE. cor., sec. 36, T. 5 S., R. 24 E.) is a massive, dense, compact, varigated, siliceous, thick bedded slate, whose original color was uniformly dull dark gray to black. The weathered portions are pink to light bluish gray. In thin section the rock appears essentially as an extremely fine grained chert, but whose particles scarcely reach the thousandth part of a millimeter they are so fine. The slide is yellow and brown with reorganized argillaceous matters some of which are brilliantly polarizing and are doubtless sericite. Chlorite

*Miser, H. D., U. S. G. S. Bull 660-C. p. 71.

is recognized and there is abundant limonite. The limonite occurs as rounded grains about .004 mm. in cross section which are bunched together in tiny spheres about four times the diameter of a single grain. These dot the slide in countless hundreds and are present in all parts of the thin section. A single prismatic grain of tourmaline is noted doubtless anamorphic in origin. Minute quartz spherules (concretions) occur sparingly and there are a few quartz veins. The veins carry minor amounts of manganese oxides.

Another specimen (No. 310 from a point 300 paces south of the N. ¼ cor., sec. 7, T. 3 S., R. 27 E.) is a dark gray to light gray, banded flint of the usual dense, compact, fine grained type. The bedding however, is unusual, for certain of the chert layers have smoothly rounded, prominent protuberances projecting into adjacent layers so that some of the bands have been separated into lenticular bodies while others are undulating on one side or both sides as the case may be. The specimen is a good example, it is believed, of subaqueous solifluction. These structures can be seen in thin section under the microscope, but the cherty mass is finely granular, massive and entirely void of flow lines or anything resembling flowage.

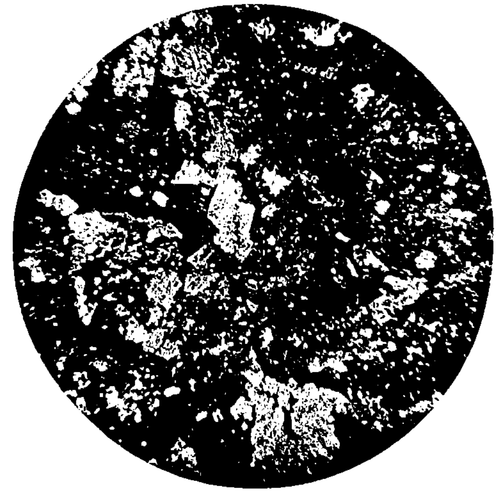
One horizon in the middle division of the novaculite formation 4 to 6 inches thick (material obtained ¼ mile north of the SE. cor. sec. 36, T. 5 S., R. 24 E.) contains numerous balls or concretions of a black, sooty-like, soft substance which burns to a white ash without coloring the Bunsen flame. The ash appears to be chiefly clay. A shell of silica encrusts the carbonaceous matter. This is fibrous and forms a crust from a fraction of a millimeter to two millimeters thick. The diameter of the balls ranges from ½ to ¾ of an inch and they are very abundant in the horizon in which they are found, but there origin is unknown.

An occasional rhombohedron of carbonate, apparently siderite, is noticed in many of the thin sections examined. The carbonate in all instances distinctly replaces the chert and is believed to be hydrothermal and magmatic in origin.

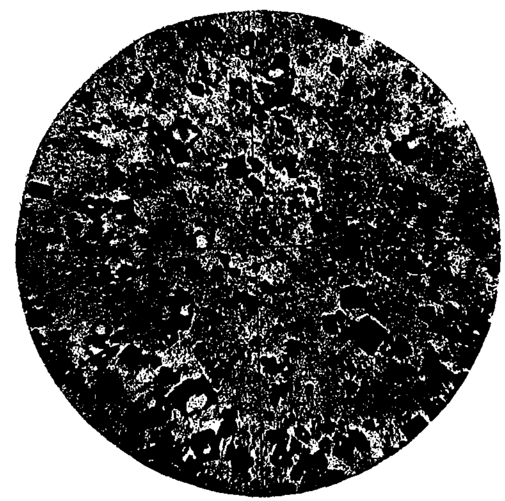
UPPER DIVISION

The upper division of the Arkansas novaculite as observed in the hand specimen is a massive, fine grained, dark purplish gray grit which becomes porous upon weathering and turns lavender to cream colored and finally white after long exposure. It possesses none of the properties of novaculite megascopically, that is, it is not translucent or shining, it is not brittle and does not have a conchoidal fracture, but looks like a sandstone when fresh. In thin section, under the microscope, however, the original ground mass of the material is truly a fine grained, pseudo-granular novaculite in every way similar to, if not identical with the pseudo-granular chert

PLATE XL.



A. Photomicrograph of typical unaltered novaculite from the upper division of the formation, abundantly replaced (?) by rhodocrosite (white). Crossed nicols x 40.



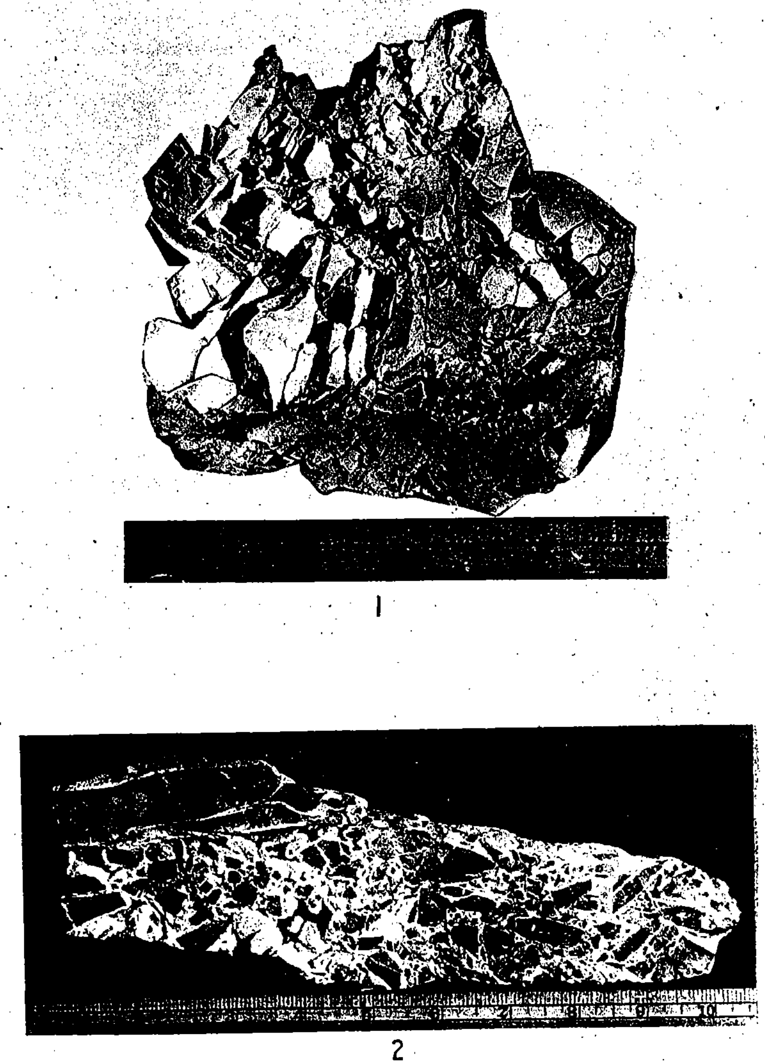
B. Photomicrograph of typical material from the upper division of the Arkansas novaculite, abundantly replaced (?) by rhodocrosite (manganese carbonate) altering to pyrolucite (black in photo.) Plain light x 40.

or novaculite from the lower portion of this formation. Associated with the silica, however, one does not find much of the chlorite, sericite, leucoxene, limonite, and other reorganization products as in the lower division. These are practically all wanting. Nothing has been found in any of the slides either which can positively be identified as volcanic ash, but some of the slides have a microscopic, mottled, patchy appearance which very strongly suggests bogen structure. It is entirely possible, therefore, that the upper division of the novaculite may be volcanic ash in part.

Clearly replacing this original siliceous or cherty material is an abundant carbonate, occurring to the extent of 50 per cent or more of the rock mass, and it is in the presence of this carbonate and through its solution that the rock differs from the ordinary novaculite, megascopically. The carbonate is present as irregular ragged grains and as well defined rhombohedra both as single crystals and twinned. It decomposes readily to a soft black compound, judged to be pyrolusite, whence it is argued that the carbonate is rhodochrosite. The rock, upon analysis, furnishes abundant manganese.

The residuum of silica which remains after the solution and removal of the manganese minerals presents excellent cutting surfaces because of the ragged and angular cavities left. Much of the weathered rock is massive, hard, and firm in spite of its high porosity and resists remarkably well any further decomposition. Such material is white to pink in color, harsh and gritty to the feel, and makes excellent abrasive material. Much of the extremely weathered product on the other hand has become cream colored to snowy white by long exposure and is so porous and friable that it can be crumbled to pieces between the fingers. The most porous material, obviously, was that containing originally the highest content of rhodocrosite and which has not been silicified subsequent to the removal of the manganese carbonate. Cavities, which are oval in cross-section and about ¼ inch long, by way of the longest diameter, are common in most of such material. These are no doubt due to the removal of the rhodocrosite, which in the fresh specimens, is seen sometimes to crystallize in bunches. Miser (Bull. 660-C, U. S. G. S., p. 70) speaks of the cavities as being due to the removal of calcium carbonate through solution and suggests that others may be casts of poorly preserved shells, but the carbonate in this formation as it occurs in Oklahoma appears to be manganese carbonate rather than calcium carbonate and the writer has seen nothing that would suggest fossil shells at this horizon.

In the case of one specimen which happens to be in the collection (No. 407, from 50 paces north of the SW. cor. sec. 28, T. 2 S., R. 26 E.) the cavities are filled with a siliceous powder encased in a shell of pyrolusite. These structures or filled cavities



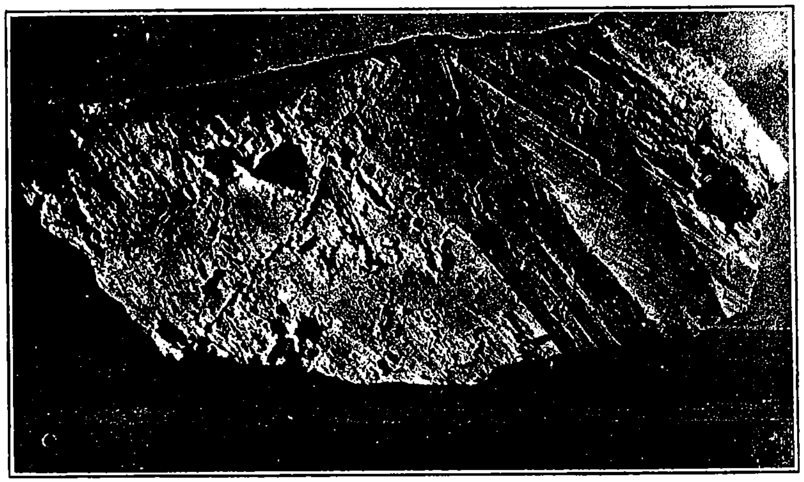
FAULT BRECCIAS FROM THE ARKANSAS NOVACULITE:
(1) An uncemented fault breccia (Arkansas novaculite, specimen No. 397) from the S. ¼ cor., sec. 36, T. 2 S., R. 26 E.
(2) An Arkansas novaculite fault breccia (specimen No. 359) from one-fourth mile south of the N. ¼ cor., sec. 27, T. 3 S., R. 26 E. Cemented with finely crystalline quartz.

occupy two definite horizons and occur sparingly, elsewhere also. For this particular specimen, and it seems to be representative, the origin of the cavities seems to be due, fundamentally to the original bunching of the manganese carbonate in the novaculite. Upon weathering, the manganese oxides immediately result, and they might temporarily form a case or shell about the border of the carbonate concretion, later to be carried away together with the siliceous powder left as a result of the extraction of the carbonate.

FAULT BRECCIAS

On account of the brittleness of the novaculite, especially of the lower portion, there are developed in this formation great quantities of fault breccia, many slickensided zones, and some minor

PLATE XLII.



SLICKENSIDED AND STRIATED SURFACE OF ARKANSAS NOVACULITE PROCURED FROM A FAULT ZONE ON ROUGH CREEK (350 PACES SOUTH AND 300 PACES EAST OF THE N. ¼ COR., SEC. 20, T. 3 S., R. 27 E.

quartz veins. A few specimens representing these structures have been collected, and a few general remarks concerning them may well be appended.

The fault breccias in general are very poorly cemented and some of them not at all. Many of the specimens for example are so tender and friable that they may be pulled to pieces with the fingers. Some remain intact by virtue of a few tiny quartz crystals loosely distributed through the cracks and crevices while others are similarly held together by ferruginous and manganiferous minerals. In a few instances the brecciated fragments have become encrusted completely with an even, thin film one millimeter thick, of finely

crystalline milky white quartz, such cavities as were more than 2 millimeters thick remaining open and being lined with the uniformly small bristling points of the quartz crystals. In some localities crevices an inch or more across may become filled with quartz but not generally.

Beautifully striated and polished surfaces occur repeatedly in many localities throughout the area. These are always accompanied by more or less brecciation on either side of the slickensided surfaces, and in most instances of movement crushing effects predominate.

RESUME AND CONCLUSIONS

The most important facts with regard to the sedimentation of the Arkansas novaculite are: (1) The sudden appearance of the formation above the Missouri Mountain slate—a sequence of beds which need not necessarily be regarded as disconformable. (2) The wide spread development of the whole formation pointing to conditions of origin of more than local significance. (3) The continual and repeated changes in the character of the sediments of the novaculite formation, stratigraphically, such as the change from white through black (carbonaceous) to purple (manganiferous) novaculite; and the irregular interbedding of shales throughout, making possible, in general, a three-fold subdivision in the formation and indicating, all told, a considerable range and diversity of conditions under which the deposits were laid down.

With regard to the lower division, in particular, the chief facts as brought out by the microscopic study are as follows: (1) The minutely pseudo-granular, massive structure of the great bulk of the material, when not recrystallized, indicating that the novaculite is not composed of grains or bits of sand or silt however small, but in fact resembles either (a) solidified colloidal silica or (b) devitrified and silicified volcanic ash more than anything else, and can best be explained, the writer thinks, either by the theory of chemical precipiation or by the volcanic theory. (2) The presence in most of the materials examined of greater or lesser amounts of shreds, flakes and grains of sericite, chlorite and limonite occurring chiefly in streaks and laminae but often also as single tiny crystals disseminated through the mass. These matters are sometimes negligible in amount and they may be abundant but observation shows that they are never entirely wanting in the basal division of the formation. They are reorganization products. (3) The presence of an occasional rounded water-worn grain of quartz, and of smaller, more irregularly rounded detrital grains of zircon, rutile, tourmaline, leucoxene (alteration product) and other similar minerals which can be nothing other than particles of silt of sedimentary origin. Certain horizons of the novaculite are crowded with quartz grains and ilmenite and zircon grains cemented in a novaculite matrix. Some of the reorganized argillaceous matters, of course were originally mud or silt also. (4) An occurrence in the westernmost exposures of angular, siliceous particles, of megascopic sizes, the flow structure in which is oriented differently for each fragment showing that these structures were developed before the fragments were deposited. The angular outlines of these flakes and scales when combined with their internal scoriacious and flow structures cannot be satisfactorily explained except from the standpoint of vulcanism. They seem to be beyond question fragments of volcanic ash and give evidence of volcanic activity at this time as well as a possible clue to the origin of the bulk of this remarkable rock. (5) The chemical composition of the novaculite which is 99 per cent SiO_2 for the bulk of the typical material, a fact which is difficult to explain from the volcanic ash point of view—better explained chemically. (6) The occurrence of microscopic stylolitic structures developed along the argillaceous streaks, and of schistose and augen structures and granulated zones in some localities—the common effects of extreme pressures brought about through diastrophic movements. In some places large masses of novaculite have suffered recrystallization through these processes and have become relatively coarsely granular and at the same time highly translucent. Such material loses its original pseudo-granular structure and like marble becomes actually granular. (7) The presence of concretions of opal, crystalline quartz and chalcedony and of the vein matters: quartz, siderite, pyrite and manganese compounds as introduced minerals. The siderite, it is thought, should be regarded as hydro-thermal if not indeed all the other secondary minerals as well. (8) The occurrence of a single specimen of Leptocoelia flabellites at the top of the lower division of the novaculite proving the Devonian (Oriskany or Onandaga) age of this portion of the novaculite.

The principal facts with regard to the agglomerate horizon in particular are: (1) The volcanic origin of the material as indicated by the nature of the fragments of which it is composed and by its occurrence, affording direct evidence of volcanic activity at this time. (2) The nature of the cementing material which is partly chert but chiefly crystaline quartz and chalcedony precipitated in the order named in the cavities as an infilteration (silicification). (3) The introduction of carbonate as a replacement mineral and of quartz and manganese compounds in veins as later phenomena.

The principal facts with regard to the middle division of the novaculite are as follows: (1) The large amount of metamorphosed shales and slates which are present in this portion of the formation aggregating fully 50 per cent of the middle division, and representing a marked increase in the deposition of mud over the amounts deposited in the lower division of this formation. (2) The large amounts of carbonaceous matter present in all the slates, shales, and cherts of the middle division whose origin is unknown. The deposits must originally have been very soft, impalpably fine, black muds. (3) The presence in the rocks of gritty particles of quartz, tourmaline, leucoxene (probably altered from ilmenite) and other similar matters indicating the silty nature of some of the muds. (4) Evidence of subaqueous solifluction in the cherty layers distinctly marked out by color bands. (5) The total absence of volcanic ash in this part of the formation so far as known. (6) The uniform polarization of the reorganized argillaceous matters (sericite, chlorite, etc.) the fine granulation effects, and the development of slaty clevages and breccias, telling of the extreme pressures which have been brought to bear upon the original muds after consolidation. (7) The occurrence of quartz and manganese veins, pyrite and opal as introduced matters.

The principle facts regarding the upper divison of the Arkansas novaculite may be summed up as follows: (1) The marked similarity in structure between the novaculite of the upper division and that of the lower division—a structure which has been described as pseudo-granular, resembling that of colloidal silica, when not recrystallized, and a material which came into existence, it is thought, either as a chemical precipitate or as volcanic ash. (2) A notable absence in most of the typical materials of the upper division of sericite, chlorite, limonite, gritty quartz and other similar reorganization products of argillaceous matter, indicating that the sea in which these particular beds were accumulated, was entirely clear and free from mud. (3) The presence in a few specimens of rounded quartz grains, particles of angular quartz, and some sericite and chlorite, indicating that at times the sea was murky and became silted up to a minor extent at least. (4) The presence in most horizons of the upper division of the novaculite of a large amount of rhodocrosite, (manganese carbonate) estimated from 25 to 50 per cent of the rock so well crystallized and of such wide-spread occurrence laterally, but of such limited occurrence stratigraphically as to be explained so it seems only from the point of view of strictly selective replacement controlled probably by the ground water level of a particular time. That the rhodocrosite replaces the novaculite seems to be the best explanation, for the carbonate has crystallized in well formed rhombohedra whose sharp points and straight edges project into the novaculite (see photomicrographs). (5) The occurrence of oval cavities up to ½ inch across which are found abundantly in certain horizons, sparingly elsewhere, and which owe their existence it is concluded to the original bunching or concretionary precipitation of the mangenese carbonate locally. (6) The high porosity of the weathered material and the excellent cutting qualities of such stone, resulting from the solution of the soluble manganese carbonate. (7) The extreme hardness and failing porosity of the upper division in certain localities as a result of silicification subsequent to or contemporaneous with the solution of the carbonate. (8) An introduction to a limited extent of quartz in veins.

ORIGIN OF THE NOVACULITE

From the foregoing resume of facts it appears to the writer that the lower and upper divisions of the Arkansas novaculite are essentially an accumulation of colloidal silica, precipitated on the sea floor, in some manner, through physical-chemical agencies, in marine waters which were more or less murky with fine black mud and silt most of the time but which were occasionally free from such matters. The causes of the precipitation of this substance are not known, but the wide spread occurrence of the formation would certainly call for causes which acted over a wide area and throughout the period of deposition of this rock. The writer does not believe that organisms of any kind had any part in the precipitation. He is inclined rather to the theory of protracted seggregation of immiscible solutions.

It is entirely possible of course, for sand (dust) and volcanic ash to fall or be blown into such an accumulation of silica or for silt, sand, and volcanic ash to be washed out to sea and become interbedded with it. When asked whence all the silica, the writer has only to reply, where did all the chert come from which goes to make up so much of the stratigraphic column the world over. Cherts are interbedded with shales just as are the novaculites and the chemical composition of novaculite very closely parallels that of chert. The chemical composition of volcanic ash is not analagous to that of the novaculite ,hence it does not seem possible that the novaculite can be ash. The exposures of the novaculite in the valley of Cypress Creek, 2 miles northwest of Bismark (SW. ¼, sec. 29, T. 5 S., R. 22 E.), where volcanic ash is definitely one of the constituents, weathers red and obviously does not carry 99 per cent SiO_2, although no analysis has been made of rock from this locality. The high content of SiO_2 in the true novaculite is the chief objection to the volcanic ash theory.

It may be argued that volcanic ash might contain originally 80 per cent of SiO_2 and that the processes of devitrification and silicification could increase this percentage, but it is hardly to be assumed that it could increase it to 99 per cent and do it so universally. If complete silicification did take place, granting that the novaculite is a silicified ash, one is moved to ask right away why was not the 100 feet of volcanic ash near the bottom of the Stanley shale formation, a short distance above the novaculite also silicified? The facts are that the Stanley tuffs carry 76.86 per cent of silica by analysis; consist essentially of acid plagioclases; and have been silicified only locally and to a very slight degree in any case. The best answer to this question is that the Stanley tuffs were originally different and that the replacement process was selective, selecting the novaculite. It will also be remembered that the agglomerate layer at the top of the lower division of the novaculite formation contains all kinds of non-silicified rock fragments; and that a layer of tuff at the top of the Missouri Mountain slate is not silicified.

It would seem also that if the novaculite be a silicified ash (or a silicified limestone as some would attempt to explain it) that the Bigfork chert (Ordovician) should also be universally and completely silicified, but in the case of the Bigfork chert silicification took place in patches as might be expected. Some of it was not replaced at all (see measured section).

As for the middle division of the novaculite formation it is no different so far as the facts indicate from any other series of black cherts and black shales and need be explained in no other way. This involves the origin of cherts generally, a problem which the writer does not care to discuss, except to state that perhaps when the origin of chert is known definitely the origin of the novaculite will be known.

Now the writer does not claim to have proven the physical-chemical precipitation theory for the origin of the true novaculite. It is the prescipitation theory that seems to him to best explain all the facts. When it can be shown that volcanic ash may consist of silica to the extent of 99 per cent or more then he is quite willing to reconsider.

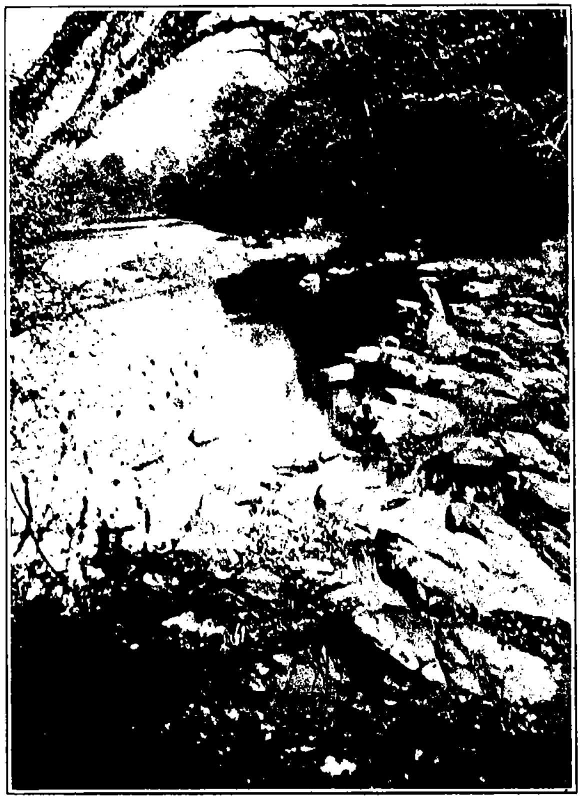
STANLEY SHALE

GENERAL DESCRIPTION

Above the Arkansas novaculite formation and apparently conformable with and transitional to it there occur some 6,000 feet or more of sandstones, shales, quartzites, slates, and other rocks, collectively known as the Stanley shale. This formation outcrops over wide areas on account of its tremendous thickness. In the area dealt with in this report it forms the surface rock over nearly half the field.

The Stanley shale formation in general is composed of materials which are non-resistant; when exposed to weathering and erosion it is easily reduced to low rounded hills and ridges and intervening flats and glades. Good exposures of the shales, slates, sandstones, and other rocks composing this formation are therefore not very plentiful, and such as do occur are unfortunately almost always interrupted at frequent intervals, the sandstones projecting, the shales covered. Along the creeks and rivers in favorable places, especially where streams flow across the strike of the rocks, partial

PLATE XLIII.



A VIEW LOOKING EAST UP MOUNTAIN FORK RIVER FROM A POINT 400 PACES NORTH OF THE SW. COR., SEC. 7, T. 1 S., R. 27 E., SHOWING RESISTANT LEDGES OF STANLEY SANDSTONE DURING LOW WATER.

sections of the strata are exposed, but elsewhere on all the slopes and hill tops one seldom sees more than exfoliated boulders of the hard sandstones or float from the thin-bedded materials.

The region is humid, trees and brush form a thick cover over most of the country and a mantle of rocky soil prevails on all the low slopes. The flats, where wet and low, often bear an impenetrable undergrowth of brambles, green briers and thorns, but where higher and drier they are sometimes grass covered and are more or less open; in such places the soil is a poor, blue clay.

The strata composing the Stanley have been unusually sharply folded, and metamorphosed over the entire region. Large and small drag-folds are practically everywhere present and slickensided zones and slates have been extensively developed. Faults of unknown displacement occur, so that it is difficult to recognize horizons within the formation except at the very bottom of it where the Stanley lies upon the recognizable Arkansas novaculite, or at the top

PLATE XLIV.

BASAL BEDS OF THE STANLEY SHALE (THE CHIEF PORTION OF ITEM 5 OF THE MEASURED SECTION) AS EXPOSED IN THE BED OF FLAT ROCK BRANCH AT THE ROAD CROSSING. SE. ¼, SEC. 17, T. 3 S., R. 26 E.

of the series where the shales disappear beneath the Jackfork sandstone. It is difficult to determine whether the beds are overturned or not, or whether they are repeated in the section. It is, in fact, impossible to find anywhere in this region an undisturbed, continuous and measurable section. Consequently, the thickness of the Stanley is not determinable in the region covered by this report. The thickness elsewhere is stated by Taff and Miser to be approximately 6,000 feet. The writer has not attempted to measure the type section of the Stanley at Stanley, Oklahoma, but concurs in the belief that it must be at least as thick as that, and with a similar if not greater thickness, in the area studied to the southeast.

The basal beds of the Stanley in the region studied are tough, hard, fine-grained, evenly bedded, blue-gray, stony slates interleaved with a little hard, even bedded, drab, slaty shale in layers one half inch or less up to three inches thick and averaging one inch. The slate beds, grading upward into thin-bedded, hard, fissile, blue, uniformly and evenly bedded, slaty shale, practically cease at a horizon 65 feet above the bottom where a very characteristic thin quartzite, one foot to four feet thick, occurs. This is cut by numerous one inch quartz veins, traversing it in all directions; it is a resistant layer and forms a shelf or projecting ledge in many places. It is found from one end of the region to the other (50 x 30 miles) which is a very good indication of widespread conditions and persistence of beds. Dr. C. Schuchert thinks the basal beds, 65 feet in thickness, should be considered as a part of the Arkansas novaculite series, thus making the heavy bedded light gray quartzite the bottom of the Stanley. (Personal correspondence.) Following is a measured section of the third or upper division of the Arkansas novaculite and the succeeding basal beds of the Stanley as observed on Flat Rock Branch at the road crossing in the SE. ¼, sec. 17, T. 3 S., R. 26 E., Oklahoma.

Basal Beds Of The Stanley Formation

	Top	*Thickness Feet*	*Thickness Inches*
18.	Dark thin fissile shale weathering greenish to bronze; one or two thin quartzitic layers	6	
17.	Light gray, heavy bedded quartzite, cut with veins of milky quartz	3	6
16.	Light gray quartzite cut by quartz veins		8
15.	Thin-bedded fissile blue slaty shale including now and then a harder quartzitic layer under two inches in thickness	29	
14.	Uniformly thin bedded fissile blue slaty shales including one inch layers of quartzite not infrequently. The quartzites are extremely hard and tough and of blue-gray color	32	
13.	Blue tough siliceous slate		3
12.	Hard even bedded drab, slaty shale		11
11.	Blue, tough, siliceous slate		1
10.	Drab, hard shale		3
9.	Blue-gray, tough, siliceous slate		2
8.	Hard, even bedded, drab clay shales	1	2
7.	Uniformly bedded, banded, white chert, banded only at the bottom, top massive gray chert	1	6

PLATE XLV.

A. POT HOLES IN THE MASSIVE DEVITRIFIED TUFF BED OF THE STANLEY OCCURRING IN ROUGH CREEK, 300 PACES SOUTH AND 50 PACES EAST OF THE W. ¼ COR., SEC. 21, T. 3 S., R. 27 E.

B. VIEW OF THE MASSIVE DEVITRIFIED STANLEY TUFF BED LOOKING EAST DOWN ROUGH CREEK, 200 PACES SOUTH AND 600 PACES WEST OF THE W. ¼ COR., SEC. 21, T. 3 S., R. 27 E.

Upper Division Arkansas Novaculite

		Feet	Inches
6.	Concretionary resistant, gray, harsh novaculite, weathering porous, white and gritty; contains abundant manganese carbonate	26	
5.	Black chert	1	
4.	Bluish gray, harsh novaculite with red tinge; weathers lavender and finally to a cream colored or white, porous chert	11	
3.	Resistant, blue quartzite, with chert layer ½ inch thick at top	2	
2.	Blue-white translucent novaculite		6
1.	Concretionary massive schistose, cream-colored, porous chert (novaculite) weathers almost white	3	

Middle Division Arkansas Novaculite

Somewhere in this basal series, farther to the south, the exact stratigraphic position not being known, there occurs locally a thin, one foot bed of chert conglomerate with pebbles ranging in size up to ¼ inch, mingled with quartz sand and cemented in cherty silica. The conglomerate may be significant as indicating an unconformity but it has been found in but three or four places and always in uncertain relationship to the adjacent strata, hence nothing definite is known about it.*

Above the quartzite ledge, at the base of the Stanley, occur some siliceous shales and sandstones which are micaceous, ripple-marked, and cross-bedded. They are greenish gray in color when fresh,but weather to a dingy, bronze appearance upon exposure. There are however, only a few feet of these and they are followed by 200 feet or more of schistose, red, soft, sandstones and grits, the red color being due to oxidation. These are usually coarse to medium-grained, are often micaceous and seem to be developed best within the eastern half of the area mapped.

A heavy bed of very resistant tuff whose thickness approximates 90 feet on Mountain Fork River, sec. 27, T. 2 S., R. 25 E. appears at this place in the section. The material consists for the most part of fresh feldspars and resembles a coarse graywacke or arkose in the hand specimen, but it is in reality a volcanic ash** It is usually gray in color, flecked or mottled with green blotches of chlorite, with a highly variable textured habit.

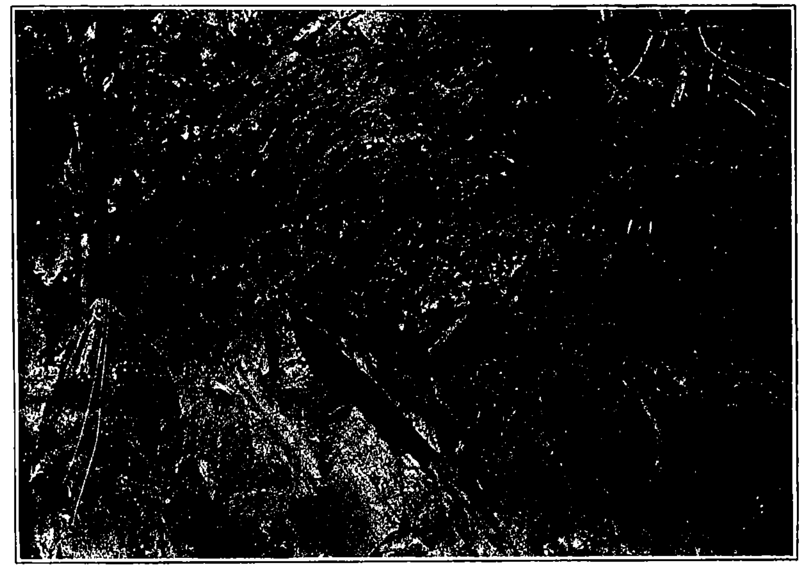
*Two of the localities where this conglomerate was found are: 350 paces south of the NW. cor., sec. 9, T. 4 S., R. 27 E.; 200 paces south of the N. ¼ cor. sec. 19, T. 3 S., R. 25 E.

**Honess, C. W., The Stanley Shale of Oklahoma, Amer. Jour. Sci. Vol. L, Jan. 1921, pp. 63-80.

This tuff is a very important layer of rock, for it is the only recognizable horizon in the lowermost 3,000 feet of the Stanley; it forms a good identifiable key ledge whose distribution makes it possible to decipher the major structural features of the lower part of this formation. The map accompanying this report shows all of the outcroppings of the Stanley tuffs.

Following is a partial section of that portion of the Stanley which involves the tuff, as observed near the source of Otter Creek (300 paces west of the SE. cor. sec. 16, T. 3 S., R. 26 E.)

PLATE XLVI.



STEEPLY TILTED LEDGES OF DEVITRIFIED TUFF (STANLEY) IN A ROUGH GORGE, 300 PACES NORTH OF THE SW. COR., SEC.12, T. 5 S., R. 25 E.

Top		*Thickness* Feet	Inches
9.	Massive, heavybedded, resistant tuff	60+	
8.	Gray fine-grained, feldspathic sandstone	2	
7.	Bluish gray, finely micaceous, feldspathic quartzite, sheared and exfoliating into flat boulders	5	
6.	Thin bedded shaly feldspathic sandstone, chalky and white when weathered	1	
5.	Resistant, blue, pyritiferous quartzite. (sp. 387)	12	
4.	Covered	20	

3.	Resistant blue pyritiferous quartzite in beds 2 to 3 feet thick	10
2.	Siliceous, hard, dark greenish, gray shales, rather thick bedded for shales	2
1.	Greenish gray micaceous, massive, thick bedded quartzite	3+
		115 feet

A study of this section reveals the fact that the basal portion of the tuff totaling 8 feet (items 6 to 8) is mingled with sediment. It does not seem worth while however to try to interpret this fact.

In the bottom of Lick Creek (at a point 300 paces south of the center of sec. 8 T. 5 S. R. 26 E.) the following section, involving the tuffs, was observed:

Presumably top of section (North)		*Feet*
24.	Quartzite layers (sp. 163)	10
23.	Thin sandstones, slates, and quartzites striking N. 25° W., and dipping 10° NE.	15
22.	Covered, probably slates	100
21.	Gray sandstone	3
20.	Covered	260
19.	Blue micaceous quartzite striking N. 80° E. and dipping 22° N. (same as item 17)	25
18.	Covered	75
17.	Blue micaceous quartzite (sp. 162)	15
16.	Covered	150
15.	Qurtzite layer (sp. 161)	6
14.	Covered	20
13.	Blue shale (sp. 160) striking N. 80° E. and dipping 60° S.	12
12.	Covered	105
11.	Layer of tuff	3
10.	Covered	15
9.	Quartzites and sandy shales	30
8.	Blue sandy shales (sp. 159)	27
7.	Covered	150
6.	Massive green tuff jointed as follows: Strike N. 20 W.______Dip 84 E. Strike N. 80 E.______Dip 80 N. Strike N. 55 E.______Dip 67 N. (Specimens 156, 157, and 158)	160
5.	Sheeted tuffs (sp. 155) strike of schistosity N. 80° E., dip 60° S.	20
4.	Massive chlorite tuffs (sp. 154)	12

3.	Massive fine-grained tuff weathering by jointing and exfoliating (sp. 153)	36
2.	Quartzites and ripple marked shaly sandstones striking N. 80° E. and dipping 80° S. (sp. 152)	42
1.	Quartzitic crumpled sandstones striking N. 80° E. and dipping 65° S. (sp. 151) South (presumably bottom of section)	37
		1328 feet

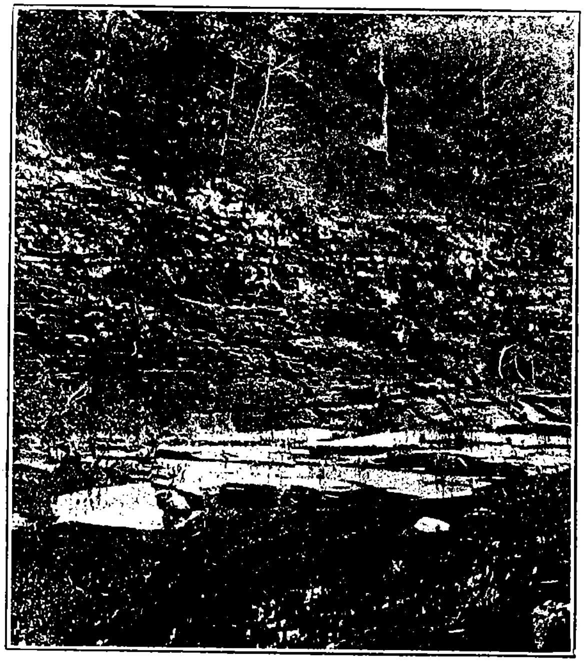
Here is a case in which on account of the sharp folding throughout the general region there is nothing certain about the

PLATE XLVII.

STEEPLY TILTED LEDGES OF THE MASSIVE, DEVITRIFIED TUFF BED, NEAR THE BASE OF THE STANLEY SHALE; LOOKING SOUTHWEST FROM A POINT ON ROUGH CREEK, 300 PACES SOUTH OF THE W. ¼ COR., SEC. 21, T. 3 S., R. 27 E.

stratigraphic succession or relative position in the geologic column of the various beds noted. There may be and there doubtless are overturned folds crumples and possibly faults in this series causing a repetition of beds in the outcroppings. The unusual thickness of the tuffs in the main mass amounting to 228 feet (items 3 to 6) would indicate some duplication of the bedding; also the three feet of tuff (item 11) occurring north of the covered interval might be

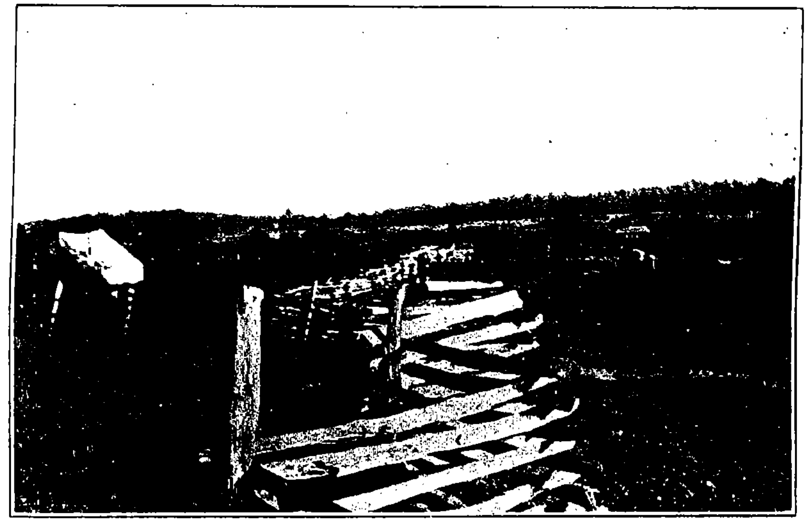
PLATE XLVIII.



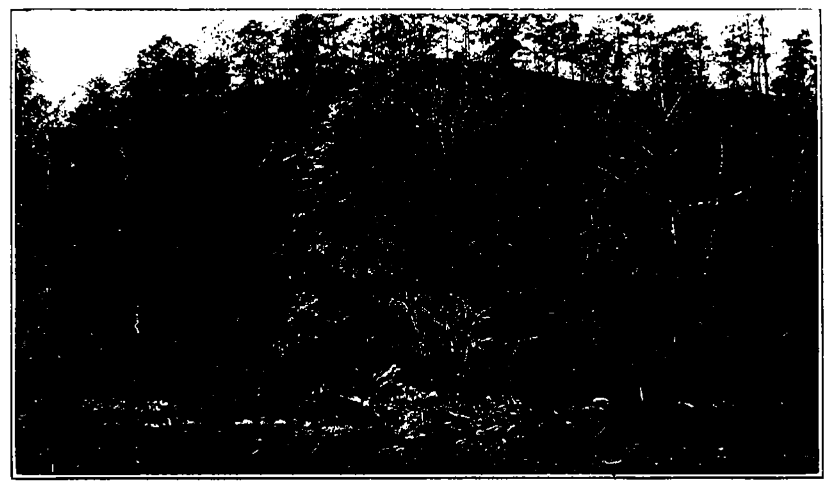
OUTCROPPING OF A VERY FINE-GRAINED, DENSE, RESISTANT VARIETY OF THE STANLEY TUFF BED, ALMOST NEVER SEEN IN A HORIZONTAL POSITION AS HERE.
Location 300 paces east of the S. ¼, cor., sec. 17, T. 3 S., R. 27 E. on Rough Creek.

brought to the surface through faulting; but not knowing positively in either case whether there has been folding or faulting one cannot say certainly from these data whether there is one or more than one bed of tuff in the normal succession of strata. It is not known either for these same reasons whether item 1 of the measured section is the bottom or top of the series. Wherever the writer has observed or tried to measure a section or part of a section of the Stanley tuffs, or any other part of the Stanley for that matter, save the very bot-

PLATE XLIX.



A. A "GLADE" FOUNDED ON THE BLUE CLAY SHALES (STANLEY) WITH TIMBERED SANDSTONE HILLS IN THE DISTANCE. VIEW LOOKING SOUTH FROM THE SE. COR., SEC. 24, T. 4 S., R. 20 E. (Burwell Springs.)



B. A RESISTANT LEDGE OF STANLEY SANDSTONE IS RESPONSIBLE FOR THE HILL IN THE SOUTHWEST CORNER OF SEC. 4, T. 1 S., R. 27 E., AND FORMS A RAPIDS ACROSS MOUNTAIN FORK RIVER AT THAT PLACE.

tom beds or the extreme top, he has invariably encountered these difficulties.

Miser* states that these tuffs "occur near the base of the Stanley shale in Polk County, Arkansas, and McCurtain County, Oklahoma, in three and possibly four or five beds, which range in thickness from 6 to 85 feet, the lowest bed being the thickest and most widely distributed."

The writer has seen no place in Oklahoma where he could positively say there are two or more beds and he is inclined to doubt very much whether there is more than one bed of the tuff.

From a purely theoretical point of view it would seem most reasonable to assume one original bed rather than several, because of the fundamental nature of volcanic activity of the explosive type. There is the possibility, on the other hand, of local secondary deposition so that it is possible to get two or more beds by thus eroding and redepositing the original ash fall. There seems to have been an admixture of silt and sand in the lower portion of the tuff bed in places as pointed out above. It is possible that in other localities the main mass of tuffaceous matter may have been so interleaved with silts and mud as to give several distinct beds, but the writer has not found any such as yet that are unquestionable.

Following the tuff is a series of hard and soft thin-bedded sandstones , slates and shales several hundred feet thick. The sandstones are fine and uniform-grained, dark greenish gray, and are usually cross-bedded and often ripple-marked.

This completes what is estimated to be about the lower third of the formation.

Succeeding these sandstones and continuing well beyond the middle of the Stanley, black shales and slates become the predominating materials. Instead of ridges and wooded slopes one finds bushy flats and glades where they outcrop. This transition to softer rock is not sudden nor are the shale masses entirely without sandstones. The latter cease gradually, and by degrees become thinner and more irregular as time goes on until gritty sediments practically are wanting. The shales are all black or dark steel-blue in color and are well indurated. Cone-in-cone concretions characterize a portion of this subdivision of the Stanley and are found widespread geographically. The thickness of the shaly portion has not been estimated, but there must be several hundred feet of the shales.

Passing upward one again encounters sandstones of the bluish gray, massive, hard, resistant variety interbedded with blue, hard clay shales; and these are succeeded by black cherty shales and thin-bedded black cherts.

*Miser, H. D., Llanoria, The Paleozoic Land area in Louisiana and eastern Texas. Amer. Jour. Sci. Vol. II, August, 1921, p. 71.

PLATE L.

A. THE "NOSE" OF AN ANTICLINE IN THE STANLEY SHALES AND SANDSTONES FORMING A HILL IN THE NW. ¼, SEC. 10, T. 1 S. R. 27 E. The anticline plunges west at an angle which is equal to the slope of the hill.

B. UNDULATING HEAVY BEDDED SANDSTONES OF THE STANLEY SHALE FORMATION, OUTCROPPING IN MOUNTAIN FORK RIVER. 200 paces west and 100 paces north of the SE. cor., sec. 12, T. 1 S., R. 26 E.

The black cherts constitute a well-defined formation in themselves of about 25 feet thickness and were encountered repeatedly in outcrop all the way from Little River (sec. 34, T. 4 S., R. 21 E.) east-northeast for 40 miles practically to the state of Arkansas (to sec. 21, T. 1 S., R. 27 E., Okla.) The black cherts are without organic remains and have not been found west of Little River.

Following is a measured section of that portion of the Stanley which includes the black cherts:

PLATE LI.

MASSIVE EXFOLIATED LEDGE OF STANLEY, FINE-GRAINED QUARTZITIC SANDSTONE, 400 PACES SOUTH OF THE N. ¼ COR., SEC. 2, T. 4 S., R. 21 E.

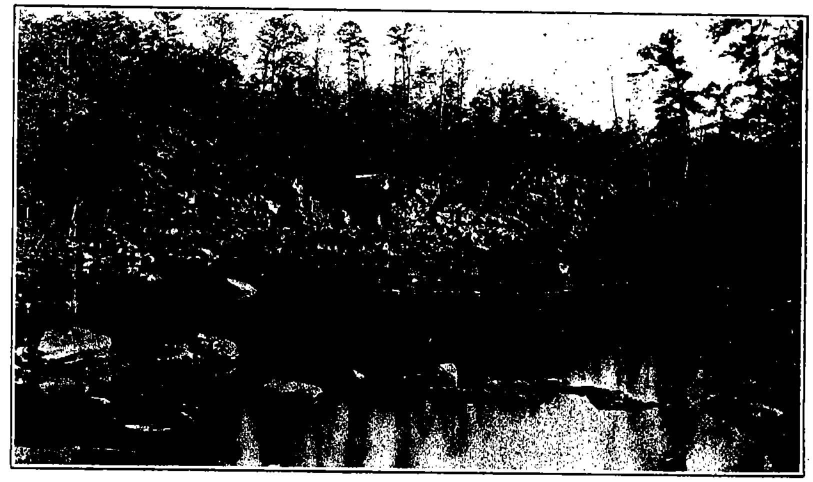
Section of a Portion of the Middle Stanley
NW ¼ Sec. 20 T. 3 S., R. 23 E.

Top (Apparently)—North — *Feet Inches*

239 Ripple marked sandstones and shales succeed the black cherts to a thickness of many feet and these in turn are over laid by massive ledges of hard sandstones 40 or 50 feet thick but these were not measured as they were poorly exposed.

238 Crumpled and twisted mass of black cherty shale en mass at base with thin bedded black chert and flints

PLATE LII.



A. MASSIVE SANDSTONES AND SHALES (STANLEY) OUTCROPPING IN MOUNTAIN FORK RIVER AT THE W. ¼ COR., SEC. 18, T. 1 S., R. 27 E.

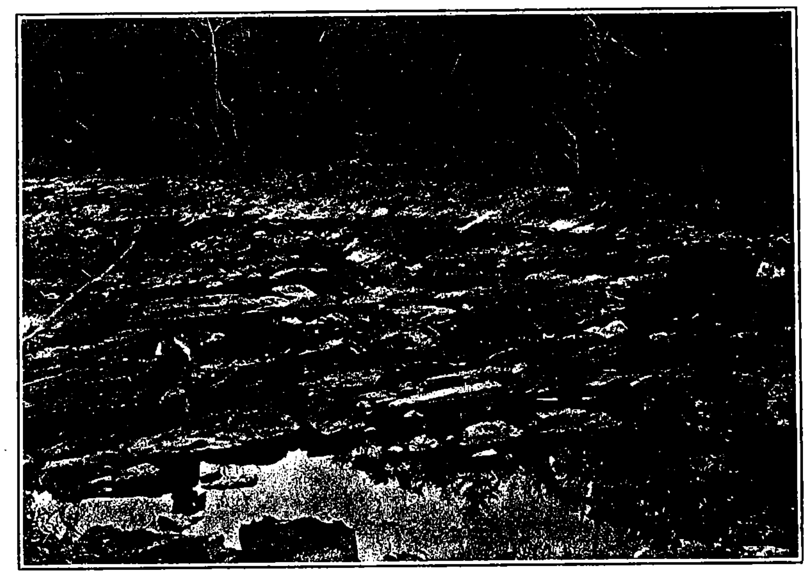
B. GENTLY FOLDED, HEAVY LEDGES OF SANDSTONE IN THE STANLEY SHALE FORMATION; LOOKING EAST-SOUTHEAST IN THE NW. COR., SEC. 19, T. 1 S., R. 27 E., AT THE MOUTH OF SIX-MILE CREEK.

	above grading into black or blue clay shales and ripple marked sandstones at top—probably doubled in thickness on account of the folding (?) overall	30	
237	Blue clay shales with cutting edges partly covered, striking N. 70° E. and dipping 60° north. Calculated thickness	20	
236	Even bedded sandstone		1
235	Clay shale with cutting edges		8
234	Hard sandstone weathering brown		5
233	Thick bedded blue clay shale with cutting edges. Undulating bed of sandstone	3	1
232	Soft clay shale		4
231	Undulating hard gray quartzitic sandstone		4
230	Soft clay shale		2
229	Undulating beds of quartzitic sandstone with 2 shale partings overall		11
228	One inch gray sandstone shale parting at top		2

PLATE LIII.

MASSIVE, FINE-GRAINED STANLEY SANDSTONES OUTCROPPING IN CYPRESS CREEK, ONE-FOURTH MILE SOUTH OF THE NE. COR. SEC. 7, T. 5 S., R. 22 E.

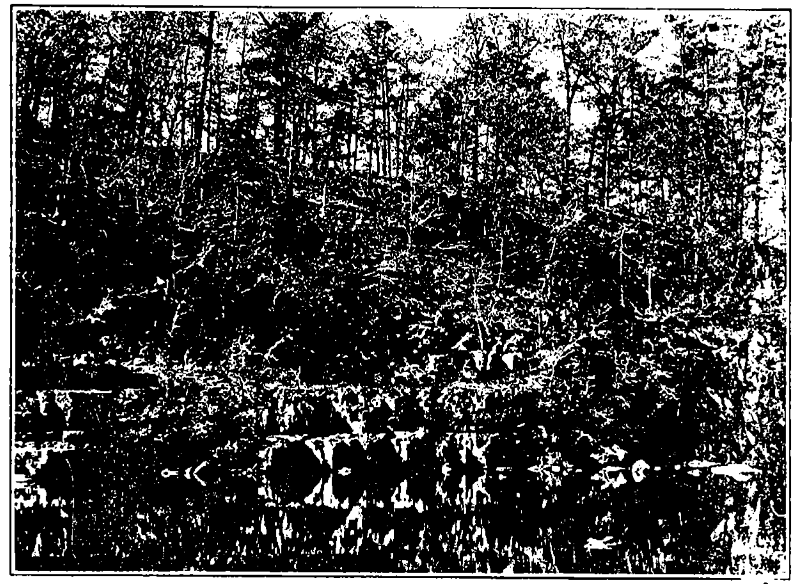
A. VIEW LOOKING NORTHEAST FROM THE SW. COR., SEC. 19, T. 1 S., R. 27 E., SHOWING THE CHARACTERISTIC TOPOGRAPHY OF THE STANLEY.
The hard sandstone ledges form the ridges; the softer materials, the valley, and both are ordinarily very brushy. A field has been cleared out in the center of this view.



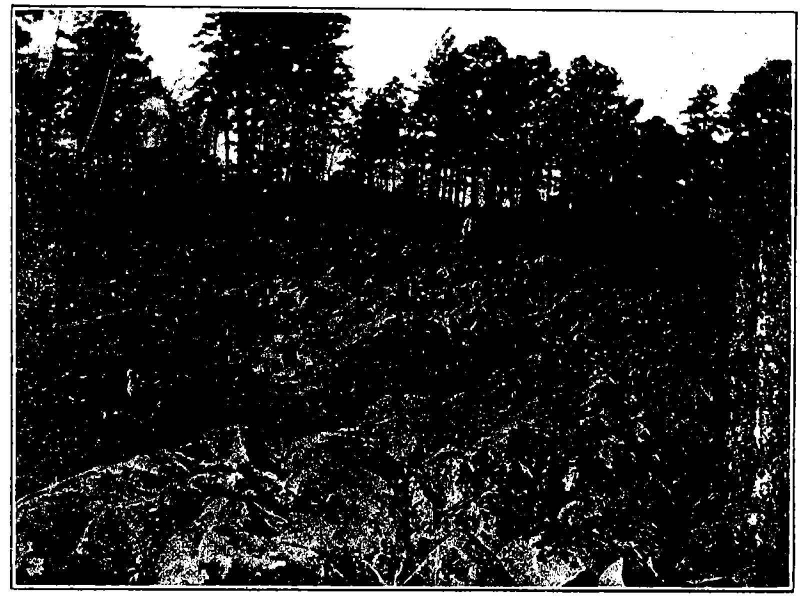
B. A VIEW LOOKING NORTH ACROSS MOUNTAIN FORK RIVER.
Location, 600 paces west and 600 paces south of the NE. cor., sec. 21, T. 1S., R. 26 E., where a mass of Stanley sandstones forms a rapids.

227	Soft, light gray, clay shale		4
226	Undulating sericitic sandstone		2
225	Siliceous shales with cutting edges		3
224	Undulating sericitic sandstone bed		3
223	Siliceous gray shale with cutting edges		7
222	Undulating, sericitic, gray quartzitic sandstone		4
221	Ripple marked shaly sandstone		3
220	Light greenish gray, sericitic, thin-bedded sandstone, jointed		3
219	Slick, hard, brittle, sandy shale, harder and more resistant at top		7
218	Sericitic ripple marked sandstone layer		3
217	Slick, hard, brittle, clay shale, weathering with cutting edges		10
216	Fine grained, gray, quartzitic sandstone		5
215	Hard, sandy shale, very resistant, forming hogback	3	
214	Coal black chert layer		1
213	Dark gray dull quartzitic sandstone in thin layers		10
212	Dark gray dull quartzitic sandstone in massive ledge	1	2
211	Siliceous, hard, thick-bedded shale		3
210	Coal black chert		4
209	Siliceous, hard, thick bedded shale		3
208	Coal black chert		3
207	Thick bedded, siliceous shale		3
206	Dark,gray, fine grained, quartzitic sandstone		3
205	Coal black chert		2
204	Hard, thick bedded, tough, cherty shale, dark gray in color		5
203	Tough, dull, stony black chert		3
202	Stony, light gray, thick bedded shale		3
201	Tough, hard, resistant, stony, cherty layer		3
200	Greenish gray, thick bedded, tough, heavy shale		4
199	Black flint layer		4
198	Coal black chert		4
197	Slaty shale		5
196	Black chert breccia slickensided, uniform in character and thickness, apparently not autoclastic		2
195	Sandy shale grading into sandstone above		6
194	Dull coal black chert shaly or slaty at top		6
193	Black hard siliceous, cherty, slate or shale	1	10
192	Coal black chert		1
191	Even, fine-grained, black, tough mass of resistant cherty, slate or shale	2	2
190	Blue clay shale, with gray quartzitic, fine-grained nodules and concretions one inch to 3 feet across, also		

PLATE LV.



A. HORIZONTAL LEDGES OF THE FINE-GRAINED, GRAY, QUARTZITIC SANDSTONE OF THE STANLEY FORMATION.
Location, in the center of the NE. ¼, sec. 13, T. 1 S., R. 26 E., at the mouth of Beech Creek.



B. MASSIVE, HEAVY BEDDED, FINE-GRAINED, SANDSTONES OF THE UPPER PART OF THE STANLEY FORMATION, OUTCROPPING IN THE BED OF TERRAPIN CREEK.
Location 400 paces west of the N. ¼ cor., sec. 4, T. 4 S., R. 21 E. The rocks strike east-west and dip 50° N.

	cone-in-cone concretions; becomes hard and slaty in uppermost 4 or 5 feet, overall	30	
189	Ripple marked, sericitic, fine-grained sandstone and shale interbedded	1	2
188	Ripple marked, sericitic, fine-grained sandstone, undulating above		5
187	Soft drab (weathered) lay shale mass splitting with cutting edges—uniform throughout	12	
186	Greenish gray, resistant quartzite, with mud markings on lower side		4
185	Slightly siliceous clay shale, cutting edges, probably same as covered interval below	2	
184	Soft blue clay shale with two or three thin, 3-inch sandstone layers in it, partially covered—calculated thickness	13	4
183	Unevenly bedded, fine grained sandstone		5
182	Thick bedded, hard, sandy shale		2
181	Light gray, ripple marked, sericitic sandstone		3
180	Light, soft, blue clay shale		2
179	Dark, ripple-marked, sericitic sandstone		4
178	Stony, thick-bedded, black shale,		
177	hackly fracture		11
176	Ripple marked sericitic sandstone		4
175	Thick bedded, dark, soft sandstone		9
174	Tough, hard, dark gray, uniformly even bedded sandstone in layers 2 inches to 4 inches thick with shaly intervals (specimens 889 and 890)	3	5
173	Hard, tough, siliceous shale		6
172	Stony blue flint		2
171	Thin bedded, tough, siliceous shale		8
170	Thick bedded, siliceous, hard shale		2
169	Dull black chert		4
168	Dull black shale		3
167	Shining black flint (specimen 988) undulating at top		4
166	Sooty, black, cherty slate		10
165	Shale parting		1
164	Fine grained heavy hard evenly bedded slate, weathering to flat slabs	1	
163	Hard, thick bedded, sandy, blue to black shale		10
162	Bluish gray, fine grained, evenly bedded sandstone, weathering to slabs	1	
161	Black cherty phyllite		1
160	Bluish gray, fine grained, evenly bedded sandstone in part shaly or slaty	3	
159	Siliceous, slaty, blue shale mass weathering with cutting edges	5	9
158	Mass of blue, slaty shale, drab in color, carrying nodular twisted concretionary masses near the base and in the middle 2 or 3 feet across, and come-in-cone concretions near the top. Calculated thickness	51	
157	Nodular, twisted, and contorted sandstone, more or less shaly in places	5	
156	Nodular, hard, sandy shale partially covered	9	10
155	Unevenly bedded, ripple marked sandstone striking N. 70° E. and dipping 90°		4
154	Light blue shale, cutting edges	1	
153	Hard, dark gray, massive, quartzitic sandstone		7
152	Thin bedded, blue shale with cutting edges—few thin, less than 1 inch sandy seams	6	
151	Thin bedded, fine grained, evenly bedded sandstone with 4 inches quartzite at top	1	
150	Dark blue shale, cutting edges	2	4
149	Cherty shale, 1 inch sandstone at top		4
148	Nodular resistant sandstone	1	
147	Siliceous, hard, light blue shale	2	6
146	Hard, dark gray sandstone		6
145	Dark, slaty shale with cutting edges, sandy near the bottom	1	4
144	Nodular hard, dark gray sandstone		2
143	Dark, slaty shale with cutting edges	1	2
142	Fairly evenly bedded sandstone, nodular at base, shale parting in the middle	1	
141	Dark, thin bedded, shaly sandstone—probably the axis of a small drag fold	5	
140	Evenly bedded sandstone, nodular at base with shaly parting in the middle	1	
139	Dark, slaty shale with cutting edges	1	2
138	Hard, nodular, dark gray sandstone		2
137	Dark, slaty shale with cutting edges, sandy near bottom	1	4
136	Hard dark gray sandstone, shattered and with hackly fracture		6
135	Hard, siliceous, light blue shale	2	6
134	Thin bedded, in 1 inch layers, ripple marked sandstone	1	
133	Thin shaly sandstone and sandy shale		11
132	Thick bedded nodular sandy shale		8
131	Thin bedded darb shale	2	
130	Ripple marked shaly sandstone shaly in middle	1	
129	Ripple marked, shaly sandstone and sandy shale crumpled apparently into a small drag fold	7	

128	Hard, tough, evenly bedded sandstone, splitting into thin, smooth slabs		5
127	Thick bedded sandy shale		4
126	Sericitic, finegrained, hard, jointed sandstone		4
125	Crushed and sheared mass of blue, hard, clay shale and nodular dark sandstone	5	
124	Unevenly bedded, ripple marked sandstone		2
123	Blue hard, clay-shale with cutting edges		10
122	Ripple marked, shaly sandstone with blue, hard shale interbedded	1	6
121	Drab to bluish gray, thick bedded shale	1	
120	Nodular, massive, sericitic, dark gray sandstone		8
119	Covered (shale)	2	
118	Hard, ripple marked, dark gray sandstone, shale parting in the middle		10
117	Thin bedded, hard shales and sandstones slightly ripple marked and beds all under one inch	2	8
116	Even bedded, hard sandstone layer, nodular at top		4
115	Hard, blue, siliceous shales	1	
114	Ripple marked sandstones		10
113	Blue hard shale weathering with cutting edges		5
112	Ripple marked sandstone with shale parting in the middle		10
111	Hard shale with hackly fracture		6
110	Dark gray, sericitic sandstone, easily fractured		2
109	Hard shale with hackly fracture and one 1" sandstone layer in the middle	1	4
108	Nodular, resistant, quartzitic sandstone		7
107	Siliceous thick bedded, blue shale with hackly fracture	2	6
106	Ripple marked, sericitic, gray sandstone, undulating parting in the middle and at the top		8
105	Ripple marked shaly sandstone and sandy shale interbedded	3	4
104	Sericitic, gray sandstone		7
103	Ripple marked, shaly sandstone and sandy shale, all thin bedded, under 1 inch	3	2
102	Shale bed		2
101	Ripple marked, shaly sandstone		4
100	Shale parting		1
99	Dirty gray, quartzitic layer with thin quartz veins		2
98	Thin bedded, blue clay shale, cutting edges	1	2
97	Greenish gray, fine grained, unevenly bedded sandstone		5
96	Sandy shale		5
95	Fine grained, gray, quartzitic sandstone		6
94	Hard, thick bedded, blue shale		1

93	Sandstone layer		1
92	Hard thick bedded blue shale		4
91	Sandstone layer		2
90	Hard thick bedded, blue shales		3
89	One inch sandstone layer		1
88	Hard, thick bedded, sericitic, blue shales		8
87	Even bedded, fine grained, quartzitic sandstone		3
86	Hard, thick bedded, blue shales		5
85	Thin layer quartzitic sandstone (sp. 986)		4
84	Thick bedded siliceous shale		2
83	Hard ripple marked, sericitic sandstone		3
82	Siliceous, slaty shale		3
81	Ripple marked, cross-bedded, sericitic sandstone		4
80	Siliceous, slaty shale weathering into thin flat pencils		11
79	Light greenish gray sandstone, jointed		4
78	Siliceous, slaty shale, weathering into thin, flat pencils	1	3
77	Slaty, shaly sandstone, splitting readily	1	6
76	Tough, hard, fine grained, siliceous shale in beds 1 inch to 2 inches		8
75	Tough hard, siliceous shale	1	
74	Tough, hard slate, splitting readily into thick slabs		4
73	Thick bedded, sandy shale with hackly fracture		4
72	Hard dark gray fine grained sandstone, splitting in thin layers		3
71	Thin bedded, shaly sandstone, firmly cemented below, shaly above		6
70	Tough, thickbedded, stony shale		4
69	Black flint layer		2
68	Sandy shale		4
67	Shaly evenly bedded sandstone		3
66	Hard, siliceous shale		3
65	Dull, black chert, shaly above and below		2
64	Hard, tough, siliceous shale, hackly fracture		3
63	Black chert layer		2
62	Black cherty shale evenly and finely bedded		3
61	Sooty dull coal black chert		2
60	Hard, resistant, fine grained, siliceous shale	1	6
59	Stony black chert ½ inch		½
58	Hard, compact, evenly bedded, siliceous shale	1	9
57	Stony, black chert		1
56	Hard, evenly, finely bedded, highly siliceous shale compact and resistant, finely and distinctly evenly bedded, splitting readily	2	6
55	Slightly siliceous, blue clay shale, weathering with cutting edges	5	8

54	Thick bedded, hard, dark colored sandy shale	15	
53	Black flint cut by thin stringers milky vein quartz		2
52	Tough, siliceous, black slate		4
51	Thick bedded, sandy shale crumpled and fractured	3	
50	Ripple marked, quartzitic sandstone		4
49	Thick bedded black sandy shale		10
48	Ripple marked, quartzitic sandstone, small quartz veins		5
47	Hard, tough, sandy shales, dark in color and thick bedded		10
46	Distinctly rippled, shaly sandstone		3
45	Hard, siliceous shale, nodular in middle and upper parts		8
44	Resistant, extremely fine grained, quartzite grading into hard slate below		4
43	Hard, ripple marked slate, unevenly bedded and ripple marked		6
42	Resistant, hard, gray quartzite layer, jointed ends thrust past each other 8 inches		2
41	Blue, hard, slaty shale		10
40	Ripple marked, sericitic, thin bedded sandstone		2
39	Blue, slaty, unevenly bedded shale		4
38	Jointed quartz veined, unevenly bedded sandstone		2
37	Ripple marked sandy shale grading upward into slate pencils and clay shale		10
36	Resistant, light gray quartzite, grading into shale above and below		5
35	Hard, siliceous, dark gray shale, breaking with blunt edges		2
34	Light gray, quartzitic sandstone grading into shale beneath		7
33	Blue-gray, sandy shale, undulating bedding		2
32	Sericitic, gray quartzitic sandstone		4
31	Metallic, black, sandy, clay shale, nodular, unevenly bedded, sheared and with concretionary, lenticular nodules of sandstone 1 foot by 6 inches	22	
30	Tough, ripple marked, quartzitic sandstone grading into sandy shale beneath		6
29	Dark gray hard, sericitic, sandy shale, unevenly thick bedded	2	
28	Massive, resistant, quartzite ledge	2	
27	Soft gray, nodular sandstone	1	
26	Massive, resistant, gray, quartzitic sandstone ledges in beds 3 inches to 1 foot in thickness, capped by a 5-foot		
25	ledge all undulating above and below	8	3
24	Soft, blue, clay shale, weathering with cutting edges	1	10
23	Bluish, gray quartzite ledge	1	4

22	Blue clay shale with cutting edges	1	2
21	Light gray, quartzitic sandstone ledge (sp. 985)	1	8
20	Dark, hard, clay shale weathering with cutting edges, carrying cone-in-cone concretions	5	
19	Hard layer, gray, fine grained sandstone		2
18	Blue clay shale weathering with cutting edges and carrying cone-in-cone concretions. (sp. 984)	10	
17	Hard sandy shale breaking with dull blunt edges; carries lenticular beds of shaly sandstone and mud markings in one layer	5	
16	Ripple marked shaly sandstone and sandy shales, unevenly bedded under 1 inch with thin, quartz veins cutting across bedding	7	2
15	Hard, sandy shale with thin quartz veins		2
14	Blue, hard, clay shale, ripple marked and unevenly bedded	1	6
13	Shaly, ripple marked, unevenly bedded sandstone variable in thickness, averaging 1 inch		6
12	Blue, hard clay shale, slightly siliceous in certain layers		11
11	Ripple marked, shaly sandstone		2
10	Hard, blue clay shale, evenly thin bedded, weathering with cutting edges		8
9	Massive, hard, greenish gray quartzitic sandstone cut by quartz veins		6
8	Ripple marked, shaly sadstone and sandy shale unevenly bedded (sps. 981, 982, 983)	3	6
7	Hard, gray, quartzitic sandstone		4
6	Ripple marked, shaly sandstones and sandy shales in beds averaging 1 inch in thickness cut by thin quartz veins	11	6
5	Massive ledge, greenish gray sandstone weathering brown	1	8
4	Blue, shaly sandstone and sandy shale		6
3	Greenish gray quartzitic sandstone		5
2	Ripple marked, unevenly bedded, shaly sandstone and sandy shale	3	6
1	Bluish gray, massive, hard, resistant sandstone ledge striking N. 70° E. and dipping 70° S., unevenly bedded but uniformly fine grained	3	4
	Total	450	8

In this section as in all parts of the Stanley formation the sandstones are extremely fine of grain and should, perhaps, properly be called grits. The grains are angular and average about 0.1 millimeter in cross section as determined by microscopic examination.

The topmost 2,000 feet or so of the Stanley is a rather monotonous series of alternating, even fine-grained sandstones and sandy shales, thin-bedded more or less ripple-marked and cross-bedded in the lower portion, but becoming heavier bedded in the uppermost member and passing gradually, by transition, into the coarser sandstones and "millstone grits" of the Jackfork sandstone formation.

PLATE LVI.

VIEW OF THE STANLEY-JACKFORK TRANSITION BEDS AS EXPOSED IN WALNUT MOUNTAIN ON THE WEST BANK OF BEECH CREEK, NW. ¼, SEC. 22, T. 1 N., R. 26 E.

The writer succeeded in obtaining a succession of the uppermost beds including the transitional series and basal portion of the Jackfork in a place where there was no doubt as to the correct sequence of the deposits. The succession occurs along Beech Creek (in the north central part of sec. 22, T. 1 N., R. 26 E.) and is as follows:

Stanley-Jackfork Transition Series
Section on Beech Creek, Sec. 22, T. 1 N., R. 26 E
Beginning 400 paces west and 300 paces south of W. ¼ cor., sec. 23, T. 1 N., R. 26 E.

Top		*Thickness Feet*	*Inches*
238	Gray sandstone unevenly bedded with partings, concluding the section 100 paces south and 36 paces southeast of the north ¼ cor. sec. 22, T. 1 N., R. 26 E.	2	6
237	Gray sandstone unevenly thick bedded with partings--	12	
236	Covered ----------------------------------	12	
235	A massive ledge of fine grained gray quartzitic sandstone, uneven at top and bottom ------------------	6	
234	A massive ledge of fine grained gray quartzitic sandstone, uneven at top and bottom ----------------	3	6
233	A fine grained gray sandstone, weathering brown----	6	6
232	A single massive quartzitic sandstone ledge undulating on top ------------------------------------	6	2
231	Covered ------------------------------------	12	
230	Massive quartzitic sandstone layer in which there is case hardening ------------------------------	3	
229	Undulating and wavy thin sandstone --------------		8
228	Heavy bed gray quartzite ------------------------	1	
227	Coal black carbonaceous shales and thin argillaceous sandstones, poorly exposed, overall about-----------	10	
226	Thin sandstone layers --------------------------		8
225	Thin sandstone layers --------------------------	1	
224	Covered, probably sandy shale and thin sandstone----	6	
223	A single massive bed of resistant quartzite ---------	7	
222	Thin sandstones and gray quartzites over all --------	1	10
221	Massive ledge of gray quartzite ------------------	2	
220	Thin shaly sandstone --------------------------		6
219	A single resistant bed of gray quartzite ------------		10
218	A single resistant bed of gray quartzite------------	6	
217	Covered, probably a clay shale ------------------	20	
216	T thin layer of gray quartzite --------------------		8
215	Thick layer sandstone gray in color, resistant--------	2	6
214	Covered, probably sandy shale and clay shale --------	2	6
213	Undulating quartzite layer -----------------------		2
212	Thin layer of gray quartzite 2 inches; 6 inches sandy shales, 3 inch layer sandstone with mud markings on bottom; and sandstone as folows: 2 inches, 5 inches, 4 inches, 2 inches, 8 inches, over all --------------	3	
211	Thin sandy layers followed by an 8-inch layer sandstone	1	

210	Thin layer of sandy carbonaceous shale followed by a thin sandstone layer 1 inch thick over all----------------		5
209	Thin layer of sandstone on the bottom side of which are numerous peculiar markings resembling moulded mud. (Specimen 472 A) -----------------------		2
208	Massive sandstone layer ------------------------	4	
207	Thin layers of sandstone under 4 inches-----------	1	
206	Thin layers of sandstone not well exposed----------	6	
205	Gray quartzite layers undulating at top and bottom in beds 4 inches to 1 foot thickness ----------------	5	3
204	Gray quartzite layers in beds 1 foot to 4 feet thick---	11	10
203	Massive sandstone layer ------------------------	3	
202	Massive sandstone in layers 2 to 10 feet thick, no shales, seams only forming cliff on mountain --------	35	
201	Massive sandstone with undulating surface below----	11	3
200	Massive sandstone weathering brown gritty uniformly fine grained and gray in color—base not exposed-----	10	
199	Poorly exposed sandy shale and sandstones forming a deep hole in Beech Creek immediately below the main road crossing ---------------------------------	62	
198	Massive gray sandstone in beds 1 to 6 feet thick separated by undulating or ripple marked seams. -------	14	
197	Thin sandstone layer with **fossil plants seeds and scales** blue clay shale parting of 2 inches at the top--------	1	
196	Resistant hard gray sandstone jointed vertically to bedding, forming bluff ---------------------------	4	
195	Fine grained ,gray, soft sandstone, massive and resistant with several seams in it -------------------	5	
194	Hard sandstone layer -------------------------	3	
193	Thin bedded blue clay shale --------------------	1	
192	Massive sandstone layer -----------------------	1	3
191	Soft, gray, sandy shales, thick bedded with plant remains and a 1-foot sandstone layer at top ----------	2	6
190	Sandstone layer -------------------------------		6
189	Sandy shales with **plant remains.** (Specimen 471)----	1	
188	A hard, gray sandstone layer --------------------	2	
187	Not well exposed, probably all sandy shale----------	6	
186	Heavy layer sandstone -------------------------	1	
185	Sandy shales ----------------------------------	1	
184	Sandstone layer -------------------------------		4
183	Shale parting ---------------------------------		2
182	Sandstone layer -------------------------------		8
181	Sandy shales ----------------------------------		10
180	Undulating layer hard sandstone -----------------		8

The Approximate Stanley-Jackfork Contact

179	Sandy, greenish gray shale and rotten sandstone------	2	
178	Layer of sandstone ---------------------------	2	
177	A layer of sandy shale containing **fossil plants.** (Specimens 469-470) -----------------------------	1	
176	Sandstone layer -------------------------------	1	
175	Ledge of greenish gray sandstone. Blue clay shale and thin sandy layers ----------------------------	1	
174	Black clay shales with 1 to 3 inch layers soft greenish gray sandstone ----------------------------	2	6
173	Gray quartzitic sandstone not so hard as that immediately below, forming a massive ledge -------------	6	
172	Same as item 167 -----------------------------	1	8
171	Same as item 167 -----------------------------		8
170	Same as item 167 -----------------------------	1	5
169	Same as item 167 -----------------------------	4	
168	Same as item 167 -----------------------------	3	
167	Massive ledge of blue gray quartzite undulating and ropy at top and bottom -----------------------	1	4
166	Two thin layers of undulating sandstone each two inches thick, overlaid by 2 inches blue clay shale-----		6
165	Heavy ledge greenish gray quartzite with what looks like old roots at the bottom impressed in the shale---	1	8
164	Thin bedded blue clay shale --------------------	1	
163	Heavy layers of gray micaceous sandstone, very hard and resistant with sandy partings ----------------	5	
162	Heavy layers of blue quartzite badly joined ---------	4	
161	Dark gray to drab, shaly sandstone and sandy shale with two beds of sandstone at top one foot thick, over all--	5	
160	Massive layer of gray quartzite with two seams dividing it into thirds ----------------------------	5	6
159	Covered, probably shaly sandstone ---------------	7	
158	A gray sandstone layer weathering brown----------	1	3
157	Massive heavy bedded gray quartzite grading into heavy bedded gray sandstone at top ------------------	14	
156	Blue clay shaly layer --------------------------	4	
155	A massive blue gray quartzite ledge --------------	4	
154	Covered, shaly material ------------------------	6	
153	Hard sandstone layer --------------------------	1	6
152	Hard sandstone layer --------------------------	3	6
151	Hard sandstone layer, pitted surface at top resembling rain drop prints ----------------------------	3	
150	Covered, probably clay shale --------------------	7	
149	A massive quartzite layer seamed in middle ---------	8	10
148	A massive quartzite layer undulating surface at top---	2	

147	A "concretionary" layer of massive sandstone and quartzite concretionary character only local	2	3
146	Massive sandstone ledge in layers 8 inches to 2 feet	4	
145	Covered	34	10
144	A massive gray quartzite, hard and resistant, weathering rusty in the joints	3	
143	An undulating shaly sandstone layer		10
142	A massive gray sandstone ledge		8
141	A massive gray sandstone ledge	2	
140	A massive gray sandstone ledge with an undulating seam 2 feet from bottom	5	6
139	A clay shale parting undulating below, evenly bedded above		6
138	A massive gray quartzite layer undulating above and below		10
137	A massive ledge of sandstone, hard, resistant, greenish gray in color, a shale parting locally, 14 inches from the bottom	4	
136	An undulating greenish gray sandstone layer		4
135	Massive greenish gray quartzitic sandstone with a seam in the middle	3	6
134	Light blue to drab clay shales containing soft clay concretions, yellow with iron oxide, not well exposed, partly sandy	18	5
133	Alternating blue clay shales and sandy shales with two inch sandstone layers, all dark colored	3	
132	A blue quartzite layer somewhat nodular at top, the nodules being large and shelling off	2	
131	A drab sandy soft shale weathering to a dark clay loam	2	
130	A quartzitic sandstone ledge		4
129	A quartzitic sandstone ledge	3	6
128	A drab clay shale with sandy layer ¼ inch thick		2
127	Massive quartzitic sandstone ledge	2	6
126	A clay shale parting weathering to a brown clay loam not well exposed	1	2
125	Massive layer sandstone	3	
124	A massive, resistant, gray quartzite layer undulating surfaces above and below		2
123	A thin bedded mass of thin sandy shales and thin sandstone layers one to two inches thick weathering in relief	1	
122	A four inch layer quartzite		4
121	A hard quartzitic sandstone layer in beds ¼ inch to 1 inch		6

120	A massive ledge of blue quartzite with locally an undulating parting in the middle	4	
119	Sandy shale parting		2
118	A massive blue quartzitic ledge	1	6
117	A massive blue clay shale with thin layers of sandstone. (Specimen 472) **and plants from this horizon.** Calculated thickness	9	6
116	A massive sandstone layer uniformly fine grained without parting or bedding, (specimen 457)	2	
115	An undulating sandy shale parting		5
114	Massive sandstone layer with two undulating partings in it, dividing it into three equal parts	2	4
113	Shale parting, undulating	2	
112	A massive sandstone layer jointed N. 18 E., dipping 80 E. Bedding strike N. 76° E. and dip 42° N. Thickness	3	6
111	Massive layer of sandstone with a parting in the middle and a second 6 inches from the top	2	4
110	Mass of blue clay shale containing a few thin even layers of sandstone with undulating bedding not well exposed	8	
109	Massive sandstone layer parted in the middle	3	
108	Blue clay shale and thin sandstone layers 1 to 3 inches thick, not well exposed	13	
107	Massive sandstone layer with an undulating parting 4½ inches from the top	1	
106	Blue clay shale with a one inch sandstone layer at the top		5
105	Massive sandstone layer without bedding blue in color and quartzitic	1	
104	Blue clay shales with three one inch sandstone layers interbedded	1	
103	Heavy sandstone ledge massive uniformly even and fine grained without bedding	1	7
102	Sandy shale layer, undulating, bedding merging into sandstone layers beneath		3
101	Massive sandstone layer, shale parting at bottom		4
100	Massive sandstone layer		6
99	A soft blue clay shale broken into thick chunks and bits usually with rounded blunt edges and points weathering readily to a dark clay soil yellow to brown in color	8	
98	A massive resistant sandstone layer		10
97	A blue rather firm clay shale, sandy in layers undulating bedding		4

96	Greenish gray, hard, resistant sandstone layer weathering brown		6
95	Covered, a V-shaped ravine piled full of hard sandstone blocks from the hills on either side. The material is undoubtedly a dark shale judging from the soil which weathers from it on the slope to the N. W. Calculated thickness of the mass	58	3
94	Quartzitic ledge in massive layers projecting into the creek strike N. 76 E., Dip 42 N. at this point the creek changes its course from south to southeast	10	6
93	Quartzitic sandstone layer	2	6
92	Blue clay shale parting		2
91	Thin quartzitic layer		6
90	Thin sandy shales and thin sandstone		9
89	Quartzitic layer	2	6
88	Blue quartzite layers 2 to 6 inches thick, over all	3	6
87	Massive resistant quartzite in beds 2 inches to 9 feet forming a bluff at the creek and shoulder on the hillside	14	
86	Covered evidently a shale judging from the soil on the hillside to the west	12	6
85	Massive ledges quartzitic sandstone forming a bluff on the hillside	21	6
84	Covered	37	
83	Boulder covered massive ledges quartzite sandstone and shale interbedded	52	
82	Hard layer sandstone strike N. 75 E., dip 30° N.	62	6
81	Massive quartzitic ledge	2	6
80	Massive quartzitic ledge	1	6
79	Massive quartzitic ledge	2	6
78	Massive sandstone ledge	26	5
77	Covered	52	10
76	Massive thick bedded ledges in layers 2 feet or more in thickness, strike N. 80 E., dip 32° N.	58	2
75	Covered (probably shale)	61	6
74	Hard ledges sandstone striking N. 78 E. and dipping 38° N.	5	6
73	Covered	9	2
72	Partially covered sandstone ledges	18	5
71	Heavy ledge gray sandstone	5	
70	Covered	18	5
69	Heavy bedded sandstone layers over all	12	3
68	Covered except sandstone layer striking N. 76E. and dip 38° N.	12	4
67	Masive quartzite ledges thick bedded	4	10
66	Massive quartzite ledges thick bedded	15	

65	Covered	20	
64	Covered except a hard sandstone ledge. Strike N. 76 E., dip 34° N.	50	3
63	Covered	21	
62	Covered, except hard sandstone ledge at top striking N. 76 E. and dipping 37° N.	9	
61	Same as item 60	13	
60	Massive gray quartzite layers in beds 1 to 3 feet thick	22	
59	Covered calculated thickness	18	
58	Hard, gray, massive sandstone layer		4
57	Hard, gray, massive sandstone layer		6
56	Massive sandstone layer	1	4
55	Covered interval (sandy shale in soil)	24	
54	Massive gray quartzitic layers in beds 1 to 3 feet thick	23	
53	Same as below. Strike N. 76 E., dip 37″ N.	1	10
52	Same as below	7	2
51	Same as below	4	
50	Same as below	3	
49	Massive gray quartzite layer separated from layer below by even seams	3	2
48	Massive gray quartzite layer undulating above and below	1	6
47	Resistant, hard sandstone layer with shaly sandstone parting at top		6
46	Fine grained gray rather soft sandstone containing **fossil plants, scales, and seeds,** from which horizon the speci- labeled 437 were taken. The collecting locality is located 650 paces west and 70 paces south of the W. ¼ cor. sec. 23, T. 1 N., R. 26 E., west bank Beech Creek just under the heavy ledge. Thickness		6
45	Resistant sandstone layer		10
44	Thin blue sandy shales		2
43	Hard, resistant, gray sandstone layer		10
42	Gray thin bedded sandstone and sandy shales, dark in color, **containing poorly preserved** plants.	1	6
41	Massive ledge, hard, resistant, gray quartzite	1	6
40	Thin undulating layers, hard, blue quartzite		3
39	Blue quartzite layer, hard, resistant, with undulating partings above and below		6
38	Unevenly thick bedded sandstones and sandy shales, gray: **containing plant stems, scales and seeds**	1	5
37	Resistant sandstone layer jointed into angular blocks		8
36	Dark sandy shale and shaly sandstone	1	
35	Gray sandstone layer jointed	1	
34	Dark sandy shale	4	

		Feet	Inches
33	Same as item 32		11
32	Even bedded layer gray, resistant sandstone with even smooth parting above and below	1	2
31	Even bedded layer of gray resistant sandstone with even smooth parting above and below	1	4
30	Massive layer of sandstone	3	
29	Shaly undulating sandstone	1	
28	A single ledge of gray sandstone with undulating seams	11	
27	Covered along creek, but farther west dark shales and thin dark sandstone layers are seen on hill slopes, capped by layers of gray sandstone 1 inch to 2 inches thick, totaling 3 feet. Mass is largely dark shale. Calculated thickness	205	
26	Thin, unevenly bedded, gray sandstone, uniformly fine grained, weathering into irregular sheets and slabs brown in color	6	
25	Massive, resistant, gray quartzite, jointed into sharp edged slices, ringing under the hammer, not distinctly separate from the underlying wavy sandstone. Top of the mass peculiarly crossbedded and wavy, (specimen 475). Thickness	14	
24	Gray sandstone, undulating bedding, weathering into thin irregular slabs, very hard	2	6
23	Massive gray quartzitic ledge with shale parting at top		6
22	Shales and sandstones not well exposed, thickness about	12	
21	Hard greenish gray sandstone layer with shale parting beneath	2	
20	Hard, greenish gray sandstone layer	2	6
19	Drab clay shale	1	
18	Massive, hard sandstone layer	2	
17	Blue clay shales, rather soft, breaking into small sharp edged, angular, thin bits (not a fissile shale) some layers sandy, upper part not well exposed	30	
16	A dark thick bedded sandy shale weathering into angular chunks and bits, grading into blue clay shale at top	3	
15	A mass of blue clay shales with small, slaty, dark concretions and bunches of gray sandy shale, unevenly bedded and crumpled. Thickness about	15	
14	Resistant massive blue quartzite layer, weathering into large boulders by exfoliation separated from the underlying massive sandstone layer only by a seam. Upper mass less quartzitic. Joints weathering to a soft rotten sandstone, greenish yellow in color. Thickness over all	15	
13	Resistant gray sandstone ledge, massive, fine grained, gray in color	1	6
12	Dark sandy shales		6
11	Undulating (ripple marked?) hard sandstone		5
10	Dark, soft, greenish gray, thick bedded, sandy shale as base of item 9 grading upward to blue clay shales	1	6
9	Dark, soft, drab to greenish, sandy shale, thick bedded with slaty concretions at the base grading upward into blue clay shales	1	8
8	Soft, greenish gray, pepper-salt sandstone, jointed N. 20° E. at right angles to bedding (specimen 474)		10
7	Soft, blue clay shale, evenly bedded	2	
6	Greenish gray sandstone layer		2
5	Blue clay shale		6
4	Gray quartzite layer		4
3 & 2	A mass of blue clay shale with some thin sandy layers, probably extends in depth to the first hard layer of sandstone (item No. 1). Nearly all covered	23	
1	Hard, gray sandstone ledges, jointed into diamond shaped pieces (a small outcrop projecting into the creek.) strike N. 76° E., dip 28° N.	2	
	Total thickness	1791	7

From the point where this section was concluded northward, higher in the series, the greater portion of the rocks is covered for some distance, certain hard ledges only being exposed to view. These materials, however, are seen to be of the same hard quartzite and resistant white or gray sandstone as occurs below, alternating with some dark clay shales and shaly sandstones, the mass as a whole forming a formidable mountain (Walnut Mountain) 2,100 feet high striking N. 70° E. many miles across the country.

Just what proportion of the Beech Creek section should be assigned to the Jackfork formation and what part to the Stanley is difficult to say. The two formations are conformable and continuous in deposition. In general the sandstones of the Stanley are dark greenish gray in color and fine grained while those of the Jackfork proper are white and coarse-grained. On this basis one would be inclined to place most of the Beech Creek section in the Stanley, but certainly the uppermost 325 feet at any rate, belong to the Jackfork. Farther west, T. 4 S., R. 20 E., one encounters the same difficulties of delimitation.

In the vicinity of Atoka, Okla., situated at the extreme western termination of the Ouachita Mountains the Stanley overlies the Talihina chert and is succeeded by the Jackfork sandstone. It was from this general region that the original description of the

Stanley was taken (Taff, J. A., Atoka Folio, U. S. G. S., Folio No. 79, 1902, Page 4) and for comparison and convenience of reference this may well be appended as follows:

Stanley shale: *This formation follows the Talihina chert in gradual transition. Siliceous chert, black shale, and greenish clay shales occur in alternate members for nearly 800 feet above the base. There are two cherty members, 30 and 40 feet in thickness, which were noted in sec. 7, T. 2 S., R. 12 E., 550 and 800 feet, respectively, above the base of the formation. These cherty strata resemble many of the thin and more shaly cherts found in the Talihina formation. Continuing upward in the section, there are greenish and dark shales alternating with drab or brown and moderately hard sandstones until the formation reaches an estimated thickness of 6,000 feet Distinct sandstone members range in thickness from 20 to 100 feet and are separated by shales or shales interstratified with sandy beds 140 to 2,000 feet in thickness. The best section of the formation in this quadrangle was noted across secs. 7, 8, and 9, T. 2 S., R. 12 E.

The sandstones are so soft that they produce little more effect upon the surface configuration than do the clay shales in which they are embedded. The whole formation invariably crops in nearly level plains or valleys and in such steep slopes at the borders of these valleys as are protected by the harder overlying formation.

The Stanley is found in the wide valley plain extending from the northeast corner of the quadrangle down Chicwasaw Creek and across North Boggy and Muddy Boggy valleys to the broad plain of the Trinity sand south of Atoka. It also extends eastward up Chickasaw and Little Chickasaw creeks, joining the broader plains and valleys of McGee and Jackfork creeks and Kiamichi River in the central part of the Ouachita Range in Indian Territory. The formation takes its name from the village of Stanley, in the Kiamichi Valley, where it is extensively exposed.

PALEONTOLOGY

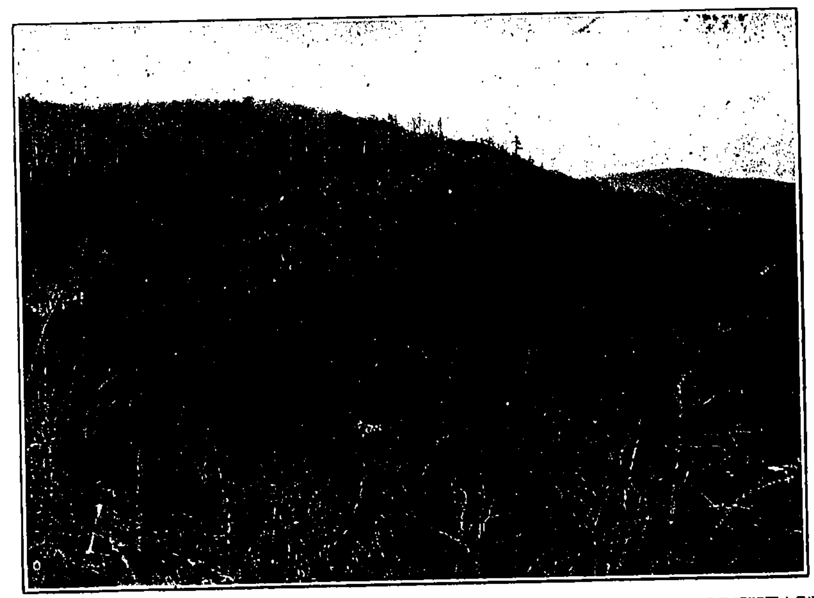
Organic remains in the Sanley shale are indeed scarce. Why there should be so few in all this 6,000 feet or more of sediments is surely not because there was no life nor does it seem that the dynamic forces operative in this region should have destroyed all traces of its existence. A few fossils have, however, been found, and the writer believes that continued search will reveal more.

A collection of plants including some ferns was made from the upper Stanley in Arkansas a number of years ago (as referred to by Miser, U. S. Geol. Survey, Bull. 660-C, p. 66). The Beech Creek locality, sec. 22, T. 1 N., R. 26 E., Oklahoma, as indicated in the description above, has yielded fragments of plants including fern pinules and some seeds in several horizons. The Jackfork sandstone above is at times quite replete with bits of wood and leaves. The

*The authorized spelling of Standley is now Stanley.

PLATE LVII.

A. A SCENE ON TOP OF BOKTUKOLA MOUNTAIN, LOOKING SOUTH 300 PACES SOUTH OF THE N. ¼ COR., SEC. 20, T. 1 S., R. 25 E, SHOWING JACKFORK SANDSTONE LEDGES AND CHARACTERISTIC GRASS AND TREES.



B. A VIEW OF BLUE BOUNCER MOUNTAIN LOOKING EAST-NORTHEAST FROM THE W. ¼ COR., SEC. 10, T. 1 N., R. 26 E.
The entire Mountain mass is composed of heavy ledges of Jackfork sandstone, some of the individual beds being 6 to 10 feet thick. The timber is practically all scrubby post oak.

writer has found great numbers of them all through the mountains from Atoka to Arkansas in the Jackfork, but they are always so poorly preserved that little use can be made of them.

Somewhere in the Stanley (exact locality not known) two plants were discovered, Nos. 977 and 882, both poorly preserved.

At a point 450 paces east of the W. ¼ cor. sec. 33, T. 4 S., R. 21 E., on the west bank of Little River near the middle of the Stanley close to the cone-in-cone horizon, were found two plants (numbers 941 and 942). In this same place on Little River in a tough, coarse sandstone layer three inches thick, and in the same outcrop, but not the same horizon, with the plants the writer found also a small marine fauna—so far as known the first animals ever found in the Stanley. These consisted of bryozoa and brachiopods and great numbers of crinoid stems for the most part, collectively numbered as specimens 943 and 944.

Near the bottom of the Stanley (within about 25 feet of the bottom) in the exact center of sec. 27, T. 2 S., R. 24 E. were found a few specimens of an inarticulate brachiopod No. 1015, and the same horizon was located also 4 miles to the east at a point 275 paces (2,000 paces per mile) south of the center of sec. 29, T. 2 S., R. 25 E., where three or four more specimens of the same brachiopod were found. (No. 1016). These occur in a hard, pinkish-white, fine-grained sandstone.

The fossil plants, poor though the materials are, were all sent to Mr. David White of the U. S. Geological Survey for identification and interpretation; the fossil shells and other animals were submitted to Dr. Charles Schuchert of Yale University who in turn showed them to Dr. Ulrich of the U. S. Geological Survey. Mr. White reports on the plants from the Beech Creek locality as follows:

> Most of the specimens contain mere fragments of stem or tissue undeterminable and of no value. A few definite forms are present and these apparently are new. At least, they are unfamiliar to me except in so far as I have seen them in the Stanley shale from other localities as, for example, near Tuskahoma.
>
> The aspect of the material is pre-Pennsylvanian and this opportunity to review additional Stanley fossil plants from a new locality only strengthens my opinion that the beds are Mississippian and probably Chester in age.

Of the scattered specimens of plants collected elsewhere Mr. White says:

> No. 941 is a specimen representing a portion of a Lepidodendron trunk. It is however, partially decorticated and therefore is not specifically determinable.
>
> No. 942 is a wholly decorticated Lepidodendroid stem, in which the nerve traces are very obscurely indicated. It may be either Lepidodendron or, more likely, Bothrodendron.
>
> No. 977. This number is given to two Calamarion fragments, each of which contains a complete internode. The rock has been so crushed and the stem fragments so deformed that it is impossible to say with confidence whether either of the stems belong to Astrocalamites. Both might belong to Calamites.
>
> No. 882 is a fragment of a fern frond, bearing slender pinnae of some Sphenopteris. The fragment is so weathered as to show only the topography and dim outlines of the pinnules, the nervation and borders of which cannot be clearly discerned.
>
> These specimens, I am sorry to say, are none of them specifically determinable. Therefore, any conclusion as to the age of the beds must rest on inferences based upon the general aspect or facies of the decorticated or badly worn and deformed fragments.
>
> The phyllotaxy of the Lepidodendron indicates a relatively ancient Corboniferous type. One of the Calamarian fragments is more suggestive of Asterocalamites than Calamites. The Sphenopteris may belong to a group found in the upper part of the Mississippian and in the very old Pennsylvanian.
>
> The collection does not contain anything specifically identifiable with any form characteristic either of Mississippian or Pennsylvanian. It appears, however, to harmonize with other material collected by Urich, Miser, and myself from the Stanley or Jackfork of Oklahoma and western Arkansas, none of which is really satisfactory, since all the fossils are very fragmentary and have generally been rubbed or deformed in the course of deposition in gritty rock. After examining your specimens the tentative conclusion that the Stanley represents either very late Mississippian, possibly upper Chester, or Pennsylvanian of earlier date than I am acquainted with in the Appalachian trough, is slightly stronger.

With regard to the small marine fauna found on the banks of Little River (specimens 943 and 944) and the inarticuate brachiopods from the base of the Stanley (specimens 1015 and 1016) Professor Schuchert writes as follows:

> It seems to me fairly certain that these specimens cannot be other than Mississippian or Pennsylvanian. As you got an undoubted Lepidodendron even beneath lots 943 and 944 and as the specimen appears to me like a Pennsylvanian form, it seems that the whole of the Stanley and Jackfork may be Pennsylvanian in age rather than Mississippian. The marine fossils do not indicate anything to the contrary. Your marine fossils are as follows:
>
> **Orbiculoidea nitida** Phillips. Loc. 1015 and 1016.
>
> I cannot distinguish the specimens from Coal Measures forms.
>
> **Crinoid columnals.** Loc. 943 and 944. Common. At least two species.

Cystodictya, sp. undet. Loc. 943 and 944.
Rhombopora, sp. undet. Loc. 944
Fenestella, sp. undet. Loc. 944
Bryozoa. Undet. Common Loc. 944.
Productus suggesting **Pustula nebraskensis,** Loc. 943 and 944
Chonetes, sp. undet. Loc. 943.
Very fragmentary. Finely striate form.
Fish bone. Loc. 943.

Dr. Ulrich reports as follows:

Frankly speaking, these Stanley remains are certainly a poor lot— not at all noisy in imparting information. Only the Orbiculoidea nitida, which identification seems as good as can be made with the material, is in sufficiently good condition to warrant a definite opinion.

The finely pustulated fragments of brachiopods I believe to belong to a species of Chonetes. As all the fragments expose the inner surface of the valves I deduce that the exterior is distinctly striated. But whether it is most like Mississippian or Pennsylvanian types one can hardly say. Still as the straiated Mississippian species of Chonetes are practically confined to beds older than the Warsaw and as it is almost too much to concede that the Stanley can be Lower Mississippian, then these fragments may be said to point toward the Pennsylvanian rather than Mississippian.

The Bryozoa also are too imperfect for satisfactory determination. And yet they are not quite hopeless. There is a fragment of Fenestella. This says nothing. Then there are a couple of branching specimens concerning which I cannot decide whether they should be called Rhombopora or Batostomella. These also throw no light on the question.

But the fragments of Cystodictya suggest Chester and Lower Pennsylvania species rather than older species of the genus.

Finally there are two fragments that seem to belong to Prismopora, a genus ranging from Mid. Devonian to Pennsylvanian. Because of their smallness these Stanley specimens suggest P. minuta, a Middle to Upper Pennsylvania species in Illinois.

The invertebrate part of the evidence by itself would not be conclusive either way. The trend of the evidence is toward the Pennsylvanian rather than the Mississippian (either early or late). Again there is nothing in the collection that may be justly cited as definitely opposed to correlation of the Stanley with lower Pottsville or basal Morrow, which conclusion I reached in my "Revision" mainly on physical and diastrophic considerations.

The fossils observed by me in the Jackfork seemed decidedly corroborative of my convictions respecting the post Chester age of the Stanley. So far as I can see your new evidence leaves the problem just about where I left it in 1911—that is, with the probabilities favoring assignment of the Stanley to the earlier Pennsylvanian.

MICROSCOPIC PETROGRAPHY

GENERAL STATEMENT

During the progress of the work of mapping the area, several hundred hand specimens of rock were collected from the Stanley. These were taken from all parts of the area of outcrop and were selected to represent every type and phase of sandstone, shale, chert, or other rock occurring in the series. A large number of the specimens, about 75 in all, came from the tuff bed near the bottom of the formation, which itself yielded a great variety of material, but most of the specimens are quartzites, fine grained, pepper-salt (feldspathic) sandstones, black cherts, dark clay shales, and shaly sandstones from beds higher in the series. Many of these are ripple marked and cross-bedded, and all are more or less metamorphosed.

On account of the disturbance wrought by the forces of deformation which folded and faulted the region the rock specimens could not be arranged in stratigraphic sequence excepting in a very general way. A microscopic study of some of them, in order to determine the mineralogy, structure, and source, if possible of the sediments, however, seemed highly worth while. Accordingly about 125 thin sections of the most interesting and least weathered of these have been prepared of which 52 are from the tuff bed near the base of the Stanley; 40 are sandstones and quartzites of one kind and another and the remainder, shales, cherts, etc. chiefly from the middle and upper portions of the formation.

It is impossible to include here a complete description of all these thin sections and rock specimens. A few of them will be taken up in detail but in the main composite descriptions will have to suffice.

TUFFS NEAR THE BASE OF THE STANLEY

In general it may be said of the tuffs occurring near the base of the Stanley that practically all of this material, when examined in plane polarized light microscopically may be seen plainly to be made up wholly or partially of angular fragments which are bounded by broadly curved, concave or convex lines meeting in sharp points, characteristic of volcanic ash fragments and known as "bogen structure." The majority of the fragments have become devitrified and between crossed nicols these lose their identity in an aggregate of quartz, feldspar, sericite and other minerals, which mask the bogen structure.

Some of the fragments (specimens H-1, H-4, from SW. ¼, NW. ¼, sec. 9, T. 5 S., R. 26 E.) have vesicular and flow structures and bear direct evidence of having dripped as a viscous liquid from volcanic bombs. Fragmented crystals of plagioclase and quartz, also angular lithic fragments of slate, pieces of limestone and sandstone of megascopic size are very common in the tuff and occasionally one sees a piece of basalt.

These matters are co-mingled with the originally glassy, now devitrified content and are regarded as ash also, blown from a volcano with volcanic violence. The feldspars are remarkably fresh in most specimens and are medium acid in composition approximating that of oligoclase or oligoclase-andesine ordinarily. Chlorite occurs in noticable amounts, frequently in large grains or blotches up to an inch in diameter. The chlorite appears to be very largely a product of devitrification of the glass.

The single instance of the occurrence of a fossil in the tuff is worthy of special mention. The specimen (No. 203) now in Columbia University, Department of Geology, Problems Set of rocks, comes from the SE. ¼, SE. ¼, sec. 24, T. 5 S., R. 21 E. and in the hand specimen, is a coarse but rather even grained fragmental of bluish gray color, firmly cemented into a compact, resistant, hard material. It is made up of fresh feldspar grains for the most part, in size up to 5 mm., chunky in habit, but scattered through the mass are dark colored angular lithic fragments and two or three segments of a crinoid stem. The rock weathers on the exterior to a coarse, rough surface with the feldspar grains in relief, but the joint planes are usually stained reddish brown with iron oxide.

Under the microscope in thin section the feldspar grains appear roughly equidimensional to tabular-chunky and average in size from 1 mm. to 2 mm. across. They are almost always twinned in broad bands and are medium acid in composition—approximating that of oligoclase or oligoclase-andesine. These are remarkably fresh, the only alteration product being sericite which is distributed uniformly but very sparingly in fine specks through the grains. There is no kaolinization. In addition to the grains of feldspar there are numerous lithic fragments such as bits of diabasic basalt, pieces of shale, and well bounded grains of crystalline limestone. There are also a few pieces of quartz. These materials are all sharply angular and are tightly cemented in an abundant matrix of fine flaky chlorite which locally is yielding some limonite as an alteration product. The chlorite occurs also in veins and as stains on the other minerals where it has lodged. There is no evidence of flowage or fracture in this slide and no banding or stratification. The rock is decidedly massive. The very singular angularity of the grains; the heterogenity of the deposit; and the bogen structure visible in the matrix point unmistakably to the volcanic origin of the material.

Of special interest are the grains of crystalline limestone which suggest that the crinoid stem fragments observed in the hand specimen might also be clastic and derived from a rock older than the

PLATE LVIII.

A. Photomicrograph of fine-grained, devitrified tuff from near base of Stanley shale, showing typical bogen structure of ash fragments in one half of the field and massive chlorite in the other half. Plain light x 40

B. Photomicrograph of a fine-grained variety of the tuff from near the bottom of the Stanley showing the typical bogen structure. Plain light x 40.

one in which they are found. At first thought it would seem that the ash fell in water which was inhabited by a marine fauna and that some of the animals were thus caught and preserved, but there is this possibility also, that the crinoid columnals, like other rock fragments of the tuff, could have been torn with explosive violence from the rim of an ancient volcano—a carboniferous Krakatoa if you please! and so be incorporated in the ash. Thus one cannot say positively weather these fossils represent a fauna which was resident in the place where the ash fell or whether they were ejected from a volcano. A thorough study of the specimens fails to decide this point.

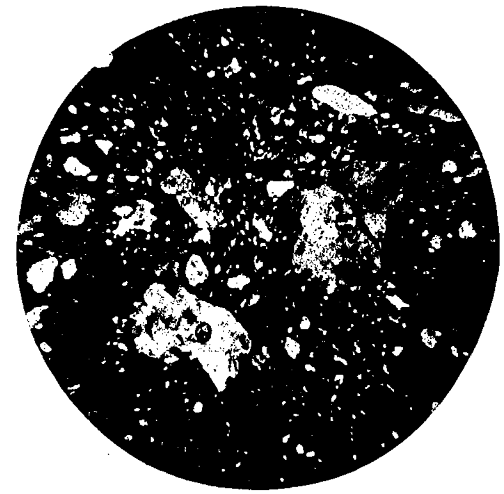
Some of the other variations and peculiarities of the tuff are brought out by the few individual descriptions which follow, but no attempt is made to include every type and phase.

Specimens 254 and 255 (from 250 paces south of the N. ¼ cor. sec. 19, T. 4 S., R. 27 E.) represent a very unusual phase of the tuff in that they are very coarse grained and carry 10 per cent to 15 per cent of water-worn pebbles. The pebbles range in size from 5 mm. to 10 mm. and consist of slate, white quartzite, ferruginous sandstone, and crystal quartz mingled uniformly through a mass of feldspar grains which average about 1.5 mm. in cross section. The pebbles are unquestionably water rounded and must have been transported, and deposited in their final resting place by water. The feldspar grains on the other hand are decidedly angular and appear not to have been washed very far. Presumably these materials are all water laid and the feldspar content derived secondarily from the ash. Unfortunately the specimens are too rotten to permit of sectioning so that it is not known whether or not any traces of a bogen structure could be found in them. Only in this one place has so coarse a material been found in the tuff bed.

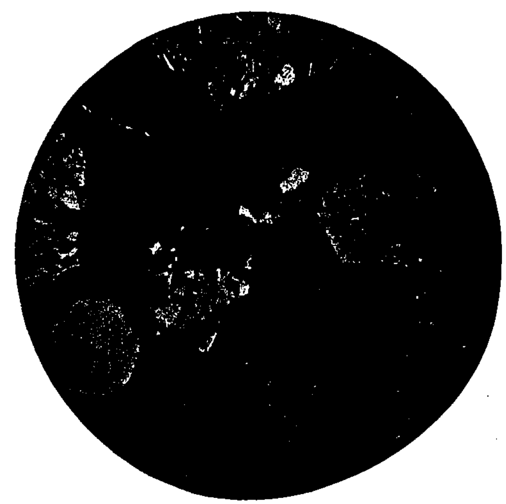
Specimen 58 is an extremely fine-grained, light gray variety of the tuff (from 50 paces south of the W. ¼ cor., sec. 11 T. 5 S., R. 26 E.) In thin section it is clearly a tuff. The ash fragments and bits of crystalline quartz and plagioclase make up the bulk of the rock which is cemented by an impalpably fine mud, now chiefly chlorite. The specimen is of special interest in that it contains a few rounded quartz sand grains the presence of which points to an admixture of water-borne or wind-blown sand but there is nothing in this particular slide to indicate whether the ash fell in the water or on land or was subsequently redeposited by wind or water. The feldspars are heavily sericitized but otherwise not altered. There are no signs of stratification either in the hand specimen or in the slide.

Specimen 343 is from a resistant ledge of blue quartzitic rock, which outcrops and forms rapids in the channel of Rough Creek (50 paces south and 300 paces east of the N. ¼ cor., sec. 20 T. 3 S., R. 27 E.) In the hand specimen this is a dense, massive, fine-grained, light bluish gray stone which is capable of taking a smooth polish when exposed to stream erosion, and very often there are pot holes developed in it. In thin section under the micro-

PLATE LIX.



A. Photomicrograph of the fine-grained tuff from near bottom of the Stanley shale formation showing fragmented crystals of quartz and feldspar (white and light gray) in a ground mass of devitrified glass. The bogen structure of the glassy content is not visible under crossed nicols. Crossed nicols x 15.



B. Photomicrograph of devitrified tuff from near the base of Stanley shale formation showing fragmented crystals of feldspar and quartz (light colored) in a matrix of devitrified glass and chlorite (dark colored). Plain light x 15. Specimen 94.

scope one sees very few fragmented crystals. These are quartz and acid plagioclase fragments. The remainder of the slide is evidently wholly devitrified ash now essentially quartz, feldspar and chlorite.

An interesting feature of this slide is the primary structure which can be seen only in reflected light—a structure which may be defined as diabasic for nearly the whole slide is composed of reorganized lath-shaped fragments. There are however, a few places where a typical bogen structure can be made out and for this reason the rock is classed as a tuff. It would appear that the products of devitrification were tiny lath shaped feldspars, which later became granular aggregates through continued metamorphism assisted perhaps by silicification. This is intersected by a net work of fine veins .075 to .150 mm. in cross section, of adularia and carbonate, a fact which would suggest that much of the fine grained, undeterminable aggregates were indeed feldspar. The adularia is entirely fresh and beautifully twinned.

Specimen 390 (from the W. ¼ cor., sec. 35, T. 2 S., R. 26 E.) and is a very fine grained variety of the tuff. In thin section there is revealed a beautiful bogen structure. Many of the fragments are vesicular and contain amygdules of chlorite. The slide is uniformly and finely recrystallized through the processes of devitrification and silicification. The few crystalline fragments of feldspar present are slightly cloudy with kaolinite, otherwise there is no alteration. All in all this is one of the best examples of the bogen structure studied.

Specimen 400 is a much metamorphosed massive, mottled green, brown and red tuff (from 500 paces north of the center of sec. 36, T. 2 S., R. 26 E.) In thin section under the microscope there appears a marked bogen structure only in spots. In general the structure is granular massive due to reorganization from pressure. Few large, millimeter-grained crystals of oligoclase and quartz occur but the most of the slide is a fine 0.03 mm. grained granular aggregate of quartz, feldspar, sericite, chlorite, and possibly other minerals stained with iron oxide and epidote. One of the remarkable features of this specimen as seen in thin section is the enlargment of some of the original plagioclase crystals, the new part and the old part of the grain being in crystallographic continuity and making up a single crystal unit, and this in spite of the fact that they are multiple twinned. The twinning planes are also carried along in the new material. The old interior portion of these grains is sericitized; the new and added portion is clear and fresh.

There are also small areas (vugs or veins) of secondary plagioclase (oligoclase and andesine) and quartz present. The plagioclases are beautifully crystallized, multiple twinned, pilotaxitic in habit and absolutely fresh. A black metalic (probably magnetite) plus a minor amount of quartz fills the interstices between the andesine laths in some instances.

Specimens 143 and 144 (from points 200 paces and 100 paces respectively south of the NW. cor. sec. 3, T. 5 S., R. 26 E.) are both fine-grained, dense, massive tuffs, bluish gray to greenish gray in color and in thin section both retain their original bogen structure telling of their volcanic origin. Sp. 144 is a splendid example preserving the structure in greatest detail and fineness. Many of the ash fragments have round holes in them showing the location of gas bubbles, others are streaked or ropy as well as vesicular and in every detail of form and structure show that they are ash fragments, once glassy but now devitrified. The products of devitrification are chiefly plagioclases in fine crystalline aggregate. Others of the ash framents as in the case in all the tuffs from this region, are pieces of crystals of plagioclase and of quartz, chiefly plagioclase. These appear not to have been originally glass fragments that have crystallized but crystalline material subsequently fragmented. The lava from which the ash was derived might have been (1) partially crystallized at the time of the explosion or opening of the vent, or (2) portions of the walls and rim of the crater may have been blown away with the lava and the two mingled together in the fall. Since the crystal fragments are, in nearly all instances single crystals or pieces of single crystals, units unto themselves, and not aggregates or granular intergrowths of several crystals the former explanation seems to best explain the facts. There are no rounded sand grains or water transported silt in either of these specimens and only a very few flecks of chlorite.

Specimen 99 (from 400 paces south of the N. ¼ cor., sec. 4, T. 5 S., R. 26 E.) is a dense, brittle massive, fine-grained rock of dark greenish gray color weathering light greenish gray. It contains no megascapically visible crystalline matter at all but under the microscope in thin section there are seen to be a great many angular crystalline fragments of plagioclase and quartz up to 0.2 mm. in cross section. These are remarkably fresh. Some of the quartz grains contain rutile needles and bubble inclusions. The great bulk of the rock however, as observed under the microscope is an extremely fine matrix of feldspar, quartz, and other matters most intimately woven together and so finely crystallized that much of this cannot be resolved into its constituents even with the highest power of the microscope. A beautiful bogen structure prevails throughout the slide in every part and is so well preserved that there can be no doubt of a volcanic origin for the whole of this rock. It is an excellent example of a devitrified tuff. Chlorite is the abundant coloring matter which gives to the rock its green hue in hand specimen. It is uniformly distributed as the minutest flakes and as a stain in all the finest of the matrix surrounding and clearly delimiting all the ash fragments which in plane polarized light are remarkably clear, colorless, and transparent. There is some carbonate present as large ragged flakes replacing certain areas in the thin section. Judging from the manner of occurrence it would seem to be introduced carbonate for it is no respector of minerals or of individual fragments..

Specimen 104 (from 500 paces N. of the center of sec. 9, T. 5 S., R. 26 E.) is a massive, tough, hard, dense rock of light gray color studded with large (10 mm.) chunks of dark green chloritic matter (fragments of altered slate or shale.) In thin section under the microscope the largest grains (up to 1.5 mm.) are crystals and fragments of crystals of plagioclase and quartz. These have angular outlines and for the most part are free from alteration. Such material is not abundant, however, and does not make up one fourth of the rock mass. The essential constituent is devitrified glass which in its present condition resembles very closely that described as occurring in specimen 99 (q. v.). The slide is etched in certain regions with carbonate which appears to have had an extraneous source and was introduced as a replacement mineral. The chlorite occurs chiefly as a stain in the matrix but in certain places there are large flakes of it.

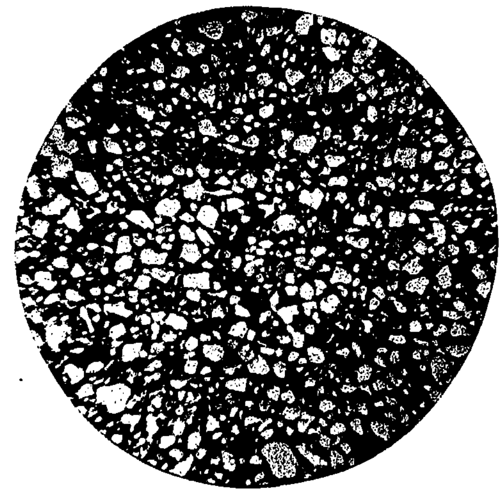
Specimen 280 is a fine grained, bluish gray tuff (from 200 paces north of the W. ¼ cor., sec. 9, T. 4 S., R. 27 E.) of extreme hardness and toughness, ringing under the hammer. It weathers by exfoliation. In thin section there is revealed a marked bogen structure characteristic of volcanic ash. This in the main does not differ from other specimens examined but special mention should be made of the fact that a few rounded quartz grains of zircon, flakes of muscovite and fragments of slate occur in the slide. These matters may be xenoliths in part but the association of quartz, zircon, and muscovite together would certainly indicate water transportation. Possibly the entire deposit fell in the water and in certain places became mingled with a small amount of sand from the sea shore. The quartz grains have suffered enlargement. Emphasis should be laid on the fact that less than five per cent of the rock mass is made up of rounded quartz grains, zircon, and muscovite.

Chemical Composition of the Stanley Tuff

Following is a chemical analysis* of the Stanley tuff from the measured section in the bed of Lick Creek (specimen No. 153) from 300 paces south of the center of sec. 8, T. 5 S., R. 26 E. (See measured section item 3, p. 147). The material selected for analysis is typical fine grained, devitrified ash, which as determined by microscopic examination in thin section, carries no lithic fragments and only a limited amount in very small specks of the broken crystals of quartz and feldspar. Carbonate is present however, estimated at 1 per cent.

*Shead, A. C., Chemist, Okla. Geol. Survey, Analyst.

PLATE LX.



A. Photomicrograph of typical Stanley grit (specimen No. 7) showing the gritty character of the quartz (white) which is embedded in a reorganized argillaceous-carbonaceous cement. Plane light x 15.

B. Photomicrograph of a rare type of Stanley sandstone showing grains of two distinct sizes, the larger consisting of complex grains of granitic quartz, and other rock fragments all well rounded; the smaller are chiefly gritty particles of quartz. Crossed nicols x 15.

TABLE I.

ANALYSIS		NORM	
SiO_2	76.86	Ilmenite	.3
Al_2O_3	12.76	Orthoclase	8.6
Fe_2O_3	.63	Albite	48.7
FeO	1.05	Anorthite	2.2
MgO	trace	Magnetite	.9
CaO	0.43	Corundum	1.
Na_2O	5.67	Silica	37.6
K_2O	1.43	Siderite	1.0
H_2O-	.12		100.3
H_2O+	1.09		
TiO_2	.177		
P_2O_5	.043		
MnO	very faint trace		
	100.26		

The norm was calculated on a water-free basis by the writer, and is interesting in that if we combine all of the An molecule with a maximum amount of the Ab molecule to form oligoclase (Ab_{12}-An_1) the result is 25 per cent of oligoclase and 13.7 per cent of free albite.

The essential facts may then be summed up about as follows:

TABLE II.

Quartz	37..6
Orthoclase	8.6
Albite	13.7
Oligoc'ase	25.0
Chlorite	14.1
Siderite	1.0
	100.0

In the majority of cases the writer has determined the crystalline fragments (of other specimens from other localities) as oligoclase and oligoclase-andesine, but there was no way of telling what might be the composition of the devitrified glass content of these specimens. The above summation (Table II) therefore throws some light on this part of the rock. In any case this is an extremely acid ash.

SANDSTONES AND SHALES

In all 60 specimens of the sandstones and 5 of the slates of the Stanley formation have been sectioned and examined with the microscope. These were taken for the most part from the eastern side of the area, but from all parts of the formation. They are typical of the Stanley sediments and represent every phase of the material that it was possible to collect.

The great majority of the sandstones are very fine grained, dark colored (carbonaceous) feldspathic grits, consisting essentially of angular particles of quartz, together with minor amounts of plagioclase, original muscovite, zircon, tourmaline, etc., of all sizes up to 1 mm., but averaging only one tenth that size, bound together usually with an abundant chloritic-sericitic cement. There are in some specimens examined, flecks of original biotite, grains of garnet and microcline, also a few scattered pieces of basalt, others carry small pieces of carbonized wood, but none of these last mentioned are common.

The cementing materials, chlorite and sericite, are anamorphic products, which have resulted apparently from the metamorphism of the original argillaceous and ferruginous matters in the sandstones. What limonite occurs is due largely to surficial weathering of the metamorphosed rock.

The shales are all richly carbonaceous and all more or less metamorphosed so that it is difficult to analyze them. Clay-slate needles are common in some of them; a great deal of rutile and leucoxene is present generally, and very frequently, pyrite.

Following are a few descriptions of individual specimens illustrating the variety of material:

Specimen No. 3 (from the N. ¼ cor., sec. 4, T. 5 S., R. 27 E.) is a slightly micaceous, fine-grained, greenish, gray, massive sandstone which in thin section is observed to consist of sharp, gritty quartz, cemented in an abundant fibrous and flaky mixture of chlorite and sericite mixed with finely divided leucoxene. The quartz grains have an average size of about 0.1 mm. these have not suffered enlargment and there distribution in the cementing material is such that they must all be original grains. There are one or two fragments of an acid plagioclase and a few flakes of original biotite and muscovite present so that the sediment must have come from an igneous region at least in part. The slide shows a slightly geneissic structure.

Specimen No. 7 (from a point 300 paces south of the NW. cor., sec. 15, T. 5 S., R. 27 E.) is a dense, dark, bluish gray, resistent, massive sandstone of extremely fine grain. In thin section it is observed to be essentially a gritty, quartz sandstone with grains averaging 0.4 mm. in size, but there are several grains of acid plagioclase present, several of zircon, one or two of garnet and some of rutile and ilmenite, the last in part changed to leucoxene. The cementing material is a finely divided, fresh chlorite, probably an anamorphic product brought about by the reduction of an original iron oxide cement. Replacement carbonate appears in very small ragged specks and grains. The structure of the rock is altogether massive.

Specimen 39 is a light gray, massive, resistant quartzite—a material which is conspicuous for its exfoliated boulders and resistant exfoliating ledges occurring over the region. The specimen comes from the center of sec. 19, T. 5 S., R. 27 E. In thin section, rounded to subangular and gritty particles of quartz and a few of fresh plagioclase are the essential consitiuents observed. There is also a little leucoxene in definite grains, some of zircon, garnet, and rutile, and a few flakes of muscovite. These materials are all firmly bound in a siliceous cement in which there is a very little sericite and chlorite intermingled. The inclusion of igneous and metamorphic minerals in this quartzite would indicate that an igneous and metamorphic region was the direct source of much of the material for there is a noticeable amount of the feldspar in the rock and several grains of garnet.

Specimen 59 (from 200 paces south of the NW. cor., sec. 11, T. 5S., R. 26E.) is a fine grained greenish gray, soft, schistose sandstone carrying an abundance of finely divided sericite. The sericite was developed through shearing processes. The rock is schistose and splits readily in the direction of the schistosity. In thin section the rock is seen to consist of fine, gritty particles of quartz all under O. 1 mm. insize cemented in an abundant limonitic-chloritic-sericitic cement. One sees practically no feldspar, zircon, or other similar material in this specimen. There are numerous small specks of leucoxene, however, and many large dark colored areas, probably shale darkened with organic matter. The thin section is typical of a fine silt.

Specimen 66 is one of the fine grained, peper-salt,, greenish gray, hard sandstones (from the SW. cor., sec. 24, T. 5S., R. 26E.) In thin section this material is observed to consist very largely of subangular to rounded grains of quartz and some of plagioclase tightly compacted in a very scant cement of finely divided sericite and chlorite. The cement is entirely an anamorphic product and adhers closely to the grains filling all pore space. Much of it is intermeshed with the quartz about the margins of the grains binding them together into a very firm whole. Aside from quartz and some feldspar there are a few flecks of muscovite, a grain or two of zircon, and a few specks of leucoxene. It is a fine silt but not so fine nor nearly so siliceous as the preceding, No. 59.

Specimen 78 (from a point 625 paces south of the NW. cor., sec. 12, T. 5S., R. 26E.) is a dark gray, massive, fine grained, resistant sandstone which weathers by exfoliation. In thin section one sees a great variety of material of various sizes up to .5 mm. and all more or less angular. In order of their importance in the slide these are: crystal quartz, shale or slate, acid plagioclase, muscovite, biotite, and basalt. Much of the quartz is granitic, consisting of interlocking grains. The cementing material is largely chlorite and sericite with grains of leucoxene scattered about. There is no doubt that such an assemblage of rocks and mineral fragments came from a structurally complex area composed of metamorphic and igneous rocks of various kinds.

Specimen 131 is a micaceous pepper-salt, fine-grained, dark greenish gray grit, massive in structure and harsh to the feel. It comes from 150 paces north of the center of sec. 17, T. 5S., R. 26E. In thin section granular, gritty, granitic quartz and some feldspar (orthoclase and acid plagioclase) are the essential constituents but there are also present: zircon, muscovite, biotite, and several fragments of basalt in the slide, indicating all together a complex, igenous area as a source of the sediments. The cementing material is a mixture of chlorite, epidote, and quartz specked with grains of leucoxene and organic matter.

Specimen 329 (from 100 paces south of the center of sec. 21, T. 3S., R. 27E.) is a dark, siliceous, thickbedded slate streaked with fine light colored bands and splitting across the bedding. In thin section it is a uniform fine pasty aggregate of chlorite, sericite, epidote, quartz, leucoxene, rutile, and doubtless other minerals intimately associated in one uniform whole. It is not sufficiently indurated or coherent and not of the proper composition however, to be commercially valuable as a slate.

Specimen 433 is from a point (75 paces east of the N. ¼ cor. sec. 24, T. 1 S., R. 2 6E.) in the middle of the Stanley series. It is a dark, smoky gray, fine-grained, quarzitic sandstone cut by thin veins of quartz. In thin section it is observed to be decidedly felspathic, somewhat micaceous and carries zircon, rutile, tourmaline, garnet, and biotite. The quartz grains are gritty and angular averaging 0.1 mm. in size but there are a few rounded grains, several times that size, present. The binding material is carbonaceous matter, chlorite, and quartz. Evidently the original was a fine, gritty silt carrying considerable organic mud and derived, judging from the fresh feldspar, biotite and other minerals present, from a metamorphic and igneous old land. The few rounded, large, quartz grains are regarded as dust particles derived from the air.

Specimen 441 is another fine grained, dense, massive, smoky gray quartzite, this time from a newly dug well (125 paces south and 125 paces west of the NE., cor sec. 19, T. 1 S., R. 27 E.) When viewed in thin section under the microscope this too is a firm quartzite similar to specimen 433 but it carries an unusually large amount, estimated at 15 per cent, of garnet, zircon, tourmaline, and ilmenite, but chiefly garnet and zircon. These heavy minerals range in size together with the quartz up to 0.2 mm. and are uniformly mingled together and firmly bound by a siliceous, slightly chloritic, in places graphitic, cementing material.

Specimen 928 is a relatively coarse to medium grained sandstone occurring well up in the Stanley (200 paces south of the N.¼ cor., sec. 17, T. 5S., R. 22E.) In hand specimen it is a light gray compact, quartzitic sandstone, very resistant and weathering by exfoliation into resistant shell like slabs ringing under the hammer. Under the microscope in thin section the largest particles are observed to be 2 to 3 mm. in cross section. These are rounded grains of quartz and acid plagioclase and irregularly shaped bits of porphyritic basalt and black slate, uniformly scattered through a mass of finer

0.1 mm. grained, gritty sand consisting of quartz, acid plagioclase, zircon, and muscovite. The whole is cemented in a thin, fine mixture of chlorite, sericite, and leucoxene, portions of which have yielded some limonite. The presence of igneous and slaty matters certainly speaks for a metamorphic igneous area as the source of the sediments. Specimen 929 is another specimen of the same rock from the same place. In this the coarser, 2 mm. grains make up fully 50 per cent of the rock mass. In thin section one sees rounded grains of quartz, zircon, orthoclase, muscovite, acid plagioclase, fragments of chert, slate, and porphyritic basalt. There are apparently but one or two thin horizons of material so coarse as this in the Stanley.

CHERT CONGLOMERATE NEAR BASE OF STANLEY

Near the bottom of the Stanley shale, some distance below the tuff bed, has been found in a number of places a thin, 1 foot bed of silicified cherty conglomerate. This has been examined microscopically and found to consist of conspicuous subangular fragments of chert up to 1 cm. in length and rounded quartz grains, cemented in an abundant fine cherty matrix. The chert fragments are streaked with sericite and limonite, while the quartz grains are characterized by minute parallel fractures in two directions and by strain shadows. The binding material is wholly silica in the form of a finely granular chert which adheres closely to the original grains, but none of these have been enlarged. There are a few grains of zircon present but no feldspar nor muscovite. A feruginous carbonate replaces the quartz in one specimen (No. 885 from a point 250 paces north of the S. 1/8 cor. sec. 10, T. 5 S., R. 25 E.)

BLACK CHERT FORMATION IN MIDDLE OF STANLEY

A microscopic study of some of the black cherts from the middle portion of the Stanley shows them to be dirty (carbonaceous-argillaceous) chalcedonic, finely granular cherts cut by veins of quartz and carbonate and replaced in places by a few rhombohedra of siderite. Some of the materials examined are uniformly and minutely streaked with the dark brown to black organic or carbonaceous material which occurs in tiny sooty specks and bunches marking out the original bedding. The original seems to have been a fine black mud.

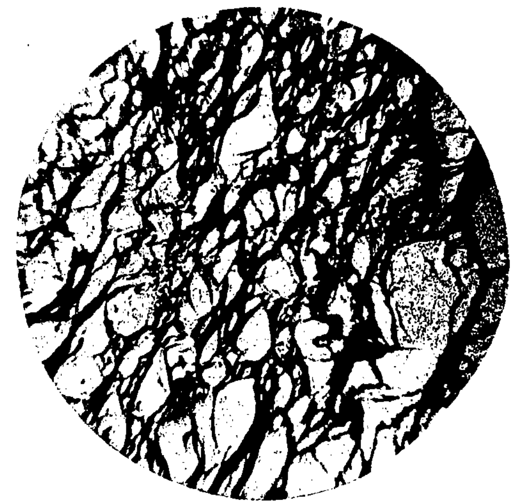
CONE-IN-CONE CONCRETIONS IN STANLEY

Cone-in-cone concretions occur in the black shales of the middle Stanley throughout the area of outcrop of this part of the formation. These are lenticular masses one foot to three feet across, by 3 to 6 inches thick, ordinarily, and occur in beds of black shale in close proximity to each other in the layers where they occur. The concretions have a central, horizontially schistose core of dark bluish gray, siliceous-argillaceous, finely granulated material out of which, all about this central mass, normal to the surface curvature, spring myriads of the cone-in-cones, growing outward and forming a

shell one to two centimeters thick. Some of these concretionary masses part in the middle, and the exterior shell of any of them may be split off with a blow of the hammer. They are nevertheless, very resistant to weathering conditions and may be found lying about on the surface or projecting from the outcropping ledges of shale in many places.

A number of specimens of the cone-in-cones were collected at a point 150 paces north and 250 paces west of the center of sec. 3, T. 6 S., R. 26 E. from which thin sections have been prepared. These reveal a microscopic structure which is very difficult to describe. (Plate LXI.) The rock resembles more than any-

PLATE LXI.



Photomicrograph of cone-in-cone concretion, in transverse section, from the Stanley shale. The light colored material is quartz, the dark substance is reorganized shaly matter. Plain light x 15.

thing else a mass of siliceous (cherty) augen crowded together in irregular rows, each eye being separated and internally streaked with a highly polarizing, finely divided, yellowish, flaky substance, probably sericite. This material polarizes uniformly throughout the slide pointing to uniform orientation of the particles and indicating in turn that shearing stresses had played an important part in its formation and present distribution. The shredded sericitic bands which cross the augen of cherty silica make a wide abtuse angle with the heavier bands which mark out the direction of the schistosity; and the former are connected or are continuous with the latter in a manner indicating that the cross fibres had been split off and bent away from the large sericite bands, silicia having been intruded in, among and around them as they were being bent, or sheared around. Continued deposition of silicia from without would only tend to separate the sericitic bands more widely, and continued lateral shearing would bend the sericite shreds, torn from the parent lamillae, still farther and farther from their original parallel position, until the rock having grown "fat" with silicia assumes its present structure. The bands of sericite form the parting planes and cause the nuggets of silicia to lie separated one from the other, but why all those on the exterior should be cone shaped the writer is unable to explain. Cone-in-cones in general are supposed to be concretions formed under pressure, but just how they formed or why they should form, the present occurrence yields no definite proof more than that they appear to originate from a shale simultaneously laterally sheared and richly silicified under pressure. Apparently some of the concretions grew very slowly (the fine textured ones) and others rapidly (coarse textured ones).

Some of the specimens are intersected with quartz veins and one of these is slickensided showing that there has been at least some movement since their formation.

FAULT BRECCIAS, SLICKENSIDES, VEINS, ETC. IN THE STANLEY

Among the collection of Stanley specimens there are 50 or more examples of slickensides, fault-breccias, vein materials, etc., which it seems should not pass without mention. Many of these are excellent examples of their kind and from the aesthetic and didactic points of view are very attractive.

The breccias are especially beautiful, consisting of fresh greenish gray sandstone cemented in a mass of milky white quartz. Some of them are very loosely cemented and the partially filld cavities glisten with myriads of tiny adamantine points and prisms of crystal quartz.

Vermicular chlorite abounds in many of the specimens of vein quartz. Some of the crystals are zonal, green, and brown, with chlorite and limonite. Mottled green and white blotches of quartz appear in the massive veins.

There are several good examples of slickensides, faulted veins, mud cracks, etc., and one specimen of a stylolite in sandstone.

The sad fact remains, that there is no gold or other metallics of value associated with this quartz. The reader is referred to the chapter in Economic Geology in Part II for a full statement concerning the metals.

RESUME AND CONCLUSIONS

CONCLUSIONS PERTAINING TO THE TUFF BED

The essential facts as brought out by the study of the thin sections and hand specimens of the tuff bed near the base of the Stanley are as follows: (1) That of the fine grained aphanitic material and practically all of the coarse grained material, where not too profoundly changed by metamorphism, reveals a typical bogen structure characteristic of volcanic ash fragments. Many of these fragments have rounded holes in them showing the location of gas bubbles, others are streaked or ropy as well as vesicular and in every detail of form and structure show that they are ash fragments once glassy, but not devitrified, some of them silicified. (2) That in the case of the coarser grained specimens and most of the dense, fine grained ones there are present noticable quantities of fragmented crystals of plagioclase (oligoclase, andesine, and labrodorite) and quartz, intimately mingled with the originally glassy, now devitrified fragments, having such angular outlines and other characteristics as to be nothing other than volcanic fragmental matter derived either from (1) previously cooled plutonic rocks about the volcano or (2) from partially cooled lava within. Such material may be negligible in amount in some specimens but in others it constitutes 90 per cent or more of the rock mass. (3) That in many of the specimens there are sharply angular bits of slate or thick bedded shale and in some few cases angular fragments of basalt, limestone, and other materials which are best explained as xenoliths derived from the volcano. These lithic fragments may be half an inch in cross section in extreme cases; those composed of shale or slate are invariably heavily chloritized and doubtless give rise to much of the binding material in the rock. (4) That the originally glassy constituents of the tuff have in all instances suffered complete devitrification yielding medium acid plagioclases, chlorite, and possibly some quartz in fine grained aggregate, often too fine to be determined. (5) That there are present in some specimens of the tuff, solitary, rounded, quartz sand grains, rounded grains of zircon, isolated patches of silty material, leucoxene and rutile, all of which indicate an admixture of a minor amount of water transported materials. These may have acumulated in the ash however, in some cases, as dust blown by the wind from an adjacent area. (6) That there is a notable absence of stratification and never a segregation of sand grains or silty matter in bands, indicating that the ash was not sorted by water or transported by water, except perhaps locally at the bottom. The primary structure is massive. (7) That the essential binding material in the rock is chlorite occurring as a fine flaky aggregate bordering each and every particle of ash and also as larger scales, grains, and stains elsewhere. The chlorite is believed to be very largely a devitrification product, but in some cases the chunks of slate or shale included in the tuffs as zenoliths seem to have given rise to large amounts of chlorite. (8) That certain of the specimens are silicified apparently by replacement processes and a few are cut by quartz veins.

(9) That certain specimens have suffered from hydro-thermal action as shown by the replacement of some parts of some specimens by ferruginous carbonates. (10) That aqueo-igenous juices have in certain localities penetrated the tuffs as indicated by the enlarged plagioclase grains and the presence of vugs and veins of fresh acid plagioclase, and quartz. (Specimen 400.) (11) That as a rule the feldspars in the tuffs are remarkably fresh, considering their history and when altered at all the resultant is largely sericite developed through deep seated shearing and metamorphism. Calcite is not an uncommon alteration product in some places, but kaolinite occurs only after surficial weathering has gone on. (12) That tuffaceous material carrying pebbles and gravel is ineed very limited. In the one place observed where such was the case it seems that those particular beds must have been sorted by water and redeposited, and (13) That, as many times as the outcrop of the Stanley tuffs has been crossed and recrossed by the writer in mapping them, and as great care as has been taken in connecting the outcroppings in a logical delineation on the map, he is, nevertheless, unable to state positively, whether there is one or more than one bed of the tuff, so great has been the deformation.

CONCLUSIONS DRAWN FROM THE SANDSTONES SLATES, CHERTS CONGLOMERATE, AND VEIN MATELIALS OF THE STANLEY

The petrographic and microscopic study of the sandstones, slates, black cherts, conglomerates, and vein materials of the Stanley series leads to the following conclusions: (1) That the direct source of the Stanley sediments was a land area consisting in large measure of acid igneous and metamorphic rocks, for in practically all of the sandstones examined, bits of fresh acid plagioclase occur; and in many of the specimens fragments of slate, shale, flint, porphyritic basalt, granitic quartz, muscovite, biotite, tourmaline ,garnet, rutile, ilmenite, and zircon are found, as well as plagioclase. The rarity of orthoclase and microcline in the Stanley sediments may be explained by reason of its relatively easy destruction by decomposition. (2) That this ancient land area must have been very large indeed to have furnished so vast a deposit as the Stanley, not to say anything of the Jackfork which doubtless also came from the same place. (3) That, judging from the large amount of chlorite present as a binding material in practically all the sandstones, the original cement must have been ferruginous. Very few of the Stanley layers are quartzites; and carbonate as a cementing material is wholly absent. The water in which these sediments accumulated must therefore have been decidedly muddy and ferruginous. Besides chlorite, there is also an abundance of sericite and leucoxene in most of the specimens and a large amount of carbonaceous matter in the slates and shales ,pointing also to muddy waters. (4) That the ancient land area which furnished the Stanley silts must have been covered with vegetation, else there could not be so much carbonaceous matter in the rocks. Some of the sandstones carry bits of carbonized wood, visible to the unaided eye. (5) That, judging from the fine grained, gritty character of the great bulk of the quartz sand of which the Stanley sandstones and grits are composed (the everage size of the grains being approximately 0.1 mm. in cross sections and seldom reaching 0.5 mm.) one would infer that they were deposited by slow moving waters and in a region considerably removed from the land mass furnishing them. (6) That the few instances of millimeter-grained sandstones, and the case of the chert conglomerate near the base of the Stanley, carrying locally, chert pebbles one centimeter in length, must mean that there were times occasionally when, because of storms at sea, high waters in the rivers or for some other reason, the sediments were washed farther out to sea than ordinarily. These layers of coarser material, on account of their limited thickness and their sudden appearance and disappearance in the succession, can hardly be the record of the shallowing of the waters. They might represent the pulse of rejuvenation of the rising distant land mass furnishing the sediments.. (7) That the few large, well rounded quartz grains found in some specimens of grits (e. g. No. 433) can best be explained as dust particles derived from the air, because there are no grains of intermediate sizes in these particular layers of rock. (8) That there were times when gelatinous silica (?) accumulated on the bottom of the ocean in the presence of much black mud, as is recorded by the 25 feet of black cherts especially, occurring in the upper middle portion of the Stanley. On the other hand the presence of doubtful sponge spicules discovered in one of the specimens examined would indicate that a part of the chert at any rate might be due to them. (9) That the sediments are now greatly changed from their original character because of the dynamic metamorphism and deformation generally which they have undergone as evidenced in the formation of chlorite, sericite, and epidote, the development of schistosity due to the slicing and granulation of the quartz; the enlargement of quartz grains in certain instances and the etching and intergrowth of quartz and chlorite in others due to deposition of silicia and chemical reaction (hydro-thermal effects) ; the replacement of the original rock mass by carbonate (apparently siderite) in some instances; the growth of pyrite cubes in others, and silicification generally.

ORIGIN OF THE STANLEY SHALE

The outstanding facts with regard to the sedimentation of the

Stanley are: (1) the dark color of all of the shales, slates, and sandstones; (2) the uniform even fine grain of the sandstones and quartzites; (3) the total absence of limestones and of calcareous cements in the sandstones; (4) the tremendous thickness of the series; (5) the ripple-marked and cross-bedded structure of nearly all of the strata, sandstones and shales alike. Whatever the theory for the origin and source of these beds the above facts especially must be accounted for. Without arguing the various possibilities and impossibilities of such an accumulation, the writer wishes only to state that the conditions involved appear to him to have been essentially a gradually subsiding area into which a large river throughout the subsiding period discharged its load. How large the basin of subsidence could have been, how well defined and what the shape of it was, are only matters of conjecture with him. That the inflowing river, which discharged its sediments into the bay or basin, was large is attested by the absence of all conglomerates and coarse sands, and by the silty nature of the deposits from top to bottom of the Stanley—a silt wihich was more sandy at certain periods than others by reason of the well-known conditions controlling all large rivers, and one which was rich in organic matter at all times.

The ripple marks, rill marks, and cross-bedding throughout the succession would indicate that mud flats were repeatedly if not almost continuously a feature of the delta on which the ancient river laid these sediments. The silts, sands, and muds were evidently washed around and shifted about on the flats, re-sorted and finally deposited in the ripple-marked and cross-bedded condition in which we find them.

That fragments of plants, pieces of wood, bark, leaves, etc., should be washed down a river and become buried in the sands is, of course, a well-known fact and in accord with the facts of the Stanley sediments.

It should also be expected that a great delta deposit at the mouth of a large river such as it appears the Stanley must have been would from time to time, especially during periods of storms and rough sea, be peopled by marine animals. These doubtless would not move voluntarily from their habitats to fresh water but might easily be washed along by littoral currents and heaved shoreward by storm waves. Thus one may account for the few brachiopods and other animals found. With reference to the bryozoa and other fossils found at the Little River locality special mention should be made of the fact that this fauna occurs in a horizon about 3 inches thick composed chiefly of quartz gravel whose grains average about 2 mm. and that the fossils are broken to bits. Regarding the character of this fossiliferous layer Professor Schuchert says:

"The physical character of the rock of localities 943 and 944 leads me

PLATE LXII.

JACKFORK SANDSTONE LEDGES OUTCROPPING ON THE SOUTH SLOPE OF LYNN MOUNTAIN ONE-FOURTH MILE NORTH OF SW. COR., SEC. 4, T. 1 N., R. 26 E.

A. JACKFORK SANDSTONE BLOCKS FORMING A TALUS ON LYNN MOUNTAIN, N. ¼ COR., SEC. 2, T. 1 N., R. 26 E.
Largest trees are Sasafras.

B. JACKFORK SANDSTONE BLOCKS FORMING A TALUS ON THE SOUTH SLOPE OF LYNN MOUNTAIN ONE-FOURTH MILE SOUTH OF THE NE. COR., SEC. 2, T. 1 N., R. 26 E.
Timber is scrubby post oak.

A. HEAVY BEDDED, MASSIVE, FINE-GRAINED RESISTANT JACKFORK SANDSTONE OVERGROWN WITH LICHENS NW. ¼, SEC. 8, T. 2 S., R. 25 E.

B. EXFOLIATING BLOCKS OF JACKFORK SANDSTONE ON THE WEST SLOPE OF BOKTUKOLA MOUNTAIN, 200 PACES EAST OF THE NW. COR., SEC. 1, T. 2 S., R. 24 E.

to the following physiographic and geologic conclusion. The material came in the main from a granitic country though I think there were present also metamorphic rocks for there appears to be present considerable micaceous schist. This schist is still in angular pieces and larger than the quartz pebbles indicating shorter transportation. In addition there is much black shale present, some of which is also metamorphosed but apparently not all of it. The quartz pebbles are fairly well rounded and with the sand appear to have come a much longer distance than the shale and schist. There are also rounded pieces of garnet present."

At no other horizon in the entire Stanley, excepting the tuff, is there so coarse a material.

Higher in the Stanley where the plant horizons were found, and in the Jackfork sandstones above, the vegetal remains occur in thin beds charged with small twigs and other plant fragments, and also as scattered individual specimens. The latter are usually large, pieces of limbs and logs, but in all cases are macerated and eroded fragments—materials, it appears, which have been floated down stream from land areas to the south and southeast and out upon the delta to the north where they were engulfed in the sands.

JACKFORK SANDSTONE

The Jackfork sandstone has been eroded from most of the region dealt with in this bulletin. Portions of the base of the formation are encountered in the extreme northern and western parts (in Walnut and Blue Bouncer Mountains north of Smithville; in Boktukola Mountain west of Smithville; in the mountains west of Bethel; and in High Hill and Signal Mountains south of Corinne; also north of Corinne), but the lower portion of the Jackfork sandstone has been described and discussed above (see Measured Section of Stanley-Jackfork Transition Series and Origin of Stanley, ante pp. 165 and 197) and needs no additional description here. A more adequate description of the Jackfork sandstone is being prepared in connection with the mapping of southern LeFlore County, north of the present area, and will be published later.

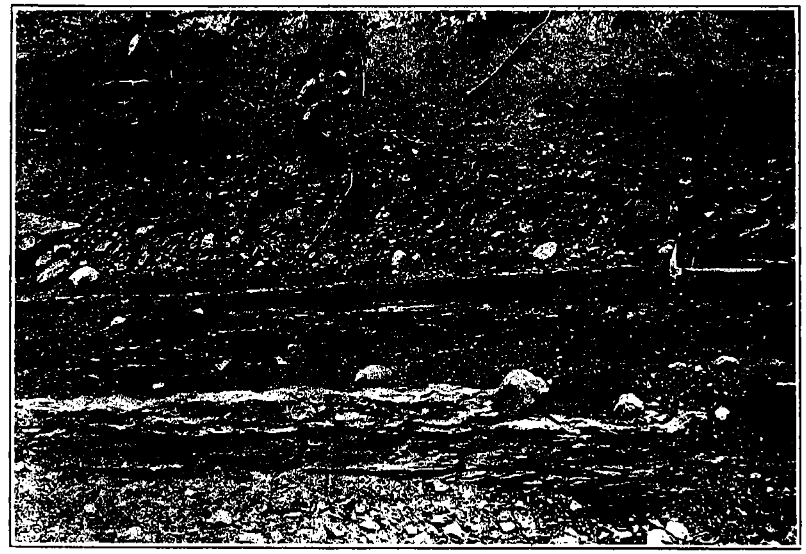
The Jackfork sandstone is regarded as Pennsylvanian in age owing to the discovery recently of the Morrow-Wapanucka fauna in the upper part of the formation.

TRINITY SAND

GENERAL STATEMENT

The Trinity sand of Lower Cretaceous (Comanchean) age appears along the southern border, and as isolated patches farther north, in the area as mapped (see map plate I). It overlies unconformably the highly tilted and truncated edges of the Paleozoic rocks, and itself dips gently to the south at the rate of about 40 feet per mile as a general average. The Trinity consists of loosely consolidated yellow sands, red and yellow clays, boulder and gravel beds, some ferruginous sandstones, and locally to the east some thin limestones. The various beds of sand, clay, gravel, etc., are much cross-bedded, irregular in their development, more or less lenticular in shape, and extremely variable in lithologic character. The total thickness of these beds combined, amounts to from 400 to 600 feet but only the lower portion of the formation has been studied in connection with the present report.

PLATE LXV.



THE CONTACT BETWEEN THE STANLEY SHALE (PALEOZOIC) BELOW AND THE TRINITY SAND (COMANCHEAN) ABOVE, AT A POINT 350 PACES NORTH AND 150 PACES WEST OF THE N. ¼ COR., SEC. 21, T. 4 S., R. 18 E. PHOTOGRAPH BY E. S. PERRY.

BASAL GRAVEL MEMBER

The bottom of the formation is usually a coarse, irregularly bedded, heterogeneous mass of waterworn boulders, cobbles, and gravel which range in size up to a foot in diameter. These materials are ordinarily unconsolidated or only loosely held together by a friable, ferruginous, sandy, cementing material but in some places the boulders and gravel are cemented into a massive, hard conglomerate. This basal member is often found to be only a few feet thick, sometimes it is wanting entirely, but it may be, and usually is as much as 50 feet thick or even more. It weathers into rounded hillocks and U-shaped valleys with 50 feet of relief where best developed.

All about the large inliers of Jackfork sandstone (High Hill Mountain and Signal Mountain) in the western part of the area the boulders are almost wholly of Jackfork sandstone, derived from the Jackfork formation in the immediate neighborhood. Farther east the gravel and boulders are largely of sandstone, quartzite, chert, novaculite, and vein quartz derived from the resistant formations of the older Paleozoics in the mountains to the north. The percentage of each kind of gravel to the whole is greatest nearest the source of the respective materials.

There is a tendency for the larger boulders, mingled with certain amounts of smaller pebbles and gravel, to occur more or less locally in patches to westward indicating that they have not been moved far from their source of origin and that they were formed in front of rocky headlands or sea cliffs in the Trinity ocean. Signal Mountain and High Hill Mountain (T. 4 S., R. 19 E., and T. 5 S., Rs. 19 E. and 20 E.) were islands in the Trinity sea. Some of the largest blocks, up to a foot in diameter, were noted around the east end of Signal Mountain. In this locality the boulders are subangular to sharply angular and in places may be found cemented with ferruginous yellow sand containing pebbles and gravel.

South of Sobol (200 paces north of the center of sec. 5, T. 5 S., R. 20 E.) there is a mass of conglomerate and ferruginous sandstone forming a hill twenty feet high. The boulders are of Jackfork sandstone some of which are rounded, but the majority of them are angular and were apparently moved but a short distance before they came to their final resting place. The average size of the pebbles here is from 2 to 3 inches, but there is much of the smaller gravel in the mass and some few large boulders. Ferruginous sandstone ledges appear at the base of the hill, below the conglomerate, but how extensive these sandstone ledges are is not known.

Where the Trinity lies in contact with the Stanley shale formation in the valleys of Turkey Creek and Little River (T. 4 S., R. 20 E. and T. 5 S., R. 21 E.) the boulder beds are very unevenly developed. In the western part of this particular strip of country only small patches of boulders are found and it would seem that over considerable stretches there are no boulders at all at the base of the Trinity. Approaching Little River however, vast quantities of boulders and pebbles are encountered and from this point eastward into Arkansas they are practically everywhere in evidence. It is believed that they attain their maximum development to the east owing to the large amounts of novaculite, chert, vein quartz, and quartzite which are so widely exposed in that direction.

The large outlier of Trinity located in the southern part of T. 4 S., R. 27 E. and in the northern part of T. 5 S., R. 27 E. is a fine

PLATE LXVI.

A. BASAL TRINITY CONGLOMERATE LEDGES, SEC. 13, T. 4 S., R. 17 E.

B. VIEW LOOKING WEST FROM A POINT 200 PACES SE. OF THE N. ¼ COR., SEC. 21, T. 4 S., R. 18 E.
Timber covered gravel hills in the distance occurring at the base of the Trinity sand. In the foreground is a flat area of sandy gravelly loam, and feather edge of the Trinity formation, reworked and aggraded by recent wash from the hills.

yellow sand with locally a little small gravel showing. It overlies the Paleozoic rocks directly without a boulder bed beneath. In the general region around about there are small amounts of gravel, up to 1 inch, scattered on the slopes and hill tops, some of which at least, is regarded as Trinity gravel. Elsewhere also there are patches of gravel and boulders, but the discussion relative to them will be taken up under the subject of Physiographic History (p. 263).

FERRUGINOUS SANDSTONES

In general the boulder and gravel beds at the base of the Trinity pass upward into soft, friable sandstones or loosely cemented sands of a straw yellow color. Intercalated with these locally are minor amounts of red clay and thin lenticles of gravel. In the western part of the area hard, richly-ferruginous sandstones are found in certain places and because of their unusual character they deserve some special mention.

These have been noted especially in the vicinity of Corinne and Sobol (in Ts. 4 and 5 S., Rs. 19 and 20 E.), only a few feet above the gravel member in the yellow sands, but they occur farther west, also outside the area under discussion and sparingly to the east, north of Slim (in T. 5 S., R. 21 E.)

One mile east of Corinne (in the center of sec. 26, T. 4 S., R. 19 E.) these sandstones are well developed and they are resistant enough to form a low ridge striking in a northeast-southwest direction. The top of the ridge and the low slopes are covered thickly with the loose blocks and slabs, which lie flat side down. These appear to be weathering from layers interbedded in loosely consilidated or unconsolidated yellow sands for no solid rock in place could be found. They are hard, highly ferruginous, fine grained sandstones of dark red and brown colors, very heavy, and locally are taken by some of the residents in the region for deposits of iron ore, but of course it is valueless as an ore on account of the high content of SiO_2 present.

The ferruginous sandstones assume many peculiar shapes, such as stalactitic and botryoidal structures and thin curved sheets. Some structures resemble moulds which might have, one time, contained bits of wood. These forms are all concretionary in structure and appear to have been formed by percolating waters carrying iron in solution which working downward through loose sand was precipitated through the action of woody and other organic matters interbedded in thin layers in sands. All the lines and markings on the slabs are roughly parallel and the majority of them straight or gently curved as though formed by the decay of woody matter. Smooth, rounded, narrowly elliptical channels occur, the largest observed being 2 inches by 6 inches by 2 feet. These may be the impressions left by decayed logs and limbs, flattened by the weight

of the overlying sands. The honeycombed and botryoidal, porous masses of ferruginous sandstone have resulted from the precipitation of iron oxide in loose sand.

Ferruginous sandstones similarly marked and with botryoidal structure occur prominently also one mile north of Sobol (in the SE. ¼, NW. ¼, sec. 30, T. 4 S., R. 20 E. and east). The layers here appear to be lenses or disconnected masses in the sand. Chunks of the rock have been thrown out of the railroad cut at several places along the tracks in this general region. These blocks show the common mammalary and botryoidal structures and some of the material is in layers—one mammalary layer deposited over another, each layer being one-fourth inch thick and sometimes there occurs a vacant space between the layers. There is no doubt that the iron was deposited as a chemical precipitate in the loose sand.

Again 500 paces south of the NW. cor., sec 9, T. 4 S., R. 20 E. and in the general region forming the hill top and covering the slopes there is a great quantity of the ferruginous hard sandstone, having stalactitic and botryoidal forms and structures. In the rock at this place there are what appear to be fragments of wood. The sandstones are uniformly fine grained but farther west they become conglomeratic and contain pebbles 2 inches to 4 inches across.

A few paces south of the NW. cor. sec. 18, T. 4 S., R. 20 E. the Trinity sand has weathered into mounds or rounded knobs and U-shaped velleys with 25 feet of relief. The ferruginous sandstones were noted here capping these rounded knobs, about 30 feet from the bottom of the Trinity, but the interval between the ferruginous sandstones and the bottom of the Trinity is very irregular.

LIMESTONES

Beginning two miles northeast of Bismark (in the center of sec. 35, T. 5 S., R. 22 E.) and continuing east in increasing thickness into Arkansas there occurs, from 30 to 100 feet above the base of the Trinity, a thin limestone. At its most westerly outcropping the rock is a white, compact, dense, fossiliferous limestone only about a foot in thickness embedded in red and pink clays. A mile and a half farther east, (300 paces south of the W. ¼ cor. sec. 31, T. 5 S., R. 23 E.), the ledge is 2 feet thick, fine grained, massive, and siliceous, and is underlaid by grayish-yellow marls and overlaid by gravel and boulders. The ledge was next seen north of Oak Hill (at the E. ¼ cor. sec. 6, T. 6 S., R. 24 E.) where it was found to be similar to the material noted 7 miles west. It is here a gritty (siliceous) pink limestone, extremely fine of grain and fossiliferous. Three miles farther east (300 paces west of the E. ¼ cor. sec. 3, T. 6 S., R. 24 E.) the limestone ledge is 3 feet thick and contains large oyster shells. One and one half miles north of the town of Broken Bow (at the W. ¼ cor sec. 7, T. 6 S., R. 25 E.) the limestone appears in the road. It rests directly on the gravel beds at this place and some of the gravel is cemented with the lime carbonate into a conglomerate. This bottom conglomerate, containing variously colored pieces of vein quartz and flint, is in beds 6 inches thick, aggregating 3 feet. Above it are some soft calcareous marls and red clays 12 to 15 feet thick followed in turn by relatively pure limestones. The limestones form conspicuous outcroppings in layers over a foot thick aggregating 10 feet over all, and are overlaid by red clays. The whole section from the bottom conglomerate ledge to the red clays at top is 35 feet thick. The lime-

PLATE LXVII.

THIN BEDDED LIMESTONES IN THE TRINITY FORMATION ABOVE THE CONGLOMERATE, OUTCROPPING ON THE WEST BANK OF MOUNTAIN FORK RIVER, IN SEC. 7, T. 6 S., R. 26 E.

stones are very fossiliferous but the rock is so firmly cemented that it is difficult to extract the fossils. In the vicinity of West Eagletown (300 paces south of the E. ¼ cor. sec. 12, T. 6 S., R. 25 E.) the limestones appear again and can be followed east as far as Mountain Fork River, one mile east. They were also noted westward (300 paces west of the NE. cor. sec. 16, T. 6 S., R. 25 E.) and could be followed for some distance east and west from this point.

The horizon is somewhat thicker in this township than anywhere else above noted. (See plate LXVII).

This limestone horizon continues east into Arkansas where Miser and Purdue* have named it the Dierks limestone lentil and where its thickness according to them ranges from 0 to 40 feet. Miser and Purdue (op. cit.) have also given the basal boulder bed a name, calling it the Pike gravel member, which they state to be 0 to 100 feet thick in Arkansas.

Near Little River (at a point 800 paces west and 250 paces south of the NE. cor., sec. 25, T. 5 S., R. 21 E.) a limestone cut by quartz and epidote veins was noted in one small outcrop on the top of a hill almost covered with gravel and boulders. This outcrop of limestone is only a few feet long; it is nodular and of greenish gray color with a slight tinge of pink in one or two places. The stratigraphic position of the limestone is not known but it appears to be at the bottom of the Trinity. A similar occurrence of limestone was found also north of Broken Bow (100 paces north of the center of sec. 5, T. 6 S., R. 25 E.) where numerous loose boulders were found all over the top of a little hill. The rock is of light greenish gray color tinged with pink, is compact and more or less nodular. It occurs at the very base of the Trinity but the occurrence so far as noted is confined to the single location given. A thin limestone conglomerate found in a well near the center of sec. 34, T. 5 S., R. 23 E. between Paleozoic red shales and Trinity red clays is regarded as a similar occurrence.

The writer has not had opportunity to study the upper beds of the Trinity, but the coming in of the marine limestones in the eastern part of the area would indicate more typically marine conditions in that direction.

*Miser, H. D., and Purdue, A. H., Gravel Deposits of the Caddo Gap and DeQueen Quadrangles, Arkansas, U. S. Geol. Survey Bull 690-B, 1918.

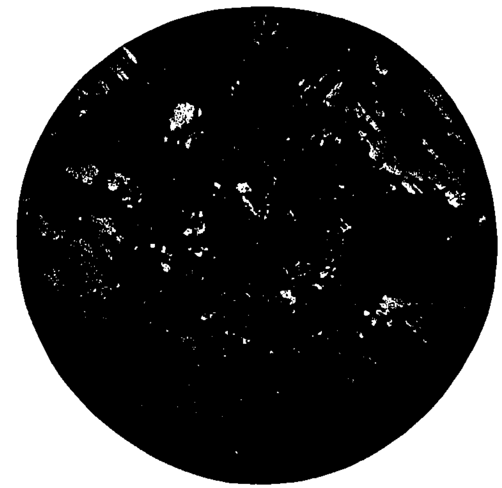
IGNEOUS ROCKS

Aside from the quartz-orthoclase pegmatites and the hydrothermal carbonate replacements, both of which are regarded as igneous phenomena and have been described above, there is but one other occurrence of igneous rocks in the region. This is a diorite sill intruded into the Womble schistose sandstones about 4 miles north of the village of Glover (in secs. 10 and 15, T. 5 S., R. 23 E.) The sill strikes N. 45° E. and dips 10° to 20° northwest parallel with the dip and strike of the sediments at that place. It has been followed from a point 250 paces south of the N. ¼ cor. sec. 15 where small outcroppings appear on the hillside to a point about half a mile distant northeast. The sill could not be traced continuously at the southern end where the thickness was observed to range from 2 to 5 feet but farther north along the west bank of a small creek the sill thickens to 10 feet and it is here that the best exposures occur. Whether the sill continues any farther in either direction could not be learned on account of the alluvial soils and abundant float both northeast and southwest from the locality where it was discovered.

In the hand specimen the fresh material is a very dense, tough, hard rock of a light greenish gray color, having a medium to fine grained granitoid texture and massive structure. It has been partially replaced generally by a ferruginous carbonate, which occurs as scattered rhombohedra up to 2 mm. in size. These weather to a yellowish brown oxide of iron and are very conspicuous on a partially weathered surface of the rock, but the exterior is usually pitted, light colored, and chalky, owing to the complete weathering away of the carbonate and to the kaolinization of the feldspars.

In thin section under the microscope this rock is observed to consist essentially of andesine plagioclase occurring in multiple twinned, tabular, interlocking crystals associated with which originally was a large percentage of ferromagnesian minerals, but the latter are now wholly destroyed and the cavities filled with a colorless chlorite. The chlorite occurs in relatively large sized grains some of which show the outlines of former crystals but much of this mineral is scattered permiscuously, as small ragged flecks and scales, everywhere. Rutile also occurs as a reorganization product distributed in bunches over certain areas as though it had come from some particular mineral. Some of the carbonate present may be an alteration product, but in the main it seems to be introduced carbonate. The rock contains very little alkalic feldspar and no quartz and should probably be called, therefore, a quartz-free dorite.

PLATE LXVIII.



A. Photomicrograph of the material of the diorite sill. The twinned andesine lies embedded in colorless chlorite, the chief alteration product of the ferromagnesian minerals which are now wholly destroyed. Crossed nicols x 15.

B. Another photomicrograph of the diorite. The irregular patches of white are areas of carbonate which in part has altered from the feldspar; a small percentage of the carbonate it is thought has been introduced as a replacement. Crossed nicols x 15.

Following is a chemical analysis* of some of the freshest of th material from the diorite sill:

ANALYSIS

SiO_2	47.44
Al_2O_3	16.59
Fe_2O_3	0.00
FeO	4.87
MgO	8.29
CaO	6.02
Na_2O	5.84
K_2O	0.53
H_2O-	.12
H_2O+	3.97
TiO_2	.886
CO_2	5.65
P_2O_5	.13
SO_3	0.00
MnO	0.10
	100.436

On acount of the much altered condition of the rock it doe not seem worth while to attempt a recast of the analysis.

*Shead, A. C., Chemist, Okla. Geol. Survey, analyst.

STRUCTURAL GEOLOGY

GENERAL FEATURES

The area under consideration in this report lies in the heart of the Ouachita Mountain Physiographic Province, in a region, whose general structure is typically Appalachian. All types of folds and faults occur in this region and they are multiplied, large and small together, in numbers almost infinite. There have been igneous intrusious and hydrothermal action, and locally, so great has been the regional metamophism as to baffle all human endeavor at an elucidation of the structure.

A complete discussion of the structure as known, especially that part pertaining to an explanation of it, involves not only the origin of the whole Ouachita Mountain region, extending from Atoka, Oklahoma to Little Rock, Arkansas, but concerns the problems of sedimentation and structure in the Arbuckles, in the Wichitas, in the Arkansas Valley, and in the Ozarks. It may be that certain structures in Texas may also have to be called into the discussion before all is known about the particular region in question. It is not within the scope of this report, however, to discuss at length the problems of orogeny of all these various provinces, but to expound the local structure of the southern Ouachitas. In the pages which follow, therefore, the writer will confine himself strictly to that region.

As may readily be observed from a study of the areal geology, this is a region of general uplift, whose major structural features are two anticlinoria separated one from the other by a synclinorium. The axis of the larger and more southerly of the anticlinoria, known as the Choctaw anticline, emerges from the Cretaceous cover at Glover, (sec. 33, T. 5 S., R. 23 E.) striking N. 45° E., continues northeast for about 12 miles, then swings gradually east to southeast for 6 miles further, giving place finally to a large normal (?) fault at the southeast corner of T. 4 S., R. 25 E. The axis of the other or more northerly of the anticlinoria, here-in-after known as the Cross Mountains anticline, originates with the west end of the Cross Mountains, (in Sec. 28, T. 2 S., R. 24 E.,) and is projected slightly south of east, almost due east, for 18 miles, thence into Arkansas for 12 miles. The axis of the synclinorium, for which the writer will adopt the name Linson Creek, from the creek by that name, extends from a point west of Sherwood (sec. 6, T. 3 S., R. 24 E.) slightly south of east to the center of T. 3 S., R. 26 E., thence east to the Oklahoma-Arkansas state line, where it may be regarded as coming to an end.

Miser, in his report upon the manganese deposits of the Caddo Gap and DeQueen Quadrangles (U. S. G. C. Bull. 660-C, p. 71) states that the Cross Mountains (in Arkansas) constitute the east end of the Choctaw anticline, which is, he says, the most prominent fold of the Ouachita region in Oklahoma. It is obvious, from his statement, that he spoke of the region in its entirety as a single anticlinorium and applied to it the name Choctaw anticline. He did not, however, at the time, know the details of the geology in the Lukfata quadrangle. The writer finds that there are two anticlinoria and one synclinorium, instead of one anticlinorium; and has, therefore, restricted Miser's term, "Choctaw Anticline," to the larger fold and uses the term, "Cross Mountains Anticline," as applying exclusively to the Cross Mountains.

CHOCTAW ANTICLINORIUM

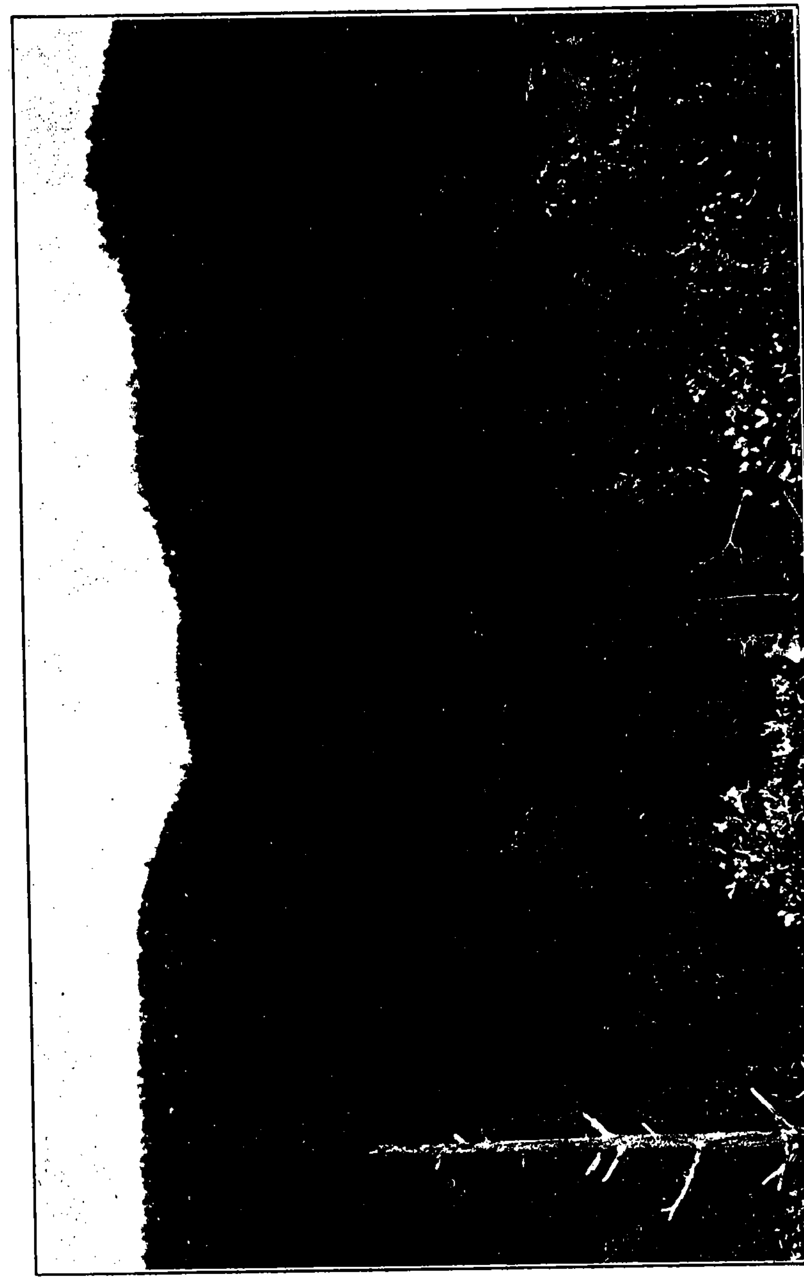
CENTRAL CORE

GENERAL

In the central part of the Choctaw anticlinorium, and here only, are encountered the oldest rocks exposed in the region, namely the Collier shale, Crystal Mountain sandstone, Mazarn shale, Blakely sandstone, and Womble schistose sandstone, having altogether an estimated combined thickness of at least 3,500 feet, and covering an area of approximately 100 square miles. With the exception of the Crystal Mountain sandstone these rocks are all soft and thin bedded materials, and they have suffered so tremendously from the shearing stresses and pressures which have been brought to bear upon them, and are, moreover, so generally poorly exposed because of their non-resistant character that their stratigraphic as well as their structural relationship is much obscured. The uncertainty of the correlation of this series of beds, has already been pointed out. It is not known positively for instance, to what extent the Collier shale crops out within this limited area, nor whether the Crystal Mountain sandstone pinches out in a northeasterly direction or is buried beneath the slates along Mountain Fork River. It is not known for certain either, whether the Mazarn shale and Blakely sandstone are so limited in their distribution as has been indicated on the map. Obviously until more is known of the stratigraphy of this central core of old rocks not much can be said definitely of its structure.

The bedding in many exposures of these ancient sediments is not discernable, and such observations of the dip and strike as it was possible to make are so at variance with one another as to lead only to great confusion. The schistosity is also irregular, but of course much less so than the bedding. Although not worked out in detail it seems only reasonable to assume, judging from the areal distribution of the Crystal Mountain sandstone, that the whole central mass was, so far as the major structural features are concerned, only gently folded. The southeast portion of T. 5 S., R. 23 E. seems to be essentially a broad, shallow syncline; the central part of T. 5 S.,

PLATE LXX.



A VIEW LOOKING N. 13° W., ACROSS A MEANDER IN MOUNTAIN FORK RIVER, FROM A HIGH POINT, 150 PACES WEST OF THE CENTER OF SEC. 34, T. 3 S., R. 25 E. THE HILL IN THE FAR DISTANT CENTER IS BLAYLOCK SANDSTONE; THE OTHERS ARE BIGFORK CHERT.

The river flows toward the observer on the right then back west beneath his feet, enclosing in the foreground a heavily timbered alluvial flat. The triangular shaped cliff to the right is the 150 foot bluff of Polk Creek shale, the details of which are shown in other photographs, while the white spot in the center of the picture is the cliff of Bigfork chert, which

R. 24 E. might be considered also synclinal; but taking into account the surface configuration and drainage farther north the remaining exposures of Crystal Mountain appear to lie almost horizontal.

The shaly formations, on the other hand, both above and below the Crystal Mountain sandstone have been crumpled into drag folds on the flanks of the larger structures, and smaller folds have developed on the sides of these, with still others between the sandy layers of the last and so *ad infinitum* even unto microscopic sizes. The drag-folds often form S-shaped outcroppings. They may plunge in any direction and any amount, and may be of any size, commensurable with the thickness of the shale mass in which they are developed. Thus the dip and strike of the bedding, over a considerable area, may range through all points of the compass. In other words the slates, etc., composing the central core of the Choctaw anticlinorium do not seem to have suffered so much from lateral compression as from an overriding by the superjacent formations. The now eroded Bigfork chert and succeeding heavy resistant beds must have moved bodily over the Womble schistose sandstone, while the Crystal Mountain sandstone skidded over the Collier shale, or "floated" at it were in the shales above and below it. A movement of this kind resulting from a thrust from the south will explain all the facts, the most important of which are:

1. The sharply folded, overturned and broken condition of the Bigfork chert and all the later formations now exposed on the flanks of this great uplift representing a shrinkage or shortening of the earth's crust in this region of several miles.

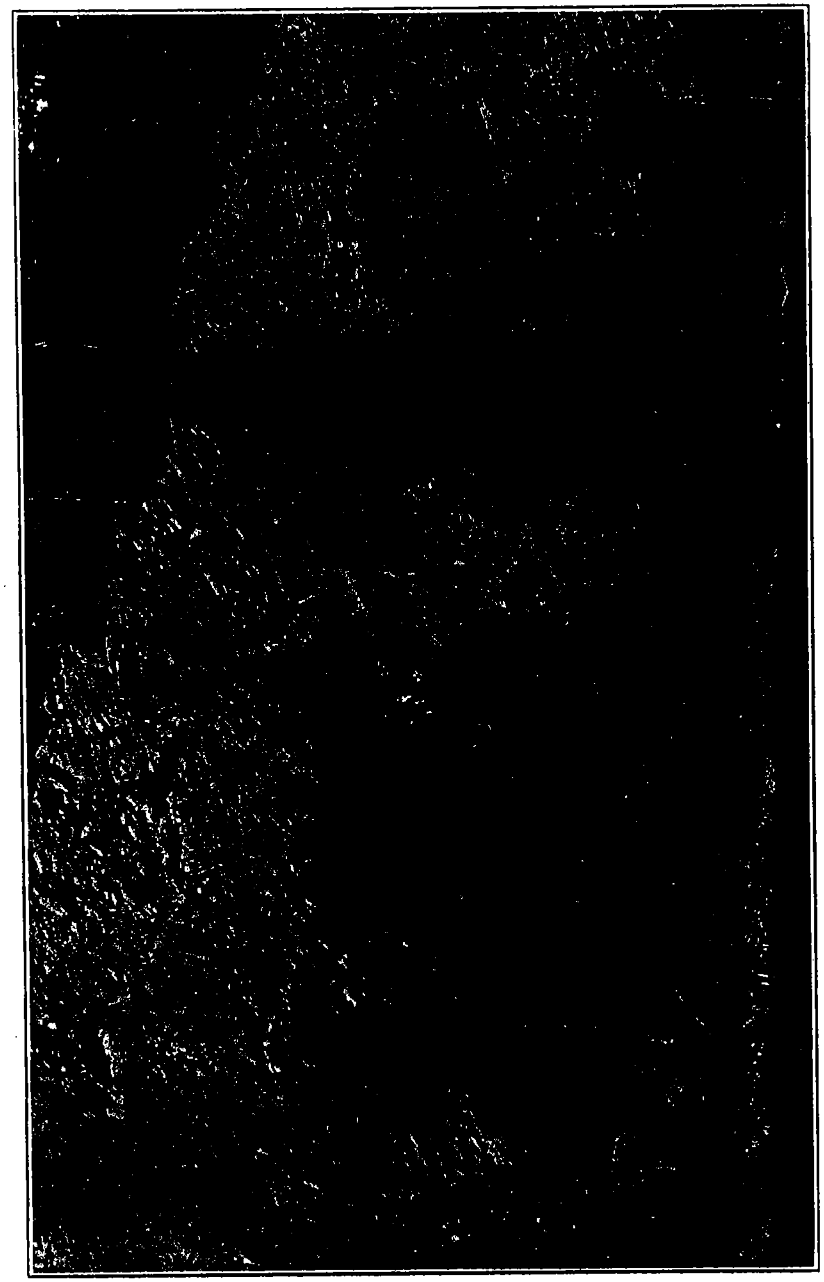
2. The prevailing north, northwest or northeast dip at steep angles of all the resistant rocks on the flanks of the structure, a condition which can result only from an overlapping and piling up of strata, moved forward from an adjoining locality.

3. The north, northwest and northeast dip of the schistosity in the central, western and eastern parts respectively of this core of old rocks which are the shearing planes resulting from relative lateral movements of beds, such movement having come, as will be pointed out later, from the south. There seems to have been a tendency for the west end to drag or resist this movement for the schistosity here has swung around to westward and is dipping at an angle of 25 degrees due west.

4. A manifold development of dragfolds, fold on fold, in all the soft and thin bedded materials which result from the rotary movement in the shales, developed through the differential movement of resistant formations, or hard layers in the formations either side of the shale masses.

5. The presence of boulder beds in certain localities, developed as a result of intense crumpling followed by a mashing down,

PLATE LXXI.



A VIEW OF A PART OF THE POLK CREEK SHALE BLUFF ONE-FOURTH MILE NORTH OF THE S. ¼ COR., SEC. 27, T. 3 S., R. 25 E., LOOKING EAST

Note especially the acute angularity of the folds and the prominent set of joint planes crossing them. The joints strike east-west and dip uniformly to the south at an angle of about 70° throughout the mass. (See also Plates XXI and XXII.)

pulling to pieces and rolling or dragging along of these folded layers, a process which is not only suggested, but absolutely proved by the slikensided and striated surfaces on the pebbles, their pinched off or dragged out ends and their occurrence—thinly distributed in slate.

6. The presence of striations, slickensides, and crush-zones among the harder layers, and among the softer ones of slate, some of which, taking the other factors into consideration, must have been caused by thrusting.

There are, no doubt, also untold thousands of small faults within this central mass providing displacement however slight, is all that is required in the definition, for all the harder beds have moved at least a trifle on their respective cushions of shale. A missing formation should, therefore, not be taken too seriously to mean a disconformity. It might be overridden.

If the sediments in the general region under consideration accumulated in a gradually subsiding trough which was later raised out of the water and folded, as appears to have been the case, it is possible that still other movements may have taken place in these ancient slates and schistose sandstones. There is evidence in the coarseness of the materials of which the Crystal Mountain sandstone is composed, and certain horizons in the other formations of the Collier-Womble series, that the sea was shallow at times during the period of early sedimentation. There is evidence also that this area of sedimentation subsided, later, some 18,000 feet to receive the younger formations now at the surface on the flanks of the anticlinorium. The question is, What happened to the early deposits during the period of subsidence? The beds of shale, especially, must have been, or might have been, depending on the nature of the subsidence, greatly attenuated, and if so there must have been a horizontal movement of some beds over others, developing schistosity at this time. It is possible that the sandstone beds were pulled apart or jointed into blocks by the same movement. The rocks which are at the surface now in the center of the uplift have an elevation above the sea of about 500 to 750 feet. They are not far from the elevation, then, at which they were deposited. They have been bent downward 18,000 feet and back up 18,000 feet—two movements—each of which is capable of producing, equally well, a slipping of beds and the development of drag folds. Solefluction would result in the slimes and muds to some extent as the progressive processes of accumulation of muds and subsidence of the area went on, but in the buried sediments a more genuine schistosity might result. The leaves of a book will glide past each other just as surely by bending it one way as another and there is no reason to assume that some of the structure in the Collier-Womble series is not

PLATE LXXII.

TWISTED BLAYLOCK SANDSTONE. VIEW LOOKING N. 66° W., FROM EAST BANK OF MOUNTAIN FORK RIVER, 550 PACES WEST AND 400 PACES SOUTH OF E. ¼ COR., SEC. 33, T. 3 S., R. 25 E.

the result of solefluction and down warping as well as of upward bending and thrusting.

During the period of uplift, those sediments in the upper part of the trough would suffer least, especially if they were sandstones like the Jackfork formation. The younger strata would tend to ride out of the sea on the backs of the anticlines beneath, which were developed in part by virtue of the weight of these overlying sediments. As a result of the combined upward thrust from beneath and the gravity of the overlying beds pressing downward, the whole middle portion of the accumulated sediments would crumple into tightly compressed folds accompanied by more or less faulting. The bottom beds, made thin by attenuation when they were lowered to the bottom of the trough by subsidence, would again be brought to their original thickness and former position relative to sea-level. If they happened to be shales and other thin bedded materials very largely, as is the case in the present instance, and if they happened to be overlaid by relatively resistant and thick bedded materials, as is the case in this strucure, there is very little doubt but that the overlying resistant rocks would crumple and glide over the soft slates in depth, so that by the time the bottom formations reached the surface they themselves would have reached horizontality again, but for the drag-folds developed in the shales as a result of dragging the harder beds over them on the way down and again during the upward journey, with emphasis on the latter movement. Moreover, the crumpled middle portion of the geosyncline (the Bigfork-Stanley series in the Choctaw anticlinorium) would have moved, in part at least, bodily over the quite fluid slate beneath, the bottoms of the Bigfork chert synclines scraping across the slippery Womble schistose sandstone.

GLOVER FAULT

A fault line has been drawn from the center of sec. 28, T. 5 S., R. 23 E., northeast for 12 miles to the west range line of sec. 18, T. 4 S., R. 25 E. between the Womble schistose sandstone on the north and some black slates (Collier?) on the south. This is an assumed line of displacement which for convenience of reference will be known as the Glover fault. Three formations are missing along this line if the correlations as made, are correct, and it is argued, therefore, that one of two conditions exist: either there is a fault or there is an unconformity. Since the line of contact between the Womble and Collier is straight and since it passes straight irrespective of the folds which approach it on the west the omission must be due to faulting rather than to unconformity or disconformity. There is an abundance of milky vein quartz in many places throughout the full extent of the fault, but as there is an abundance of quartz in general throughout the shale mass to the south this sig-

PLATE LXXIII.

A VIEW LOOKING WEST AT SOME CRUMPLED BLAYLOCK SANDSTONES ON THE WEST BANK OF MOUNTAIN FORK RIVER, 550 PACES WEST AND 400 PACES SOUTH OF THE E. ¼ COR., SEC. 33, T. 3 S., R. 25 E.

nifies nothing in particular. Brecciated, red sandstones (Womble) were noted in one place, (near the W. ¼ cor., sec. 32, T. 4 S., R. 24 E.). Usually the country south of the Womble sandstone is flat and overgrown with brush concealing from view all the direct evidence of faulting.

Whether this fault is a normal fault or the reverse becomes also a question of theory. It is regarded as normal on the assumption that the dip of the fault plane should coincide in direction with the dip of the bedding. The downthrow side is on the north side and the dip of the bedding planes is to the north also, hence it is assumed that the fault plane dips north. At the same time the opposite view that this is a thrust fault must be respected, for it is conceivable that the whole mass to the south could have been thrust northward over and upon the Womble shale, in which case however, the fault plane would lie across the schistosity, which dips to the north. This does not seem consistent. The Glover fault, therefore, seems to fit the associated structural conditions best if it be regarded as **normal.** Its age would then perforce have to be subsequent to the period of folding for normal faulting could scarcely take place during a time of thrust. However, to place the date of the fault more definitely than post-Paleozoic seems impracticable.

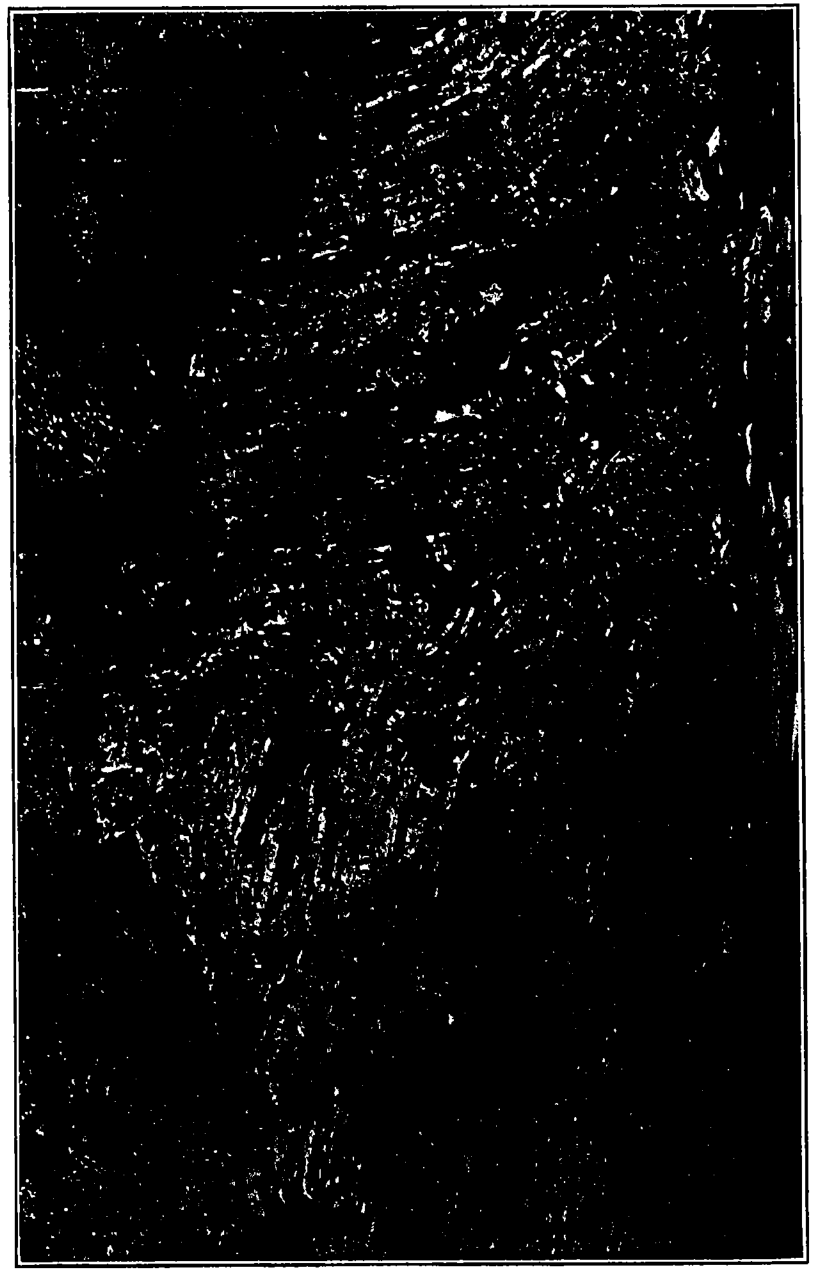
LOWLANDS ANTICLINE

In the center of T. 5 S., R. 23 E., the Blakely sandstone and Mazarn shale appear at the surface as a tightly compressed series of folds whose structure in detail is very complicated, but in general is anticlinal. Because of the low relief throughout the general region the name Lowlands anticline is applied to the structure. The writer's interpretation of the outcroppings appears on the map, but this should be looked upon as not final. In the center of this mass the bedding is almost vertical and strikes northeast, while the planes of schistosity dip 25 degrees west and strike due north. It is difficult to understand the orientation of the planes of schistosity in this locality. It was intimated above that this part of the structure had been dragged around. The schistosity in the rock may have been developed before the mass had been gragged into its present position—conceivably in the early part of the same movement. The strike of the schistosity farther south and south-east is also north-south.

CONCLUDING STATEMENT

The writer is fully aware of the fact that much more time and intensive study must of necessity be given this gnarled and knoted mass of old slates and schistose sandstone in the heart of this great structure, before its history and structure can be untangled. The present discussion is his understanding and interpretation of the data now at hand.

PLATE LXXIV.



VIEW LOOKING S. 65° W., AT AN OVERTURNED SYNCLINE IN THE BLAYLOCK SANDSTONE, 300 PACES WEST OF THE SE. COR., SEC. 33, T. 3 S., R. 25 E., ON THE WEST BANK OF MOUNTAIN FORK RIVER.

WEST FLANK

GENERAL

On the flanks of this large upfolded central mass, succeeding the Womble schistose sandstone, are found the Bigfork chert and Polk Creek shale (Ordovician), the Blaylock sandstone and Missouri Mountain slate (Silurian), the Arkansas nevaculite (Devonian) and the Stanley shale (Pennsylvanian?), whose structure, thanks to the cherts and novaculites, is more definitely known.

On the west flank these later Paleozoics are folded sharply into a number of overturned anticlines and synclines which plunge gently west-southwest and dip to the north at an average rate of 45 to 60 degrees, the folding being sharper in the softer Stanley to the north.

OPAH SYNCLINE

In the southeast corner of T. 4 S., R. 23 E., and extending northeast and southwest into the adjacent townships, there occurs a large overthrust syncline which is essentally a deep, narrow trough of Bigfork chert, 8 miles long, somewhat ruffled in the bottom but lined with Polk Creek shale, and holding within its interior an outlying mass of Blaylock sandstone and Arkansas novaculite. The Bigfork chert alone is attached to the main line of outcroppings encircling the central mass of the structure. The axis of this syncline strikes N. 60° E. and the strata dip from 20 to 40 degrees north in both limbs of the fold. This is a very unusual structural feature for this region, for there is not another like it in the area. There are inlying anticlines, several of them, but no other outlying synclines of importance. It is a sag on one side of the main structure, and one of no small size. It will be referred to later as the Opah syncline, from a one time Opah settlement in sec. 34, T. 4 S., R. 23 E.

To the southwest in T. 5 S., R. 22 E., in alignment with the structure just described but separated from it by a bulge in the Womble in T. 5 S., R. 23 E., is the continuation of this synclinal axis. The fold is here more tightly compressed and only the Bigfork chert is pinched into the trough. It is less than a half mile wide but it is deep and the rocks dip 40° N.

OTHER STRUCTURES

A narrow belt of Womble sandstone less than half a mile wide lies to the north of the Opah syncline, and a similar but larger mass to the southwest, along the strike separating this belt of downfolding from the main belt of Bigfork and later rocks outcropping to the north in a direction about N. 60° E. This is an overturned anticline dipping about 35° N. No name has been given to it.

The main belt of exposures of the Bigfork chert, Polk Creek shale, Blaylock sandstone, Missouri Mountain slate, and Arkansas

PLATE LXXV.

DRAG FOLDS IN BLAYLOCK SANDSTONE, 200 PACES WEST AND 300 PACES NORTH OF THE S. ¼ COR., SEC. 34, T. 3 S., R. 25 E.; LOOKING EAST.

novaculite striking N. 60° E. from sec. 29, T. 5 S., R. 22 E. to sec. 13, T. 4 S., R. 24 E., some 18 to 20 miles, has not been severely crumpled. It strikes across country pretty uniformly and is in the main *per se* a monocline. The novaculite, however, has been folded in two or three places quite sharply along this line. In sec. 12, T. 5 S., R. 22 E. it makes a very peculiar turn and one which is worthy of special mention. This is a small narrow anticlinal fold one mile in length which arises suddenly and very unexpectedly from the steeply dipping monocline, and is odd, not only because it is short but because it is isolated and because its axis trends almost due west, altogether out of harmony with the general trend of other structures in the general locality. The fact seemed so unreasonable and out of joint at first that the ground was gone over a second time in an endeavor to find some possible error, but none was found. The rocks dip 65° N. generally, in this anticline, but are vertical at the west end, where a fault is in evidence. Only the middle and upper portions of the novaculite reach the surface in this short spur.

A mile or two to the northeast, in the valley of Glover Creek, there are other folds in the novaculite, but these are more in keeping with the general structure of the region and are perfectly normal developments of the thrusting movement. Their axes trend in the same direction as the axes of the dominating folds and they are tightly compressed. Their position to westward of the Opah syncline and north of the Lowlands anticline would seem to be significant, for there is a shortening of the earths crust in both the Opah and Lowlands structures. If the thrust came from the southeast in this particular locality there should be an area between these two folds which was not foreshortened. The bulge in secs. 4 and 8 of T. 5 S., R. 23 E. is not sufficient to account for all of this, but it is taken up and disposed of completely in the folds in the novaculite farther north. If the wave had not been halted at this place it would have been carried over and incorporated in the folds in the Stanley.

In the Stanley shale area beyond, northwest, the crumpling is most intense. Throughout the whole area in this direction (T.4S., Rs. 22 E. and 23 E. and T. 5 S., R. 22 E.) the strata dip almost invariably to the northwest at angles ranging from 15° to 90° but averaging about 45°. It was found impossible to discover and map all of the folds and faults in this area, but an idea of their number and complexity may be had from the distribution at the surface of the bed of tuff which occurs near the base of the Stanley. The outcrop of tuff swings smartly back and forth in rapid succession to form long parallel ridges. Small bits of it (synclines) have been pinched in on the east side of the main line of exposures and back-bones of it (anticlines) project on the west. In general all the westward projecting points in the main line of exposures are anticlines and the eastward

projecting re-entrants, synclines, but faulting must also have brought about some of the discontinuity of the tuff exposures. It is impossible to trace these however, and in no case is the writer positively sure that faulting has occurred in the Stanley.

The repeated occurrence of the tuff bed, a score of times in Glover Creek valley, even as far north as the top of T. 4 S., R. 23 E. is proof of the fact that the Arkansas novaculite is not far beneath the surface, possibly 300 to 500 feet more or less, over all this township and elsewhere where the tuff appears at the top of the ground. The structure in the base of the Stanley, moreover, is a fairly good indication of what may be expected in depth in the novaculite, for eastward of the Stanley exposures, in the northern half of T. 4S., R. 24E., one may observe at the surface just what has happened. The novaculite is as tightly folded as is the Stanley to the west and there is no reason to assume that the buried novaculite in Glover Creek valley should look any different.

Even as far west as Alikchi and Ringold, in the valley of Little River the intensity of the pressure must have been almost as great as in the valley of Glover Creek, judging from the dip of the sandstones at the surface in that part of the country. The strata stand vertically in numerous localities and the average dip seems to be between 50° and 90°, but there are certain places where this high dip is directed to the south, pointing to deep and narrow but normal synclines. Nevertheless there are localities also where these folds are overturned and dipping north. The tightness of the compressibility must be judged from the uniform strike and steep dip of the bedding. A south dip in places should be expected at any rate, even with a pressure equal to that in the Glover Creek country, owing to the greater resistance of the sandstones in the upper part of the Stanley over the more shaly and thinner bedded strata of the lower Stanley. Occasionally a south dip of the bedding may be seen also in the latter.

It is impracticable to attempt to outline even in a general way the axes of the folds in the valley of Little River, for there is no key rock which can with safety be relied upon as depicting the structure in this region. The tuff bed which is the only reliable guide in the Stanley is deeply buried in the Little River country. An abundance of vein quartz appearing in a broad zone through the central part of T. 4 S., R. 21 E. and a similar occurrence of quartz south of Alikchi would indicate, possibly, some faulting in these two regions. Some of the larger folds would presumably fall in alignment with the axes of the known folds farther east providing they extend that far. Similarly the axis of the Hugo syncline and Corinne anticline to the west (to be described below) should be considered as having their influence south of Ringold, and north of Ringold, respectively.

Returning farther east to speak of the folds and faults in the northern part of T. 4 S., R. 24 E. and in the southern part of T. 3 S., R. 24 E. one is immediately struck with the unusually narrow and tightly compressed condition of the folds, which are so crowded and jammed against one another and so numerous as to make it impracticable to speak of them individually. Such structure can come only as a result of most unusual and extreme lateral pressures. This whole belt seems to have been caught and firmly held between a powerful thrust on the one side and a rigid resistance on the other, which two forces slowly closed upon it, like the jaws of a great vise, and subjected it to a powerful squeeze which doubtless acted through a long period of time. The locality seems to have been in a direct line between this thrust and the resistance, and to have been caught squarely between the two forces with no chance to get away. However, under these conditions some slipping of the strata (faulting) might occur, and this brings us to the question: Are the faults in this general region normal or reverse? There are about half a dozen of them in secs. 4 to 8 inclusive of T. 4 S., R. 24 E. and three or four more farther north in the lower row of sections of T. 3 S., R. 24 E. In all these instances, for it seems best to speak of them collectively, the downthrow side is on the north side, the strike of the fault plane is, in general, east or slightly north of east, parallel with the strike of the bedding, and there is a tendency for them to be *en èchelon.* In this general region the prevailing dip of the bedding is to the north from 30° to vertical and if we assume, as heretofore, that the fault plane should dip in the direction of the bedding these should all be normal faults. It seems that a force which produced a series of thrust folds or overturned folds tilted uniformly to the north throughout could not at the same time produce a series of thrust faults with the fault plain tilted in the opposite direction, and they are not under thrust faults with the fault plane dipping to the north because the north side of the fault is the down throw side. It seems more reasonable to think of these faults as having been produced at some later period as the result of tension, and in as much as the region has been uplifted several hundred feet since Createaceous times it is very likely that the faulting took place during that time.

It is significant that the faulting should occur just at the place where the strike of the strata and the trend of the folds changes from due west to southwest. The result is that the noses of the westward and southwestward plunging novaculite anticlines are chopped off in several instances. Those that have not been truncated by faulting have been bent in a southwesterly direction. This is the most natural place in which to expect faulting, for this whole block of Siluro-Devonian rocks (the northern part of T. 4 S., R. 24

PLATE LXXVI.

MINOR THRUST FAULTING IN BLAYLOCK SANDSTONE.
View looking east from a point 200 paces west and 250 paces n orth of the S. ¼ cor., sec. 34, T. 3 S., 25 E.

E. and the southern part of T.3S.,R.24E.) appears suddenly and unexpectedly, like a great bay-window, on the side of the structure. A general uplift, especially if accompanied by some straining or twisting, which would be most sure to take place, would surely shatter any such projecting addition. Also the more tightly squeezed and compacted the area the more easily normally faulted, subsequently, that is evident. Their *en èchelon* arrangement or relationship to one another is an indication that they are tension faults and not due primarily to compression.

These faults, no doubt, continue southwest into the basal portion of the Stanley. Two or three of them have been drawn on the map a mile or two in that direction, but it is an impossibility to identify faulting, no matter how great the displacement, in the Stanley.

Along the fault in the center of sec. 6, T. 4 S., R. 24 E. the rocks have been saturated with siliceous solutions which appear to have gained egress along the crush-zone. Southwestward one half mile the slope north from the top of the mountain where the fault line occurs, is usually long and gentle and covered with rather fine bits of shattered flint as direct evidence of the fault. In the northern part of sec. 32, T. 3 S., R. 24 E., the crush-zone in the novaculite, rusty and dingy with age, may be followed along for some distance at a low elevation, but the fault plane itself is not visible. Elsewhere in this particular quarter the faults are recognized by the omission of formations and parts of formations.

NORTH-CENTRAL PORTION

North of Hochatown in the northern part of T. 4 S., R. 25 E. a great knot of Bigfork chert several square miles in extent, crumpled, and folded, is raised bodily out of the depths. It is a series of four or five northward dipping, overturned anticlines and as many synclines whose axes strike nearly east-west and plunge eastward on the east side of the chert mass and westward on the west side, beneath younger beds. The whole series of folds has been mashed together and the tops of the anticlines eroded. The edges of the projecting strata dip to the north from 20° to 45° over practically the entire surface. Rocks dipping to the south are rarely seen in this region. It is from the areal distribution of the exposures only that the details of the folding may be ascertained. The mass as a whole has suffered the same compression and metamorphism practically as has the mass of younger rocks adjoining it to the west and was caught in the same vise at the same time. Faulting in the Bigfork chert mass is not so common as in the novaculite, however, or if it is, is has not been discovered.

One fault does occur in the Bigfork chert which extends from the center of sec. 16, T. 4 S., R. 25 E. to westward about 4 miles. It all but severs the great mass of chert north of Hochatown from the outcroppings southwest. Throughout its length the Polk Creek shale is faulted out and in the middle of the line the Bigfork chert is practically all below ground so that the Womble shale is almost in contact with the Blaylock sandstone at one point (at the west range line of this township). As further evidence of this fault should be mentioned a fault valley, occurring in sec. 17, traversing the Bigfork chert. The chert formation appears in the valley and on the slopes of the sandstone ridges either side, but not on top of the ridges, which constitutes a notable exception to the general rule. A narrow strip of black chert, accompanied by vein quartz, locates the fault one-fourth mile north of the center of sec. 18. Here, as with the Glover fault to the west, the downthrow side is on the north side and is thought to be a normal fault. It was, no doubt, produced at the time of origin of the Glover fault and the two may unite in depth although at the surface, they fail to join by about half a mile.

In the northeast corner of sec. 1, T. 4 S., R. 25 E. and striking west-northwest and east-southeast into the adjoining townships, the Bigfork chert appears again, as a double anticline folded back upon itself and dipping north at an angle of about 40°. The outcroppings are about 3 miles long by half a mile broad. Still further north (secs. 25 to 30 inclusive, T. 3 S., R. 25 E.) is yet another anticlinal ridge of Bigfork chert.

This also is a double anticline at the east end, but gives place westward to a single structure. It, too, is doubled back upon itself so that the two flanks come together and dip to the north at an angle of about 45°. The outcroppings are 5 miles long and a half mile broad.

These chert masses are, of course, clothed in a soft black mantle of the Polk Creek shale, which was dragged and rolled during the period of folding into a very complex structure. The Bigfork chert was resistant and, barring a few undulations of the bedding, it folded more or less simply, but the Polk Creek for complexity of folds can have no equal and defies description. However, some idea of the extent and character of it may be had from the photographs.

Between these Bigfork anticlines and interfingering on their margins are deep, complicated troughs, jammed full of Blaylock sandstone. The major structure lines are very accurately depicted to either side of the central chert masses by the long synclinal tongues of novaculite which interdigitate with the anticlinal axes of Bigfork chert, but the Blaylock is shaly and thin bedded—a large part of it—and its internal structure is complicated indeed. (See Plates LXVIII, LXIX, LXX, LXXI, LXXII and LXXIII).

There are dragfolds in all the softer strata; the simplest troughs are crumpled on their flanks; schistosity is common throughout.

From Hochatown (in the center of T. 4 S., R. 25 E.,) north for six miles to Linson Creek (in the center of T. 3 S., R. 25 E.) and as far east or west as the Blaylock is exposed, approximately 10 miles in either direction, the Blaylock sandstone, and other rocks involved in the folding as well, dip to the north, sometimes as low as 15° but ordinarily 45° to 50° and frequently 60° to 70° or more. It is a most wonderful series of thrust folds and one cannot help marvel at the force required to crumple it.

It is not deemed worth while to name and describe individually all the folds in this locality. This would be an irksome task, and to no useful purpose. The structure is essentially the same in all and their character and relationship to each other can best be had by a study of the photographs and structural cross sections.

EAST FLANK

GENERAL

On the east flank of the Choctaw anticlinorium there are, all told, fifty thrust folds (anticlines and synclines) in the upper Ordovician, Silurian, and Devonian rocks. These are clearly shown by the zigzag outcrop of the Arkansas novaculite, without which it would be impossible to map them, but with it all the little kinks can be traced. The axes of all these folds have a common direction east-southeast as they plunge beneath the Stanley shale from the axis of the main structure. The dip of the strata throughout the series from sec. 2, T. 6 S., R. 24 E. to sec. 31, T. 3 S., R. 27 E., is north-northeast 30° to 60° generally, but there is here and there some further variation both in amount and direction of the dip. The compression or intensity of the folding seems on first thought to have been greatest in the extreme southern part and in the northern half with lesser pressures evidenced in the south-central part (T. 5 S., R. 25 E.), but a part of the apparent variation in the intensity of the folding is due, no doubt, to the steeper plunge of the structures in the south-central part, for any given fold truncated at a steep angle will yield a less crooked and shorter intersection (or line or outcrop) than if cut at a small angle. The folds in T. 5 S., R. 25 E. have a steep plunge, are truncated at a steep angle, hence produce a shorter and less sinuous line of outcrop which in turn would indicate apparently lesser compression. The limited distribution of the tuff bed in the overlying Stanley in this region and its proximity in outcrop to the exposures of older rocks as compared with the area north-east is abundant evidence of the steeper plunge of the structures. It is also true, as a result of the steeper plunge, that the more resistant beds (the Bigfork chert and the Arkansas novaculite in particular) lay deeper in the earth in T. 5 S., R. 25 E. and offered, therefore, greater resistance to the forces of compression than elsewhere so that even with intense pressure there should not be the severe crumpling that would othewise result.

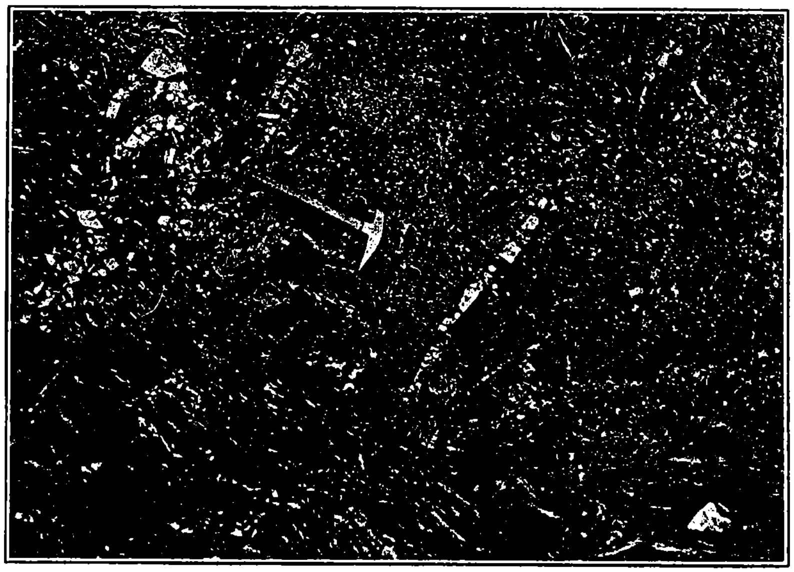
The folds which are indicated by the outcrop of the novaculite are not all in evidence in the Bigfork chert. The larger ones are all carried below, but the smaller ones seem to die out. It is impossible to trace them in the Blaylock sandstone but here as north there can be no doubt of the most complex structure for the exposures along Mountain Fork River in secs. 3, 4, and 9, T. 5 S., R. 25 E. show all the characters of the folds observed six miles north along the river. There are numerous drag folds and crumples of every description accompanied by shear zones in all the softer beds and the shales are cut across by a northward dipping schistosity. In the Polk Creek shale as exposed in Beaver Bend one sees the same structures as were noted farther north. Most of these appear to be extremely complicated, multiple drag folds (see photographs). On the west bank of the river in the NW. ¼, sec. 3, T. 5 S., R. 25 E. there occurs in some black slates and cherts a recumbent fold which has been mashed down until it actually lies horizontal. It is not known whether the particular ledge of rock is in the Bigfork chert or Polk Creek shale. In Beaver Bend such structures lie upon one another several yards in depth. (See Plate XX.)

The intensity of the folding is manifest in the Stanley shale also, everywhere in T. 4 S., Rs. 26 E. and 27 E., and in T. 5 S., Rs. 25 E., 26 E., and 27 E. as far east as the State of Arkansas. In this whole area there has been pronounced thrusting as shown by the general north dip of the shales and hard sandstones of this series, but there is no readily identifiable key rock by which to indicate the details of this structure. Being a softer, less resistant formation than the novaculite the shales and sandstones of the Stanley should be more intensely crumpled than the other, at least in so far as it occurs in the same locality. Far out on the flank of this anticlinorium near the Oklahoma-Arkansas State line the strata stand vertically in some places and occasionally are seen to dip to the south at high angles. These facts, of course, indicate isoclinal and sharply V-shaped folds, which are the result of severe pressures, but not so severe as a general north dip indicates. Over all of secs. 33 and 34 of T. 5 S. R. 27 E. in the vicinity of Ultima Thule, the sandstones strike northeast and dip uniformly southeast 25° to 35°. Here is evidence of normal folding and failing lateral thrust. The writer has not studied the structure eastward of the State line, but it is reasonable to assume that even gentler folds prevail in that direction. This locality of normal folding lies 20 miles southeast of the central axis of the anticlinorium. It is about 20 miles in the opposite direction from the central axis west-northwest to Ringold before any indication of normal folding appears on the left flank of the structure thus making the area of intense thrusting, (and this would coincide with the width of the Choctaw anticlinorium), about 40 miles.

Throughout the Stanley shale area on the east flank of the anticlinorium there are a great many quartz veins. These are usually of good size, from a few inches to several feet in thickness and frequently a quarter of a mile or more in length. They appear to be of the type known as gash veins and they pinch and swell laterally.

The veins do not appear to occupy fault fissures or zones necessarily, and their distribution as noted at the surface does not point to any particular zone or zones of weakness. The fissures seem to have been joints, merely, in the rocks.

PLATE LXXVII.



GASH VEINS OF MILKY QUARTZ IN THE SANDSTONES OF THE STANLEY SHALE FORMATION AT GILLHAM ARK., (9 MILES EAST OF SEC. 33, T. 4 S., R. 27 E., OKLA.); SHALES NOT PENETRATED. Photograph by E. S. Perry.

There is a fault in the valley of Yashoo Creek in the southern part of T. 5 S., R. 24 E., which can be traced a mile or more in a northwest direction, but it may possibly have a greater length. It is best shown in sec. 35 where the end of the novaculite syncline has been cut off. The fault plane can not anywhere be seen but a shallow fault line valley is very prettily shown at one place. The west end of the fault is not so well known. The north side in sec. 26 is a swamp-covered country, the foundation of which is probably Wamble sandstone. The south side in the same locality is a talus covered

slope of Bigfork chert extending beyond the center of sec. 27. If the outcroppings have been interpreted correctly the upthrow side of this fault appears to be on the south side in sec. 35 and on the north side in sec. 27, indicating a kind of swivel movement, but the evidence of faulting is so very obscure in sec. 27 that perhaps this kind of movement had best not be supposed. It is entirely possible that the very broad outcrop of Bigfork chert in secs. 27, 32, and 33 is a folded mass, (an anticline and a syncline) which happens to terminate in sec. 27 in direct line with the strike of the fault plane to the southeast, and that the fault does not extend that far. The evidence of fauling is conclusive in sec. 35. Assuming once more, that the fault plane should dip in the direction of the dip of the bedding the fault should then be normal.

There is another fault in the northern part of T. 5 S., R. 26 E., where one is confronted with a problem similar to that encountered on Yashoo Creek, for here too, at one end the faulting seems to be normal and at the other the reverse. In sec 5, T. 5 S., R. 26 E. the Bigfork chert is raised up against the Stanley shale. On both sides of the fault the strata swing around locally to dip to the south as though the rocks had suffered a thrust movement and had been dragged up on the north side and dragged down on the south side. Three or four miles to the east the opposite seems to have taken place for the strata dip to the north over there. The downthrow side however, is to the north as far as the fault can be traced in either direction, and since the general dip of the strata, excepting in the one small locality, is north, and assuming that the fault plane should roughly coincide with the dip of the bedding, it is concluded that this is a normal fault. What appears to be an eastward extension of this fault occurs in secs. 4 and 5 of T. 5 S., R. 27 E. The two have not actually been traced into each other, but one cannot doubt but that they do join. The strata are not behaving properly in this locality either, but there is as much evidence for normal faulting as for the opposite. The amount of displacement is not known, but the fault is so situated on the very roof of the structure, in line with the east end of the Choctaw anticline as to have opportunity of being very great. In sec. 5, of T. 5 S., R. 25 E., there has been a vertical movement of at least 2,000 feet.

ASH CREEK FAULTS

In secs. 1 to 4 inclusive of T. 4 S., R. 26 E., there are several faults in the novaculite and basal part of the Stanley shale which may conveniently be referred to as the Ash Creek faults since Ash Creek rises among the hills where they occur. The general locality is one of very complicated structure and, although the ground has been gone over twice in an effort to straighten it out, it still defies a logical solution. There appears to be a fault of considerable importance extending from a point 250 paces south of the N. ¼ cor. sec. 4 east-southeast to a point 400 paces south of the W. ¼ cor. sec. 1. There are also other fractures connecting with it on the south and striking southeast. In general the main line of faulting throws the Stanley down on the north side; the minor faults on the south are merely breaks in the shattered and slivered south block. Whether these faults are normal or reverse is not known, but they are thought by the writer to be of the normal type. How far east the main fracture has reached is also unknown. It is quite possible that it extends much farther than has been indicated on the map, but as heretofore remarked it is quite impossible to determine whether or not there is displacement in the Stanley.

As to the fault occurring on the south side of the novaculite mass in the northern part of secs. 3 and 2 etc. there is no evidence of its existence excepting at the west end. It was first interpreted as a thrust fault, but on second thought it seems that the west end could better be joined in some way to the fault to the south.

NORTH SIDE

The northern boundary of the Choctaw anticlinorium is determined by a long fault which extends practically continuously for 15 miles, all the way from the west range line of T. 3 S., R. 25 E., to the Oklahoma-Arkansas State line. To the south lies the great upfolded mass of Ordovician, Silurian, and Devonian rocks; to the north is a great downfolded and faulted mass chiefly of Stanley shale. This fault brings the Blaylock sandstone against the Stanley shale at one place in the valley of Mountain Fork River while various parts of the Missouri Mountain slate and Arkansas novaculite are thrown against it at other points either side, depending on the type of the fold which is cut across by it. The east end of the fault is not so well known, but at no place is the Stanley shale in contact with the Missouri Mountain or Blaylock at this extremity. At most, only portions of the novaculite and basal Stanley shales are faulted out here. The displacement lessens to eastward, therefore, and probably amounts to nothing at the State line. The dip of the bedding and the schistosity both sides of the fault line throughout the 15 miles is to the north at an average rate of about 45° and the downthrow side is to the north. Under these conditions it seems most reasonable to conclude that the fault is normal. It is possible that the fault forks in sec. 24, T. 3 S., R. 25 E. the north bifurcation connecting with the faults 3 miles due east. The quick termination of the tuff bed at several places in the locality in question would support such a supposition.

CROSS MOUNTAINS ANTICLINORIUM

The Cross Mountains anticlinorium is a relatively long and narrow belt of folds which extends from sec. 28, T. 2 S., R. 24 E.,

Oklahoma into sec 1, T. 5 S., R. 31 W., Arkansas. The structure is named from the mountains by that name which indirectly are the result of the uplift. The total length of the range is about 30 miles and the width about 4 miles but the folded and faulted structure may be considered as extending somewhat farther. Only that portion of the structure which lies in Oklahoma, the western 3/5 of it, will be discussed here.

The oldest formation which appears at the surface in this particular belt of folding is the Bigfork chert. The area of outcrop lies in secs. 1, 2, and 3 of T. 3 S., R. 26 E., but it is less than 200 paces

PLATE LXXVIII.

VIEW LOOKING SOUTH-SOUTHEAST, FROM A POINT ON THE TOP OF JONAH MOUNTAIN (300 PACES NORTH OF THE S. ¼ COR., SEC. 16 T. 2 S., R. 27 E.) SHOWING IN THE DISTANCE THE CREST OF THE CROSS MOUNTAINS.

The intervening territory is a bushy, wooded, gently undulating area of Stanley shale, 3 miles broad. The Sw. Cor., of T. 2 S., R. 27 E., falls on the top of the mountain at "X".

across and is only a mile and a half long. However, it is symmetrically placed with respect to the eastern and western limits of the structure and is in the center north and south, hence should be regarded in every sense as the central core of the anticlinorium. On its borders is the thin belt of Polk Creek shale, which in turn is succeeded by the Blaylock sandstone. The Blaylock sandstone is exposed for about 6 miles in either direction east or west, over an area two miles broad as a maximum, and is found to be dipping throughout at high angles to the south. Structurally then, the whole central portion of this arch is in a large way a recumbent anticline dipping south 40° to 60°, the east end of which plunges gently east, the west end, west, and whose top has been cut away by erosion. The north side or inverted flank of this central arch is folded very simply, so far as can be detected; the south flank, on the other hand, is more complex, and carries on its side at least four overturned folds, two of which, an anticline and a syncline, are of considerable importance. The wide outcrop of the Blaylock would indicate some further complications but with a uniform dip south it is impossible to locate them.

On the north side of this central axis there arise other folds, some of which bring the Blaylock sandstone to the surface, others pinch in rocks that are later than the tuffs of the Stanley. These folds occupy a belt one and one half miles broad; they are overturned, in the main dip to the south; and are much faulted. The most prominent of these folds is a southward dipping, overturned syncline extending from the south central part of sec. 35, T. 2 S., R 26 E., west to the SW. cor. sec. 19, T. 2 S., R. 25 E., more than 10 miles in length but only ½ mile wide and extending in depth as far as a dip of 135° would be likely to carry it—probably five thousand feet. The Stanley tuff bed lies in the upper part of this long trough and forms a double line of outcroppings almost from one end of it to the other. In two localities these combine to form a single line of exposures but at no place is the line pinched in two. The structure may conveniently be referred to as the Ten Mile syncline.

In the northern part of secs. 31 to 34 inclusive of T. 2S., R. 26E. there is a tightly compressed and overturned anticline terminated at both ends by faults. North of this again is a deep syncline truncated at each end by faults and bounded on the north by a fault. In these structures the strata dip 50° to 60° north in general but there are reversals of dip in a few places. It is not known positively whether the faults are normal or reverse, but judging from the conditions farther west it is thought they must be of the latter type. The writer is inclined to think that so great was the force of the thrust at this place that the whole upper crust, crumpled and broken, was skidded over the slates below and raised bodily and vertically upward.

Immediately to the west, north of the Ten Mile syncline there are two novaculite arches, overturned and dipping to the south 45° to 60° which are so tightly compressed that the one to the south actually lies on top of the more northerly one. Very naturally there is a syncline between the two anticlines, but this gives away to a sheer zone and a thrust fault where the two anticlines were slid by each other in the northern part of sec. 27, T. 2 S., R. 25 E., and east. Not

only was one novaculite anticline thrust up upon the other but both have overridden bodily several hundred feet, at least, of the Stanley shales, for on the north side of these two novaculite folds there is another fault beyond which the Stanley tuff and whole basal portion of the Stanley fails to appear. This fault has been traced from the W. ¼ cor. sec. 21 to the SE. cor. sec. 25, T. 2S., R. 25E. and is regarded as a thrust fault. The block of Stanley on the south side of the fault at the west end has been badly shattered and slivered apparently, for the tuff bed appears repeatedly at the surface in that locality in such manner as to indicate some faulting.

South of the Ten Mile syncline and forming the west end of the Cross Mountains there are 4 or 5 tightly compressed, long, narrow anticlines crowded into a belt 7 miles long by 1 mile wide. These structures all plunge gently westward and strike east-west. The average dip of the strata is 75° S. The Blaylock sandstone forms the centers of four of the anticlines and in all of these a thrust fault occurs at the east end of the Blaylock exposures, as though each anticline had been broken off at the east end and the butt tilted up.

All the faults at the west end of the Cross Mountains except the final one in secs. 27 and 28, T. 2 S., R. 24 E., are regarded as thrust faults, arguing from the point of view that the fault plane should dip in the same direction as the bedding in a tightly compressed and overturned series of rocks. In this region the prevailing dip of the strata is south and the downthrow side is on the north side of the fault line, hence all the faults, save one, should be thrust faults.

In secs. 35 and 36 of T. 2 S., R. 26 E. and secs. 31 to 34 inclusive of T. 2 S., R. 27 E. there have occurred some important displacements, but with only a minor amount of folding. For a distance of two miles for example, the tuff bed of the lower Stanley has been faulted against the Blaylock sandstone representing a movement of at least 1,000 feet. It is not known what part of the Blaylock may also be faulted below ground nor how far the fault may reach to the east, for it is impossible to distinguish one part of the Blaylock from any other part; hence a missing portion would not be discovered. The faults in the southern parts of these two townships (T. 2S., Rs. 26E. and 27E.) are all joined together and repeatedly bifurcate. In most instances the younger rocks are on the north side of the fault line, as is usual in this whole region, but there are places where the reverse is true. The dip of the strata is north in some places but south in others. A careful study of these facts yields no definite conclusions as to the kind of faulting here displayed, but some of the faults, at least, are of the thrust type and since they are all linked together and especially since the faulting to the west seems to be thrust faulting all the faults in Rs. 26E. and 27E. are regarded as thrust faults. In one or two instances there appears to have been minor underthrusting as in the case of the block in the center of sec. 32, T. 2S., R. 27E. and of the fault passing through the southeast corner sec. 36, T. 2S., R. 26E.

The structure in the Stanley shale on the borders of the Cross Mountains uplift is not so well known as that of the Siluro-Devonian rocks of the mountains themselves. Here, as elsewhere in the general region, it is next to impossible to recognize faulting and there is no readily identifiable horizon outcropping over the area which will serve as an index to the folds. One would infer from the dip of the strata, which in general ranges from 40° to 90° ordinarily, and from the nature of the folding and faulting in the older rocks that the Stanley should have, and no doubt does have, a most complex structure.

On the north side of the central belt of old rocks the Stanley sandstones in most places dip to the north or stand vertically This is an unexpected turn when it is observed that the strata to the south are overturned and dipping generally to the south. The trend of the folds and the parallel arrangement of the faults *en echelon* together with the intense compression evidenced by the steep general dip and overturned strata throughout the Cross Mountains, point to a shearing movement accompanied by intense lateral pressure which, so it seems, caused the strata not only to fracture and fold, but to rise and push northward and westward over the Stanley. The folds and faults of the Cross Mountains, in other words, constitute a belt along which the stresses produced by the forces of deformation were relieved.

It is a belt of severe thrusting and a zone in which the whole surface section of rocks broke and gave way. The shales on the north, speaking of a narrow strip, say a mile or two broad, suffered the same compression, but not the same subsequent movement. Their structure is more nearly comparable with that on the east and west flanks of the Choctaw anticlinorium, and with this idea in mind it is not to be supposed that the faults in the main structure of the Cross Mountains extend very far into the Stanley shale area nor should the folding be so sharp, omitting the dragfolds. That the Stanley sinks quite rapidly (without repeated upfolding and down folding) is indicated by the unusually limited distribution of the tuff outcroppings north of the older rocks. The broad outcrop of the Stanley farther north is the result of other structures to be mentioned later. The Stanley shale to the south of the Cross Mountains will be taken up under the heading "Linson Creek Synclinorium."

LINSON CREEK SYNCLINORIUM

The Linson Creek synclinorium is a name applied to the belt of downfolding and faulting which lies between the Choctaw anticlinorium on the south and the Cross Mountains anticlinorium on the north. It has a width of from 2 to 4 miles and a length of some 20 miles, reaching from a point approximately 4 miles west of Sherwood, Oklahoma east to the State line.

In this trough, at the eastern end, there are four long narrow belts of Arkansas novaculite, one of which is associated with a small area of Blaylock sandstone and Missouri Mountain slate. They are all anticlinal folds and each is accompanied by extensive faults. Lying between the novaculite belts and hedging them about generally are numerous outcropping ledges of the Stanley tuff bed, some of which, extending downward, unite in depth to form deep and narrow troughs; others are the backs of anticlines.

Exposures of the tuff are relatively few west of the novaculite ridges; at the extreme west end of the synclinorium, this horizon lies buried completely beneath the middle and upper portions of the Stanley.

Of these various folds, of which there must be ten or a dozen all told, the most important are the novaculite anticlines. One of these, the Pine Mountain anticline, extends from the southern part of sec. 12, T. 3 S., R. 25 E. into the SE. ¼, sec. 15, 3 S., R. 26 E., and is 5 miles in length. This is an overtunned fold dipping north and plunging east, in the center of which there is exposed a small area of Blaylock sandstone. The northern side of this structure is faulted down, and the fault has bitten so deeply that the Blaylock sandstone is brought against the Stanley shale for a distance of a mile and a half—almost the entire length of the Blaylock outcroppings. The fault will be known as the Pine Mountain fault.

A mile and a half east, but having a length of only two and a half miles, a second novaculite anticline raises its head. It is directly in the line of strike of the Pine Mountains structure and is bounded on the north by the same fault that cuts the Pine Mountains anticline in two, hence is essentially a part of that structure. The Pine Mountains fault is thus 11 miles in length, the downthrow side is on the north side of the fault line, and the bedding dips toward the north. The fault is regarded as normal.

Seal's Mountain anticline extends from the southern part of sec. 18, T. 3 S., R. 26 E. to the center of sec. 21. T. 3 S., R. 26 E. 8 miles. It is composed entirely of novaculite and is accompanied by two faults, one of which appears on the south side at the west end, and the other on the north side at the east end. Where Rough Creek crosses the fault line at the east end of the structure the fault plane is exposed and it is observed to be striking N. 80° W. and dipping 74° N. at this place. Since the downthrow side is to the north the fault is normal. The strata throughout the general locality dip to the north 45° to 70°, which is consistent with the theory that the dip of the fault plane should slope in the general direction of the dip of the bedding of a tightly compressed and overturned series of strata. And if this in reality be true then the long fault on the south side of Seal's Mountain should be an underthrust fault, for throughout the full extent of Seal's Mountain, the strata dip persistently to the north 30° to 60°, and the down throw side, in this instance, is south of the fault line.

The fourth novaculite inlier extends from the SE¼, sec. 19, T. 3 S., R. 26 E. to the northern part of sec. 27 of the same township and range. This is an anticlinal nose tilted west, the eastern end of which is determined by the intersection of two faults, one passing west-nothwest along the north side of the novaculite ridge, the other extending east-west along a part of the south side. Since the strata all dip to the north in this locality and since the country between the faults is upward thrown relative to the areas either side, the fault on the north should be a normal fault and that on the south, an underthrust fault. The normal fault, north of the ridge, cannot with certainty be traced westward, but it is very possible that it does continue and connects in sec. 24, T. 3 S., R. 25 E. with the normalfault in the valley of Linson Creek, described above. It is not known whether there are other important faults in this region of general down folding or not. There is nothing to indicate positively that there are, yet a large number might well be expected. The discontinuity of the tuff bed and its association with vein quartz in secs. 15 to 22 inclusive, T. 3 S., R. 27 E., and westward looks very suspicious The sudden termination of the tuff bed in sec. 8, T. 3 S., R. 27 E., and in sec. 22, T. 3 S., R. 26 E., are other cases in point.

It is not possible to trace out with any degree of accuracy the folds in the Stanley as indicated by the tuff. In general the areas lying between the novaculite arches are all sharply synclinal and mostly complexly so. The long narrow inliers of tuff crossing Mountain Fork River in secs. 4 and 16, T. 3 S., R. 25 E., and perhaps some others in that general locality are, no doubt, the axes of anticlines, but farther west we only know that the older rocks lie buried deeper, i. e., the synclinorium plunges west.

The dip of the strata throughout the eastern half of this great trough is practically everywhere northerly, sometimes locally as low as 15 degrees, but averaging as much as 45° to 60°. West of the area occupied by the novaculite ridges, in the northern half of T. 3 S., R. 25 E., to be exact, the dip of the rocks is more frequently observed to be 80° to 90°, and it is not unusual to see, along the river, steep southward inclinations of the bedding. West of the river the rocks may dip as low as 25°S. in places, but this is the locality north of which the prevailing dip is south (in the west end of the Cross Mountains). Coming farther west into R. 24 E. outcroppings become more widely separated, but such observations as are available for study seem to indicate what may be styled as a sharp narrow V-shaped type of folding, indicating lessening pressures to westward. Whether the rocks which lie deeply buried at Sherwood are more sharply crumpled than those now at the surface at the same place would be hard to say, but it seems that they should be less so.

STRUCTURES BORDERING THE ANTICLINORIA.

BOKTUKOLA FAULT

North of the west end of the Cross Mountains in Ts. 1 and 2 S., Rs. 24 E. and 25 E., and west, there occurs a large mass of Jackfork sandstone, which overlies the Stanley shale and which is folded normally into a broad syncline on the north and into a sharp anticline on the south. The southern border of this Jackfork sandstone mass is a straight line, which strikes slightly north of west from the NE. cor., sec. 14, T. 2 S., R. 25 E., to the NW. cor., sec.. 7, T. 2 S., R.

PLATE LXXIX.

A VIEW OF THE NARROWS IN THE SW. ¼ SEC. 9, T. 2 S., R. 25 E. LOOKING EAST.
So named because the road which passes between the mountain to the left, and Boktukola Creek to the right is not wide enough for wagons to pass. Boktukola Creek joins Mountain Fork River just ahead. High water in the river floods this road which is the main road and only road through this part of the country. Boktukola Creek marks the location of the Boktukola (thrust) fault at this place.

24 E., and the heavy ledges of the Jackfork on the north dip to the south 20° to 40° directly against, or beneath the Stanley shales on the south, which also dip south. Evidently the contact between the Stanley and Jackfork throughout this 11 miles is a fault line, with upthrown side on the south, but there is no direct evidence bearing on the nature of this fault—whether it be normal or reverse.

It has already been stated that the strata in the Cross Mountains two or three miles distant to the south have been overturned and are dipping to the south, and the writer has attempted to show that the faulting in that region is of the thrust type. Over all the intervening ground between the Cross Mountains and the Jackfork sandstone outcroppings, the prevailing dip of the rocks is south, although in the Stanley there is a greater variation in the dip than is the case with the more resistant rocks. It is reasonable, therefore, to expect thrust faulting in the present instance; and applying the same reasoning here as elsewhere, that the fault plane should dip in the same direction as the dip of the strata in a tightly folded series, and since the south side is the upthrow side it is regarded as a thrust fault. The amount of displacement is unknown, for it is impossible to tell what portions of the Jackfork and Stanley are wanting. It is not known, either, how far east this fault carries, but there is every reason to expect that it extends perhaps well into Arkansas. It is proposed to call this fault the Boktukola fault from the creek by that name which flows into Mountain Fork River near the fault line.

Between the Cross Mountains and the Boktukola fault extending due west 4 miles or more from the center of sec. 17, T. 2S., R. 25 E., there is another fault. This is indicated by a crush-zone and an abundance of milky vein quartz in a number of places. It is entirely a matter of inference as to whether this fault be of the normal or reverse type but being associated with reverse faults it too should be reverse, although not necessarily.

NUNIHCHITO ANTICLINE

All across the northern part of T. 2 S., R. 24 E., about a mile north of the Boktukola fault and parallel with it, there is an anticlinal axis from which the sandstones dip in either direction north and south from 10° to 25°, ordinarily, but farther out on the flanks, at somewhat steeper angles. This anticlinal structure is made manifest also by the indentation of the Jackfork-Stanley contact in secs. 4, 5, and 6, of T. 2 S., R. 25 E., and again, several miles farther east, by the unexpected appearance of the Stanley tuffs south of Watson, Oklahoma. This general line of uplift is one of the prominent structural features of this part of the country, deserving of a special name, and since the axis passes through the Choctaw settlement of Nunihchito it may conveniently be known as the Nunihchito anticline.

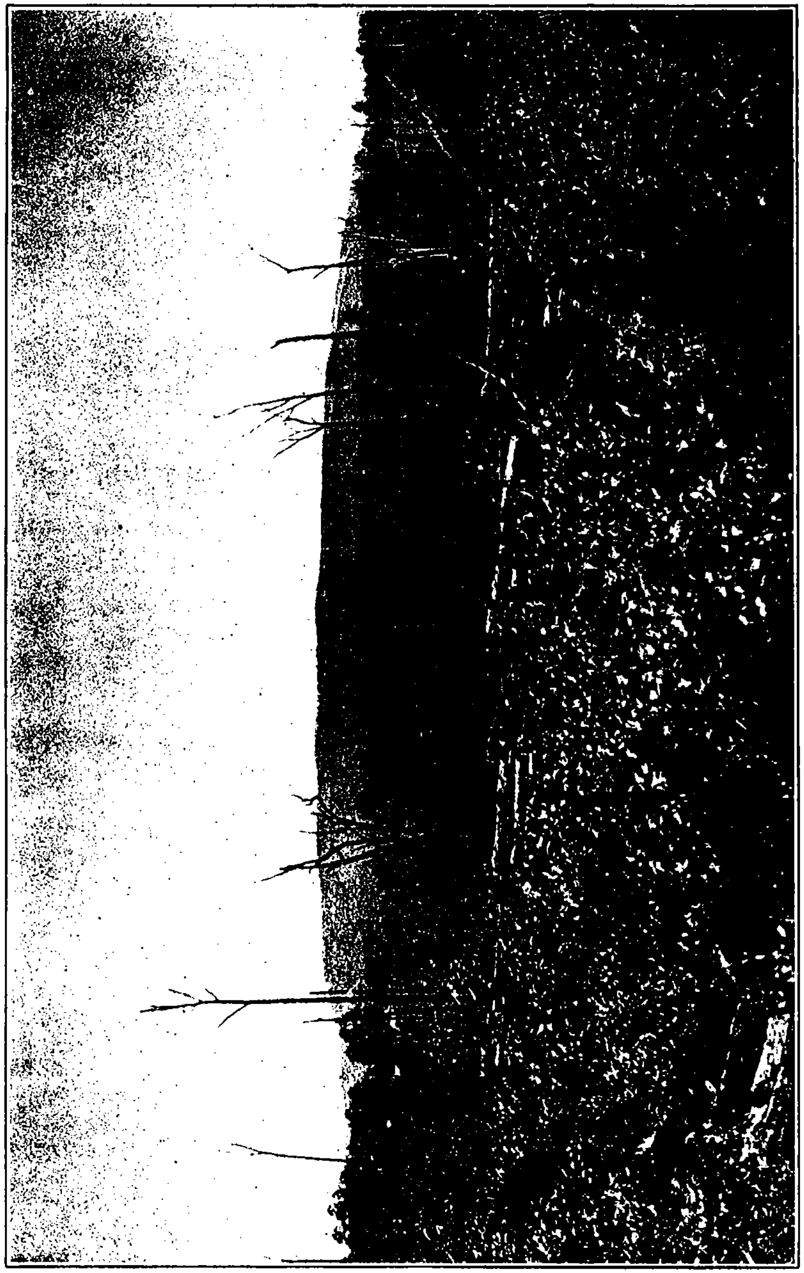
This anticline is not a simple structure, except at the western end where the capping rock is heavy bedded sandstone. Where the surface rocks are Stanley shales and sandstones there is considerable irregularity in the matter of dip and strike of the bedding evincing numerous dragfolds and other structural features of an analagous origin. The outcroppings of the tuff south of Watson, for example, reveal at least 5 folds and a small fault in that locality, and the dip of the sandstones shows at least 3 anticlines crossing the river near Nunihchito. The main structure, of which these smaller folds form a part, plunges westward. Granting that the thickness of the Stanley above the tuff bed is 5,000 feet, this plunge should amount to 625 feet per mile, for it is 8 miles along the axis of the fold from the base of the Jackfork sandstone east to the tuff bed near the bottom of the Stanley.

BOKTUKOLA SYNCLINE

North of the Nunihchito anticline the Jackfork sandstone is bent downward into a broad, shallow, westward-plunging syncline, which may suitably be called the Boktukola syncline, naming it from the creek by that name which flows across it and from a high mountain by the same name, standing in this trough. The axis of the syncline may be said to begin at the SE. cor., sec. 20, T. 1 S., R. 25 E., and to extend due west for 15 miles or more into a region at present unknown to the writer. At the east end this structure has a width of 6 to 8 miles and plunges westward, as indicated by the 15°W. dip of the beds along the axis, at the rate of 1,414 feet per mile. Westward, as shown by the contours of the topography, outside the area under discussion, the width of the syncline increases to 10 miles, but the plunge apparently lessens.

Eastward of the Jackfork exposures in the belt of Stanley shales in T. 1 S., Rs. 25 E., 26 E., and 27E., it is impossible to recognize the Boktukola syncline, although it doubtless extends entirely across this area, parallel with other structures to the north and south, and no doubt maintains its westward plunge, although not at so great an angle, else older rocks would appear. The upper portion of the Stanley, outcropping west of Smithville maintains a dip and strike which conforms closely to that in the overlying Jackfork sandstone, but farther east the main structure flares out into a corregation of small folds and crumples which obscure the main axis and dominant structural feature. It is not deemed advisable to mention all of these folds individually. Some of them may be traced along for a considerable distance; their axes are noted to lie in a general E-W direction and they always plunge sharply westward, indicating, according to Pumpelly's rule the nature of the large syncline. These small folds may be best observed along Mountain Fork River, where exposures can be had almost continuously.

PLATE LXXX.



VIEW LOOKING WEST DOWN THE AXIS OF THE BOKTUKOLA SYNCLINE FROM A POINT 2 MILES NORTHWEST OF SMITHVILLE.

The interior of this large basin is composed of resistant Jackfork sandstone, the basal portion of which rises in the background as Boktukola Mountain,—a large horseshoe mountain. (the view is the front of the "horse-shoe"). The Stanley shale dips beneath the Jackfork sandstone all round and outcrops in the foreground.

PLATE LXXXI.

A. CONCENTRIC RINGS OF HARD SANDSTONE (STANLEY) OUTCROPPING IN THE BED OF MOUNTAIN FORK RIVER MARKING THE AXIS OF A SHARP, WESTWARD PLUNGING ANTICLINE STRIKING EAST-WEST THROUGH THE NE. ¼, SEC. 10. T. 1 S., R. 27 E. VIEW LOOKING NORTH EAST.

B. VIEW LOOKING EAST DOWN THE AXIS OF AN ANTICLINE IN THE UPPER STANLEY SANDSTONE, 200 PACES NORTH AND 150 PACES WEST OF THE S. ¼, COR., SEC. 18, T. 2 S., R. 25 E.

The dip of the bedding throughout this general region ranges from 5° to 90° both north and south, but it is believed that there are no overturned folds. Over considerable areas in some localities, in secs. 13 and 14 of T. 1 S., R. 26 E., and west-northwest for example, the dip does not exeed 25° to 30° ordinarily. One is rather surprised to find the normal type of fold adjacent to some of the most severe thrusting of the whole region. The Jackfork sandstone, it would seem, with its thick massive beds of sandstone, acted as a strong arm of resistance which held firmly against the thrust pushing against it from the south. It acted as a protection also to the Stanley beneath.

OCTAVIA ANTICLINE-FAULT.

In the vicinity of Octavia in sec. 29, T. 1 N., R. 25 E., the Stanley shale outcrops as a large re-entrant projected westward between two large masses of Jackfork sandstone—one to the north, the other to the south—in such a manner as to suggest a major anticline, but there is some evidence of faulting on the north side. It is proposed to call this structure the Octavia anticline-fault, but no further mention will be made of it at this time.

LYNN MOUNTAIN SYNCLINE

In the northern part of T. 1 N., R. 26 E., and R. 27 E., and extending west and north into the unmapped area there occurs a mass of Jackfork sandstone which has been folded into a broad, westward plunging syncline. The heavy sandstone ledges projecting along the south side of this great trough and dipping 30° to 50°N., form Blue Bouncer and Walnut Mountains . They rise on the north at an angle of 15 to 25 degrees to form Lynn Mountain and Kiamichi Mountain. It is proposed to designate this structure the Lynn Mountain syncline, naming it from the formidable and majestic ridge by that name.

HUGO SYNCLINE

Beginning in sec. 32, T. 4 S., R. 19 E., and extending east-southeast, thence south and southwest about 8 miles to sec. 19, T. 5 S., R. 20 E., outcropping in a hyperbolic curve, is a large island of Jackfork sandstone in a sea of Trinity sand. This inlier is a belt about ½ mile wide that rises to an elevation of 750 feet, or 250 feet above the plains to form what is known as High Hill Mountain to the west and Signal Mountain to the southeast. In the region of the most northerly exposures in sec. 34, T. 4 S., R. 19 E., the strata dip to the south 43°; to the east in sec. 8, T. 5 S., R. 20 E., the dip is 10° W.; while in sec. 18, T. 5 S., R. 20 E., in the region of the most southerly outcroppings the dip is 10° northwest. Also in sec. 26, T. 4 S., R. 19 E., at Corinne, exposures of the Stanley shales and sandstones are encountered in the creek dipping south, and the Stanley is exposed again in sec. 8, T. S., R. 20 E., dipping west. It is evident then that this large inlier of Jackfork sandstone is synclinal and that it plunges west-southwest at the rate of about 930 feet per mile or 10°. Moreover, it is the basal portion of the Jackfork that is exposed and knowing that the Stanley crops out at Corinne, and in sec. 8, T. 5 S., R. 20 E., and knowing the dip and strike of the bedding, and the structure it is not difficult to draw the Jackfork-Stanley contact at the base of the Trinity sand in this general region. It may be thought of as extending from the S. ¼ cor., sec 35, T. 5 S., R. 19 E., northeast around the end of Signal Mountain, thence west through the southern part of sec. 27, T. 4 S., R. 19 E., south of Corinne. The bisectrix of this curve is approximately the axis of the syncline and since it strikes toward Hugo, and beyond any doubt whatever, extends that far, it comes very handy to speak of this structure as the Hugo syncline. In a northeasterly direction the axis passes through the center of sec. 25, T. 4 S., R. 20 E., and is in evidence even farther east, but in the valley of Little River it is crumpled into a series of smaller structures making it impossible to recognize it. This syncline may be thought of as extending on across Glover Creek as a belt of general down folding, and joining perhaps to the Linson Creek synclinorium but there is no direct evidence that the structure is synclinorial all the way to that point.

CORINNE ANTICLINE

The north flank of the Hugo syncline is also the south flank of a large anticline just north, for north of Corinne, from sec. 12 to sec. 19, inclusive of T. 4 S., R. 19 E., the Jackfork sandstone dips 40° to 60° northwest and strikes northeast. In the township to the east the Trinity sand has been removed from the underlying Paleozoics over most of the township permitting of observations and the mapping of some of the details of the structure in this region. The dip of the rocks in this region ranges from 10° to vertical, with an average inclination well above 45°; and there are repeated and sudden reversals of the dip indicating, all told, complex dragfolding and much crumpling on the flanks of the major structure. The axis of the main fold can be mapped with precision in the western part of the township but eastward the complexity of the structure increases so that it cannot be followed so well. However, the strike of the bedding along the axis is uniform and with this as a guide the axis of the fold has been drawn from the NE. cor., sec. 6, T. 4 S., R. 21 E., west-southwest through the village of Corinne, whence the name of the anticline, to the W. ¼ cor., sec. 31, T. 4 S., R. 19 E. How far west the fold extends beneath the Trinity is not known but it may be regarded as holding out at least as far west as Cody, 7 miles north of Hugo. That the anticline plunges rapidly westward is indicated bythe converging outcroppings of Jackfork sandstone north and south respectively of Corinne. The Stanley shale probably does not lie in contact with the Trinity sand west of sec. 30, T. 4 S., R. 19 E. but plunges beneath the Jackfork at that place.

It is not possible to follow the axis of the fold in the opposite direction farther than Little River.

BETHEL SYNCLINE.

Another large syncline of Jackfork sandstone occurs north of the Corinne anticline, beginning near Bethel and plunging west-southwest 30 miles or more to the Trinity sand formation where it is lost from view. This is fully 10 miles in breadth and will be known as the Bethel syncline. It is bounded on the north by the Boktukola (thrust) fault.

The general average dip of the beds on either flank of the structure is about 30°; the axis strikes N. 75° E. (from the S. ¼ cor. sec. 31, T. 2 S., R. 22 E. to the S. ¼ cor. sec. 13, T. 2 S., R. 23 E.); and plunges west-southwest about 15°.

GENERAL CONCLUSIONS.

It has been shown that the region under consideration in this report from the point of view of structure, falls readily into several subdivisions, the most important of which are: the Choctaw anticlinorium, the Cross Mountains anticlinorium, the Linson Creek synclinorium, and certain large, westward plunging anticlines and synclines lying to the north and west of the large folds just mentioned. The principal facts of these structures may be summarized further and from another point of view as follows:

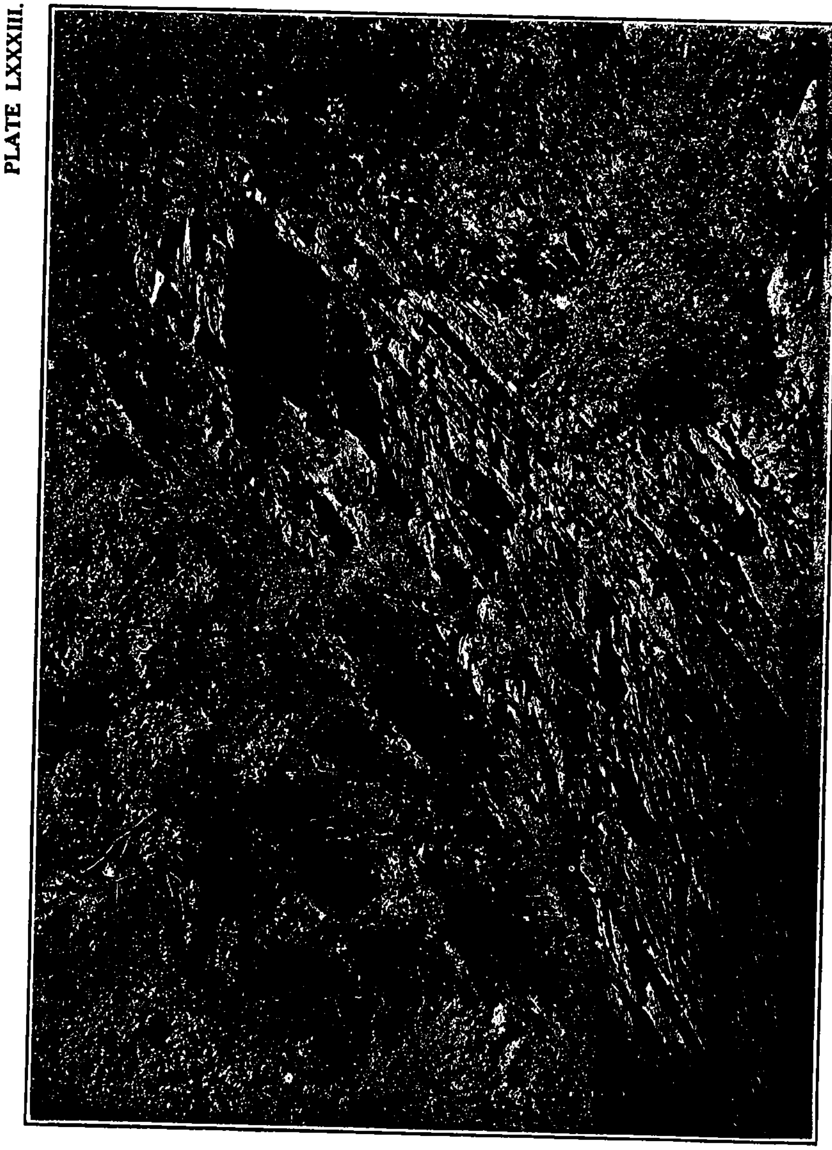
1. A belt of thrust folding and normal faulting, with prevailing dip of the strata to the north 45 to 60 degrees, embracing all of the Choctaw anticlinorium and the southern half of the Linson Creek synclinorium.

2. A belt of thrust folding and thrust faulting, with prevailing dip of the strata toward the south 45 to 90 degrees, embracing the Cross Mountains anticlinorium, the northern part of the Linson Creek synclinorium and the Boktukola fault, and

3. A belt of gentle folding in which are developed normal anticlines and synclines, with prevailing dip of the rocks, north and south, of 15 to 45 degrees, embracing the Nunihchito anticline and the Boktukola syncline, also other similar structures farther north and west, such as the Octavia anticline-fault, Lynn Mountain syncline, Hugo syncline, Corinne anticline and Bethel syncline.

The axes of all the principal folds and the other structure lines, except those lying to the extreme west and north have been drawn to scale in their true relationship on the map (Pl. LXXXII) and the essential facts of the three belts of deformation indicated. These ideas have also been embodied in a diagrammatic cross section shown on the same plate, which reveals very clearly, in general, the fanshaped

PLATE LXXXIII.



A CLOSE VIEW OF THE DETAILS OF THE BLAYLOCK SANDSTONE AS EXPOSED 500 PACES NORTH AND 200 PACES WEST OF THE E. ¼ COR., SEC. 3, T. 4 S., R. 25 E.

The planes of schistosity dip 15° N., while the dip of the bedding is about 40° N. It is argued that the deeply buried sediments beneath were thrust under (north) while the Blaylock and overlying masses lagged or in effect resisted this movement.

structure of the region as a whole and gives one a suggestion as to the origin of the whole complex.

In this ideal section only one fault has been shown. This has been drawn in a position to represent the Boktukola fault, but in general may be looked upon as representing the sum total of movement due to thrust in the Cross Mountains as well as in the Boktukola fault. (Since the normal faults belong to a later period of movement, they should not be included in the diagram.)

Looking at the matter broadly and with all the facts of the folding, the faulting, and the schistosity in mind it is of course obvious that tremendous compressive forces have been brought to bear upon the region and that these necessarily are thrust and resistance, which, in effect, acted in opposite directions to squeeze and crush the mass which happened to be caught between these two forces. The questions at hand mainly are: From which direction did the thrust come? What was the primal cause of it? When did it occur? and, What was the resisting force?

The answer to the first question should be found in part in the trend of the tectonic lines. The folds strike southwest on the west side of the main structure and east-southeast on the east side, giving expression at the surface, in general, of arcuate mountains. Obviously it is more reasonable to think of the advanced middle portion of the arc as being pushed up from the south, than it is to think of the two flanks as being pushed down from the north by a dual sort of thrust passing either side of the center. If the latter has happened one should expect to find greater compressibility evidenced on the flanks than through the central axis. Just the opposite is true, for one finds evidence of the greatest thrusting in the center of the arc, with gradually lessening pressures indicated on the flanks as one travels either east or west from the center. This fact is further brought out by the convergence of the tectonic lines on the advanced central (northerly) portion of the arc.

Another line of attack of this problem has to do with the intensity of the folding in the southern part of the area as versus that in the extreme northern part of the field. It has been observed that the rocks to the south are more sharply crumpled than the formations in the north. The Stanley shale as exposed in Ts. 1 S., and 2 S., Rs. 25 E., 26 E., and 27 E., north of the Cross Mountains, reveals no overturning of the strata. The folds in this general region are of the normal type and the inclination of the bedding is often as low as 10° to 25°. On either flank of the Choctaw anticlinorium the folds in the same (Stanley) formation, for it is fair to consider only the same formation, are invariably overturned excepting far out on the flanks. It is only reasonable to think of the tighest compression as lying nearest the source of the thrust, since we are dealing with the friable, weak crust of the earth and not with a good conductor of vibrations, heat, and motion. If the source of the thrust lay to the north the Stanley shale in the north should surely be overturned also.

Looking at the problem from the point of view of the schistosity and dip of the strata, it will be recalled that the inclination of both the bedding planes and the planes of schistosity in the Choctaw anticlinorium is toward the north. There is usually a westward or an eastward component locally also, which is westward on the west flank of the structure and eastward on the east flank. Throughout the whole central core of old rocks the planes of schistosity are more nearly due north than on the flanks, yet there is everywhere considerable variation as to the east-west deflections. Ordinarily a single observation of the dip and strike of the schistosity, however small the exposure of rock, should serve for a wide area but in the region under discussion the direction of dip and strike of the schistosity is not so consistent. It may be that the writer has confused slaty clevages with jointing in his work in the field in some instances and it may be also that there was more than one movement which developed a slaty clevage in the shales; or, possibly the one movement was protracted to such length and in such a manner as to develop schistosity in more than one direction. At any rate there is in the dip of the schastosity, except in the valley of Glover Creek where the dip is due west, always a strong northern component. The prevailing dip of the bedding in the Choctaw anticlinorium is also north. These are striking facts, and moreover, the planes of schistosity cut across the bedding at a low angle, always below 30° often 10° and sometimes approaching horizontality. (Note schistosity in photographs of Blaylock sandstone, Plates LXXXIII, LXXXIV, and LXXXV.)

This is another remarkable fact, for usually slaty clevages dip at high angles and cut the bedding planes vertically along the axes of the folds. In this region the schistosity seems to have been developed, as has been stated above, not so much from static rigid compression as from the gliding of the beds over each other horizontally and by a lateral movement of folded masses over or under other folder masses. It would seem at first that the schistosity and bedding should dip south rather than north in the Choctaw anticlinorium if the thrust came from the south, but on the other hand if it came from the north it would be just as difficult to explain the general south dip in the Cross Mountains and all those thrust faults up there. It is easier to account for the north dip of the schistosity and the bedding in the country to the south by assuming that the thrust came from the south, which caused the strata to crumple gradually and gently at first, but as time progressed, more sharply, until the folds became isoclinal. By this time the country should have been elevated, the tops of the anticlines eroded and at this point any further pressure would act chiefly on the deeply buried sediments which would be shoved **under** the overlying, crumpled and raised up masses. In other words, a horizontal zone of crumpled strata (Bigfork to Jackfork inclusive) moved forward (north) over the soft, little disturbed, deeply buried sediments, during the early and middle stages of the period of folding, while the top of this

PLATE LXXXIV.

HORIZONTAL SCHISTOSITY IN STEEPLY DIPPING BLAYLOCK SANDSTONE, INDICATING ACTUAL LATERAL MOVEMENT OR GLIDING DURING THE LATTER STAGES OF THE FOLDING
Faulting is in evidence also. View looking due east at a point 400 paces east and 100 paces south of the N. ¼ cor., sec., 34, T. 3 S., R. 25 E.

zone arose high in the air, and fell back or lagged as the lower portion (Collier to Womble inclusive and older rocks) continued to advance, during the later stages of the thrust. The schistosity must have been developed during the latter stages of this thrusting movement, during the lagging, or while the **underthrusting** was going on. The diagram (figure 5) represents 4 stages of such a movement.

The faulting in the Cross Mountains should have been caused relatively early during this process. There should not be any faulting, necessarily, anywhere excepting in the Cross Mountains. Here

PLATE LXXXV.

ANOTHER VIEW SHOWING HORIZONTAL SCHISTOSITY CUTTING ACROSS HIGHLY TILTED BEDS OF BLAYLOCK SANDSTONE, AND AN UNDERTHRUST FAULT IN THE LOWER RIGHT HAND CORNER.
View looking N. 75° E., from a point 200 paces north and 300 paces west of the SE. cor., sec. 34, T. 3 S., R. 25 E. Oklahoma.

was a belt of weakness and when it gave way to the accumulated, pent up pressures it was forever afterward a zone of weakness just as much or even more than ever and could act as a vent for any further relief of pressure. Had these Siluro-Devonian rocks been more resistant, having once broken they might have been shoved bodily for miles over the Jackfork sandstone, but they happened to be thin bedded materials (especially thin in this northerly latitude) and became complexly folded and multiple thrust faulted instead. A lagging of the upper portions of the folds farther south

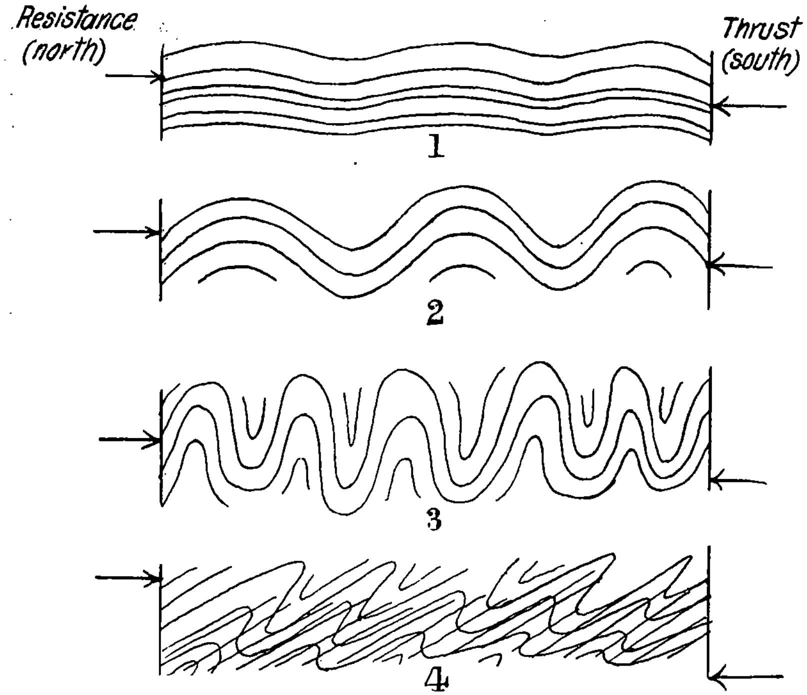


Figure 5—Diagram illustrating four stages in the development of the folds and the schistosity in the region of the southern Ouachita Mountains.

in the Choctaw anticlinorium might easily be accompanied by underthrust faulting. This appears to have happened south of Williams Mountain and again in one or two places north of this mountain, thus accounting for the underthrust faults in these localities. (There were no normal faults developed during the thrust; these all belong to a later period to be considered presently).

With regard to the inconsistencies of the strike of the planes

of schistosity or slaty cleavages it is conceivable that the development of drag folds might locally yield results which would be at variance with the general trend of the shear zones. It is more likely that schistose structures, developed early during the thrust, could be tilted out of their proper orientation by later movement. Since the most tightly compressed folds lie in the regions where the axes of the folds lie farthest north, since the axes of the folds are bent in the center convexly to the north, and since the most profound thrust faulting occurs in the west end of the Cross Mountains—all in Rs. 24 E. and 25 E. there can be no doubt but that this N.-S. belt was the axis of maximum thrust and that along this axis, north, occurred the greatest mass movement or the greatest shortening of the crust. To the east and to the west there was lesser movement and lesser shortening of the earth's surface. Whether this was because there was greater pressure applied in the center than on the sides or whether there was greater resistance on the flanks than in the center is not known. At any rate the result is the same and there has been retardation on the flanks. This is especially noticeable on the west. Recalling that the schistosity dips due west on the west flank, west of Glover Creek, is it not feasible that the schistosity in this particular region was swung around to dip west after it had been developed—turned about by the continued push north in the center? It would be far easier to explain the twist, 35°, to the northeast on the east flank, by such a movement than it is a turn of 90° west, west of Glover Creek; yet in either case a better explanation seems lacking entirely.

It is only natural to inquire now into the cause of such a thrust, which is the second question to be answered. It has been pointed out in the foregoing discussion of the stratigraphy that many of the formations from the Collier to the Jackfork thin toward the north, some of them pinching out entirely in that direction, and that there is a tendency in general—most marked in some cases—for the formations to become finer of grain toward the north, coarser toward the south. These facts point unmistakably to a southerly source for these beds.

It has also been discovered, largely by a microscopic study of the sediments, that small quantities of feldspathic minerals and in certain horizons large percentages of these and other igneous minerals abound in the various rocks. Several horizons of volcanic ash occur. These facts indicate just as conclusively that the source of the sediments was in part at least an igneous and metamorphic area dotted with volcanoes.

Moreover, this igneous, metamorphic and volcanic old land must have been of tremendous size to have furnished 18,000 to 20,000 feet of material spread over several thousands of square miles of country. The depths of sediments furnished by this land mass must have been even greater than 20,000 feet for there were sands and muds laid over the Jackfork sandstone, which have not been considered in this report, but which must have come from the same southerly source. In-as-much as there does not now exist anywhere in the south any such area as these facts indicate positively once existed it must have disappeared. In its stead to the south there are vast thicknesses of Cretaceous and later rocks thousands of feet thick. The subsidence of a large land mass where now lie the thick deposits of Mesozoic and Cenozoic strata seems a good and sufficient cause for the thrust movement.

From their studies in Arkansas, Griswold* and Purdue** conclude that the pressure which gave rise to the Ouachitas in that state, came from the south, but Miser*** in describing the structure of the Caddo Gap and DeQueen quadrangles, covering parts of the southern Ouachitas of Arkansas says, "In some parts of the area the pressure that produced such overturning was exterted from the north; in other parts from the south." One gathers from the reports of most geologists, including Branner, Griswold, Purdue and Miser, who have worked in the Ouachita Mountains in Arkansas that the majority of the sediments at least composing those mountains came from the south. Schuchert**** has long recognized the existence of a Paleozoic land mass in Mexico, with an arm extending into Texas and Louisiana known as Columbia-Llano. Ulrich† refers to the same old land but thinks Llano was distinct from Columbia. Recently Miser†† has critically reviewed all the evidence bearing on this old land, bringing the subject up to date, and he concludes that "a land area existed in Louisiana and eastern Texas during much if not most of the Paleozoic era and during the Triassic and Jurassic periods of the Messozoic era."

Assuming for the sake of argument that the thrust originated in the north, somewhere on the continent of North America, instead of in the land of Columbia or Llanoria where is there any evidence of subsidence or thrust in the north to have produced these mountains? One may look in vain for such data anywhere in the Prairie Plains, Arkansas Valley or the Ozarks, so it would seem. Thus by the process of elimination also we must conclude that the thrust came from the south. If there is any place in the Ouachitas themselves where the thrust appears to have come from the north it is because there has been superior resistence to the thrust at that point or because the tops of the folds have lagged behind during their forward (northward) movement.

*Griswold, L. S., Novaculite of Arkansas, Ark. Geol. Survey, Ann. Rept., 1890 vol. 111, p. 213.

**Purdue, A. H., Slates of Arkansas, Ark. Geol. Survey, 1909.

***Miser, H. D., U. S. G. S. Bull. 660 C, 1917, p. 72.

****Schuchert, C., Paleogeography of North America. Bull. Geol Soc. Amer. vol. 20, 1910, p. 464.

†Ulrich, E. O., Revision of the Paleozoic System; Geol. Soc. Amer. Bull. vol. 22, fig. 7 p. 368, 1911.

††Miser, H. D., Llanoria, the Paleozoic Land Area in Louisiana and Eeastern Texas; Amer. Jour. Sci. vol. 2, pp. 61-89, August, 1921.

As to the time of the orogenic movement it is necessary to find out, first of all, what are the latest sediments involved in the folding and secondly to consider whether or not gradation processes have removed or covered up any of the formations caught in the folding, and if so to what extent. Since the Jackfork sandstone suffered compression and since no younger beds are preserved in the area under discussion it is clear that the folding is at least post-Jackfork and that the answer to this question can come only by looking farther afield. To westward and north so far as known there are presumably in the Ouachita Mountains (bounded on the north and west, so far as Oklahoma is concerned, by the great Choctaw fault) no younger beds than the Jackfork, and whether the folding north of the fault is to be correlated with the movement which folded the Ouachitas or not is a question which may be considered as not finally settled.

In the Arbuckle Mountains, "it is evident that the deformation of the Glenn formation was effected at the same time as that of the Arbuckle Mountain area and that the geological data of the orogenic movement was at least post-Glenn," so says R. C. Moore* who also correlates the Glenn** with the series: Wapanucka limestone to Holdenville shale inclusive. The Holdenville shale belongs well up in the Allegheny series so that the folding in the Arbuckles must have taken place at least post-Holdenville. Moore concludes that this epoch of mountain making and erosion came in mid-Pennsylvanian (Hercynian) time. The writer is inclined at present to correlate this particular orogeny of the Arbuckles with the folding in the Ouachitas, but until more is known concerning the limits of the forces of the compression which folded the Ouachitas the exact time of the uplift cannot be known, positively.

From the nature of the folding in the Collier to Stanley formations inclusive in the Ouachitas which may be described in general as fan shaped, it is clear that not only was there great pressure brought to bear through the thrust, but there must have been very

*Moore, R. C., Folding in Southern Oklahoma Oil Fields; Bull. Amer. Asso. Petrol. Geologists, vol. 5, p. 38, 1921.

**Idem. p. 34.

great resistance to such a movement. This was abundantly supplied by the massive thick beds of the Jackfork sandstone, some single layers of which are 10 to 20 feet thick and together with a few shales aggregate approximately 6,600 feet. This formation lay heavily over the Choctaw and Cross Mountains anticlinoria and surrounding regions and stretched back into the interior many miles to the north and west. It was the "cap sheaf" which in addition to the Stanley shale and Arkansas novaculite bore down so heavily upon the Ordovican and Silurian rocks beneath causing them to break and shear and become schistose. The heavy ledges of Jackfork in the rear of the mass which buckled up and gave way acted as powerful buttresses against the push initiated by the subsidence of Columbia-Llanoria. These resistant heavy ledges, however, were not themselves unyielding. They too bent and in places broke, but they constituted, nevertheless, the main resistance in the other jaw of the pinchers. The eroded upturned edges of the Jackfork sandstone form the high ridges farther north, some of the more important of which are Kiamichi Mountain, Winding Stair Mountain, Jackfork Mountain, Rich Mountain and Blackfork Mountain, also Blue Bouncer, Walnut, Lynn, and Boktukola Mountains in the immediate region now under consideration.

NORMAL FAULTS.

There is very little information in hand, bearing on the age and origin of the normal faults in this region. They must have been produced during some period of subsidence or uplift after the thrust, but just when they were formed is not known. It is conceivable that subsequent to the thrust movement in Pennsylvanian (?) times there might have been a contrary reaction or settling back of the upfolded masses accompanied by normal faulting. The Triassic and Jurassic periods are noted for rather severe diastrophic activities elsewhere. Pronounced faulting took place in the Appalachian region during this period and it is possible that also in the Ouachitas there might have been contemporaneous faulting, although there is no positive proof in sight at this time for assuming that there was, except that the Jura-Trias and the Comanchean must have been for the Ouachita region a time of prolonged base leveling—a period of development of the peneplain upon which were deposited the Trinity sand and later formations of Comanchean age, and that subsidence and normal faulting might possibly have been factors in this process.

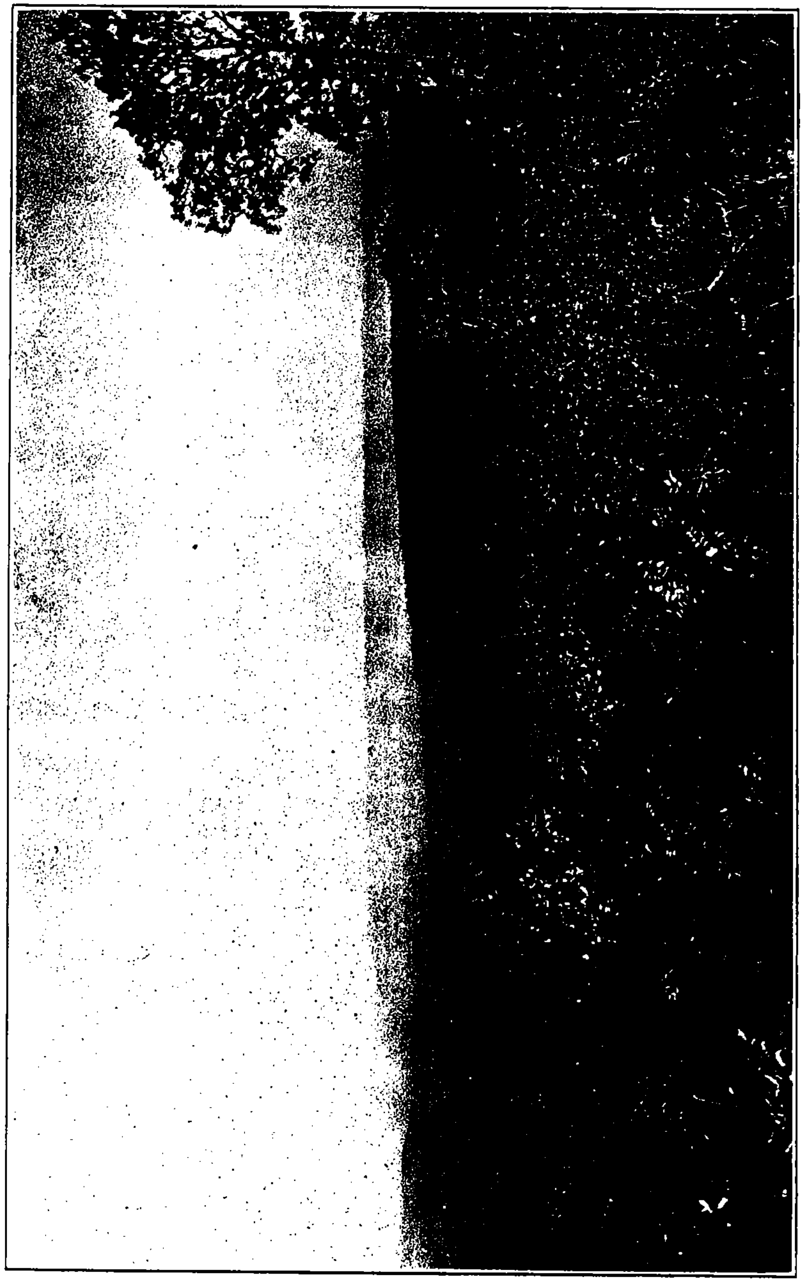
What seems to the writer to be the most plausible excuse for the normal faults is the post-Cretaceous uplift which raised the southern border of the Ouachitas 500 feet, and the central portion of the range (Rich Mountain, Blackfork Mountain, Round Mountain, and others) more than 2,500 feet above sea. These figures represent the consequent warping of the Cretaceous peneplain. Under such circumstances at such a time normal faulting should not be out of order. Since this uplift may still be going on the faults may range in age from the beginning of Tertiary time to the present, yet again there is no positive proof that any faulting occurred at any time during this interval.

IGNEOUS HISTORY

The exact date of intrusion of the igneous matters is likewise unknown. The carbonates have replaced portions of all the early Paleozoics up to and including the novaculite and probably also younger rocks, while the quartz-orthoclase pegmatites appear abundantly and of large size in all the formations from the Collier to the Stanley inclusive, but more abundantly and of largest size in the Cambro-Ordovician shales. It seems, therefore, that these introduced matters came in at the time of the thrusting. The diorite sill, on the other hand, is fractured to bits by the thrusting movement and must, therefore antedate this period (the period of thrusting and folding). It cuts the Womble shale, however, so must have been intruded sometime during or after upper Ordovician.

If the introduction of large quartz-orthoclase pegmatites into sediments to form dikes; and if the escape of vast quantities of carbonated alkaline and ferrugineous thermal waters and gases from the depths to form important replacement deposits of carbonate in sandstone, cherts, and shales, may be regarded as dying igneous action, one may think of the crystallines in depth as intrusives which bored their way into the underlying foundations of the Choctaw anticlinorium at some previous time. The relatively early introduction of the diorite sill into Ordovician sandstones may be connected with this earlier history.

PLATE LXXXVI.



VIEW LOOKING SOUTH FROM 150 PACES EAST OF THE W ¼ COR., SEC. 16, T. 1 N., R. 25 E.

The even, horizontal crest of Boktukola Mountain (a horse-shoe mountain) in the far distance marks the position of the Comanchean peneplain. (See also photo, plate LXXXVII.)

PHYSIOGRAPHIC HISTORY

MESOZOIC ERA.

It is believed that in Pennsylvanian time there occurred a readjustment of earth segments in the southwestern Mississippi Valley region involving a sinking of a vast area south of the present location of the Ouachita Mountains in Louisiana and Texas*.

It is further believed that the subsidence of this mass caused the uplifting and crushing of the mass of sediments accumulated in a great geosyncline beneath the sea to the northward, producing a lofty range of mountains of the Applaachian type. The remnants of this lofty range form the Ouichitas of today, and the sediments composing them have been fully described on the preceding pages. That the uplift is believed to have been accompanied by a thrust from the south has already been indicated.

Just how long the period of thrusting lasted is a matter of speculation. To answer this question would demand correlation with other diastrophic movements in adjacent areas which is impossible until more is known of the general stratigraphy in the Paleozoic areas of the Arbuckles and the western Ouachitas; in the Pennsylvanian area of the Arkansas Valley region; and in the Comanchean and Cretaceous areas of the Gulf Coast.

That the folding began as late as basal Pennsylvanian is shown by the fact that the Jackfork sandstone, is involved in the folding and is conformable on the Stanley. The beginning may have been much later—possibly as late as mid-Pennsylvanian, as the writer has attempted to show in discussing the Structural Geology; but as the field studies upon which this report is based have not been extended into the post-Jackfork area, he will not make a postive statement on this point. A part of the coal measures strata of the Arkansas Valley region may have been derived from the upraised Ouachita Range during the very early stages of the uplift. On the other hand the sea may have persisted over the area until very late Pennsylvanian. This is a matter which will have to await further field studies. At any rate the area under consideration, and the whole of the Ouachitas as well, must have been land during a part at least of the Jura-Trias.

Long exposure to the agents of subaerial denudation permitted the reduction of the Ouachitas to a lowland of faint or moderate relief so that with the advent of Comanchean time the land mass

*For an excellent and critical review of the literature presenting the evedence for this ancient land, see "Llanoria, The Paleozoic Land Area in Louisiana and Eastern Texas," Hugh D. Miser, American Journal of Science Vol. 2, pp. 61-89, 1921.

was in an old stage of development. In the Comanchean period the sea transgressed the area, like a great cross-cut saw, the waves, sharpened with boulders and sand from the novaculite and sandstone formations, literally cut its way across the roots of these former majestic ranges, reducing them to a still more subdued peneplain. Remnants of this peneplain are seen today in the even crested, and in numerous instances, flat topped ridges, which characterize the present topography. There are water worn boulders and some gravel on many of these high elevations, where the streams of later times never could have deposited them. Farther south occurs the Trinity sand with its boulder beds, red clays, thin limestones, and sandstones lying across the truncated and upturned edges of the Paleozoic strata—the saw-dust pile left by the Comanchean saw. The boulders and gravel on the mountain tops to the north can be correlated with the Trinity sand deposit by projecting the 40 feet per mile inclination of the Trinity upward to the north over the hills. In many instances, however, boulders and gravels, formerly covering the upland, have slumped down the hillsides into the present drainage lines; also there are gravels of either Tertiary or Quarternary age (and possibly of both) in the region, which must not be confused with the earlier deposits. Only the higher gravels can positively be correlated with the Comanchean peneplanation.

The Comanchean sea floor was not an absolute plain nor was it perfectly level. Minor undulations, produced by resistant sandstones, have been noted in favorable places along the northern feather edge of the outcropping Trinity. The shore of the advancing sea must therefore have been somewhat irregular. There were rocky headlands, and a few large islands and archipelagoes off shore, as shown in High Hill Mountain and Signal Mountain south of Corinne and west of Sobol, (northern part of T. 5 S., R. 20 E., and westward.) These mountains at the present time rise 100 feet or more above the Trinity sand plains which completely encircle them. The weathering away of the Trinity has uncovered a rocky headland along the east side of Signal Mountain. That this cliff may have been formed by waves of the Comanchean sea is suggested by the fact that there are large blocks at its foot cemented in the basal conglomerate of the Trinity. North of the main ridge, which forms High Hill Mountain, 7 miles long, there are numerous small outcroppings of Paleozoic rocks surrounded by Trinity, showing that peneplation was not complete in this region and that archipelagoes existed. Certain other mountains (for example Williams Mountain in sec. 35, T. 3 S., R. 26 E. and the high points in secs. 24, 25, 35, 36, T. 2 S., R. 25 E.) are certainly monadoncks on the Comanchean peneplain and may have been islands in the Trinity ocean.

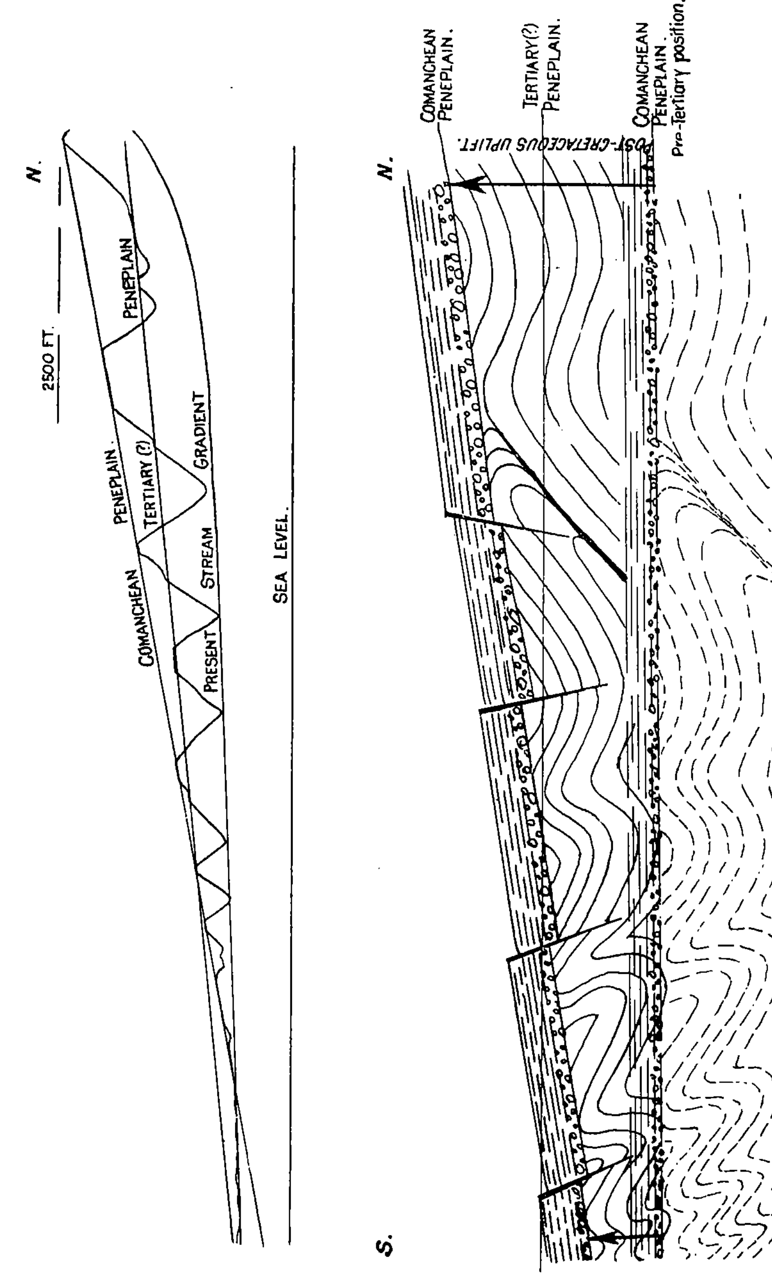


Figure 6. Diagrams illustrating original and present relative position of the Tertiary (?) and Comanchean peneplains, and the present stream gradient with reference to sea level.

In Arkansas, Miser and Purdue* have pointed out that:

The gravel thins out at few places, as near Murfreesboro and Lebanon where rocky headlands and islands of Carboniferous sandstones along the old Cretaceous shore were not completely buried by the gravel though they were by higher beds.

There is abundant evidence of widespread peneplanation and submergence of the land all over the continent of North America during Cretaceous times. The thick Cretaceous sediments in Texas and Mexico and the outliers of Cretaceous limestones in western Oklahoma can only mean wide spread submergence there. The Ouachitas presumably also disappeared completely beneath the Comanchean sea in time, although there is no conclusive record of this in the region itself.

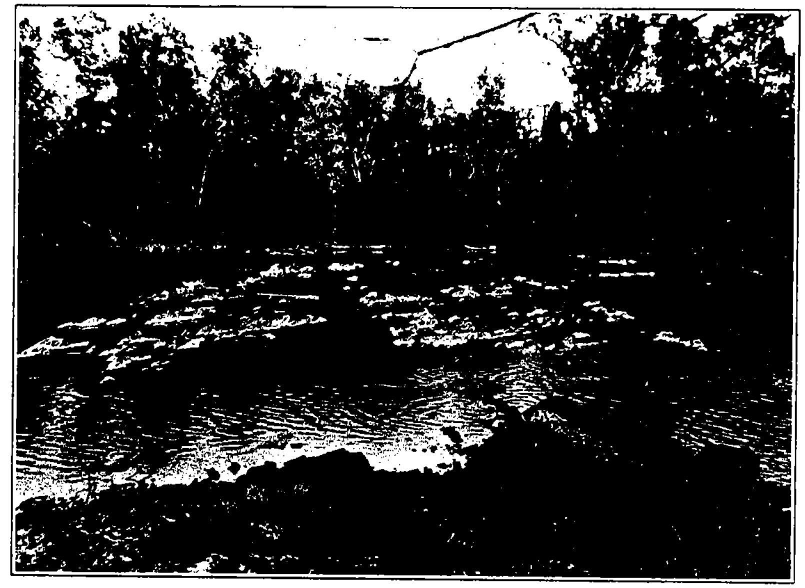
CENOZOIC ERA

The Tertiary history of the area is likewise obscure owing to more recent extensive erosion. There are water-rounded boulders of large size, and patches of gravel scattered over the valley regions very generally. These cannot be distinguished from the boulders and gravels of Comanchean age in the southern part of the area (e. g., in T. 4 S., and farther south, and not with certainty in all cases in T. 3 S.); but farther north at elevations of from 750 to 1,000 feet they are of such size and in such abundance on the low hills and slopes above the present drainage as to be unmistakably later than Comanchean or Cretaceous in age, and earlier than the present cycle of erosion; but whether they are of Tertiary or Quaternary age, or both, the writer does not know.

The boulders are most numerous north and south of Smithville, and were derived chiefly from the Stanley and Jackfork formations, although chert pebbles and boulders also abound; they are all well rounded and range in size ordinarily from 6 inches to one foot in diameter. Sometimes the low rounded or flat topped hills (western part of sec. 12 and extending north into the southwest quarter, sec. 1, center of sec. 2, and throughout the northern part of sec. 3) are completely covered with sandstone boulders 6 inches to one foot or more in diameter. In this general region (especially in the northern part of sec. 3) the boulder beds are clearly not of the present period, because they are most abundant on the tops of the lower hills, sparce on the slopes, and the present drainage is dissecting the boulder hills by headward erosion. In the southern part of sec. 1, two parallel streams flowing south, and uniting in the center of sec. 12, below, have between them a north-south, rather

*Miser, H. D. and Purdue, A. H., Gravel Deposits of the Caddo Gap and De-Queen Quadrangles, Arkansas; U. S. G. S. Bull. 690-B, 1918. p. 20.

PLATE LXXXVII.



A. LOW WATER IN LITTLE RIVER, A CONSEQUENT STREAM, SEC. 25, T. 5 S., R. 21 E., LOOKING EAST.
The outcropping rocks are Stanley sandstones dipping 30° NW.

B. HIGH WATER IN LITTLE RIVER ON A RAPIDS OF STANLEY SANDSTONE, SEC. 11, T. 5 S., R. 21 E., LOOKING WEST.

abruptly rounded divide one mile long. This is completely covered with boulders of red (weathered) Jackfork sandstone, of all sizes up to a foot or more in diameter; is overgrown with brush and timber and looks not unlike a glacial moraine. Indeed the resemblance is so striking as to be worthy of special mention, but there can be no doubt that it is a boulder fan which accumulated on a southward sloping surface at the foot of the heavy sandstone ridge immediately to the north, and which is now being dissected by modern streams. The age of the boulder fan may be either Tertiary or Quaternary.

From the evidence it seems clear that during the Tertiary period the Comanchean peneplain was uplifted and the Cretaceous sediments covering it in large measure removed, and the Paleozoics beneath greatly eroded to form a lower peneplain in places. About 750 feet of land (Paleozoic sandstones and shales) must have been removed at this time from parts of the newly upraised region, (T. 1 S., R. 25 .) as this is the difference in elevation between the Comanchean peneplain on the top of Boktukola Mountain and the boulder fans below about Smithville. This is assuming that the boulder fans are Quaternary in age. If they are Tertiary then the same amount of work was accomplished in half the time approximately. Farther south a much lesser thickness of sediments was removed; in the latitude of the south township line of T. 3 S., practically none, for the (presumably) Tertiary subaerial peneplain descends toward the south at a lower angle than the Comanchean peneplain and intersects the latter along an east-west line passing through the middle of this area roughly in the vicinity of Hochatown.

Concerning these two peneplains and their intersection in the Tishomingo and Atoka Quadrangles to the west and their extent and character elsewhere, the reader is referred to the Tishomingo and Atoka Folios of the United States Geological Survey Nos. 98 and 79 by Joseph A. Taff. He says in part (quoting from the Tishomingo Folio p. 1:)

> The surface of the north half of the Tishomingo quadrangle is a nearly flat plain which rises very gradually northward and extends beyond the boundary of the quadrangle. This is the plain of the Arbuckle Mountain region. The Trinity sand, which is the lowest Cretaceous formation, outcrops along the south border of this plain. It is the shore deposit of the Cretaceous sea which transgressed northward and westward to an unknown distance beyond the present limit of the Cretaceous rocks and reduced the land to a surface of marine planation. Since the Trinity sand is a soft rock it is being removed so rapidly in comparison with the wear of the hard rocks that considerable areas of the Cretaceous plain are exposed before it is appreciably defaced. The exposed border of this marine plain continues along the outcropping

PLATE LXXXVIII.

A. A VIEW LOOKING UP MOUNTAIN FORK RIVER AT THE FORD ONE-FOURTH MILE SOUTH OF THE N. ¼ COR., SEC. 7, T. 1 S., R. 27 E.
The large trees and some of the small ones are white beech or American beech of rare occurrence in Oklahoma.

B. A VIEW LOOKING SOUTHEAST DOWN MOUNTAIN FORK RIVER AMONG BLAYLOCK SANDSTONE HILLS.
From a point 550 paces north of the SE. cor., sec. 8, T. 5 S., R. 25 E., showing the river to be almost dry excepting for deep holes, in August, 1918.

edge of the Cretaceous sediments southward to central Texas, and it extends southeastward beneath the Cretacaceous rocks toward the Gulf of Mexico. Northward from this bordering plain the surface of hard rock rises gradually to an elevation of about 1,200 feet above sea at the northern edge of the Arbuckle Mountain region, in the adjoining Stonewall quadrangle. In the central part of the Arbuckle Mountain region, including the northern half of the Tishomingo quadrangle and the southern part of the Stonewall quadrangle, the marine Cretaceous plain extends farther north than elsewhere because of the broad expanse of hard rocks composing it.

At the northern and eastern borders of this elevated plain of the Arbuckle Mountain region there is an abrupt descent of 100 to 200 feet to the general level of an undulating plain of later age and broader exposed surface. This plain has been developed generally in softer rocks than occur in the Arbuckle Mountain region, and the agents of erosion which have made it have both uncovered and obliterated much of the marine Cretaceous plain north and east of its present limits above described. Southwestward, toward the Gulf, this plain descends approximately with the grade or fall of the rivers which flow across it. Near the present Cretaceous-Tertiary boundary in northeastern Texas, southeastern Indian Territory, and southwestern Arkansas, it extends beneath widespread deposts of gravel and sand which, in the high lands, rest upon this worn-down surface of early Tertiary, Cretaceous, and Paleozoic rocks. These deposits continue toward the Gulf coast and have been classed with late Tertiary rocks. Though the plain in this region, like its northward extension, has been more or less dissected by recent erosion, yet there are considerable areas near the present Cretaceous-Tertiary boundary where it has been but recently exposed or is still covered by a thin mantle of gravel. This border of the peneplain is analogous to the marine Cretaceous plain described above, in that it descends toward the coast beneath marine sediments. The northern limit of this gravel-covered plain is elevated approximately 600 feet above the sea, and leading from it upward and along the present river valleys there are remnants of flat, meandering channels which are only slightly depressed below the general level of the nearly flat, rolling plain or peneplain, and which contain deposits of gravel and sand. Likewise along and near the Arkansas and Canadian river valleys there are still more extensive but similar ancient wide and flat channels filled with gravel, sand, and silt. This peneplain stretches west and north beyond the Arbuckle Mountain and Ouachita Mountain regions across Indian Territory. It is inclined toward the south at a lower angle than is the Cretaceous base-level and intersects the Cretaceous base-level in the vicinity of the Arbuckle Mountains at elevations between 800 and 900 feet above sea. Toward the north the horizon of the Cretaceous marine plain rises above the land, while this Tertiary peneplain is now preserved in almost innumerable flat-topped ridges and hills in the Arkansas Valley region and in the uplands of the broad valleys of the Ouachita Mountain range. These ridges are composed of beds of hard rock, and their generally level crests rise to an elevation approximating

PLATE LXXXIX.

A. A VIEW LOOKING SOUTH-SOUTHEAST DOWN MOUNTAIN FORK RIVER FROM THE HIGH POINT, 700 PACES SOUTH OF THE N. ¼ COR., SEC. 27, T. 2 S., R. 25 E.
Showing the size of the stream and the general character of the country. Mountain Fork River is one of the largest consequent streams.

B. MOUNTAIN FORK RIVER AT THE FERRY IN SEC. 7, T. 6 S., R. 26 E., WHERE THE RIVER IS FLOWING THROUGH THE TRINITY SAND BELT.

850 feet. The higher eminences, a few of which rise to 1,000 feet above sea, are usually table-like, being protected by flat, hard strata, while in lower eminences the hard ridge-making beds are either steeply upturned or are composed of thin strata. Higher than this peneplain of level-crested ridges and hills in the Arkansas Valley region are limited areas where the broad folds in the strata have favored the preservation of monadonck-like mountains and peaks. The most prominent of these in Indian Territory are the Sansbois, Cavanal, Poteau, and Sugarloaf mountains, which rise to heights of from 1,700 to 2,500 feet above the level of the sea, approximating the higher levels of the mountains of the Ouachita and Ozark regions. These mountains occupy broad synclines and culminate in narrow crests or peaks and are generally isolated. The broad distribution of surficial deposits in the wide, shallow, elevated river channels, the relation of these deposits to the Tertiary gravels, and the almost universally equal degradation of both hard and soft rocks to the same general level, strongly support the hypothesis that the surface approached near the level of the sea at the time of its reduction to a peneplain in what has been considered late Tertiary time.

That the Comanchean peneplain intersects the Tertiary (?) peneplain does not necessarily mean that the line of intersection was an axis about which the Comanchean plain rotated, the south part subsiding, the north part rising. On the contrary, the entire Comanchean peneplain was deeply buried both north and south of the line of intersection in Cretaceous times; and when the post-Cretaceous uplift came, that portion south of the intersection of the plains may simply have been raised less rapidly than the part north of the intersection. This would account for all of the observed facts.

It is possible that this period may have experienced some normal faulting, but there is no physiographic evidence for assuming this to be so.

PRESENT CYCLE OF EROSION.

When the old Comanchean peneplain, covered with its deposit of boulders, gravels, sands, and clays, was upraised and tilted to the south, the streams consequent to this upheaval very naturally flowed south. These quickly entrenched themselves in the sands and developed short tributaries presumably of dendritic pattern. Little River, Glover Creek, Lukfata Creek, and Mountain Fork are typical examples of the southward flowing consequent streams which, upon cutting downward through the soft coastal plain deposits, found themselves superimposed upon the east-west folded Paleozoics. Both the main consequent streams and many of their branches thus came to occupy superimposed courses across the hard rock ridges of the older series.

PLATE LXXXX.

A. A PILE OF JACKFORK SANDSTONE CREEK BOULDERS THROWN UP BY THE RUSHING HIGH WATERS IN BOKTUKOLA CREEK, 200 PACES NORTH OF THE CENTER OF SEC. 30, T. 1 S., R. 25 E.
The outcropping ledge in the creek is Jackfork sandstone striking north-south and dipping 15° W.

B. JACKFORK SANDSTONE LEDGES PROJECTING FROM A HILL SIDE AND UNDERCUT BY A CREEK, 400 PACES WEST OF THE N. ¼ COR., SEC. 29, T. 1 S., R. 25 E.,—A SOURCE OF STREAM BOULDERS.

As time went on and the Comanchean peneplain with its costal plain covering was raised more and more, a lengthening of the trunk streams at the lower ends and the introduction of new consequents between them became possible. Thus one finds a second set of consequent streams, such as for example: Cypress Creek, Wolf Creek, Horsehead Creek, Yashoo Creek, Yanubbe Creek, Lick Creek, and Lukcuklo Creek; and these have enlarged their drainage basins by developing insequent branches. The second set of consequents probably wes born with the latest uplift which raised the Tertiary (?) peneplain.

PLATE LXXXXI.

AN OVERTURNED SYNCLINE IN BLAYLOCK SANDSTONE IS RESPONSIBLE FOR A VALLEY IN THE CENTER OF SEC. 35, T. 3 S., R. 24 E. VIEW LOOKING NORTHWEST.

As the southward flowing, parallel, consequent rivers and their dendritic (insequent) branches cut down into the folded Paleozoics, they discovered parallel belts of strongly contrasted resistant and non-resistant rocks. New streams began to eat headward along the weak rock belts, and because the subsequent streams could work more effectively in the non-resistant materials than could the less fortunate consequent and insequent streams superimposed across hard rock barriers, they progressively captured more and

PLATE LXXXXII.

A VIEW LOOKING DUE SOUTH DOWN MOUNTAIN FORK RIVER VALLEY FROM THE HEIGHT IN THE EXACT CENTER OF SEC. 34, T. 3 S., R. 25 E.

The river swings against a Blaylock sandstone bluff on the right, flows toward the observer, thence east and southeast against the Blaylock sandstone hills on the left and encloses in the bend a partially cleared and alluvial flat, in the center of the picture. The majority of the hills farther back are of Bigfork chert, but the high points in the upper left hand corner are formed of Arkansas novaculite. The ridge farther back to the right, six and one-half miles distant, is the south township line of T. 4 S., R. 25 E., three miles this side (north) of which, but invisible in this photograph, is Hochatown.

more drainage developing prominent valleys parallel to the rock structure. Thus the dendritic, or tree-like pattern superimposed from the Comanchean costal plain, began to give place to a trellis, or grape-arbor-like pattern determined by the underlying structural features.

Today the process is very incomplete and the result is a curiously composit drainage pattern, combining elements of two distinct origins. Some of the best examples of subsequent streams are Long Creek, which flows into Little River from the east side below Ringold; the headwaters of Beech Creek in the north, and numerous unnamed branches in the central part of the region, all flowing on soft rocks between the resistant formations. These in turn have tributaries (obsequent and resequent) flowing off the mountain ridges, which are usually very short, V-shaped ravines and gorges, in a youthful stage of development.

None of the streams of this region, nor any part of the Ouachita Mountains for that matter, have reached old age. Certain sections of the largest rivers may be said to be in a condition of late maturity, but the majority of all the streams are in the condition of youth or early maturity, characterized by steep gradients, rapids and boulder shoals, V-shaped rocky valleys, and in some instances, narrow alluvial margins. The upland over most of the area is in a mature state of dissection producing rugged mountains; but the southern part is in youth and the evidence of the southward tilted peneplain is especially clear.

Miser and Purdue* refer to this youthful portion in Arkansas as "a dissected piedmont plateau 15 miles wide." Geo. Otis Smith in replying to my letter in regard to a change of name for the Ouachita Mountains (bottom p. 30) says, in part, under date of February 28, 1920, that:

The subdivisions of the Interior Highlands, as they are to be used by the U. S. Geological Survey, are as follows:

Interior Highlands	Ozark Plateaus	Springfield - Salem plateaus.
	Arkansas Valley	Boston "Mountains"
	Ouachita Mountain region	Ouachita Mountains Athens Plateau

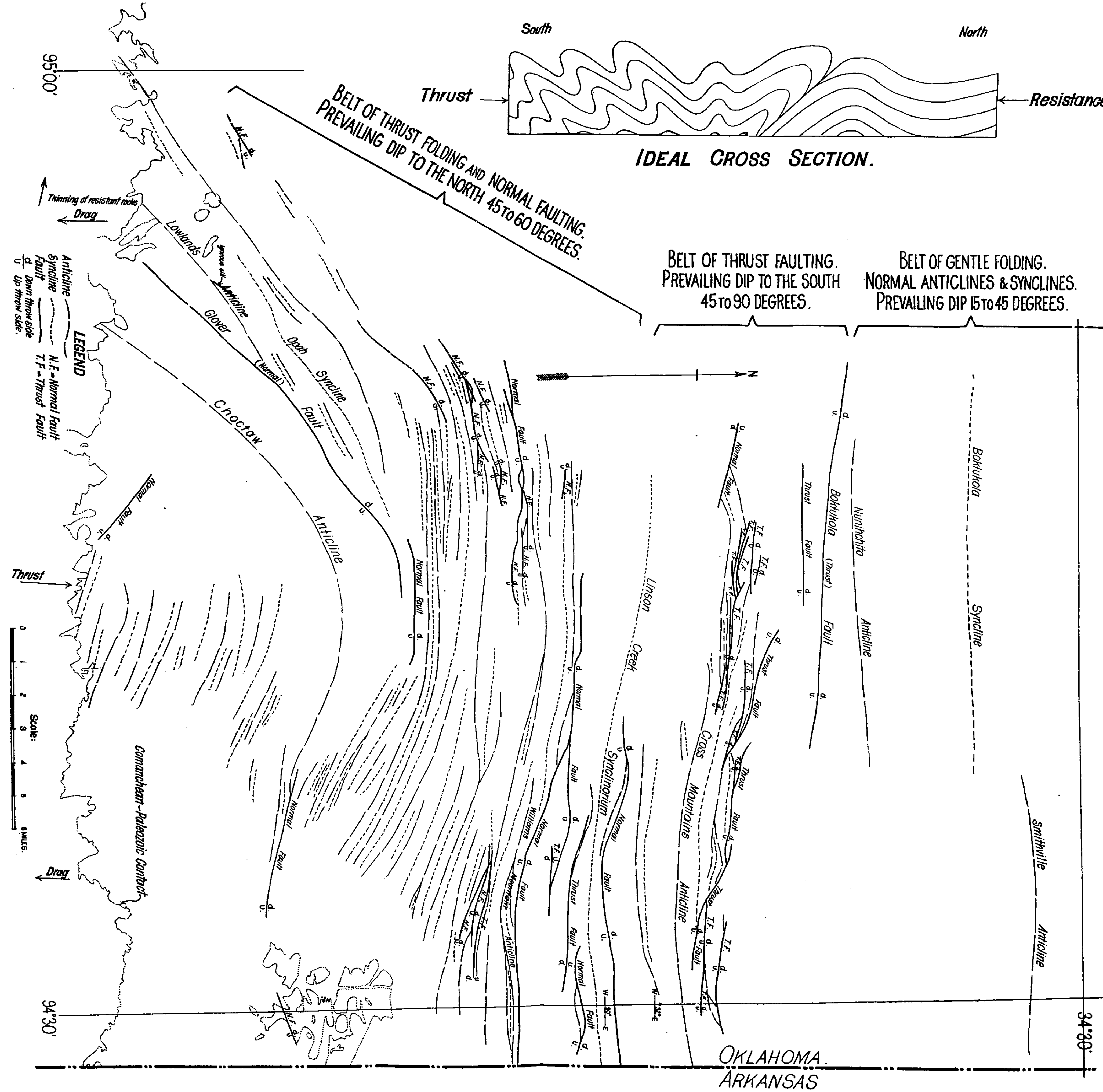
*Miser, H. D. and Purdue, A. H. Gravel Deposits of the Caddo Gap and DeQueen Quadrangles, Arkansas; U. S. G. S. Bull. 690-B. p. 16; Asphalt Deposits and Oil Conditions in Southwestern Arkansas, U. S. G. S. Bull. 691, p. 271; Miser, H. D., Manganese Deposits of the Caddo Gap and DeQueen Quadrangles, Arkansas, U. S. G. S. Bull. 660-C. p. 64; and elsewhere.

The terms Arkansas Valley, Ouachita Mountain region, Ouachita Mountains, and Athens Plateau, as they are to be used according to the recently adopted classification, are physiographic terms for the reason that these areas are not everywhere clearly distinct in their topographic features. The limits of the Arkansas Valley and the Ouachita Mountain region in this classification would correspond with those used by Taff in the Tahlequah, Muskogee, Coalgate, Tishomingo, and Atoka folios, in Part 2 of the Twenty-first Annual Report, and in Part 3 of the Nineteenth Annual Report. The use of the term Ouachita for the mountainous region of west-central Arkansas and southeastern Oklahoma also accords with the decision of the United States Geographic Board. The Ouachita Mountains comprise the larger part of the Ouachita Mountain region and the Athens Plateau comprises only a small part of it. This plateau which is so named from the village of Athens, Howard County, Arkansas, is a belt of country about 15 miles wide lying between the Ouachita Mountains on the north and the Gulf Costal Plain on the south, and extending from near Arkadelphia, Clark County, Arkansas, westward into McCurtain County, Oklahoma, where it ends several miles west of the State line. The northwest boundary of the plateau in the Lukfata quadrangle which includes a part of that county runs north-northeastward from a point on Mountain Fork River in the southwest corner of T. 5 S., R. 26 E. The southern border of the plateau in that area runs eastward through a point 2 or 3 miles north of Eagletown.

The Athens Plateau as defined above extends westward to the breaks to Mountain Fork River where it ends. It is quite a useful term and is a physiographic unit founded on the fundamental principal of genesis of the particular region. There are two other similar regions farther west which deserve special designation and for the same reasons.

The first is the entire, roughly circular area comprising about 75 square miles bounded on the east by the drainage basin of Mountain Fork River; on the north by the drainage basin of Cedar Creek; on the west by the drainage basin of Glover Creek; and on the south by the Gulf Costal Plains. It is an upland in a youthful stage of dissection drained to the south by Lukfata, Yashoo, and Yanubbe Creeks, named from west to east, and also in the order of their impartance. It is proposed to name this area for the largest creek which flows across it, the Lukfata Plateau, which is also the name of the quadrangle covering this area.

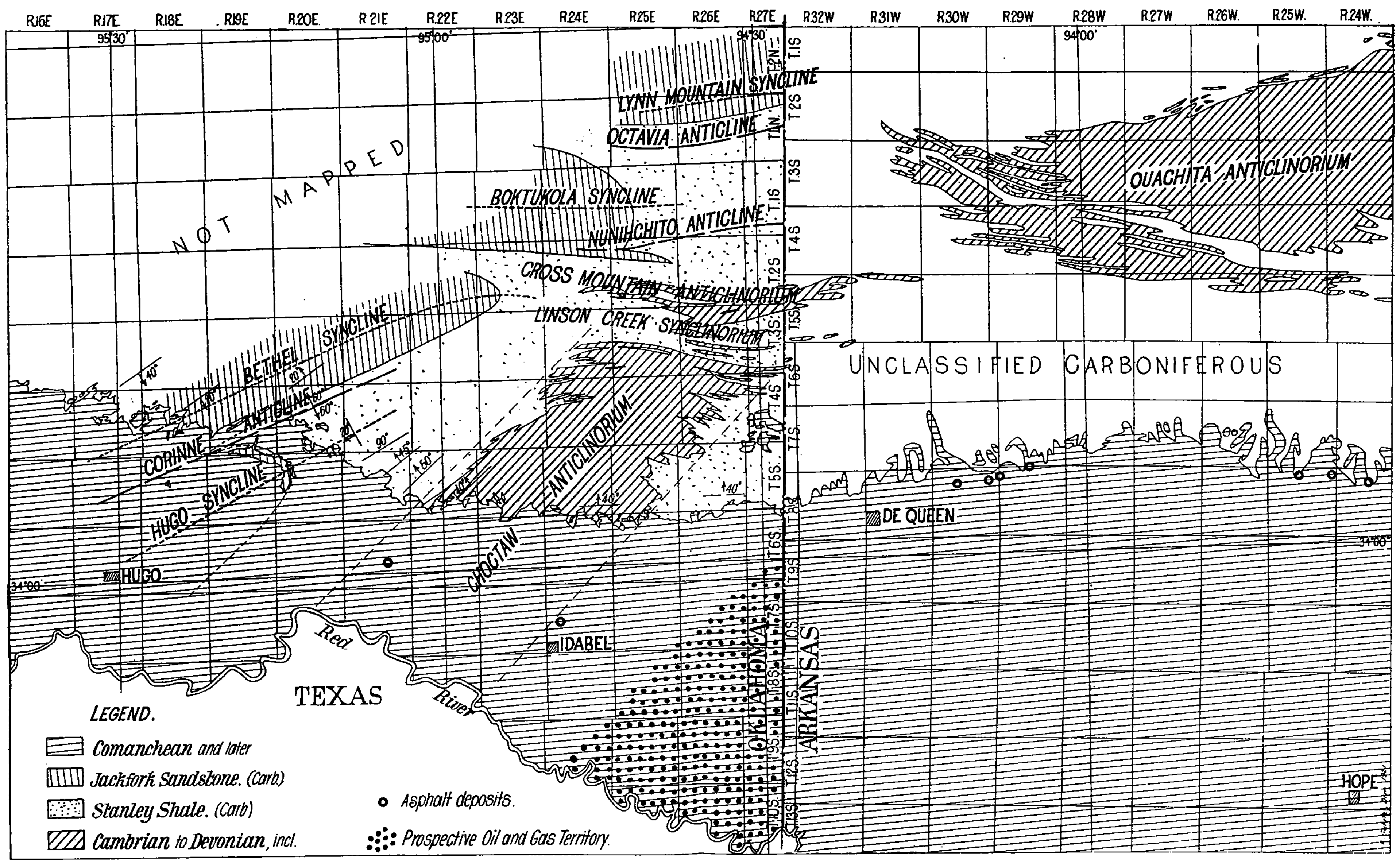
The second is a roughly rectangular area of about the same size as the first bounded on the east by the Glover Creek drainage system; on the north by Long Creek Valley (might as well be extended to Terrapin Creek valley); on the west by the breaks to Little River; and on the south by the Costal Plains. This area is likewise an upland in a youthful stage of dissection, drained to the south by Cypress, Wolf, and Horsehead creeks named in order from west to east, and it is proposed to call it the Alikchi Plateau, naming it from the deserted village of Alikchi (sec. 35, T. 4 S., R. 21 E.) for which place the topographic atlas sheet for this region was named.



MAP SHOWING ESSENTIAL STRUCTURAL FEATURES AND IDEAL NORTH—SOUTH CROSS-SECTION OF THE AREA

GENERALIZED STRATIGRAPHIC COLUMN.

SYSTEM.	FORMATION.	CHARACTER OF THE FORMATION.	THICKNESS IN FEET.
COMANCHEAN.	Trinity	Loosely consolidated, yellow sands and red clays at the base of which are boulder beds (A); and near the bottom fossiliferous lenticles of limestone (B) and ferruginous resistant sandstone (C).	400'+
PENNSYLVANIAN.	Jackfork.	Heavy bedded, massive, medium to fine grained, gray sandstones with dark shales at wide intervals. Fossil plants, seeds, and scales occur at several horizons in the basal portion (A); also in the higher beds.	1500'+ (6600' in complete section)
(?) PENNSYLVANIAN.	Stanley.	Thin bedded, ripple marked, fine grained dark colored, hard sandstones, and blue clay shales and slates irregularly interbedded in one vast series. A bed of tuff 100 feet thick occurs near the bottom (A); a layer of cone-in-cone concretions appears in the middle (B); and a formation of black cherts 25 feet thick in the upper middle portion (C). A zone of Orbiculoidea nitida Phillips occurs at the very bottom (D). A marine fauna consisting of Cystodictya sp., Rhombopora sp., Fenestella sp., Productus sp., Chonetes sp. and crinoidal columnals was found in the middle (E) and plants in several horizons notably at the top (F)	6000'±
DEVONIAN.	Arkansas Novaculite.	Heavy bedded, white novaculite forming the lower ⅓ of the formation; thin bedded black novaculite, and interbedded black slates and shales forming the middle portion and a rhodocrosite (Manganese carbonate) bearing white novaculite 25-100 feet thick forming the top. A thin 4" bed of agglomerate occurs locally to the east at the top of the basal division (A) and lenses or pockets of psilomelane and other manganese minerals occur in two definite horizons in the basal division (B). In S W. ¼ Sec. 29, T 5 S., R. 22 E ashy tuffs occur.	250'-540'
	Missouri Mtn.	Red and green metamorphosed shale and slate with carbonated pyroclastic material near the top.	70'-100'+
SILURIAN.	Blaylock.	Thin bedded, fine grained, greenish gray, hard sandstones and interbedded shaly sandstones and dark shales weathering red. Thin veins of smoky quartz are common. "Worm trails" occur abundantly at (A) and sparingly elsewhere.	800'
ORDOVICIAN.	Polk Creek.	Coal black, graphitic, soft slate and shale carrying an abundance of undeterminable graptolites.	100'±
	Bigfork.	Hard, black chert, in beds 4" to 2' in thickness, interbedded with which are some coal black shales and a number of heavy ledges of black, cherty, fossiliferous limestone.	500'+
	Womble equivalent.	Schistose, micaceous, fine grained sandstones and grits, green in color when fresh, weathering red, interbedded with which are a few shales. Massive spongy, brown sandstones appear at the top.	1000'±
	Blakely.	Dark, smoky gray quartzite cut by "penetration veins" of smoky quartz.	0-15'
	Mazarn.	Dark colored, carbonaceous, hard clay shales and slates penetrated by a few veins of Kaolinite and quartz.	1000'±
CAMBRIAN (?)	Crystal Mtn.	Uniform, medium grained, massive, gray sandstone, portions of which are veritable quartzites, other parts are partly replaced by an abundant carbonate, these upon weathering become porous and ferruginous. A 14' basal conglomerate occurs to westward at the base of the formation carrying boulders of chert and limestone up to 6" in diameter. Numerous large and small quartz-orthoclase pegmatites occur throughout.	500'±
	Collier	Graphitic, unctuous shales carrying boulder beds in the upper part and capped by 30 feet of thin bedded replacement limestones. Large quartz-orthoclase pegmatites occur.	200'+



Geology in Oklahoma by C.W. Honess — Geology in Arkansas by H.D. Miser & A.H. Purdue.
From U.S.G.S. Bull 691 Pl XXXIII.

GENERAL STRUCTURAL MAP SHOWING RELATIONSHIP BETWEEN THE AREA IN SOUTHEASTERN OKLAHOMA AND THAT OF WEST CENTRAL ARKANSAS.