OKLAHOMA GEOLOGICAL SURVEY

Governor Robert L. Williams, State Superintendent R. H. Wilson, President Stratton D. Brooks, Commission.

C. W. Shannon, Director.

BULLETIN NO. 23.

THE GEOLOGY AND ECONOMIC VALUE OF THE WAPANUCKA LIMESTONE OF OKLAHOMA.

WITH NOTES ON THE ECONOMIC VALUE OF ADJACENT FORMATIONS.

BY
B. FRANKLIN WALLIS.

NORMAN
May, 1915.

SCIENTIFIC STAFF.

C. W. Shannon---------------------------------------Director
L. C. Snider---------------------------------Assistant Director
L. E. Trout-----------------------------------Field Geologist
Fritz Aurin---Chemist

CONTENTS.

ILLUSTRATIONS.

PREFACE.

A geological study of the Wapanucka limestone was undertaken during the summer of 1914 primarily to determine the nature and extent of the oolitic stone so admirably exposed near the town of Bromide. Tests have shown this stone to be of superior quality, and greater crushing strength than the famous stones quarried at Bedford, Indiana, and Bath, England, thus placing it on a par with the best structural limestones in the world. As the determination of the areal extent and amount of this stone is one of great economic importance to the State of Oklahoma, no pains were spared to secure adequate data on this point.

Other reasons, of economic importance, for undertaking the study were to determine the nature of other beds of limestone occurring in the formation with special reference to their use for burning into lime, for use in cement manufacture, for railroad ballast, road metal, and glass manufacture.

From a purely scientific standpoint, a geological survey of the formation was undertaken in order to determine its areal extent, its structural features, its stratigraphy, and correlation with strata in other areas.

While working in the region, it was deemed advisable for the party to inquire into the economic value of deposits of useful minerals and rocks occurring in adjacent formations. The result of this work has been included in the present report.

In making a study of the general geology of the region, the writer reviewed all of the literature published on the subject. A complete bibliography will be found at the end of this report. From the information thus obtained as well as from personal observation in the field, the writer has prepared the introduction and the chapters dealing with the physiographic history, structure, and general stratigraphy of the region in such a way as to serve as a setting for the detailed description of the Wapanucka limestone proper. It is believed that these chapters will prove of additional value due to the fact that in them a discussion of the geology of the entire area has been brought together in one volume and the latest views in regard to the correlation of the strata have been given. The most important and satisfactory work that has been done in the region was by Joseph A. Taff, formerly a geologist of the United States Geological Survey. It has been the source of no little satisfaction to the writer to have been able to base his geologic work on so firm a foundation as that established by this able geologist.

In the preparation of the geologic map, the part representing the area in the vicinity of Wapanucka was taken from the Atoka and Coalgate folios of the Geologic Atlas of the United States, it being deemed unnecessary to make a new survey in order to map that part of the areal extent of the formation. The area was carefully worked over in the field, however, in order to determine the geologic structure, and the lithologic character of the various members, especial attention being paid to the oolitic member at the top of the formation. In the Limestone Ridge area, which is represented by all the remainder of the map, a careful instrumental survey was made.

In conclusion, the writer wishes to thank Director C. W. Shannon of the Oklahoma Geological Survey, Professor Wm. Bullock Clark, and the other professors of the Department of Geology of the Johns Hopkins University for kindly assistance and advice rendered during the preparation of this report.

B. FRANKLIN WALLIS,

Johns Hopkins University,
Baltimore, Md.
February, 1915.

THE GEOLOGY AND ECONOMIC VALUE OF THE WAPANUCKA LIMESTONE OF OKLAHOMA.

CHAPTER I.

INTRODUCTION.

The Wapanucka limestone formation is composed of strata of early Pennsylvanian age. It is exposed in the south-central and southeastern parts of Oklahoma, skirting the northeastern and eastern flanks of the Arbuckle Mountains, and the western and northern flanks of the Ouachita Mountains. The outcrops occur as several low, level-crested, parallel ridges. The strata comprise limestone, sandstone, chert, and shale.

Before taking up a discussion of the details of the geology of the Wapanucka formation, the subject may be rendered more intelligible by the presentation of a brief sketch of the geology and geography of the State of Oklahoma as a whole. This will be followed in Chapters II, III, and IV by a more detailed discussion of the physiographic history, stratigraphy and structure of south-central and southeastern Oklahoma. With such a setting, the reader will be able to follow more intelligently the detailed description of the Wapanucka formation that will follow.

GENERAL GEOLOGY OF OKLAHOMA.

The greater part of the State of Oklahoma is underlain by strata of Pennsylvanian and Permian age. Roughly, the eastern half of the State is underlain by non-red Pennsylvanian strata while the western half is underlain by red strata of Permian age.

There are certain areas, however, in which representatives of nearly the entire geologic column from the pre-Cambrian to the Tertiary are exposed. These are the regions of the Wichita, the Arbuckle, and the Ouachita mountains. In the Ozark Mountain region, in the northeastern part of the State, strata of Mississippian, Devonian, Silurian and Ordovician age are exposed.

PHYSIOGRAPHIC PROVINCES.

In the Tishomingo folio of the Geologic Atlas of the United States, J. A. Taff has shown that the State may be divided into six physiographic provinces. Both the Oklahoma and United States Geological Surveys are now following a division of the State into nine provinces.

These are respectively the regions of the Ouachita Mountains, Sandstone Hills, Redbeds Plains, Gypsum Hills, High Plains, Arbuckle Mountains, Wichita Mountains, Coastal Plains, and Ozark Highland. The area covered by each is shown in the accompanying figure 1.

The following correlation table of physiographic provinces is given for reference:

Taff	Oklahoma Geological Survey
Ouachita Mountain region	Ouachita Mountain region
Arbuckle Mountain region	Arbuckle Mountain region
Ozark region	Ozark region
Red River Valley region	Coastal Plains region
Arkansas Valley region	Sandstone Hills region (southeastern part)
Prairie Plains region	Sandstone Hills region (northern and western parts)
	Redbeds Plains region
	Gypsum Hills region
	High Plains region
	Wichita Mountain region

Following Taff, in part, the physiographic features of each will be briefly described.

Ouachita Mountain region.—This region lies in the southeastern part of Oklahoma and in southwestern Arkansas. It extends from the town of Atoka eastward to Little Rock, Arkansas, and covers an area of about 200 by 50 miles. It is composed of a number of high, flat-topped ridges, separated by broad, flat valleys. The general bearing of the ridges is east-west. The relief of the region is due to the differential erosion of strata of unequal hardness, the ridges being composed of chert and sandstone, the valleys of shale. Near the western end of the range the crests of the ridges attain an elevation of about 400 feet above the broad valleys, and 1000 feet above sea level. They rise gradually towards the east, attaining an elevation of 2000 feet above the large valleys and 2900 feet above sea level near the Oklahoma-Arkansas line. Farther east the elevation decreases gradually to about 500 feet above sea level near the eastern end. There is also a gradual rise in elevation from south to north.

The structure of the region is that of a number of narrow folds, the general bearing of whose axes is east-west. Toward the western end, however, they bend toward the south, and pass beneath overlapping Cretaceous sediments. Many of these folds are overturned toward the northwest and are broken by thrust faults. The region is bounded on the north, and separated from the Sandstone Hills physiographic region, by a great overthrust fault. This great displacement, known as the Choctaw fault, has, in places, a stratigraphic throw of at least 8000 feet, bringing rocks of Ordovician age in contact with Pennsylvanian.

The strata of the region are composed of sandstone, chert, shale,

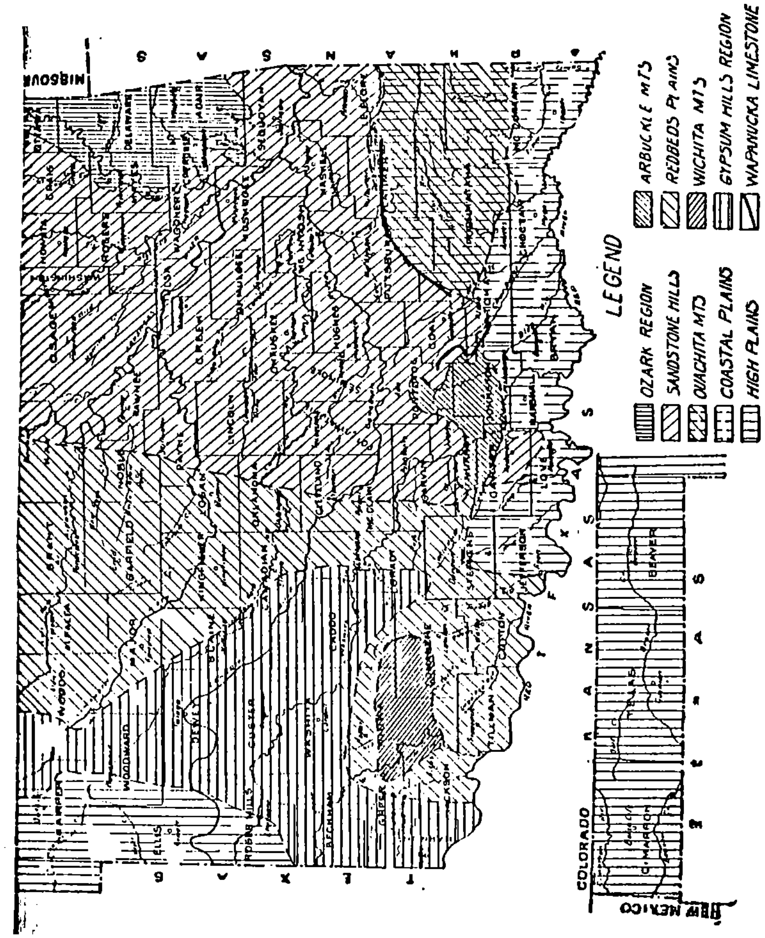


Figure 1. Sketch map showing the physiographic provinces of Oklahoma. The heavy black line represents the outcrop of the Wapanucka limestone.

and a small amount of limestone, and range in age from the Ordovician to the Cretaceous, the Devonian, Permian, Triassic, and Jurassic being absent.

Sandstone Hills region.—This region includes the Arkansas Valley and a part of the Prairie Plains region of Taff's physiographic provinces, and lies between the Ouachita Mountains on the south and the Ozark Mountains and Redbeds Plains on the north and west. In the southwest it coalesces with the Coastal Plains region in the area between the Arbuckle and Ouachita mountains. Topographically and structurally, it may be considered as a northward extension of the Ouachita Mountain region, with the exception that the physiographic features are less pronounced. The topography is that of a rolling upland, the low, level-crested ridges attaining an altitude of about 850 feet above sea level. Broad plain-like valleys of shale lie between the sandstone ridges. The axes of the folds parallel those of the Ouachita region. The folding is most intense in the southern part, but is, however, more gentle than that in the Ouachita region, the folds being open and symmetrical. The folds finally into the monocline of the Redbeds Plains. The strata are gradually decrease in size toward the north and west, and merge of Pennsylvanian age, and are composed of sandstone and shale.

Redbeds Plains, Gypsum Hills, and High Plains regions.— These regions lie to the west of the Sandstone Hills region. They form part of a great physiographic province that extends westward into Texas, and northeastward to the Great Lakes. To the west, they coalesce with the Great Plains which extend westward to the base of the Rocky Mountains.

The topography is of the step and terrace type, the country rising gradually to the northwest with escarpments facing east and south.

The structure is that of a monocline, the strata dipping gently towards the northwest with an inclination of about 100 feet to the mile in the eastern portion of the area but decreasing toward the west until the strata are practicaly level in the High Plains region. The strata, in Oklahoma, are composed largely of sandstone and shale of Permian age.

Arbuckle Mountain region. —This region lies in the south central part of the State, and covers an area of about 70 by 20 miles. The surface dips gently towards the southeast. The drainage has been imposed upon the region, the Washita River flowing across it in a deep and narrow gorge, while the other streams, which rise within the region itself, have cut broad but shallow valleys. At its eastern end and along its southeastern side, the region coalesces

with the bordering Sandstone Hills and Coastal Plains regions. The surface rises gradually from an elevation of 700 feet at the eastern end to 1350 feet in the western part. Along its northeastern and southwestern borders, there is an abrupt descent of 200 feet to the suronding plains.

Structurally, the region is made up of several broad, flat folds which together form a great geanticline. The general direction of the axis of the uplift is N. 70° W. The region has also been extensively faulted, the faults following the general direction of the uplift.

Representatives of the entire geologic column from the Archean to the Mississippian are exposed. The rocks represented are granite and other igneous rocks, limestone, shale, chert, and sandstone. It is a remarkable fact that the strata of this region are composed mostly of massive limestone, while those of the same age in the nearby Ouachita Mountain region are composed almost entirely of sandstone and shale.

Wichita Mountain region. --- This region is, in many respects, similar to the Arbuckle Mountain region. Like the latter it is composed of cores of igneous rock, surrounded by sedimentary strata. The igneous cores are, however, of much greater prominence. The mountains consist essentially of a number of isolated masses of igneous rock rising abruptly out of the plain of flat-lying Permian strata. In places, strata of Cambrian and Ordovician age skirt the outcrops of igneous rock.

The topography is unusually rugged, the mountain slopes being strewn with large granite boulders, which, in places, make ascent impossible.

The structure is roughly that of a great anticline, the general direction of the axis of which is 70° W. In this respect, the structure is similar to that of the Arbuckle Mountains. It is thought that the two mountain masses owe their origin to the same orogenic movements.

Coastal Plains region—This region constitutes the broad flat valley of Red River. The structure is that of a monocline dipping gently towards the south. The strata are of Cretaceous age, and are composed of conglomerate, sandstone, shale, limestone, and loose sands and clays.

Ozark region—But a small part of this region lies in Oklahoma, and nowhere is it contiguous to outcrops of the Wapanucka limestone. It will, however, be briefly described for completeness. This region is rudely quadrilateral in outline and about 225 miles on a side. It covers the greater part of southern Missouri, northern Arkansas, and northeastern Oklahoma. It is described as a broad, relatively flat, dome-shaped, dissected highland. Topographically it consists of three dissected plateaus which succeed one another concentrically westward, starting from the St. Francis Mountains in southeastern Missouri as a center. These are known respectively as the Salem platform, the Springfield structural plain, and the Boston Mountain plateau. The last of these attains elevations of 1000 to 1500 feet above sea level and is, structurally, a monocline dipping towards the south.

The strata exposed in Oklahoma are of Ordovician, Silurian, Devonian, and Mississipian ages and are composed of limestone, shale, and sandstone.

Recapitulating the above, the highly folded and faulted region of the Ouachita Mountains is seen to grade northward into the rolling upland of the Sandstone Hills region which in turn grades into the monocline of the Redbeds Plains. In the south-central part of the State lies the highly folded and faulted area of the Arbuckle Mountains, and along the southern border the flat southward-dipping monocline of the Coastal Plains region. Finally, in the northeastern part of the State there is the Springfield structural plain of the Ozark region.

With the above introductory remarks in regard to the geology and geography of the State of Oklahoma as a whole, the reader may be brought a step nearer the problem in hand by the presentation of a description of the physiography, stratigraphy, and structure of the Arbuckle Mountain and Ouachita Mountain physiographic provinces, and the southern part of the Sandstone Hills physiographic province, these provinces constituting the south-central and southeastern parts of the State.

CHAPTER II.

PHYSIOGRAPHY

PHYSIOGRAPHIC HISTORY.*

Sedimentation is thought to have been practically continuous in the Arbuckle Mountain region from Middle Cambrian to Mississippian time. Sedimentation also occurred in the Ouachita Mountain region during the Ordovician, Silurian, and Mississippian periods.

Near the beginning of Mississippian time the western part of the Arbuckle Mountain region and possibly parts of the Ouachita Mountain region were elevated above the sea, and subjected to folding and faulting. Then followed a prolonged period of erosion which reduced the entire area to a region of slight relief. In the Arbuckle Mountain region the products of this erosion were laid down on the eroded edges of Devonian, Silurian, Ordovician, and Cambrian strata as a coarse conglomerate, to which the name of Franks conglomerate has been given. Gravel beds of the same age are found in the Ouachita Mountain region.

Near the close of Carboniferous time the entire area was uplifted and profoundly folded and faulted. Then occurred another prolonged period of erosion followed by subsidence and the deposition of Permian Redbeds in the western part of the area. Land conditions are thought to have prevailed during Triassic and Jurassic time.

Marine plain of Cretaceous age.—By the beginning of Lower Cretaceous time the region had been reduced to the condition of a peneplain, and the transgressing Cretaceous sea reduced it still further, forming a flat, wave-cut, marine plain. The erosion that produced this plain must have been of long duration as strata of all ages, from the Carboniferous to the Archean, were exposed. This plain and the unconsolidated Trinity sands of Lower Cretaceous age that were laid down upon it, extended an unknown distance to the north. Subsequent erosion has removed these sands from the northern part of the area, thus exposing the marine plain. The tops of the Arbuckle Mountains at the present time are the remnants of this plain.

To the north of the Arbuckle and Ouachita mountains and in the region lying between them, great thicknesses of Pennsylvanian sandstone and shale are exposed. As the Arbuckle Mountains are

*Data obtained in part from Professional Paper 31, U. S. Geological Survey.

made up largely of indurated Cambro-Ordovician limestone, and the Ouachita Mountains largely of sandstone and chert, post-Cretaceous differential erosion has caused these areas to stand above the general level of the land.

Peneplain of probable Tertiary age.—By mid-Tertiary time the region is thought to have been again reduced to the condition of a peneplain. This plain is now represented by the tops of the ridges in the Arkansas Valley region, which have a general elevation of 850 feet above sea level. It is also represented by the broad shallow valleys in the Ouachita Mountain region. This plain dips toward the south at a lower angle than the marine plain of Cretaceous age and intersects it in the latitude of the Arbuckle Mountains. As a result of this, the Cretaceous plain is intact south of this intersection, but has been obliterated to the north of it.

Since Tertiary time, the region has been elevated and tilted slightly towards the southeast. Already the larger streams have cut broad valleys to a general depth of 200 feet beneath the level of the Tertiary plain.

TOPOGRAPHIC FEATURES.

The physiographic history sketched above shows that the present topography of the region is due to the differential erosion of hard and soft strata in a region that has been subjected to folding, faulting, and repeated planation.

TOPOGRAPHY OF THE ARBUCKLE MOUNTAIN REGION.

As described more fully in the introduction, the surface of the Arbuckle Mountain region slopes gently towards the southeast, with abrupt descents to the surrounding country on the northeastern and southwestern sides.

TOPOGRAPHY OF THE OUACHITA MOUNTAIN REGION.

In the Ouachita Mountains there are a number of level-crested, sandstone ridges separated by broad shallow valleys of shale. The general direction of the ridges is east-west, but near the western end they turn southward and merge into the Coastal Plain.

TOPOGRAPHY OF THE SANDSTONE HILLS REGION (Southern Part).

Between the two mountain regions there lies an area that has been referred to the Sandstone Hills type of topography. Here occur a number of low, level-crested ridges, usually composed of sandstone, separated by broad valleys of shale. In the western part the ridges have a northwest-southeast trend and skirt the Arbuckle Mountains. In the vicinity of Lehigh they are elliptical due to the fact that the structure of the region is that of a plunging syncline. The crests of the ridges lie in the Cretaceous peneplain. The exposures of shale are so broad compared with those of sandstone, that the country appears relatively flat. The strata are of Mississippian and Pennsylvanian age. It is here that the type exposure of the Wapanucka limestone occurs. The single outcrop occurs as a narrow, level-crested ridge, 50 to 100 feet high, which extends from Boggy Depot in T. 3 S., R. 9 E. to Jesse in T. 1 N., R. 7 E. Due to the low dip of the strata to the northeast the northeastern slope of the ridge is gentle, while the southwestern slope is precipitous. The region is drained by Clear Boggy Creek, a tributary of the Red River. The drainage is mature, but the shaly nature of the soil makes the roads all but impassable in wet weather.

The Sandstone Hills type of topography with its narrow, level-crested sandstone ridges separated by broad valleys of shale also occurs in the region to the north of the Ouachita Mountains. The trend of the ridges parallels those of the Ouachita Mountains. Their crests have a general elevation of 850 feet above sea level and lie in the Tertiary peneplain.

Limestone Ridge, which constitutes the main outcrop of the Wapanucka limestone in this area skirts the northwestern and northern sides of the Ouachita Mountains. It extends from near Stringtown in T. 1 S., R. 12 E. to Leflore in T. 5 N., R. 22 E. Structurally it forms part of the Ouachita Mountain region as it lies just to the south of the great Choctaw fault. Topographically, however, it lies in the Sandstone Hills region, as the topography is similar to that of the country to the north.

The Wapanucka limestone is exposed here in from one to five narrow, parallel ridges. Due to the generally steep dip of the strata towards the southeast, the ridges are very steep sided. Their level crests attain an altitude of about 850 feet above sea level and 50 to 250 feet above the main valleys.

The region is drained by North Boggy Creek, a tributary of the Red River, and by Brushy, Gaines, and Fourche Maline creeks which are tributaries of the Canadian and Poteau rivers. The drainage is mature, but the shale valleys become boggy in wet weather. In dry weather the majority of the streams shrink to pools of standing water, but are converted, at irregular intervals, into impassable torrents by heavy rains. Drinking water is provided for the towns by impounding the water of streams. In rural districts recourse is had to springs and wells. It is only in exceptionally dry weather that the problem of procuring sufficient drinking water arises. It may then have to be hauled for several miles from the more persistent springs or pools of standing water. The water supply is derived from the runoff and seepage of mountain slopes and is of excellent quality.

CHAPTER III.

STRATIGRAPHY.*

In the present chapter, a brief discussion of the general stratigraphy of the region will be presented. A more detailed discussion of the stratigraphy of the Wapanucka limestone will be given in chapter V.

PRE-CAMBRIAN IGNEOUS ROCKS.**

The oldest rocks exposed in the region are igneous rocks of Archean age. They occur in the Arbuckle Mountain region in an area of about 20 by 10 miles lying just north of Tishomingo, and in two small areas in the western part of the mountains known as the East and West Timbered Hills. The area lying to the north of Tishomingo is made up largely of coarse-grained, pink granite. In places the granite grades into quartz-monzonite and aplite. Aplite dikes occur, especially in the area near Tishomingo. The formation of dikes ceased before the earliest Cambrian sediments were laid down as they are not found in these.

The granite is overlapped on the south by unconsolidated Cretaceous strata. Along its northern border, it is brought into contact with younger strata by extensive faults. To the west it is succeeded by Middle Cambrian strata.

The East and West Timbered Hills are composed largely of granite porphyry. Numerous dikes of diabase are found here also.

SEDIMENTARY ROCKS.

Sedimentation is thought to have been practically continuous in the Arbuckle Mountain region from Middle Cambrian to Mississippian time. In the Ouachita Mountain region, outcrops of rocks definitely known to be older than the Ordovician do not occur. Strata of Ordovician, Silurian, Mississippian, and Pennsylvanian age are known to occur, while the Devonian seems to be lacking.

CAMBRIAN ROCKS.

Rocks of this age are found only in the Arbuckle and Wichita Mountain regions.

Reagan sandstone.—Near the beginning of Cambrian time the

*The reader will find it advantageous to consult the correlation table that has been placed at the end of the chapter. Data for Arbuckle Mountain Region obtained from Professional Paper 31, U. S. Geological Survey.

**For areal distribution of formations in the Arbuckle Mountains Region see Plate I (in pocket).

region was partly submerged and the Reagan sandstone laid down as a beach and off-shore deposit. As this sandstone consists of the products of erosion of the nearby granite land mass, its lower beds are composed of coarse, arkosic materials. The region (so far as known) was soon entirely submerged, and several hundred feet of thin-bedded, siliceous limestone and shale were deposited. The fossils found in these strata are clearly of Middle Cambrian age. Due to the irregularity of the surface on which the Reagan sandstone was laid down, the formation is very variable in thickness, ranging from 10 to 500 feet, with an average of 300 feet. It is exposed in several places in the Arbuckle Mountain region, namely in a small area about three miles south of Belton, at Reagan, along the western border of the granite west of Mill Creek, and skirting the southern borders of the granite-porphyry in the East and West Timbered Hills. In all of these areas it lies directly on the granite and therefore constitutes the oldest sedimentary rocks of the region.

CAMBRO-ORDOVICIAN ROCKS.

Arbuckle limestone.—The Reagan sandstone is succeeded conformably by the Arbuckle limestone, which is of Cambro-Ordovivian age. This formation is composed of light blue and white limestone, and cream-colored to white crystalline dolomite. It has a variable thickness of from 4000 to 6000 feet. The lowermost 700 feet are of Cambrian age. The next 2000 feet contain no fossils. The rest is of Ordovician age. Due to its thickness and massive character, it resisted the folding to which the region was subsequently subjected, more successfully than the thinner strata which succeeded it, and hence occurs as broad, flat folds, throughout the greater part of the area of the Arbuckle Mountains. Its outcrops extend from the southeastern part of the Arbuckle Mountains, where it is overlapped by Cretaceous strata to the northwestern end, where it passes beneath Pennsylvanian and Red Beds conglomerates.

ORDOVICIAN ROCKS.

The Ordovician system includes the Simpson formation, and the lower and middle parts of the Viola formation in the Arbuckle Mountain region, and the Stringtown shale and Talihina chert in the Arbuckle Mountain region.

Simpson formation.—Locally, evidences of a slight unconformity have been noted between the Arbuckle limestone and the succeeding Simpson formation. There is also a marked change in the character of the sediments, the massive limestone giving place to beds of sand of remarkable purity. The Simpson formation consists essentially of beds of pure sand, green clay shale, and shaly limestone.

locality along Blue and Delaware creeks in T. 1 S., R. 7 E.

Viola limestone.—The Viola limestone succeeds the Simpson formation conformably. It has a total thickness of 700 feet and may be divided into three members on the basis of the character of the limestone. The lowest member is described as a bed of light colored, coarse textured, rough-bedded limestone, having an average thickness of 100 feet. The middle member consists of white to light blue limestone and carries bands and nodular masses of chert. It is also abundantly fossiliferous, carrying especially the genus Trinucleus. The upper member is coarsely crystalline, resembling marble in texture, and is light gray to pink in color. The lower and middle members are of Ordovician age. The upper member is of Silurian age; i. e., latest Richmond. In fresh exposures the limestone appears massive, but on weathered surfaces shows stratification in beds usually about one foot in thickness.*

The formation is exposed in a number of places in the Arbuckle Mountains, especially in the highland north of the town of Bromide in T. 1 S., Rs. 7 and 8 E.

Stringtown shale and Talihina chert.—While the Viola limestone was being deposited in the Arbuckle Mountain region, sedimentation of a markedly different character was taking place less than twenty miles distant in the Ouachita Mountain region. * * To the lower part of this series of sediments, the name Stringtown shale has been given, the type locality occurring along the northwest flank of Black Knob Ridge from Stringtown to Atoka. The base has not been observed anywhere in Oklahoma. This formation must, therefore, serve as the exposure of the oldest strata observed in this part of the mountains. Older strata of Ordovician and possibly of Cambrian age have been described as occurring in the Crystal Mountain area of Arkansas.* The Stringtown shale is composed of green clay shale grading upward into black, fissile, cherty shales. The only other exposure described in Oklahoma

*While the above may serve as a general description of the Viola limestone, the writer measured a section 1½ miles southwest of Wapanucka which had a thickness of nearly 1,000 feet, and in which the lower member had a different lithologic character and thickness from that described above. See chapter on Economic Geology.

**See Bulletin 377, U. S. Geological Survey by G. H. Girty. Also Atoka folio of Geologic Atlas of United States by J. A. Taff.

**See report on Slate by A. H. Purdue. Arkansas Geological Survey reports, 1909.

The thickness varies from 1200 to 2000 feet. It is exposed in many places in the Arbuckle Mountain region, especially in a narrow band along the southwestern side of the uplift and in the type lies in the dome-like uplift 8 miles northeast of Tuskahoma.

To the upper part of this series, which has been correlated with the Viola limestone, the name Talihina chert has been given. This formation is exposed in Black Knob Ridge near Atoka and in the type area near the town of Talihina in the Tuskahoma quadrangle. It has a thickness of about 1200 feet, and consists of flint, chert, black and bluish shales, and lentils of dense limestone.

SILURIAN ROCKS.

Strata of Silurian age include the upper member of the Viola limestone, the Sylvan shale, the Chimneyhill limestone, and the Henryhouse shale in the Arbuckle Mountain region, and an unnamed chert in the Ouachita Mountain region.

Sylvan shale.—In the Arbuckle Mountain region, the Viola limestone is succeeded conformably by the Sylvan shale. This formation consists of dark-blue to black and green clay shales, and has a variable thickness of from 50 to 300 feet. It occurs in a number of localities in the Arbuckle Mountains, especially along the borders of the uplift. It has been correlated with the Medina of New York.

*Chimneyhill limestone.**—This formation lies unconformably on the Sylvan shale. On lithologic grounds, it may be divided into an oolitic, a glauconitic, and a pink crinoidal member. It has a variable thickness of from 0 to 53 feet with an average of 35. It has been correlated with the Clinton of Ohio.

Henryhouse shale.—This formation lies unconformably on the Chimneyhill limestone. It is composed of bluish to yellowish limestone strata with beds of shale and white marl. The thickness varies from 0 to 223 feet with an average of 90 feet. It has been correlated with the Bob and Lobleville formations of Tennessee, which are of Niagaran age.

Unnamed chert in the Ouachita Mountain region—In the Ouachita Mountain area, the Talihina chert of Ordovician age is generally unconformably overlain by the Stanley shale of Mississippian age. There is one small area, however, in secs. 3, 4, and 5 of T. 2 N., R. 15 E., which lies in the southern part of the McAlester quadrangle, where unnamed chert and limestone strata of upper Silurian age are found. These strata are overlain by Caney shale of Mississippian age. Thus, in this small area, Silurian strata occur that are absent elsewhere, and the Stanley shale and Jackfork sandstone, that are otherwise universally present in the Ouachita Mountain region,* are absent.

DEVONIAN ROCKS.

Rocks of Devonian age occur only in the Arbuckle Mountain region.

Haragan shale.—This formation lies unconformably upon the Henryhouse shale. The strata are composed of blue white shales and thin-bedded earthy limestones. The thickness varies from 0 to 166 feet with an average of 100 feet. It has been correlated with the New Scotland of the New York section.

Bois d'Arc limestone.—This formation lies conformably upon the Haragan shale. The strata are composed of thin-bedded crystalline and noncrystalline limestone. The thickness varies from 0 to 90 feet with an average of 60 feet. It has been correlated with the Becraft of the New York section.

Woodford chert.—Wherever studied locally, the Woodford chert appears to rest conformably on the Bois d'Arc limestone. There is, however, evidence to show that land conditions prevailed throughout Onondaga and Hamilton time. The Woodford chert has an average thickness of 650 feet. It is variable in lithologic character, but consists essentially of chert and shale. It becomes less cherty from the base upward, the upper part consisting of fissile, bituminous, black shale. Fossil wood has been found in many places. In one instance an upright trunk was found which

---

*The Chimneyhill limestone and Henryhouse shale of Silurian age, and the Haragan shale and Bois d'Arc limestone of Devonian age, are equivalent to the Hunton formation as defined by Taff, the same having been later subdivided by C. A. Reeds. (Hunton formation of Oklahoma by C. A. Reeds: American Journal of Science, 4th series, vol. 32, October, 1911).

Reeds was led to make this subdivision by noting: (1) the variable thickness of the Hunton formation from point to point; (2) the consequent thinness and even absence of some of the members in some sections; (3) the recognition of unconformities at the base of the Chimneyhill limestone, Henryhouse shale, and Haragan shale formations.

These four formations into which the Hunton limestone has been divided are found in many localities in the Arbuckle Mountain region. They usually occur wherever the Viola limestone is found, and are separated from it by a narrow valley of Sylvan shale.

*See Bull. 377, U. S. Geological Survey by G. H. Girty.

investigation proved to be a species of *Dadoxylon*, a common Devonian form.

Strata of Devonian age are not known in the Ouachita Mountain area.

MISSISSIPPIAN ROCKS.

The Stanley shale and Jackfork sandstone in the Ouachita Mountain region and the Sycamore limestone and Caney shale in the Arbuckle Mountain region have been referred to this age.

Stanley shale, Jackfork sandstone.—The Stanley shale rests unconformably upon the Talihina chert of Ordovician age. It has an estimated thickness of from 5000 to 6000 feet. In the lower part it consists of chert, black shale, and greenish clay shales. Higher in the section, brown and drab sandstones alternate with thick beds of shale. Due to the softness of the sandstone, the formation outcrops in nearly level plains. It is widely exposed in the Ouachita Mountain area.

The Jackfork sandstone lies above the Stanley shale and is of about the same thickness. It is the mountain-making formation in the Ouachita range in Oklahoma, consisting almost entirely of brown and gray sandstone. It makes up the mass of Rich, Jackfork, and Kiamichi mountains. The Jackfork sandstone is overlain by the Caney shale, also of Mississippian age.

Sycamore limestone, Caney shale.—Along the southern side of the Arbuckle uplift, the Woodford chert is succeeded by a light-bluish to yellow limestone to which the name Sycamore limestone has been given. This limestone occurs as a lentil, having a variable thickness of from 10 to 200 feet.

Above the Sycamore limestone in the southern part of the mountains and lying conformably on the Woodford chert in the northeastern part, occurs the Caney shale. This formation has an estimated thickness of 1600 feet. The basal part is made up of black bituminous clay shale containing limestone and argillo-calcareous segregations. The upper part of the formation consists of bluish shale containing small ironstone concretions and occasional lime septaria. The limy segregations in the black shale both in this area and in the Ouachita Mountain region, have been studied by G. H. Girty. After several changes of opinion, Dr. Girty has come to the conclusion that this formation is of late Mississippian age.*

The Caney shale extends eastward without variation into the

*Girty, G. H., The fauna of the Caney shale: Bull. U. S. Geol. Survey, No. 377, 1909.

Ouachita Mountain region. Here it is underlain by the Jackfork sandstone and Stanley shale which have an estimated thickness of 10,000 to 12,000 feet. These strata were formerly thought to be of Ordovician age, but have lately been shown to be Mississippian.** The Stanley shale, it will be remembered, rests unconformably on the Talihina chert of Ordovician age.

How the Caney shale can be underlain by 10,000 to 12,000 feet of Mississippian strata in the Ouachita Mountain region and at the same time grade conformably into Devonian strata in the Arbuckle Mountain region not 20 miles away is an unsolved problem. It has been suggested that the unconformity below the Stanley corresponds to that below the Woodford, thus making these strata of Devonian age and correlated with the Woodford. It has also been suggested that these strata may represent the period during which deposition did not occur in the Arbuckle Mountain region, i. e., the time gap between the Hunton and the Woodford. But fossil evidence points strongly to the Mississippian age of the rocks. It thus appears that the Jackfork and Stanley formations of the Ouachita section are absent from the Arbuckle section, and that the Woodford and Sycamore formations of the Arbuckle section are not found in the Ouachita section.

PENNSYLVANIAN AND LATER ROCKS.

The Franks conglomerate, Glenn formation, Wapanucka limestone, Atoka, and other formations not described in this report have been referred to this age.

Franks conglomerate.—Near the close of Mississippian time, the strata in the western part ofthe Arbuckle Mountain region were elevated, folded, faulted and subjected to long continued erosion. The erosion reached the heart of the uplift, exposing strata of all ages from the Mississippian to the Cambrian. The products of this erosion were laid down across the upturned, worn edges of these older strata as a coarse limestone conglomerate to which the name Franks conglomerate has been given. This conglomerate extends over broad areas to the north of the mountains. Southeastward from Franks, the formation thins rapidly and changes from a heavy conglomerate to thin limestone, sandstone, and shale strata. Two miles south of Jesse it cannot be distinguished from the Caney below (upon which it lies unconformably) and the Atoka above. A short distance to the east of this point the Wapanucka limestone occurs, occupying approximately the same position in the section. The thickness of the Franks conglomerate varies from 0 to 500 feet.

Glenn formation.—Along the southern side of the Arbuckle

**Op. cit.

Mountains the Caney shale grades conformably into the Glenn formation. The strata of this formation are made up of friable bluish clay, shales, and beds of thin brown or drab sandstone. It has an estimated thickness of from 1000 to 3000 feet, and occurs as a lens, not being present on the northern or northeastern flanks of the mountains. Fossils found in the lower beds determine its age as Pennsylvanian. The Franks conglomerate rests unconformably upon it.

It appears from the above discussion that the strata in the northeastern and southern areas may be correlated as follows:*

Southern area.	Northeastern area.
Franks conglomerate Glenn formation	Wapanucka limestone
Caney shale	Caney shale

Wapanucka limestone.—In the type locality at Wapanucka and in Limestone Ridge in the northern part of the Ouachita Mountain region, the Caney shale is conformably overlain by the Wapanucka limestone. Only a brief general description of the formation will be given in this chapter.

The Wapanucka limestone consists of one or more beds of massive white to light brown limestone, together with chert, sandstone, and shale strata. Near the town of Bromide a bed of exceptionally fine, massive oolite, 70 feet in thickness occurs. In Limestone Ridge the formation is composed of several members of fairly constant occurrence but variable thickness. Near the eastern end the strata are composed mostly of sandstone. Due to the resistant nature of the strata and to the fact that the Wapanucka occurs between two shale, valley-formations, the outcrops occur as narrow, steep-sided ridges. The formation has a variable thickness of from 100 to 800 feet, the average being about 300 feet.

*In chapter VI, the writer will advance evidence to show that an unconformity exists within the Wapanucka formation. Future work may show that the part below the unconformity is equivalent to the Glenn formation. This would make the upper part of the Wapanucka more nearly equivalent to the Franks conglomerate.

Atoka formation.—The Wapanucka limestone is succeeded abruptly by beds of shale which constitute the basal part of the Atoka formation. This formation has an estimated thickness of 3000 feet,

and is composed of alternating beds of sandstone and shale. The shale members are much thicker than the sandstone and crop in broad valleys separated by the prominent but narrow sandstone members. The sandstone is ferruginous, massive, and in places conglomeratic. The shales are dark blue clay shales, weathering to shades of blue and yellow.

It has not been deemed advisable to include a discussion of the 7000 to 8000 feet of Pennsylvanian strata that lie above the Atoka formation as such a discussion would have no bearing on the problem in hand. Their stratigraphic position is shown in the correlation table placed at the end of this chapter. They consist of alternating beds of sandstone, shale, and coal, and their outcrops constitute the broad valleys and prominent ridges lying in the Sandstone Hills region to the north. They are fully described in the Atoka and Coalgate folios of the Geologic Atlas of the United States.

Near the close of Pennsylvanian time the entire region was elevated above sea level and intensely folded and faulted. Following these diastrophic movements there occurred a prolonged period of erosion. This erosion was succeeded by a subsidence and the unconformable deposition of Red Beds of late Pennsylvanian or early Permian age. These strata now overlap the western end of the Arbuckle Mountain region and lie in a nearly flat position over the eroded edges of strata varying in age from the Pennsylvanian to the Ordovician. They have not suffered folding nor are they overlain to the north and west by younger strata. They dip gently away towards the northwest and form the rolling land of the Prairie Plains.

The region remained above sea level during Triassic and Jurassic time.

Before Cretaceous time had far advanced the region had been reduced to the condition of a wave-cut marine plain. Upon this surface the Trinity sand, the earliest Cretaceous deposit, was laid down. It has a thickness of about 300 feet and consists of loose sands and clay lentils. The base is locally conglomeratic. Above the Trinity sand lie other strata of Lower and Upper Cretaceous age having an aggregate thickness of 800 to 1000 feet. They have been described in the Tishomingo folio of the Geologic Atlas of the United States.

With the exception of certain Neocene and recent gravels these strata constitute the youngest rocks exposed in the region.

A correlation table for the region, compiled from various sources* is given in Plate II.

*See especially Folio 98, Bulletin 377, and Professional Paper 71 of the U. S. Geological Survey, also American Journal of Science, 4th series, vol. 32, October, 1911.

CORRELATION TABLE.

System	Series	Generalized Section of North America	Sandstone Hills and Arbuckle Mountain Regions		Ouachita Mountain Region:	
Carboniferous.	Pennsylvanian.	Monongahela formation.				
		Conemaugh formation.	Seminole conglomerate	50'		
			Holdenville shale	260'	Undifferentiated in Ouachita Mountain Region.	
			Wewoka formation	700'		
			Wetumka shale	120'		
			Calvin sandstone	145'-240'		
			Senora formation	410'-485'		
			Stuart shale	90'-280'		
			Thurman sandstone	80'-260'		
		Allegheny formation	Boggy shale	2000'-2600'		
			Savanna sandstone	1000'		
			Mc Alester shale	1800'-2800'		
		Pottsville	Hartshorn sandstone	150'		
			Atoka formation	3100'	Atoka formation	3100'
			Wapanucka limestone	100'	Wapanucka limestone	250'-800'
	Mississippian.	Chester group	Caney shale	1600'	Caney shale	1000'
		Meramec group				
		Osage group			Jackfork sandstone	6000'
		Kinderhook			Standley shale	6000'
Devonian.		Chemung	Woodford chert	650'	(Wanting)	
		Portage				
		Hamilton	(Wanting)			
		Onondago				
		Oriskany				
		Helderberg	Bois d'Arc limestone	0'-90'		
			Haragan shale	0'-160'		
Silurian.		Cayugan	(Wanting)		Unnamed chert of Upper Silurian age	
		Lockport	Henryhouse shale	0'-223'		
		Clinton	(Wanting)			
		Albion	Chimneyhill limestone	0'-53'		
			Sylvan shale	60'-300'		
		Richmond			?	
Ordovician.		Lorraine	Viola limestone	500' to 700'	Talihina chert	1200'
		Frankfort				
		Utica				
		Trenton				
		Black River	Simpson formation	1200' to 2000'	Stringtown shale	600'+
		Upper Stones River			?	
		Chazy				
		Beckmantown	Arbuckle limestone	4000' to 6000'		
Cambrian		Upper Cambrian				
		Middle Cambrian	Reagan sandstone	0'-500'		

PLATE II

CHAPTER IV.

STRUCTURE.

Only the major structural features of the region, in general, and of the Wapanucka limestone in particular, will be presented in this chapter. This will serve as an introduction to the detailed discussion of the structure that will be given in chapter V.

As the region includes parts of three structural provinces that are coextensive with three of the physiographic provinces discussed in the introduction, it will be best to consider each of these separately and to show the part each has played in moulding the structural features of the Wapanucka limestone. These structural provinces are, respectively, the Arbuckle Mountain and the Ouachita Mountain structural provinces, and the southern part of the Sandstone Hills structural province.

STRUCTURE OF THE ARBUCKLE MOUNTAINS.

It has been stated in the preceding pages that sedimentation was practically continuous in the Arbuckle Mountain region from Middle Cambrian to Mississippian time. That there were slight changes of level, accompanied at times by short periods of erosion is shown by the varying character of the sediments.

The statement was also made that the diastrophic movements that produced the structural features of the Arbuckle Mountains started in Mississippian time and ceased before the close of the Pennsylvanian.

The deformation took place in two stages, separated by a period of erosion. The first period of deformation occurred in Mississippian time and involved the western part of the region. The period of erosion that followed was very long, strata of all ages from the Mississippian to the pre-Cambrian being exposed. The products of this erosion were laid down across the upturned edges of the older strata as a coarse conglomerate to which the name of Franks conglomerate has been given. At the same time the Wapanucka limestone was deposited to the east in the clear water off shore. At a later time, the entire region was uplifted and profoundly folded and faulted. These later orogenic movements involved the Wapanucka limestone and the Franks conglomerate as well as the older strata. In Professional Paper number 31 of the U. S. Geological Survey, J. A. Taff has shown that the major structural feature of the Arbuckle Mountains is that of a great geanticline, the axial part of which is composed largely of massive Cambro-Ordovician (Arbuckle) limestone, lying in a practically horizontal position. The sides of the geanticline consist of strata ranging in age from the Ordovician to the Devonian and, as they were less resistant than the massive limestone in the axial part of the fold, are bent steeply downward. The geanticline is made up of four broad, flat anticlines, separated by three synclines. The region has been profoundly faulted, the faults following the general direction of the axis of the uplift, namely N. 70° W. As a result of the faulting only the resistant axial parts of the anticlines remain. The sides are concealed by faulting and with them in many cases practically the whole of the intervening synclines. The structure is well illustrated in Plate III* (in pocket) which shows the areal distribution of the anticlines and synclines and several sections across the area. In the section C-D the massive, flat-lying Arbuckle limestone may be seen lying in the axial parts of the anticlines. Chester A. Reeds, in Bulletin No. 3 of the Oklahoma Geological Survey, has pointed out that a second system of folds intersects the first almost at right angles. This is shown by the plunging of the anticlines and synclines to the east and west, by several quaquaversal folds near the Washita River in the western part of the area, and by folds of a higher order scattered throughout the region. The major structural features have been named after some town or natural feature occurring in the area. Starting from the north they are respectively: the Hunton anticline, the Wapanucka syncline, the Belton anticline, the Mill Creek syncline, the Tishomingo anticline, the Washita syncline, and the Arbuckle anticline.

As the Wapanucka limestone occurs in the Hunton anticline and Wapanucka syncline, these structures will be described in detail. The part of the Hunton anticline that is of interest in the present discussion lies in T. 1 S., Rs. 8 and 9 E. It makes up the high land lying to the north of the town of Bromide. The north and south sides are very precipitous due to extensive east-west faults. The anticline plunges towards the east at an angle of about 10°, thus exposing strata of all ages from the Cambrian to the Pennsylvanian. The Wapanucka limestone outcrops as a prominent north-south ridge in secs. 6, 7, 18, and 19 of T. 1 S., R. 8 E. The faults that bound the anticline on the north and south sides have displaced these strata eastward a distance of more than half a mile.

The Wapanucka syncline lies to the south of the Hunton anticline and underlies the broad valley of Wapanucka Creek. It extends from the hills lying north of Bromide to those lying south of Viola or Spring Brook. It includes the Caney shale which forms

---

*Reeds, Chester A., Geology and mineral resources of the Arbuckle Mountains, Bull. Okla. Geol. Surv., No. 3, 1910, pl. 16.

the valley south of Bromide and all of the sedimentary strata (Woodford chert, Chimneyhill limestone, Henryhouse shale, Haragan shale, Bois d'Arc limestone, Sylvan shale, Viola limestone, and Arbuckle limestone) lying in the highland to the south of the valley as far south as the granite. It is bounded on the north and south sides by extensive faults, those on the southern side being very complex and having displacements in places totaling 8000 feet. The syncline plunges to the east, thus exposing successively the Caney shale, the Wapanucka limestone, and the Atoka formation. Due to the plunging of the syncline and to the fact that the faults on the north and south sides coalesce, the syncline comes to an end in T. 2 S., R. 7 E. The diminished fault continues westward to the town of Sulphur in T. 1 S., R. 3 E. Potentially the Wapanucka syncline may be considered to extend along this fault.

The outcrop of the Wapanucka limestone occurs as a prominent ridge, lying in the sides and axis of this plunging syncline.

STRUCTURE OF THE OUACHITA MOUNTAINS.*

This region constitutes the second of the three structural provinces under discussion.

While sediments were being deposited in the Arbuckle Mountain region, sedimentation was in progress in the Ouachita Mountains also. Although the periods of sedimentation were roughly parallel in the two regions they were not so in a strict sense. There is no record of sedimentation during the Devonian and the sediments are of a very different character from those in the Arbuckle Mountains, being made up largely of chert, sandstone, and shale.

The diastrophic movements that caused the deformation of the strata of the Arbuckle Mountain region during Mississippian and Pennsylvanian time affected those of the Ouachita Mountains also. The region was thrown into a number of narrow folds, the general direction of whose axes is east-west. Near the western end, the folds turn southward and pass beneath flat-lying Cretaceous strata. In the northern and northwestern parts of the area the folding was most intense, the folds being in many cases overturned and broken by thrust faults. One of these, the Choctaw fault, has, in places, a stratigraphic throw of at least 8000 feet, bringing Ordovician rocks in contact with Pennsylvanian. This fault separates the steeply southeasterly dipping strata of the Ouachita Mountain region from the more gently northerly dipping strata of the Arkansas Valley region.

---

*Data for this section obtained from the Atoka folio of the Geologic Atlas of the United States.

STRUCTURE OF SANDSTONE HILLS REGION

(Southern Part).*

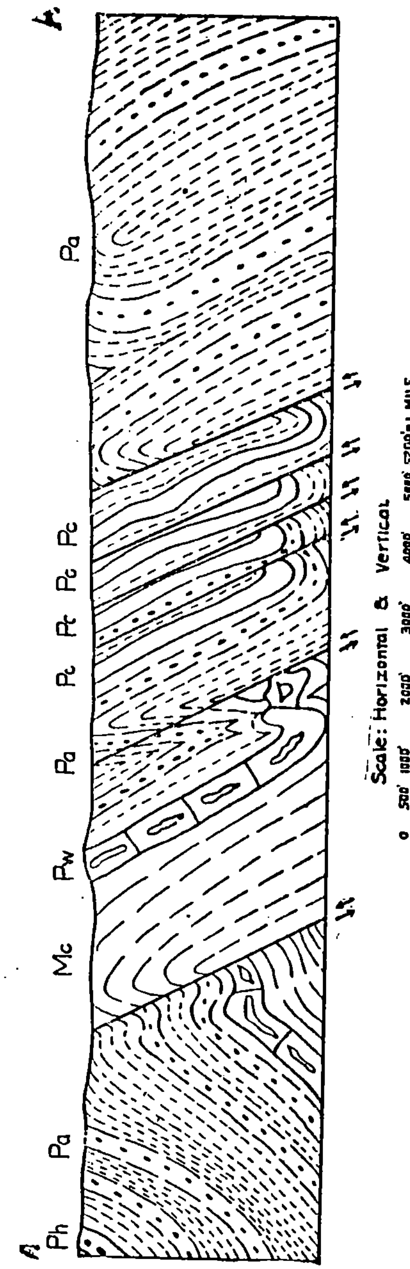
This region constitutes the third of the three structural provinces under discussion. In this section, more space than usual will be devoted to the discussion of the general structure of the Wapanucka formation. The strata are of Pennsylvanian age and are composed largely of beds of ledge-forming sandstone separated by thick beds of shale.

The strata were deformed near the end of Pennsylvanian time by the same orogenic movements that caused the second deformation of the Arbuckle and Ouachita Mountain regions, and were thrown into a number of folds whose axes parallel those in the Ouachita Mountain region. The folds are, however, relatively flat and die out towards the north in the monocline of the Red Beds plains. In the western end of the region this monocline extends south to within a few miles of the town of Lehigh.

That part of the Sandstone Hills region which lies between the Arbuckle and Ouachita mountains was affected by the movements in these regions, being thrown into a deep, unsymmetrical, northward plunging synclinal trough in which the eastern limb is steeper than the western. This structure may be best described as resembling the shell of a power boat or racing yacht. The gentle monocline to the north of Lehigh represents the flat step which makes up the rear part of such a boat. The spoon-like syncline to the south of Lehigh represents the prow. But the structure is made more complex by the buckling of the strata in the Hunton anticline and Wapanucka syncline. These structures throw the right side of the boat into two folds or corrugations whose axes extend from keel to gunwale. Further, a large part of the left side of the boat has been cut off by the Choctaw fault, and the bow has been covered up by overlapping Cretaceous strata. The extent of the Caney shale, Wapanucka limestone, and later formations beneath the surface can best be represented as the shells of a number of boats placed one within the other. The outcrop of the Wapanucka limestone is seen to represent the gunwale of one of these boats.

The major structural features of the strata that compose Limestone Ridge and neighboring outcrops of the Wapanucka limestone may now be taken up. These strata lie just to the south of the Choctaw fault and hence lie in the area of highly folded and

*Data for general discussion obtained by a study of the maps of the Atoka folio of the Geologic Atlas of the United States by J. A. Taff.



Pa = Atoka formation. Pw = Wapanucka limestone Mc = Caney shale.
Pc = Chickachoc chert lentil Ph = Hartshorne sandstone.

Figure 2. Section showing structure in sec. 22, T. 1 N., R. 12 E.

faulted rocks that compose the northern part of the Ouachita Mountain region. Structurally, these strata should be placed in the Ouachita Mountain region, just described. But topographically, they are more nearly related to strata lying to the north in the Sandstone Hills region. They are hence described with these strata. The accompanying section, figure 2, shows the structure in sec. 22, T. 1 N., R. 12 E. near the end of Limestone Ridge. The section represented runs northwest-southeast as shown by the line A-A on Plate IV in the pocket at the end of the report. Here the Wapanucka limestone is represented as a thin bed dipping sharply to the southeast.

The structure of the strata in the Atoka formation which immediately overlies the Wapanucka is shown, in the section, to be that of a number of narrow, closed folds which have been overturned towards the northwest and broken by strike, thrust faults.

Tracing the outcrop of the Wapanucka limestone northeastward along the strike of the rocks, the number of outcrops is found to increase until as many as five are encountered in the vicinity of Hartshorne. The determination of the cause of this repetition of strata constituted a most important structural problem, and a large amount of data bearing on the subject was collected. The phenomena observed prove most conclusively that the repetition of strata is due to the presence of a number of narrow closed folds that have been overturned toward the northwest and broken by strike, thrust faults. The structure is thus seen to be similar to that observed in the Atoka formation farther southeast as represented in figure 2. This fact is brought out very clearly in figure 3, which represents a section along the line B-B on Plate IV, in T. 3 N., R. 15 E. The folding included part of the Atoka, all of the Wapanucka, and part of the Caney formations. The faulting probably occurred in the axes of the anticlines, and in such a manner as to conceal the Wapanucka limestone in the northwestern limbs of the folds. The positions of the fault planes could not be determined in the field due to the fact that they occur in shale with much residual soil but the positions shown on the map are regarded as being approximately correct.

Any cross section of the area, therefore, would show a number of limestone ridges with strata repeated in the same order and dipping at about the same angle towards the southeast. That the strata in the limestone ridges are repeated in the same order is shown most conclusively in the field by the presence of well defined and easily recognized limestone, sandstone, and shale members. The contact between the Caney shale and Atoka formations, which are present in any one of the valleys between the ridges, is hard to

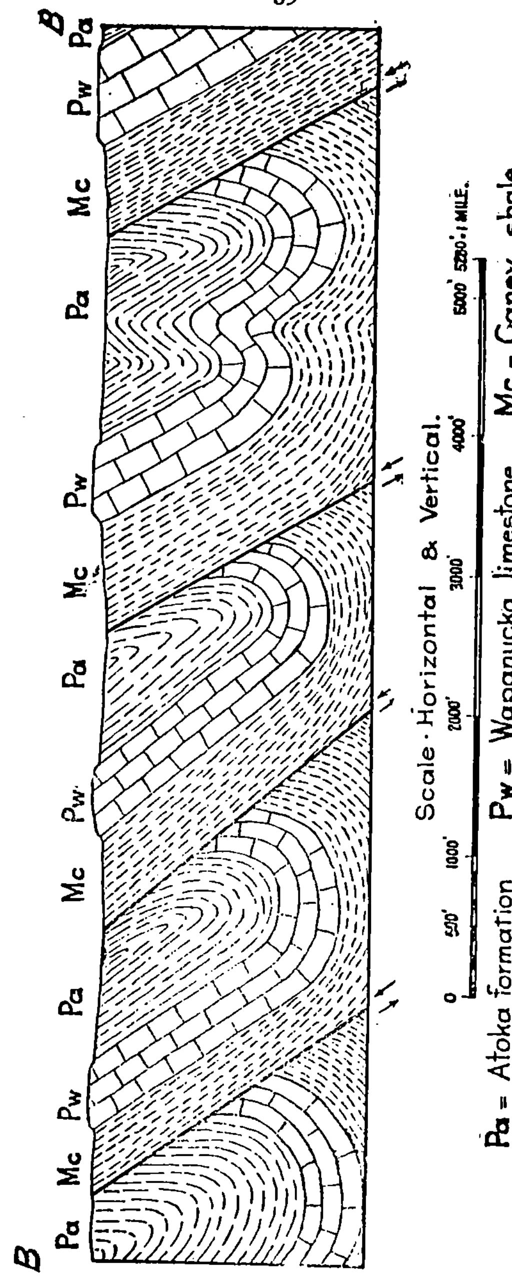


Figure 3. Section showing structure in T. 3 N., R. 15 E.

find as both formations are composed of blue shale. The Atoka, however, contains cherty and sandy strata at times, and this helps to differentiate the two. The termination of the ridges (outcrops) along the strike is accounted for as follows:

When any one outcrop is considered it is thought to have the structure of a narrow anticline which plunges under younger strata at each end. In some instances this plunging was noted in the field and is shown on the map by the arrows which indicate the direction of the dip of the strata. In other instances, this plunging was not observed. In such cases, it is thought either that the strike fault has swerved in such a manner as to cut across the bedding or that the outcrop was terminated by a minor cross fault. Where such interpretations were made the fault lines have been drawn on the map in such a way as to represent these facts. Whenever an outcrop has been terminated along the strike by faulting, it is believed that this faulting occurred near the point at which the anticline would have plunged under younger strata even though it had not been terminated by the fault. In other words, the second type of termination is but an abbreviated form of the first. The outcrop would not have extended for a much greater distance even though the faulting had not occurred.

The plunging of the anticlines necessitates some crumpling of the strata beyond the ends of the ridges, and it is believed that this crumpling does occur.

It is believed that all of the faulting is a result of the folding and occurred simultaneously with it.

For a considerable distance east of Gaines Creek but one fold is present. At first the Wapanucka in the northern limb is concealed by strike faulting. South of Wilburton the throw along the fault plane is not great enough to conceal the Wapanucka and it is exposed in a fragmental manner. By the time Cravens is reached the fault is thought to have died out, the one broad outcrop representing the two limbs of a fold which has been overturned towards the north. The odd outcrop of the southern exposure at the east end of the map is due to the presence of two anticlines overturned towards the north and plunging to the east and to the west.

The folding and faulting in the Limestone Ridge area, as a whole, is most intense in the southwestern part. Towards the northeast the folding is less intense and the faults have smaller throws. This fact is well represented by the Choctaw fault. In the vicinity of Stringtown the fault has a stratigraphic throw of 8000 to 10,000 feet, Ordovician strata being brought into contact with Pennsylvanian. Proceeding northeastward, where the first

outcrop of Wapanucka is reached, Caney shale is found to lie in contact with Atoka, a displacement in which the stratigraphic throw is not more than 4000 feet and probably less. Farther northeast this fault is confined to the Atoka formation alone. The actual displacement on the fault plane is of course greater. The Choctaw fault, in the Limestone Ridge area, is confined, at the surface, to shale strata covered with residual soil. Its exact position is therefore hard to find. The writer did not attempt to locate it but has drawn it from maps made by geologists who have worked for many years in this general area. Although it is described as being a great fault, it should hardly be thought of as having any greater throw than those which lie immediately to the south. It is interesting in that it bounds the northern limit of this fault zone, and separates a region of highly folded and faulted, southeasterly dipping rocks from one in which the folding is more gentle, and in which the prevailing dip of the strata is towards the northwest.

The above discussion accounts for the presence and repetition of the Wapanucka limestone strata south of the Choctaw fault. The Wapanucka limestone strata that are present in the Lehigh syncline extend northeastward and underlie the Atoka formation to the north of the Choctaw fault. Their extent northward is not known as the limits of the formation in that direction are concealed by younger strata. These relations are brought out by the section in figure 2.

In the light of the structural features brought out in this chapter, it may be said in conclusion that the question of the areal extent and possible outcrops of the Wapanucka limestone presents a clear-cut, well-defined problem which leaves little room for speculation. At the time that the Wapanucka limestone was deposited, the western part of the Arbuckle Mountain region was above sea level. Further, the Arbuckle Mountains are composed entirely of strata that, with the possible exception of the Glenn formation and Franks conglomerate, are older than the Wapanucka. Further, the conditions that gave rise to the formation of limestone, at this time, did not exist to the west of Jesse in T. 1 N., R. 7 E. so one may not expect to find the Wapanucka (as such) west of this point. (It has been pointed out in Chapter III that the Franks conglomerate and the upper part of the Glenn formation may be correlated with the Wapanucka and represent strata of that age west of Range 7 East. Outcrops of the Wapanucka may not be found between Boggy Depot and the Gulf of Mexico due to the presence of strata of later age. To the north of the area described in this report, the Wapanucka strata form part of the Prairie plains monocline and lie at a greater and greater depth below the surface. For this reason outcrops in this direction may not be expected to be found.

To the east, near the town of Leflore the Wapanucka dips below younger formations.

The writer made a reconnaissance to the east as far as the Arkansas line but did not find any evidence of the reappearance of the Wapanucka limestone. In the Arkansas Geological Survey report on slate, A. H. Purdue gives a section for the Ouachita Mountain region in which the Atoka formation is made to lie on Jackfork sandstone of Mississippian age. This would indicate that the Wapanucka formation does not extend into Arkansas. (The Caney shale has, however, been correlated with the Moorefield and Fayetteville shales of Arkansas*). To the south, in the Ouachita Mountain region, the Caney shale is overlain by the Atoka formation, indicating that that region was above the sea at the time that the Wapanucka limestone was deposited, or that the basal Atoka beds of this region are equivalent to the Wapanucka farther north.

Due to the presence of younger strata, no exposures of the Wapanucka formation can occur between the Ouachita Mountains and the Gulf of Mexico.

---

*Girty, G. H., The fauna of the Moorefield shale of Arkansas: Bull. U. S. Geol. Survey No. 439, 1911.

CHAPTER V.

DETAILED DESCRIPTION OF THE WAPANUCKA FORMATION BY TOWNSHIPS.

In the present chapter an attempt will be made to present the details of stratigraphy and structure that were noted during the course of the survey.

The discussion naturally falls under two heads:

(1) The area comprising the type locality in the vicinity of Wapanucka.

(2) The area comprising Limestone Ridge and neighboring outcrops of the Wapanucka formation.

The areal distribution of the Wapanucka formation is shown on Plate IV in the pocket at the end of the report.

WAPANUCKA AREA.

The Wapanucka limestone outcrops in this area as a prominent but narrow, steep-sided, level-crested, zigzag ridge, extending in a general northwest-southeast direction from Boggy Depot to a point about 2 1-2 miles southeast of Jesse.

It has been explained previously that the present topographic features of this district are due to the differential erosion of strata of unequal hardness, giving rise to prominent, but narrow, ridges separated by broad, flat valleys of shale. The ridges rise to the same general elevation, their level crests lying in or slightly below the Cretaceous peneplain.

If one were to stand on the ridge which forms the Wapanucka outcrop near the Chickasaw Rock Academy, he would see to the east and west the broad flat valleys formed respectively by the Atoka and Caney shales. To the northwest and southeast, he would see the highland of the Arbuckle Mountains which meets the valley in many places in prominent fault scarps. Some little distance to the east he would see successive ridges of Atoka sandstone rising out of the plain of Atoka shale.

The major structure of the district, as previously noted, is that of a syncline plunging towards the north, in which the areal extent of the strata may be likened to the shells of a number of boats (or more properly the bows of boats) placed one within another, and having their bows pointing toward the south. This structure is shown very clearly in the outcrops that swing around to the south of Lehigh. Thus, generally speaking, the strata all dip towards the keel of the boat, and the Caney shale and Wapanucka limestone are present in the valley to the east of their outcrops, underlying the Atoka formation.

But the simple synclinal structure referred to above is modified by the structure of the contiguous Arbuckle Mountain region, the Hunton anticline and Wapanucka syncline throwing the right side of the boat into transverse folds or corrugations whose axes extend from keel to gunwale. When the structure of the Wapanucka syncline is examined more in detail, it is found to be a small scale replica of the major syncline. Its structure is that of a syncline plunging towards the east and opening out as it proceeds just as the major syncline opens out towards the north. The structure is clearly shown on the map by the arrows indicating the dip of the strata.

The problem of determining the upper and lower limits of the Wapanucka limestone in this district was not one of great difficulty. The residual soil that lies on the Caney shale is dense and blue-black in color. The concentric ironstone concretions that occur in the upper part of this shale are characteristic horizon markers and define the upper limit of the formation very accurately. In the gorge in which Delaware Creek breaks through the ridge, the Caney shale is succeeded at once by limestone so that the contact may be determined with great certainty. Farther southeast where the basal member of the Wapanucka consists of shale, the contact is not so evident but may, however, be determined to within a few feet. The upper member of the Wapanucka limestone, which usually consists of massive limestone, is succeeded by the blue-black shale of the Atoka formation so that the upper limit may be determined with equal facility. The shale of the Atoka formation is very similar to that in the Caney but lacks the ironstone concretions.

On lithologic grounds, the Wapanucka formation, in this area, may be divided into several rather illy-defined members.

At the top of the formation, and extending throughout the area, there occurs a bed of massive limestone which has a variable thickness of from 25 to 115 feet. This limestone is not constant in lithologic character. In the area to the southeast of Wapanucka, it occurs as a brown fossiliferous limestone. In T. 2 S., R. 8 E., it is oolitic or occurs as oolite interbedded with brown limestone. In T. 1 S., Rs. 8 and 9 E., it occurs either as oolite underlain by hard, fossiliferous, blue limestone, or as oolite interbedded with this limestone. It is, however, to be regarded as a unit. It is referred to in the text as the oolite-brown limestone member.

Beneath this limestone, there occurs a bed of massive sandstone which has a variable thickness of from 5 to 20 feet. In the northern

half of the area, this member is represented by beds of cherty sandstone or by beds of pure chert.

These two members are the only ones that extend throughout the Wapanucka area. Beneath the sandstone in the southern half of the area, there occur various beds of limestone, shale, and sandstone. At one point in T. 2 S., R. 8 E., local beds occur above the limestone at the top of the formation. These are fully described in the text.

With these introductory remarks, a more detailed discussion of the strata may now be taken up.

TOWNSHIPS 2 AND 3 SOUTH, RANGE 9 EAST.

The Wapanucka limestone emerges from beneath the covering of overlapping Cretaceous sediments about one mile northwest of Boggy Depot. Thence it extends northwestward to Wapanucka as a straight, narrow, level-crested ridge. The strata dip uniformly towards the northeast at an angle of 15°. Due to this low dip, the northeast slope of the ridge is gentle, while the southwest one, being made up of the broken edges of the beds is precipitous. The separate outcrop in secs. 4, 5, and 6, T. 3 S., R. 9 E. is due to minor folding. The structural features are brought out in figure 4 which also shows how the Wapanucka limestone underlies the plain to the northeast.

Several sections were made, the most complete of which was in the northwest quarter of sec. 32, T. 2 S., R. 9 E. where a branch of Sandy Creek cuts through the ridge. The following section was made at this point:

Section in NW. 1-4 sec. 32, T. 2 S., R. 9 E.

Description	Thickness in feet
Massive, light-brown limestone	25
Brown, shaly sandstone	20
Blue, massive limestone	15
Dark-blue, fissile shale	20
Argillaceous limestone	20
Shale and brown sandstone (base)	30
Total	130

TOWNSHIP 2 SOUTH, RANGE 8 EAST.

As this township contains the deposit of exceptionally high-grade oolite, the desire to determine the extent of which prompted the undertaking of this survey, a very detailed study of the nature of the strata was made. The results of this study are given in chapters VI and VII and, therefore, to avoid unprofitable repetition, will not be cited here. A general description will suffice.

The ridge in sections 24 and 25 is similar to that to the southeast. The massive limestone at the top of the formation contains such a large number of crinoid steams that the outcrop is locally known as Button Mountain. At Wapanucka, the ridge turns due west and continues for about a mile and a half. It then turns to slightly west of north and cuts across the axis of the Wapanucka syncline, passing out of the township in the northeast quarter of section 5, one mile east of the town of Bromide.

At the bend in the ridge at Wapanucka a dip of 60° was recorded but this quickly drops and remains constant at 15° until the ridge turns towards the north. In the axial part of the Wapanucka syncline the dip varies from 7° to 10° thus accounting for the relatively broad outcrop. As in the preceding township, due to the low dip towards the northeast and east, that side of the ridge has a gentle slope while the southwest side is precipitous. Two sections will be given. The first was made at the reservoir in section 22 where Sandy Creek cuts through the ridge:

Section in sec. 22, T. 2 S., R. 8 E.

Description	Thickness in feet
Oolite	5
Massive, light-brown limestone	25
Ferruginous sandstone	10
Fossiliferous limestone	10
Brown sandstone	5
Hard limestone	2
Shale to base	
Total	57

The second was made in section 4 at the point where Delaware Creek cuts through the ridge.

Section in S. 1-2 sec. 4, T. 2 S., R. 8 E.

Description	Thickness in feet
Limestone breccia	2
Fossiliferous and dense, blue limestone with chert	20
Brown sandstone	5
Massive oolite to base	70
Total	97

The strata occurring above the oolite in this section are local and are not found elsewhere.

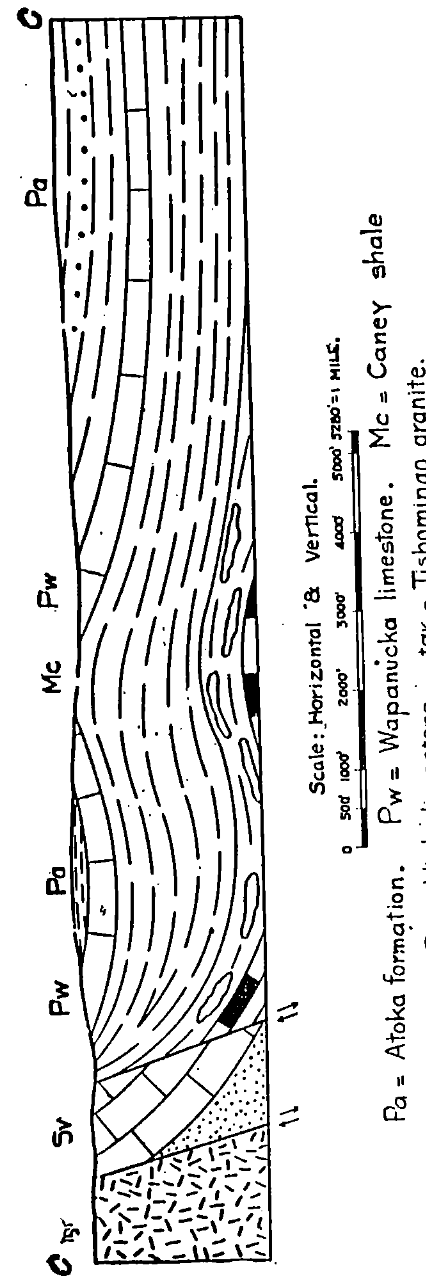


Figure 4.

As is described more fully in chapter VI, the oolite is to be considered a local phase of the massive limestone member that occurs at the top of the formation. An angular unconformity occurring at the base of this oolite-massive limestone member, was noted in this township. (See fig. 6). This fact was considered of sufficient geologic importance to warrant the devotion of a separate chapter to it. (See chapter VI). Between Sandy and Delaware creeks the oolite-massive limestone member is underlain by chert and fossiliferous limestone strata. (See fig. 6). At Delaware Creek, due to the unconformity, the chert and fossiliferous strata are absent, the oolite resting directly upon the Caney shale. North of the creek, in section 4, the chert and fossiliferous limestone reappear, lying unconformably under the oolite. The oolite soon disappears and the chert extends to the top of the formation. This condition maintains until the northeast quarter of section 5 is reached where a small amount of non-oolitic limestone occurs, lying unconformably above the chert.

TOWNSHIP 1 SOUTH, RANGES 8 AND 9 EAST.

Southern part of Range 8.—Shortly after entering the township, in section 32, the ridge turns sharply towards the east. This is due to the fact that the outcrop passes from the axial part to the side of the syncline. The dip of the strata is towards the south and very high, ranging from 50° to 70°. This high dip accounts for the narrowness of the outcrop. Another result of the high dip is reflected in the topography of the ridge. Cross-sections thus far discussed have shown gentle slopes toward the east and steep slopes toward the west. Here the edges of the beds, which were the causes of the steep western slopes heretofore, lie practically in the crest of the ridge. The steep dip towards the south causes the massive limestone, which makes up nearly the whole section, to form a veritable wall in that direction. The Caney shale, piling up behind this wall, forms a gentle slope to the north. The topographic cross-section is, therefore, just the reverse of that heretofore noted. The slight displacement to the north noted in section 33 is due to minor faulting.

The following section was made in the southeast quarter of section 33.

Section in the SE. 1-4 of sec. 33, T. 1 S., R. 8 E.

Description	Thickness in feet
Hard, massive limestone	60
White oolite	10-20
Chert (base)	5-10
Total	85

Two things are to be noted in this section:

(1) Practically the whole section is composed of limestone (that between this point and Delaware Creek being chert and sandstone).

(2) The reappearance of the oolite.

Range 9 East.—Here the outcrop lies in the axis of the Hunton anticline. The low dip, varying from 9° to 13° towards the east accounts for the broad outcrop. The slope of the ridge is gentle towards the east and precipitous towards the west. The topography, viewed from the west, is that of a prominent, steep-sided, grass-covered ridge, having the appearance of an enormous mound.

The entire mass has been displaced one-half mile towards the east, due to two normal faults. The following section was made:

Section on east-west section line between secs. 7 and 18, T. 1 S., R. 9 E.

Description	Thickness in feet
Oolite	15
Blue fossiliferous limestone	100
Chert and brown sandstone (base)	10
Total	125

Northern part of Range 8.—The outcrop in this part of the township lies in the northern limb of the Hunton anticline just as that in the southern part lies in the southern limb (or what is the same thing, in the northern limb of the Wapanucka syncline). The dip of the strata is towards the north, varying from 35° to 50° in the eastern part of the township, but dropping to 3° in the western part. The narrow outcrop in the eastern part of this area is due to the high dip and also to the fact that the outcrop occurs on the southern slope of a ridge. The basal part of the Atoka formation here is composed of sandstone. This sandstone forms the crest and northern slope of the ridge, thus covering up what would otherwise have been part of the outcrop of the Wapanucka limestone.

In the western part of the township, where the dip is but 3°, one would expect to find a broad exposure occurring in a ridge with a gentle slope towards the north and a precipitous one (due to the outcropping edges of hard strata) towards the south. The precipitous southern slope does occur but the northern one, though present, is covered by a thin layer of Atoka shale which has resisted erosion due to the protection of sandstone hills a short distance to the north. The Wapanucka outcrop is thus limited to little more than the edges of the strata. The following sections were made:

Section in SE. 1-4 sec. 3, T. 1 S., R. 8 E.

Description	Thickness in feet
White oolite with blue limestone near base	50
Hard, massive blue limestone	50
Shale and chert (base)	5-10
Total	105

Section in northeast quarter of section 5, T. 1 S., R. 8 E.

Description	Thickness in feet
Blue oolite	35
Hard massive blue limestone	65
Shale and chert	5-10
Total	100

TOWNSHIP 1 NORTH, RANGE 8 EAST.

The ridge enters the township in section 31 and runs practically due north through sections 31 and 30. Shortly after entering section 19, it swings towards the northwest and comes to an end in the northwest quarter of that section, a few hundied feet beyond Goose Creek. The dip of the strata is towards the east and northeast and varies from 30° to 35°. The sinuous nature of the outcrop is due to minor folding. Throughout sections 31, 30, and part of 19, the outcrop forms a low independent ridge, a narrow strip of shale separating it from the hill of Atoka sandstone to the east. After crossing Goose Creek, however, the outcrop lies on the southwest slope of a hill and is in direct contact with Atoka sandstone which lies above it. The outcrop is, therefore, limited to little more than the edges of the beds. The width of the outcrop at Goose Creek is about 100 feet, the thickness of the strata about 55 feet. From this point on, the outcrop becomes rapidly narrower and pinches out entirely a few hundred feet beyond Goose Creek. Here the Atoka sandstone is directly underlain by Caney shale. The entire section of the Wapanucka limestone near the end is composed of white oolite. The end of the outcrop is supposed to represent the western limits of the conditions that gave rise to the formation of this limestone. A short distance to the west, the first traces of the Franks conglomerate are met at this horizon, thus indicating that the Franks conglomerate is to be correlated with the oolitic member of the Wapanucka limestone, i. e., the upper rather than the lower part of the Wapanucka. The hill of Atoka sandstone was traced almost due west to the point where it crosses the north-south township line between ranges 7 and 8 east. Here a single large boulder of limestone was encountered but was found upon examination to be entirely different from anything found in the Wapanucka limestone. Two sections were made in this township:

Section in the SE. 1-4 sec. 19, T. 1 N., R. 8 E.

Description	Thickness in feet
Limestone, soft and white but non-oolitic	50
Chert to base	5
Total	55

Section at point where Goose Creek crosses ridge, northeast quarter of section 19, Township 1 North, Range 8 East.

Whole section oolite	55

A general review of the sedimentation in this district shows that the Wapanucka limestone is composed of several members, only the uppermost one of which extends throughout the whole area. In the vicinity of Wapanucka the lower part is composed of sandstone and shale. These members become less important towards the northwest and are not found near the end of the exposure. The most important member is the massive limestone that usually occurs at the top of the formation. It has a variable thickness of from 25 to 100 feet, and varies in lithologic character from a massive light-brown limestone which is often fossiliferous to one composed entirely of pure white oolite.

LIMESTONE RIDGE AREA.

GENERAL DESCRIPTION.

As in the Wapanucka area, the topographic features of this region were produced by the differential erosion of strata of unequal hardness. Here again, there occur narrow, level crested ridges separated by shale valleys. The general direction of the ridges is east-west, becoming northeast-southwest in the western part of the area. The crests of the ridges lie in the peneplain of Tertiary age, and have a general elevation of 800-850 feet above sea level. The Wapanucka limestone outcrops in several of those ridges, constituting the entire ridge wherever present. If one were to stand on the northernmost outcrop of the Wapanucka in the vicinity of Arch Post-Office (7 miles southwest of Hartshorne) he would see to the north the valley formed by the Caney and Atoka shales, the level-crested ridge formed by the Hartshorne sandstone, and still farther other level-crested ridges of later Pennsylvanian age lying in the Sandstone Hills region. Lying to the south, he would see several ridges of Wapanucka limestone separated by valleys of Caney and Atoka shale and then Pine Mountain, a level-crested sandstone ridge of the Atoka formation rising to a height of 1000 to 1200 feet above sea level and forming the northern limit of the Ouachita Range proper. The topography of any one of the ridges composed of Wapanucka limestone is that of a narrow, steep-sided ridge, rising from 50 to 150 feet above the valley floor. Due to the high dip towards the southeast (usually over 50°) the massive strata stand practically on edge with soft shales occurring above and below, i. e., on each side. Differential erosion has, therefore, produced a ridge with unusually precipitous sides. Where the dip is more gentle, 30°-35°, the southeastern side is not quite so precipitous, but the edges of the massive strata, now being present in the northwestern slope instead of in the crest of the ridge, present a truly perpendicular face. It is thus seen that these ridges would, if unbroken, form practically impassable barriers. The drainage has, however, been imposed upon the strata and has cut water gaps through the ridges at frequent intervals, giving rise to easy routes of travel.

As previously noted in the chapter on structural geology, the repetition of outcrops of Wapanucka limestone in this area is due to the presence of folds that have been overturned towards the northwest and broken by strike, thrust faults. The Atoka formation which lies above the Wapanucka limestone and the Caney shale which lies below it, have been included in this folding. Their outcrops, therefore, have been repeated also. These facts are clearly brought out in figure 3, along the line B-B on Plate IV which represents a section in T. 3 N., R. 15 E. In this figure it is seen that the ridges are composed of Wapanucka limestone and that the intervening valleys are composed of shale referable to the Atoka and Caney formations. As the Caney and Atoka formations in the valleys are composed of shale with heavy coverings of residual soil, it was impossible to determine the exact positions of the major strike faults. Hence on the large map the fault lines have been drawn, roughly, midway between the limestone ridges, or, in cases where intermediate ridges have terminated to the east or west, nearer the south ridge.

The Atoka may often be distinguished from the Caney, however, by the presence, in the former, of beds of chert and sandstone. These aids were made use of in the field and it is believed that the positions of the faults as shown on the map are approximately correct.

The thickness of the Caney and Atoka strata involved in the folding is not known, first because no determination of the dip could be obtained, and second, because of the difficulty with which the shales in the two formations were differentiated. In regions in which the full thickness of the formations are exposed, the Caney shale has a thickness of 1500 feet, while that of the Atoka is given as 3100 feet in the western part of its outcrop. No conclusions may

be drawn from this data, however, as it is not known how much of each formation is involved in the folding.

The problem of determining the upper and lower limits of the Wapanucka limestone in this area is not more difficult than in the type area at Wapanucka. The Caney shale below may be recognized by its characteristic blue-black color. The Atoka formation, above, is composed of shale with ferruginous sandstone.

On lithologic grounds, the Wapanucka formation in this area may be divided into eight well defined members. The thickness of these members varies from point to point but they are present either throughout the entire length of the outcrop or a considerable portion of it. A very large number of sections were made during the course of the survey. From the data thus obtained, a diagrammatic section (figure 5) has been drawn parallel to the strike of the rocks (along the ridge) in such a way as to show the persistency of the various members in the western half of the area and the thickness of the strata at any point. This diagram may serve, in a sense, as a section of the original Wapanucka sedimentation, i. e., a section of the sedimentation before the region was elevated and folded. There may be some distortion in the diagram due to the fact that a datum plane had to be assumed. As the chert and limestone members at the top of the formation have a more constant thickness than lower members, it has been assumed that the top limestone, at least, was deposited on a nearly level surface and that the top of the formation formed a truly level plain.*

Each of the eight members will now be briefly described. For reference in future descriptions, they have been numberd and will be referred to by these numbers. The beds are numbered and discussed in order from top to bottom since the upper beds are more persistent than the lower ones.

Bed No. 1.—The uppermost member of the series is composed of massive limestone. The color of this limestone on weathered surfaces is bluish gray. Fresh exposures are very light brown to almost white. The rock weathers into a number of fantastic forms, the massive strata first breaking down into layers from one to three feet in thickness and the layers, in turn, being carved by transverse erosion into what may be likened to miniature perpendicular walled cirques. The rock is exceedingly fine-grained, hard and compact. Minute fissures filled with calcite are characteristic and

*Other features shown in the diagram, especially those suggesting unconformities, are discussed in chapter VI.

diagnostic. The rock may be recognized at once by a combination of the above characteristics, the color, massive character, calcite veination, and erosion forms being most diagnostic. The bed has a variable thickness of from 50 to 75 feet. It is scantily fossiliferous.

Bed No. 2.—The massive limestone of the first member grades downward in some places into bluish limestone containing nodules of dense, blue chert. More often, however, it passes at once into thin-bedded, siliceous, bluish-gray limestone inter-bedded with bands of dark-blue chert of equal thickness. Of the two, the chert is the more notable and conspicuous so the bed will be referred to simply as the chert member. We have, therefore, a mass of thin-bedded, dark-blue chert interstratified with beds of siliceous limestone of equal thickness. The bedding of the chert is regular, the individual beds having a thickness of from two to six inches. In quarrying for railroad ballast it may be blasted out in such a way as to expose single sheets, thousands of square feet in area. The chert itself is exceedingly pure and and dense. It is very brittle and may therefore be easily crushed. The writer did not have an opportunity to study this chert microscopically and can, therefore, make no positive statement in regard to its origin. It is fossiliferous, however, and the suggestion is made that a bedded limestone in which the individual beds had an average thickness of 12 inches was impregnated along the bedding planes by siliceous waters, the silica replacing the limestone for a distance of three inches on each side of the bedding planes. This explanation would best explain the phenomena observed in the field, especially the somewhat sinuous line of contact between the chert and limestone layers. This member has a variable thickness of from 30 to 90 feet.

Bed No. 3.—The chert is underlain by a bed of massive ferruginous sandstone. This bed although constant enough in occurrence to be ranked as a major member is very variable in thickness. South of Wilburton it forms the backbone of the ridge, forming a vertical cliff 100 feet high. At other places it is much less prominent and in some absent. Generally speaking, it is relatively unimportant in the western part but thickens notably eastward. The thickness varies from 10 to 700 feet. The average thickness west of Wilburton is less than 100 feet.

Bed No. 4.—The sandstone is underlain in places by beds of massive limestone but the next true member consists of beds of fissile, blue clay shale, having a variable thickness of from 100 to 200 feet. This shale, being bounded above and below by massive strata, frequently crops in the crest of the ridge as a longitudinal

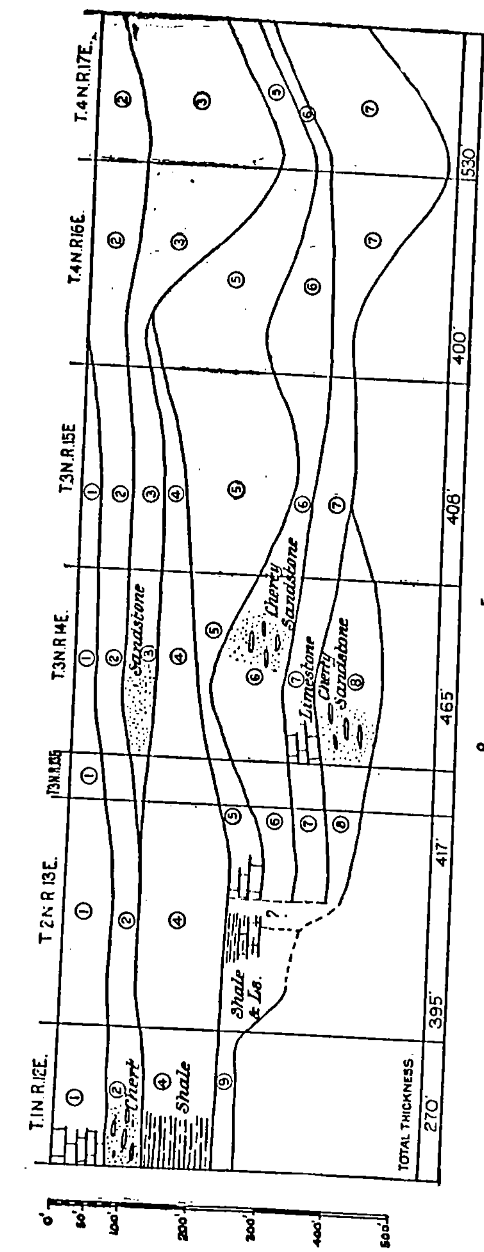


Figure 5. Diagrammatic section along the strike of the Wapanucka limestone in the western half of its outcrop.

valley, the massive strata occurring on either side. The ridge, therefore, frequently presents a U-shaped cross-section.

Bed No. 5.—Below the shale there occurs a bed of massive limestone having a variable thickness of from 5 to 170 feet. Weathered surfaces are blue-gray in color but fresh surfaces are light-brown. This member is important because of its limestone content.

Bed No. 6.—This bed is made up of cherty sandstone. It has a variable thickness of from 20 to 100 feet. It is relatively unimportant.

Bed No. 7.—This member is composed of massive, cherty limestone. It is one of the most important of the series, being one of the three important limestone members. The other two are the massive limestone occurring at the top of the formation, bed No. 1 and bed No. 5. It is extremely cherty, large masses of chert being laced through the limestone in a very irregular manner. The color of weathered surfaces is dusty gray. Fresh surfaces are dark brown. It may be easily recognized by the irregular masses of weathered chert that stand out prominently on weathered surfaces. Certain layers in this bed are extremely fossiliferous. It has a variable thickness of from 50 to 180 feet. The average is about 100 feet.

Bed No. 8.—The lowest member of the series consists of beds of cherty sandstone. This sandstone is very similar to that in bed No. 6 above. It has a variable thickness of from 30 to 100 feet.

Bed No. 9.—Beds numbers 5 to 8 are not present as such from the extreme western end of the area to a point about two miles northeast of Limestone Gap. Their place is taken by beds of hard, massive, blue limestone and shale. These beds are best exposed in the railroad cut at Limestone Gap. The member has a variable thickness of from 25 to 90 feet. For more ready reference the above description of the various members has been condensed into the following table:

Reference No.	Description.	Thickness in feet
1	Massive blue-gray limestone	50- 75
2	Thin-bedded chert and limestone inter-stratified	30- 90
3	Ferruginous sandstone	10-700
4	Fissile blue shale	100-200
5	Massive dusty gray limestone	5- 50
6	Cherty sandstone	20-100
7	Massive, cherty dusty gray limestone	50-180
8	Cherty sandstone	30-100
9	Massive blue limestone, blue shale, and ferruginous sandstone	25- 90
	Total thickness of formation	250-800

The diagram, figure 5, brings out clearly the longitudinal extent of the various members. The following facts should be emphasized:

The important limestone members are beds Nos. 1, 5, and 7. The only other important member, economically speaking, is the chert, bed No. 2. From the western end of the area to a point two miles northeast of Limestone Gap, bed No. 1 is the only important limestone found in the quarry at Chockie. From the point two miles northeast of Limestone Gap to Arch in section 11, T. 4 N., R. 16 E., beds Nos. 1 and 5 are of equal prominence. From this point to Gaines Creek, beds Nos. 5 and 7 constitute the important limestone members. East of Gaines Creek but one limestone member occurs. This should probably be correlated with bed No. 5. Beds Nos. 5 and 7 are exposed in the quarry at the cement plant near Hartshorne.

The strata in this area appear, at first sight, to be quite different from those exposed in the type area at Wapanucka. A closer examination, however, shows that there are at least two points of similarity. The massive limestone beds at the top of the formation in each area are quite similar, both being heavy, massive, and light brown in color. In sections 9 and 16, T. 2 S., R. 8 E. the siliceous beds underlying the limestone were found to contain thin-bedded cherts. These cherts are quite similar to those found in the Limestone Ridge area.

Generally speaking, the limestone strata in Limestone Ridge are non-oolitic. At two points, to be described later, beds of oolite, 10 to 20 feet in thickness were found. At rather frequent intervals beds from 1 to 3 feet in thickness were noted. These oolitic lenses occur in beds Nos. 1 and 5.

With the above introductory remarks a detailed description of the strata in Limestone Ridge may be taken up.

TOWNSHIP 1 NORTH, RANGE 12 EAST.

The Wapanucka limestone occurs in this township as a narrow, steep-sided, level-crested ridge. The sinuous outcrop attests to the contorted condition of the strata, the region having been subjected to intense folding and faulting. The structure is clearly shown in the cross-section figure 2. The outcrop lies in the southeastern limb of an anticline that has been overturned towards the northwest and broken by a strike, thrust fault, in this case the Choctaw fault. The strike of the rocks follows the sinuous outcrop, the change in direction at times amounting to as much as 90° (example section 15). The strata dip at very high angles towards the southeast, the dip amounting in places to 80°

The following section was made in the quarry at Chockie, where the strata are well exposed.*

Section in sec. 1, T. 1 N., R. 12 E.

Bed No.	Description	Thickness in feet
1	Limestone	70
	Oolite	3
2	Chert	43
	Contorted, semi-oolitic, argillaceous, blue limestone	15
4	Shale	115
9	Ferruginous sandstone	15
	Blue limestone	5-10
	Total	271

The quarry at Chockie is described in the chapter on Economic Geology.

TOWNSHIPS 2 AND 3 NORTH, RANGE 13 EAST.

In these townships the first instance noted of a repetition of Wapanucka outcrops occurs. This repetition, as has been previously described, is due to close folding accompanied by faulting parallel to the strike of the rocks. The thinning of the two northernmost ridges is accounted for by a swerving of the fault in such a way as to truncate the strata. The southernmost outcrop has been terminated by this fault. To account for the termination of the middle outcrop in section 1, cross faulting must be appealed to. As has been previously explained, the ridges which terminate here are to be regarded as narrow anticlines which plunge at each end. In this instance it is believed that the ridges have been terminated by faulting but that this faulting has occurred near the points where the anticlines would have plunged under younger strata even though the faulting had not occurred. This interpretation requires some crumpling of the strata beyond the termination of the outcrops.

The northernmost ridge has been broken locally by cross faults, as noted on the map. The dip is usually very high towards the southeast in many instances approaching 90°. In one locality (section 3) the dip exceeds 90° to the southeast, the fold being overturned with the strata dipping 68° towards the northwest. This was the only instance in which a southeastern limb was noted to

*The bed numbers refer to the descriptions of the various members already given. This system will be used in all sections given for this area. Unnumbered beds represent local phases of sendimentation.

dip in this manner. This occurrence is probably tied up with the twisting to which the strata have been subjected as is evidenced by the cross faulting.

The topography of the northernmost ridge through sections 31 and 29 is similar to that in township to the southwest. In section 21, however, the lowermost member, bed No. 9, is replaced by beds 5 to 8 which consist of massive limestone and cherty sandstone strata. From this point northeastward to Brushy Creek, a distance of 12 miles, the ridge has a U-shaped cross-section due to the fact that the shale member, bed No. 4, which lies in the crest of the ridge, forms a valley flanked by hard limestone strata.

The northernmost ridge, which is the most important and prominent of the several outcrops is known as Limestone Ridge. It extends as a single unit from sec. 22, T. 1 N., R. 12 E. to sec. 2, T. 3 N., R. 15 E., a distance of 25 miles. From this point eastward to Gaines Creek, the ridge immediately to the north is known as Limestone Ridge. This unit has a length of 17 miles. From Gaines Creek eastward to the end of the exposure the single outcrop bears this name, this unit having a length of 25 miles. Two sections will be given. The first is from Limestone Gap in section 31, where an excellent section is exposed in the railroad cut.

Section at Limestone Gap, sec. 31, T. 2 N., R. 13 E.

Bed No.	Description	Thickness in feet
1	Limestone	65
	Oolite	3
2	Chert	30
4	Shale	200
9	Fossiliferous limestone	5
	Hard blue siliceous shale	9
	Hard blue limestone	3
	Hard blue siliceous shale	9
	Hard blue sandy limestone	18
	Hard blue shale	3
	Hard blue limestone	8
	Hard blue shale	6
	Hard blue limestone	8
	Hard blue shale	4
	Hard blue limestone	12
	Hard blue shale	3
	Hard blue limestone	3
	Hard blue shale	6
	Total	395

Below bed No. 9 occurs blue shale with ironstone concretions which are characteristic of the Caney shale.

Strata similar to bed number 9 do not occur elsewhere in the Wapanucka formation. The relation that this bed bears to the rest of the Wapanucka and to the Caney shale is discussed in chapter VI. (See also fig. 8).

The second section was made in section 10 at the point where Ward's Creek crosses the ridge.

Section at Ward's Creek, sec. 10, T. 2 N., R. 13 E.

Bed No.	Description	Thickness in feet
1	Limestone	70
2	Chert	30
4	Shale	135
5	Limestone	52
6	Cherty sandstone	130 (beds 6–8, bracketed)
7	Limestone	
8	Cherty sandstone	
	Total	417

In sec. 36, T. 3 N., R. 13 E. the massive sandstone, bed No. 3, apears and is present as a member of variable thickness from this point to the east end of the exposure.

TOWNSHIP 3 NORTH, RANGE 14 EAST.

In this township the Wapanucka limestone is exposed in three outcrops. The topography is typical, the narrow limestone ridges being separated by flat valleys composed of Caney and Atoka shale. Just to the south of Pittsburg, the northernmost ridge is broken by a thrust cross fault which is almost parallel to the strike of the rocks. This was one of the best examples of minor faulting noted during the course of the survey, the phenomena observed being clear and evident. The middle ridge has suffered cross faulting in section 33.

The valley between the first and second ridges, from the north, is wider than those farther east due to the fact that an intermediate ridge is not present. It is thought that the resulting broad exposure of Atoka shale is due to minor folding. The Atoka shale can be distinguished from the Caney to some extent in this locality, due to the presence of cherty, sandy beds that form little hillocks in the Atoka outcrop. Cherty beds between Limestone Ridge and Pittsburg also help to differentiate the Atoka from the Caney in that locality. The following section was made on Limestone Ridge just south of Pittsburg:

Section in NE. 1-4 sec. 29, T. 3 N., R. 14 E.

Bed No.	Description	Thickness in feet
1	Limestone	30
2	Chert	38
	Limestone	38
3	Sandstone	23
4	Shale	69
5	Limestone	14
6	Cherty sandstone	108
7	Cherty limestone	46
8	Cherty sandstone	100
	Total	466

TOWNSHIP 3 NORTH, RANGE 15 EAST.

In this township the repetition of strata is typical, the structure being clearly shown in the cross-section figure 3, along the line B-B on Plate IV. The second and third ridges, counting from the north, are terminated along the strike by faulting.

An interesting structural feature is to be noted in section 17. Here the outcrop in the north ridge has been thickened by faulting. The faulted portion forms a complete anticline which plunges towards the west. The dip of the strata is shown by the arrows. A very fine bed of blue oolite containing large crystals of calcite was noted near the west end of this anticline at the point where the road from Blanco crosses Brushy Creek. The bed measures about 10 feet in thickness but is of small extent.

In section 11, Arch Creek, instead of flowing through the second ridge from the north in a valley, passes under a picturesque natural bridge. Brushy Creek cuts transversely across the ridges in a manner characteristic of drainage that has been superimposed on the strata. The divide between the Arkansas and Red rivers lies just to the west of Brushy Creek, this stream being a tributary of the Arkansas River.

The following section was made on the north ridge in section 10:

Section on North Ridge, sec. 10, T. 3 N., R. 15 E.

Bed No.	Description	Thickness in feet
1	Limestone	26
2	Chert	50
3	Sandstone	50
4	Shale	30
5	Limestone	170
6	Cherty sandstone	27
7	Cherty limestone	55
	Total	408

The points to be noted in this section are the increased thickness of bed No. 5 and the disappearance of bed No. 8.

TOWNSHIP 4 NORTH, RANGE 16 EAST.

It is in this township that the maximum number of outcrops occur, as many as five being noted. Another point to be noted is the change in direction of the outcrops from northeast-southwest to east-west. Prominent knobs occur on the ridges at the points where the change in direction takes place. This is probably due to the squeezing of the strata thus increasing their ability to withstand erosion. The massive limestone members, beds Nos. 5 and 7, have become so prominent as to cause the ridges to become most striking topographic features, their crests rising in places 200 feet above the valley floors. The southern slopes of the ridges are variable in steepness due to the changing value of the dip of the strata. The northern slopes, however, being made up of the edges of bed No. 7, which now constitutes the basal member, presents a truly perpendicular wall of massive limestone.

To the east of Blue Creek, in sections 26 and 27, there appear suddenly mountainous masses of sandstone, probably of Atoka age. Younger strata are to be expected to occur here due to the plunging of the Wapanucka strata, but such a marked change could hardly be brought about without the added assistance of cross faulting.

A subdued sandstone ridge occurs in the valley between the first and second ridges from the north, extending from Arch Post Office in section 31 to Gaines Creek in the next township. It becomes quite prominent in section 17 of the next township, culminating here in a prominent sandstone knob. This sandstone bed should probably be referred to the Atoka formation. The broad outcrop of the Atoka formation in this valley is probably due to minor folding, but may be due, in part, to the thickening of the formation toward the east.

The following section was made in the north ridge in section 31 at the point where Short Creek cuts through the ridge.

Section on North Ridge, sec. 31, T. 4 N., R. 16 E.

Bed No.	Description	Thickness in feet
		60
2	Chert	30
3	Sandstone	10
4	Shale	170
5	Limestone	100
6	Shale and sandstone	30
7	Limestone	——
	Total	400

PLATE V

A.

B.

The point to be noted in this section is the disappearance of the massive limestone member, bed No. 1. This member is still present, however, in some of the ridges to the south.

TOWNSHIP 4 NORTH, RANGE 17 EAST.

But two of the five outcrops described in the last township extend into township to the east. The northern outcrop is very broad and prominent in the western part of the township, but becomes thinner eastward. The sandstone member, bed No. 3, becomes very prominent in the southern ridge, making up nearly the entire outcrop in the eastern half of the township.

Both ridges are terminated abruptly at Gaines Creek by cross faulting, the strata not being found on the east bank of the stream

A very interesting structure occurs in sections 10 and 11. As is indicated by the arrows, representing the dip of the strata, ther occur here two synclines, separated by an anticline with all thre structures plunging towards the west. It is believed that th southernmost part of this structure lies in the north limb of th overturned fold of which the main north ridge forms the souther limb. Due to a tilting of the north limb of the fold towards the west after the rupture had occurred, the throw on the fault plane was not great enough to conceal the Wapanucka strata lying in the north limb of the fold at this point A bed of very good oolite, 20 feet in thickness, occurs in this structure in proximity to the Chicago, Rock Island and Pacific Railway. The beds are so contorted, due to the structural features, however, that the bed is of but little value.

An outcrop of the Wapanucka starts in the north-central part of section 11 and continues eastward into the next township.

Economically, an interesting feature in this township is the large plant of the Choctaw Cement Company, situated in section 18 at the point where Blue Creek cuts through the north ridge. This plant is fully described in the chapter on Economic Geology.

The following section was made near the cement plant in the northwest quarter of section 18.

Section in NW. 1-4 sec. 18, T. 4 N., R. 17 E.

Bed No.	Description	Thickness in feet
		80
2	Chert	200
3	Sandstone	50
5	Limestone	20
6	Sandstone and shale	180
7	Cherty limestone	
	Total	530

The point to be noted in this section is the disappearance of the shale bed No. 4.

TOWNSHIPS 4 AND 5 NORTH, RANGE 18 EAST.

In these townships the outcrop of the Wapanucka limestone occurs as a single ridge which has but slight relief.

A heavy bed of massive sandstone, whose outcrop is erroneously called Limestone Prairie, parallels the ridge, lying about a quarter of a mile to the north of it. This sandstone bed is thought to represent the Atoka strata which lie in the north limb of the overturned faulted fold in the southern limb of which the Wapanucka outcrop occurs. The displacement here has been great enough to conceal the Wapanucka strata in the north limb. Farther east, this is not the case.

The folowing section was made in section 6 of Township 4 North:

Section in sec. 6, T. 4 N., R. 18 E.

Bed No.	Description	Thickness in feet
3	Sandstone	235
5	Limestone	122
	Total	357

The strata in this ridge cannot be definitely correlated with those in the area to the west. They have been correlated tentatively with beds 3 and 5 on lithologic grounds as they appear to be similar to them. It is to be noted that the sandstone member, bed No. 3, is now the prominent member. To the east it becomes even more so.

TOWNSHIP 5 NORTH, RANGE 19 EAST.

In this township the massive sandstone member, bed No. 3, constitutes a striking topographic feature, the northern slope presenting a vertical wall 250 feet high. Such a feature gives the ridge a truly mountainous aspect. About one-fourth of a mile north of this ridge, fragmental strata of limestone and sandstone were found, standing practically on edge. These were interpreted as representing Wapanucka strata lying in th north limb of the overturned faulted fold, the throw on the fault plane not having been great enough to conceal them.

The folowing section was made in section 22:

Section in sec. 22, T. 5 N., R. 19 E.

Bed No.	Description	Thickness in feet
3	Sandstone	255
5	Limestone	135
6	Sandstone	43
	Total	433

In this township the sandstone member increases to enormous proportions, a thickness of 700 feet being recorded. The fragmental exposures were still noted to the north.

By the time section 23 is reached the strike fault is thought to have died out, and the increased thickness to represent both limbs of the overturned fold. The following section was made on the township line between ranges 19 and 20:

Section on line between secs. 19 and 20, T. 5 N., R 19 E.

Bed No.	Description	Thickness in feet
3	Sandstone	700
5	Limestone	94
6	Sandstone	?
	Total	794

TOWNSHIP 5 NORTH, RANGE 20 EAST.

The northern outcrop, in this township, has a maximum exposure of 2100 feet with a total thickness of 1270 feet. This great thickness is accounted for by the fact that both limbs of an overturned fold occur, thus causing a repetition of strata. This fact is brought out clearly by the following section which was made in section 24 of the last township:

Section in sec. 24, T. 5 N., R. 20 E.

Bed No.	Description	Thickness in feet
3	Sandstone	490
5	Limestone	114
6	Sandstone	235
5	Limestone	50
3	Sandstone	380
	Total	1269

This would give a thickness cf 650-700 feet at this point.

Farther east the anticline narrows considerably and finally plunges under younger strata. Two very interesting structures occur in the southern exposures in this township and the one immediately to the west. Here there occur two small anticlines each of which plunges to the east and to the west. The westernmost anticline has been broken by a fault in such a way as to conceal a large part of the northern limb. The larger fold to the east is more perfect, although even here the northern limb is somewhat fragmentary. The crests have been eroded away in such a manner as to expose the Caney shale which occurs as valleys between the limestone strata exposed in the limbs of the folds. Both folds have been overturned toward the north as indicated by the southerly dip of the strata in the northern limbs. That the structure is anticlinal was definitely determined by noting a repetition of strata in inverse order.

In the township immediately to the east several narrow ridges occur that have very much the same appearance as the ridges of Wapanucka limestone that have been described in this chapter. Still farther east similar ridges may be traced as far as the Arkansas line. The belief has been prevalent, therefore, that the Wapanucka limestone extends eastward into Arkansas. Upon examination these ridges were found to be composed entirely of sandstone. Further, this sandstone is of an entirely different lithologic character from that found in the Wapanucka formation, the structure being either thin-bedded or markedly concretionary, while that in the Wapanucka is massive. The structure of this sandstone is similar to that found in younger strata to the south. It has therefore been interpreted as being younger than the Wapanucka, most probably of Atoka age.

The writer made a reconnaissance to the east as far as the Arkansas line but was unable to find any trace of Wapanucka strata. Farther east, in the Ouachita Mountain region of Arkansas, the Atoka formation lies directly on Jackfork sandstone of Mississippian age, thus indicating that the Wapanucka limestone dies out and that the Caney shale is not present in that locality.

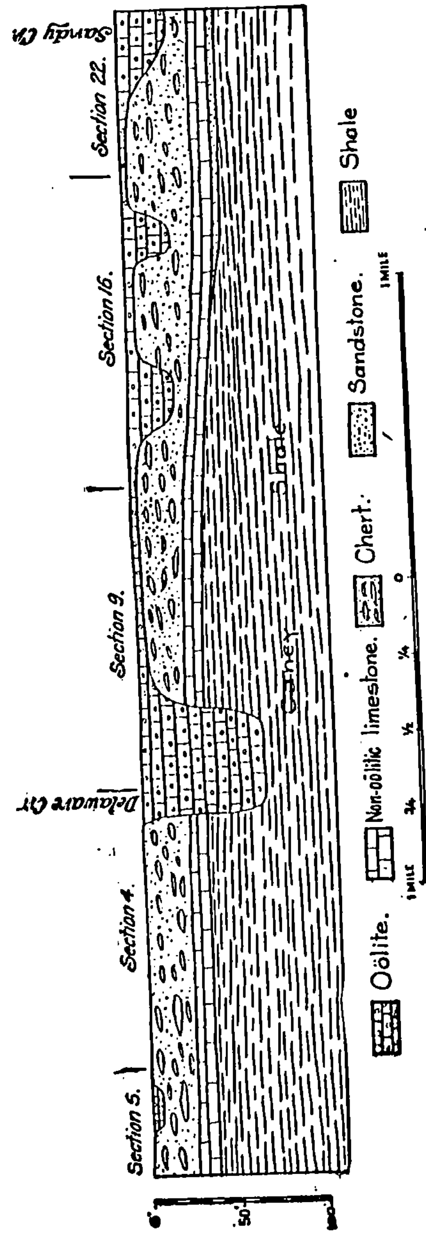


Figure 6. Diagrammatic section along the strike of the Wapanucka limestone in T. 2 S., R. 8 E.

CHAPTER VI.

UNCONFORMITIES WITHIN THE WAPANUCKA FORMATION.

Evidences of an angular unconformity were noted in T. 2 S., R. 8 E. This fact was deemed of sufficient geologic importance to warrant the devotion of a separate chapter to it. Evidences of other unconformities will also be discussed.

In all of the preceding discussion, statements relating to the general geology of the region, (and to the limited areas of individual formations outside of the Wapanucka thus far published upon) have been adapted from the writings of previous workers in this area, especialy those of Mr. J. A. Taff. Mr. Taff's conclusions in regard to the structural features have, in general, been accepted by the writer without question, as many facts corroborating these conclusions were noted in the field. In the present chapter, the writer wishes to call attention to certain stratigraphic features that have not been described up to this time, and to express his opinion in regard to the age of the Wapanucka formation.

UNCONFORMITY AT THE BASE OF THE BROWN LIMESTONE MEMBER.

In both the Wapanucka and Limestone Ridge areas, the Caney shale, Wapanucka limestone, and Atoka formation have been described by previous writers as succeeding each other conformably in the order named. So far as the writer has been able to learn, this conclusion has been based on the fact that the strata in the three formations have the same general dip. Although the contacts between the formations may, in most cases, be determined to within a few feet, true contacts in unweathered rock are of but rare occurrence due to the presence of residual soil and talus. When the strata included in the Wapanucka formation are considered, however, definite evidences of an angular unconformity were noted in T. 2 S., R. 8 E. This fact is clearly brought out in figure 6 which represents a section drawn parallel to the strike of the rocks (along the ridge) in sections 9, 16, and 22. The data for making the section were obtained by a study of the west slope of the ridge where the strata are well exposed. The following facts were noted:

The following section was made in section 22 of T. 2 S., R. 8 E. at the point where Sandy Creek cuts through the ridge.

Section in sec. 22, T. 2 S., R. 8 E.

Description	Thickness in feet
Oolite	5
Massive, light-brown limestone	25
Sandstone	10
Fossiliferous limestone	10
Sandstone	5
Shale to base	?
Total	57+

The oolite should be considered as a local phase of the massive, light-brown, limestone member as many instances were noted throughout the exposure in which the massive limestone was found to grade, both vertically and horizontally into the oolite. Instances were also noted in which they were found to be interbedded. This fact will be found of importance in the following discussion as it shows the relation that the oolite bears to the massive, light-brown limestone.

In section 16 the sandstone bed underlying the brown limestone becomes very cherty and finally grades into a bed of pure chert. The beds underlying the fossiliferous limestone are soon lost to view due to the presence of talus. As they are not found farther north, they probably die out in this section. At two points in section 16, as noted in figure 9, the massive brown limestone member lies unconformably upon the chert. In each instance the limestone is oolitic. In the northernmost of the two, the oolite is interbedded with brown non-oolitic strata. In the south half of section 9, the chert is very prominent, the brown limestone member, which is here composed entirely of oolite, being reduced to a bed 5 feet in thickness.

In the northeast quarter of section 9 the oolite thickens within a short distance to about 10 feet. About a quarter of a mile south of the point where Delaware Creek breaks through the ridge, the chert and fossiliferous limestone terminate suddenly along the strike, their place being taken by the massive bed of oolite which here has a thickness of 70 feet. As the entire formation just south of this point is certainly less than 40 feet in thickness, it is evident that the oolite has replaced some of the Caney shale also. It is very evident, therefore, that the oolite here lies unconformably on the chert, the fossiliferous limestone, and the Caney shale. In the gorge cut by Delaware Creek the Caney shale, with its characteristic ironstone concretions, was observed to underlie the oolite. This conditon maintains northward into the southern part of section 4, where the fossiliferous limestone and chert appear again as suddenly as they disappeared in the last section. Here the chert extends to the top of the formation. In the northeast quarter of section 5 a small amount of brown limestone was noted, lying above the chert.

It is thus seen that the oolite was deposited in a basin-shaped depression, and that it rests unconformably on underlying strata. This unconformity was not traced for any great distance. It may be only local but may be co-extensive with the formation. Where observed it is at the base of what may be called the oolite-brown limestone member. This member occurs at the top of the formation and extends throughout the area.

LIMESTONE BRECCIA AT DELAWARE CREEK.

In the small area (2000 feet north and south) in which the principal basin-shaped deposit of oolite occurs, other local beds aggregating 25 feet in thickness occur. The following section was made at this point, namely, at the point where Delaware Creek breaks through the ridge:

Section at Delaware Creek in sec. 9, T. 2 S., R. 8 E.

Description	Thickness in feet
Limestone breccia	2
Fossiliferous blue limestone	20
Sandstone	5
Oolite	70
Total	97

The local beds occurring above the oolite are not shown in the section, figure 9. The uppermost foot or two of these deposits consists of a breccia of very great geological significance. This breccia is composed of highly angular fragments of a very dense light-gray to white limestone similar in appearance to the Arbuckle limestone. Particles of pyrite occur very abundantly within this dense limestone. There are also present fragments of an oolite which is very different from the Wapanucka oolite proper. The oolitic particles are very small, not exceeding one-third of a millimeter in diameter. They are very perfect and have well defined nuclei. The particles are not in contact but are imbedded in a fair amount of matrix. Both the nuclei and matrix consist of calcium carbonate.

The particles in the Wapanucka oolite, on the other hand, are large (one-half to one and one-half millimeters), have grown in such a way as to interfere with each other, and have but a very small amount of matrix.

The oolite in the breccia is so fine grained that the weathered surface can hardly be seen to be oolitic even with the aid of a lens. A polished surface, however, brings out the details clearly.

The only oolite described as occurring below the Wapanucka, is found at the base of the Chimneyhill limestone. The oolite occurring in the Chimneyhill limestone was examined by the writer and found to be coarser grained than that found in the breccia, being at times even pisolitic. The oolite found in the breccia may be of Chimneyhill age or may belong to another formation (Viola or Arbuckle limestone) the oolitic character of which, due to the fine grain of the rock, has been overlooked.

The fragments in the breccia, both oolitic and non-oolitic, vary in diameter from a millimeter to two or three centimeters.

The surfaces, and in some cases the entire mass of the fragments have been oxidized and iron-stained as though they had lain for a long period of an arid region. They have been cemented together with a ferruginous cement which gives a highly oxidized appearance to the rock.

Interpreting the above, it seems to the writer that strata, varying in age from Chimneyhill limestone to Arbuckle limestone, were above the sea, and were subjected to erosion during the time of the deposition of the Wapanucka limestone; that the angular particles accumulated at the base of a cliff, and lay exposed for a long period in an arid climate; that they were washed, probably by torrential action, such as would be prevalent in an arid region, into the not far distant sea and here cemented with a ferruginous cement. Such a history would not involve much rolling of the particles and would thus account for their highly angular character. The very sinuous character of the unconformity at the base of the oolitic bed in the Wapanucka formation would also indicate that the climate was arid.

The above interpretation is in accord with that of Taff to the extent that the western part of the Arbuckle Mountain region is thought to have been above the sea during the time of the deposition of the Wapanucka limestone.

UNCONFORMITY AT THE TOP OF THE WAPANUCKA FORMATION IN THE WAPANUCKA AREA.

The non-occurrence of oolite in sec. 4, T. 2 S., R. 8 E., requires explanation. Either oolite was never deposited here or it was removed by erosion before the Atoka shale was deposited. The latter method would require an unconformity between the Wapanucka and Atoka formations. The writer advances the following (additional) evidence to show that an unconformity probably does occur.

In the SE. 1-4 of sec. 32, T. 1 S., R. 8 E., no outcrop of the Wapanucka could be found. Here, the Atoka shale apparently rests upon the Caney shale. A similar occurrence was noted in the NE. 1-4 of sec. 9, and in the NW. 1-4 of sec. 10, T. 1 S., R. 8 E. It would seem, therefore, that the entire Wapanucka formation was removed by erosion at these points before the Atoka formation was deposited. The points at which no outcrops of the Wapanucka formation were noted have been indicated on the map by dotted lines. If this unconformity does occur, it probably does not extend beyond the Wapanucka area.

No evidences of an unconformity were noted at the base of the Wapanucka formation in the Wapanucka Area. A study of the sections given in chapter V shows that sandstone and shale strata occur in the southern half of the area that are not present in the northern half. This may be explained by assuming that the southern half of the area lay nearer the shore. In a direction perpendicular to the strand line it should be possible to pass from sandstone to shale and limestone within a very short distance.

In taking account of the angular unconformity that occurs at the base of the oolite, the writer suggests the possibility of correlating the oolite (and the brown limestone of which the oolite is a local phase) with the Franks conglomerate, and the part lying below the unconformity with the Glenn formation.

UNCONFORMITIES IN THE LIMESTONE RIDGE AREA.

Figure 5 was constructed by placing a large number of columnar sections side by side. The figure thus represents a cross-section of the original Wapanucka sedimentation. In view of the fact that the vertical scale is 125 times the horizontal, the irregularities are much less than the figure would seem to indicate.

There are, however, evidences that at least one unconformity exists in this area. In T. 2 N., R. 13 E., (see figure 5), the beds change along the strike from blue limestone and shale strata (bed number 9) into limestone and cherty sandstone strata (beds 5 to 8) of an entirely different nature. Such phenomena indicate the existence of an unconformity. The strata composing bed number 9 are unlike anything found elsewhere in the Wapanucka formation; nor are they similar to strata described as occurring at the top of the Caney shale.

The above described phenomena may be interpreted in two ways: Either bed number 9, having been deposited as the basal member of the Wapanucka formation, was later largely removed by erosion, or it represents sediments that were deposited in a very limited area. Either interpretation would demand an unconformity at the top of the Caney shale to the east of R. 13 E. The former interpretation seems to be the more probable.

The possibility of an unconformity occurring between beds 3 and 5, is indicated by the absence of beds number 4 to the east of R. 16 E. Due to the absence of bed number 3, an unconformity may exist between beds 2 and 4 to the west of R. 14 E. The absence of these strata may, however, be explained by appealing to a shifting of the strand line, so that the evidences of unconformities in these cases are much less clear.

If the massive limestone occurring at the top of the Wapanucka formation in the Limestone Ridge area is to be correlated with the limestone which occupies an analogous position in the Wapanucka area, it is evident that the unconformities described as occurring in the Limestone Ridge area lie below those occurring in the Wapanucka area, and that no relation exists between them. As described below, it is believed that the strata occurring in each area were deposited near their respective shore lines. Minor oscillations, resulting in elevation and erosion, could therefore occur in one area without affecting the strata in the other area. Such a sequence of events would give rise to an unconformity in one area, while no unconformity would occur in the other.

The columnar sections from which figure 5 was constructed were measured on the northernmost outcrop of the Wapanucka formation, the same being locally known as Limestone Ridge. When the Wapanucka outcrops lying immediately to the south of Limestone Ridge were examined, it was found that not all of the members shown in figure 8 were present, beds no. 1 and 2 being the only ones that were persistently present. This fact may be explained by the following: The Wapanucka formation does not occur to the south of Pine Mountain which lies just to the south of the area here described. Both the Caney and Atoka shales do occur. This would indicate that the shore of the Wapanucka sea lay in the vicinity of Pine Mountain, and extended practically parallel to the present outcrops of the Wapanucka formation. In a direction at right angles to the strand line, the character of the sediments would be expected to change within short distances. As the Wapanucka outcrops occur at different distances from the shore, the same kind of strata would not be expected to occur in each.

AGE OF THE WAPANUCKA FORMATION.

In concluding this chapter, the writer would like to express his

personal opinion in regard to the age of the Wapanucka formation, and to state the conditions under which its strata were probably deposited.

In taking up work in this area, the writer has accepted the formational units as defined by J. A. Taff in the Atoka and Coalgate folios of the Geological Atlas of the United States. In these folios the age of the Wapanucka limestone is earliest Pennsylvanian. In Bulletin No. 377 of the United States Geological Survey, G. H. Girty has decided that the age of the Caney shale is late Mississippian. The fossils upon which this decision was made were obtained from near the base of the Caney shale. It is not known, therefore, whether the upper part of the Caney shale represents strata of Mississippian or of Pennsylvanian age. The writer wishes to call attention to the fact that the Caney formation (which lies below the Wapanucka) is composed of 1500 feet of shale, indicating a period of long duration during which the conditions of sedimentation were uniform. The Atoka formation, which lies above the Wapanucka, is composed of very thick deposits of shale, separated by relatively thin deposits of sandstone, indicating fairly constant conditions of sedimentation during a long period of time. In the Wapanucka formation, on the other hand, there occur within the short vertical range of 100 to 500 feet, repeated transitions from limestone to shale and sandstone, and back again. Such sedimentation would indicate repeated and rapid changes of level in the nearby landmass with alternate deposition of terrigenous and clear-water sediments.

A period of such rapid oscillations, occurring between periods of long continued quiescence may well seem to mark the transition from one geologic period to another. The Wapanucka strata are therefore thought, by the writer, to represent a transition series being composed of late Mississippian and early Pennsylvanian age.

CHAPTER VII.

ECONOMIC GEOLOGY.

STRUCTURAL STONE.

OOLITE.

One of the principal reasons for undertaking a study of the Wapanucka limestone was to determine the nature and extent of the oolite. Comparative tests have shown this stone to be the equal of any structural or ornamental oolitic limestone known. Its value, therefore, becomes at once apparent.

DISTRIBUTION.

Deposits of oolite of commercial value occur only in the Wapanucka Area.

As has been stated in chapter VI, the oolite is to be considered as a local phase of the massive limestone member that occurs at the top of the formation. The deposit has a variable thickness of from 5 to 70 feet and extends from Sandy Creek in T. 2 S., R. 8 E. to the end of the exposure in T. 1 N., R. 8 E. The deposit will be described by townships, starting at the southern end.

Township 2 South, Range 8 East.

By far the most important deposit in the area occurs in this township, namely, the massive, basin-shaped deposit occurring in sections 4 and 9, at the point where Delaware Creek breaks through the ridge. The thickness and extent of the oolite in this township is shown in figure 6. The thickness is seen to be very variable. Starting as a thin bed, 5 feet in thickness at Sandy Creek, it extends as a continuous bed northward through sections 15, 16, 9, and 4. At two points in section 16, basin-shaped deposits 20 feet in thickness occur. The only deposit of economic importance in the township, occurs in sections 4 and 9. Here, there occurs a massive bed of oolite 70 feet in thickness. This deposit extends from a point 1300 feet south of Delaware Creek to a point about 500 feet north of the Creek. The limits of the deposit can be determined very accurately by a study of the west slope of the ridge where the strata are well exposed. At the limits of the deposit, the oolite is found to lie unconformably on deposits of thin-bedded chert.

The strata dip gently, 7° to 10°, towards the east, a fact of great importance from a quarrying standpoint. Delaware Creek has cut a gorge through the ridge at this point, exposing the oolite in perpendicular walls.

Quarry of the Bromide Oolitic Stone Company.

The Bromide Oolitic Stone Company owns all of the oolite in the vicinity of Delaware Creek, and is operating a quarry and mill in the gorge above referred to. A branch of the Missouri, Oklahoma, and Gulf Railroad has been built to the quarry and extended to the town of Bromide, one and one-half miles to the northwest. With an abundance of water, ideal quarrying conditions, and up-to-date mill, the company is in a position to turn out large quantities of dressed and ornamental stone at a minimum cost. Two views in the quarry are shown in Plate VI.

In the quarry, practically no stripping is required, as the local beds occurring above the oolite have been largely removed by erosion. Both steam and electric channellers are used, and blocks of any size may be cut. After three sides of a block have been cut, pins are driven under it, and the block is pulled up, breaking parallel to the incipient bedding planes. The nearly horizontal dip of the strata is therefore seen to be of great practical importance from a quarrying standpoint.

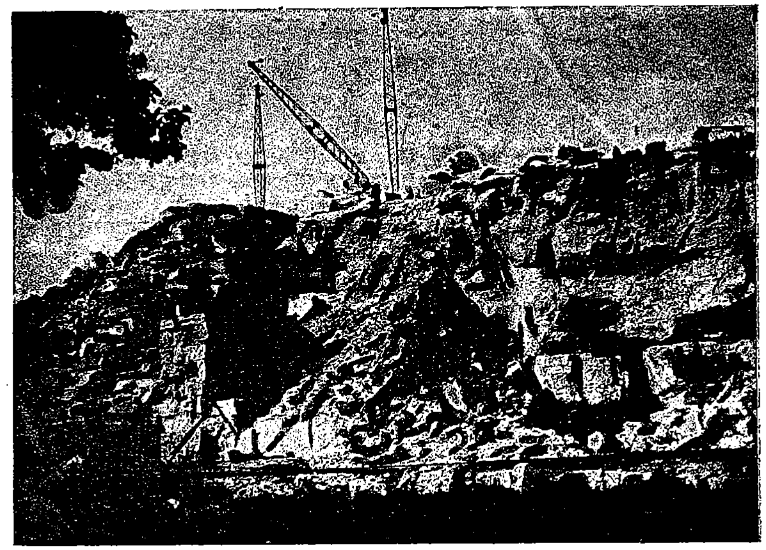
Although the deposit has a thickness of 70 feet, only the lower 40 feet are used for high grade structural stone. The rest is being set aside to be used for such purposes as demand may require.

The mill is equipped with a 300 horse-power steam engine, 2 traveling cranes, 4 gang saws, 2 diamond rotary saws, 4 horizontal planers and 1 rotary planer. A large dynamo furnishes electricity for light and power. It is thus seen that nothing is left to be desired in the way of equipment.

The stone is of a uniformly fine texture and may be easily milled and carved for use as a high grade ornamental stone. It may be polished for use as a marble, the oolitic texture yielding a very pleasing effect. When taken from the quarry the stone is dark in color. In a very short time, however, it bleaches to a chalk white and remains so permanently. From an aesthetic standpoint, this may be said to be its most distinctive and valuable quality. Many high grade oolitic limestones, as is well known, soon become dark, and assume a cement color. The dead white of the stone is relieved by a subdued blue veination which adds a pleasing quality.

The following comparative analyses with other well-known oolitic limestones were furnished by the company:

PLATE VI



A.

B. TWO VIEWS OF QUARRY OF BROMIDE OOLITIC STONE COMPANY NEAR BROMIDE.

Comparative Analyses of Bedford, Ind., Bromide, Okla., and Bath, England, limestones.

	Bedford, Ind.	Bromide, Okla.	Bath, Eng.
Calcium carbonate, $CaCO_3$	96.80	97.83	97.52
Magnesia, MgO	.11	.49	2.50
Iron, FeO	.91	.52	1.20
Silica, SiO_2	.70	.80	.00
Sulphuric acid H_2SO_4	.20	----	----
Alkali	.32	----	----
Moisture	.92	.10	1.78
Total	99.96	99.74	103.00
Compression strength	5750	7540	7200

Far be it from the intent or desire of the writer, by presenting the above comparative analyses, to attempt to belittle the qualities of the Bath or Bedford stones. In point of uniform texture, uniform hardness, and color (the three most essential qualities of an ornamental stone), however, the Bromide stone is believed to be superior to the Bedford. As will be described later, the Bromide stone is a true oolite while the Bedford is not. In point of durability neither stone may be said to possess an advantage over the other. It may be stated with confidence that the life of either stone will be found to be much longer than that of any building for which it may be used. In the 21st Annual Report of the Indiana Department of Geology and Mineral Resources for 1896, T. G. Hopkins has stated that the stone found in buildings 50 years old (year 1896) appeared to be in as good condition as when the structure was built. An equally good record has been established for the Bromide stone in the case of the Chickasaw Rock Academy which is located near the quarry of the Bromide Oolitic Stone Company. The stone in this building, which was erected more than 60 years ago, still bears the marks of the dressing tools.

Before passing to the description of other deposits, it may be well for the writer to state what uses could be made of the upper 30 feet of this deposit, which is at present considered as waste, or is used only as a low grade stone. Practically no use is made of this material at the present time.

The Bromide company has recently installed an Austin gyratory crusher in anticipation of receiving orders for crushed stone to be used for railroad ballast and road metal. In the opinion of the writer, this stone should not be used for road material as it is too soft. The Viola limestone, about which more will be said later, is much better adapted for this purpose. There are, however, many

purposes for which this stone could be used, and to better advantage. The chemical analysis given above shows it to be practically iron-free and very low in magnesium. It would, therefore, make an excellent lime. It should, however, be hydrated at once, as tests have shown that the stone burns to a very porous mass which, if not hydrated, would soon take up carbon dioxide from the air and pass back into the form of calcium carbonate. As the present price of lime in Oklahoma is $11.00 per barrel, it can readily be seen that the use of waste material for this purpose would be the source of a very considerable revenue.

A closely related use would be for the manufacture of Portland cement for which its low magnesium and low free silica content make it well adapted. This would, however, require the outlay of a very large amount of money. Further, the cement industry of Oklahoma, as will be described later, is for the present, already well cared for.

Another use that might be made of this material and one for which there is a considerable demand, is as pulverized limestone for use in glass manufacture. As the stone is practically free from iron it is admirably suited for this purpose.

Its low iron content would make it desirable for use in the manufacture of paper. Another use, and one for which there is a growing demand, is as ground limestone for fertilizer and as a ground sweetener. Planer dust is now being sold in large quantities throughout the country for this purpose.

Finally, the stone, crushed to any desired size, could be used for concrete work.

Summing up the above, it may be said that this waste stone should find a ready market for any purpose for which a soft, silica free, iron free, low magnesium stone would be required. In the writer's opinion the stone is of such unusually high grade that it should be able to stifle competition for these products.

A discussion of the other deposits of oolite in the Wapanucka Area will not be taken up.

Township 1 North and 1 South, Ranges 8 and 9 East.

Starting in the southern part of T. 1 S., R. 8 E., the oolite may be said to extend as a practically continuous layer, of variable thickness, northward to the end of the exposure. Although the thickness is variable, the change from point to point is gradual, no basin-shaped deposits, such as have been described above, having been noted. The oolite is still to be regarded as a local phase of the massive limestone member that occurs at the top of the formation, as instances were noted in which the non-oolitic stone was found to be interbedded with the oolite. For complete sections in these townships the reader is referred to the detailed description of the Wapanucka limestone given in chapter V. The quality of the oolite compares favorably with that which occurs at the quarry at Delaware Creek. The statement may be made, however, that deposits of economic value comparable with that at Delaware Creek do not occur. This is due either to the fact that the deposits are too thin or to adverse structural conditions.

In the southern part of T. 1 S., R. 8 E., a deposit of limestone 50 to 75 feet in thickness occurs. The upper part is white but non-oolitic. The lower 20 feet are oolitic. Due to the very high dip (over 50°) towards the south it would be impossible for anyone attempting to quarry this stone to compete with the quarry at Delaware Creek. The quarrying conditions would be immeasurably more difficult and the stone, being largely non-oolitic, would be of poorer quality.

In T. 1 S., R. 9 E., the structural conditions are similar to those at Delaware Creek in that the dip is low (9°) towards the east, and the exposure is broad. The width of the outcrop of the oolite was found to vary from 60 to 300 feet. In the latter instance the dip was noted as 9° towards the east with a hill slope of 6° in the same direction. This would give a total thickness of but 15 feet. These figures have been given in order to correct a statement that occurs in the Atoka folio of the Geologic Atlas of the United States to the effect that a heavy deposit of oolite occurs in this township. It is most probable that the weather has affected this deposit to such an extent that it is of but little commercial value.

In section 3 of T. 1 S., R. 8 E., a deposit of oolite 50 feet in thickness, and underlain by blue limestone of equal thickness, was observed. The dip was noted to be 44° towards the northwest. The deposit lies on the side of a hill and is overlain by a heavy deposit of sandstone. With such a high dip, the sandstone overburden would at once assume prohibitive thickness. Although the oolite is of good quality, the structural conditions would prevent its development. The transportation facilities would be excellent as the main line of the Missouri, Oklahoma, and Gulf Railroad passes within a half mile of the deposit.

In section 5 there occurs 35 feet of blue oolite underlain by 70 feet of hard blue limestone. The dip is very low (6°) toward the north. The quarrying conditions would therefore be excellent. The narrow outcrop is due to the fact that the oolite is overlain by a thin deposit of shale. The blue color might be considered an attribute rather than a detriment. With the exception of the deposit

at Delaware Creek, this is the only one that the writer can recommend as the site of a quarry for high grade oolitic stone. But even this stone can hardly hope to compete with the Delaware Creek product.

In T. 1 N., R. 8 E., the strata dip at an angle of 30° to 35° towards the east. The oolite has a thickness of about 50 feet. South of Goose Creek the deposit occurs as an independent ridge. The stone is soft and white but, to some extent, non-oolitic. It could be worked to some extent but the high dip would be a great disadvantage. North of Goose Creek the oolite is overlain by sandstone, and hence could not be worked.

It is thus seen that the only deposit of commercial importance is that at Delaware Creek. In the Limestone Ridge area, thin bands of oolite averaging 3 feet in thickness were noted from point to point throughout the whole area. At two points, namely in sec. 17, T. 3 N., R. 15 E., and in sec. 10, T. 4 N., R. 17 E., deposits of oolite 10 to 20 feet in thickness were noted. In each case, however, the strata were found to be very much twisted and broken due to diastrophic movements, so that the deposits are not to be considered of economic value. All of the limestone in Limestone Ridge is very hard and massive and hence could not be profitably quarried for use as a building stone. A polished section of the stone taken from the quarry of the Choctaw Cement Company at Hartshorne, was found to be minutely fractured. The color of the polished surface is dark gray. This stone will take a high polish, and would make a beautiful marble.

LIME, CEMENT, CRUSHED STONE, AND OTHER LIMESTONE PRODUCTS.

In taking up the subject of limestone products, other than structural stone, it may be well to state briefly what qualities are regarded as desirable in each case, and then to state what limestones in the general area in this report seem best adapted for manufacture into any specific product.

Lime.—Any grade of limestone may be and is burned into lime. For high-grade lime, however, the limestone should be practically free from iron, free silica, and magnesium. Iron gives the lime a dark color, free silica forms glass in the kiln, and magnesium oxide is difficult to hydrate.

Cement.—The desirable qualities are the same as for lime.

Crushed stone.—Any grade of limestone is used for this purpose.

The stone should be fairly hard and brittle.

Glass and paper-manufacture.—Only selected limestone of the highest grade may be used for this purpose. The rock should not contain more than the slightest trace of iron and should be soft to facilitate the fine grinding that is necessary.

Ground limestone for fertilizer.—As a rule, raw material is not ground for this purpose, the main source of supply being dust from planer mills.

LIMESTONES IN THE WAPANUCKA AREA.

The limestones that are available in this area are the Arbuckle, Viola, Hunton, and Wapanucka limestones.

Wapanucka limestone.—For all purposes, except for use as crushed stone, the oolite deposits occurring in the Wapanucka formation are by far the most valuable as this stone is iron free, silica free, and very low in magnesium. For use as lime, however, the burn should be hydrated at once as the rock burns to a porous mass that will readily take up carbon dioxide from the air and pass back to the form of calcium carbonate.

Other deposits of limestone occurring in the Wapanucka formation may be used for lime, cement, and crushed stone. As will be described in the next paragraph, however, the Viola limestone possesses certain advantages over the Wapanucka for use in the manufacture of these products.

Viola limestone.—The following section of the Viola limestone was made in the northwest quarter of sec. 27, T. 2 S., R. 8 E.

Section in NW. 1-4 sec. 27, T. 2 S., R. 8 E.

Description	Thickness in feet
White, gray, and pink, crystalline limestone	150
Fossiliferous limestone with lentils and nodules of chert	300
Dense cream-colored limestone with veins of calcite	550
Total	1000

The crystalline limestone member is of unusual purity. It would make an excellent lime. The massive limestone member at the base is as dense as lithographic stone. It could not be used for this purpose, however, as it is strung through with minute veins of calcite. It is hard and very brittle, flying to pieces under a moderate blow of a hammer. These qualities make it very desirable for use as crushed stone. The strata stand practically on edge, the dip being 87° towards the northeast. The entire thickness of the formation, 1000 feet, is exposed, therefore, within a like distance.

At the time that the writer visited the region, a corporation was planning to erect a plant at this point with a capacity of 1000 tons

of crushed stone per day. The company was also planning the erection of a lime kiln with a capacity of 50 tons per day, the crystalline limestone to be used for this purpose. There is a large and growing demand in Oklahoma for crushed stone for railroad ballast, road metal, and concrete work, so that the industry should prove a profitable one.

Viola limestone is used in the large cement plant at Ada, Oklahoma, and has proved to be very satisfactory for this purpose. At the present time there are three large cement plants in Oklahoma with several nearby in the state of Texas. These plants are able to meet the present demand. For this reason, the writer cannot recommend the erection of additional plants at the present time. When the demand does arise for additional plants the advantages enumerated above would point to the Viola limestone as the best stone for this purpose.

Considerable amounts of asphalt, but not enough to make the deposits of commercial value, occur in this limestone.

Chimneyhill and Bois d'Arc limestones.—These limestones are quite similar, lithologically, to the middle member of the Viola formation, with the exception that they are free from chert. Analyses show it to be even lower in magnesium than the Viola. They should, therefore, make an excellent lime. They are thinner than the Viola, however, the thickness in the vicinity of Wapanucka averaging 100 feet

The following are comparative analyses of Wapanucka, (non-oolitic), Viola, and Chimneyhill limestones:

Comparative analyses of Wapanucka, Viola, and Chimneyhill limestones.

	Wapanucka.	Viola.	Hunton.
Calcium carbonate	96.20	97.09	97.94
Magnesia	1.19	1.16	.55
Iron and Alumina	2.61	1.75	1.91
Total	99.90	100.00	100.40

Arbuckle limestone.—Analyses have shown the Arbuckle limestone to be high in magnesium. It would therefore be unfit for lime or cement. It could be used for crushed stone, but is very hard and therefore more difficult to crush.

LIMESTONES IN THE LIMESTONE RIDGE AREA.

The Wapanucka is the only formation in this area which contains limestone. Two very different types of limestone occur. The massive limestone, bed No. 1, which occurs at the top of the formation, is hard but pure, and free from chert. It would make an excellent lime or cement. The lower members, beds Nos. 5 and 7, are very hard, and bed No. 7 is exceedingly cherty. They may be used for cement manufacture, but the free silica is a distinct disadvantage, causing the formation of glass in the kiln. One large quarry for crushed stone and one cement plant occur in this area.

Quarry of the Missouri, Kansas, and Texas Railroad at Chockie.

A quarry for railroad ballast has been maintained at this point for 25 years. The stone quarried is taken from the limestone member, bed No. 1, and the chert member, bed No. 2. The two beds have a total thickness of 100 feet. The dip is very high, 75°, towards the southeast. Contrary to rule, the chert may be quarried and crushed very easily. It may be blasted out in sheets 50 feet across, breaking parallel to the bedding. It is very brittle and therefore crushes easily. Both the chert and the limestone are very hard, and hence make good ballast and road metal. The quarry face is more than half a mile long. Standard guage tracks run direct to the quarry. Views of the quarry are shown on Plate VII.

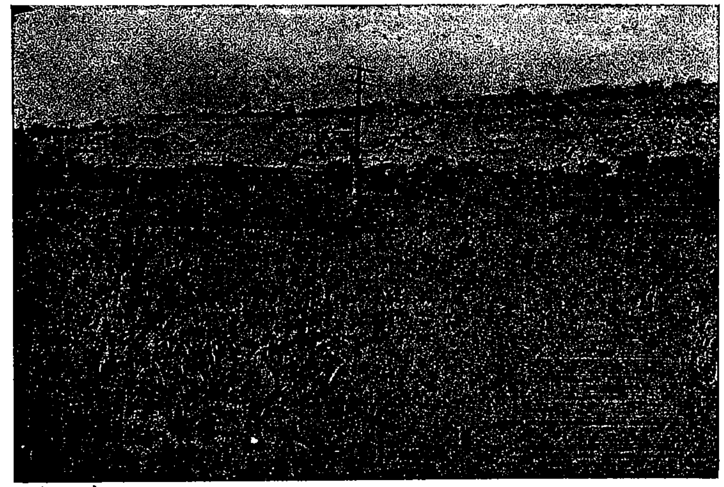
Plant of the Choctaw Cement Company at Hartshorne.

The plant and quarry of this company are situated on the Wapanucka limestone at the point where Blue Creek breaks through the ridge. The buildings are constructed of reinforced concrete and are modern in every respect. The stone is quarried from beds Nos. 5 and 7. Bed No. 5 is free from chert, but Bed No. 7 is exceedingly cherty. The two members have a total thickness of about 200 feet.

Due to financial difficulties, the plant has never been completed. A reorganization of the company is in progress and plans are being made to complete and even enlarge the plant. When completed it will be one of the most modern in the country. One No. 8 and one No. 5 1-2 gyratory crushers have been installed at the quarry. From here the crushed stone will pass over a 400-foot tipple to the raw grinding building. After passing through dryers it will be ground in two 7 x 9 ball mills and one 8 x 26 tube mill. Space is provided for two rotary kilns 8 feet in diameter and 110 feet long. It is planned to pass the waste heat from the kilns over vertical boilers. The steam thus generated will be used in turbines which will generate 1500 K. W. of electricity. No shafting will be used, each piece of machinery being driven by an individual motor. The clinker will be ground by five 40-inch Giant Griffin mills. The sacking will be done by automatic machinery. A view of the plant is shown on Plate VIII A and one of the quarry on Plate VIII B.

A branch of the Chicago, Rock Island and Pacific Railway has been built to the plant from Hartshorne. An artificial lake covering 242 acres will supply the plant with water. This same lake supplies the town of Hartshorne with drinking water.

PLATE VII



A. VIEW OF M. K. & T. QUARRY AT CHOCKIE.

B. VIEW IN QUARRY SHOWING WELL-BEDDED STEEPLY DIPPING STRATA.

The following analysis of Wapanucka limestone, taken from the quarry, was made by the Kansas City Testing Laboratory.

Analysis of Wapanucka Limestone from Quarry of Choctaw Cement Company.

Silica (SiO_2)	1.10
Iron oxide (Fe_2O_3)	0.10
Alumina (Al_2O_3)	0.60
Lime (CaO)	54.70
Magnesia (MgO)	1.10
Loss (CO_2 and organic matter)	42.10
Alkalies (K_2O and Na_2O)	
Sulphur trioxide (SO_3)	trace
Total	99.70

When this plant is completed and put into operation there is no doubt but that it will be successful. The presence of mud seams in the quarry and of free silica in the form of chert, will, however, be a continual source of annoyance.

CHERT IN THE LIMESTONE RIDGE AREA SUITABLE FOR FURNACE BLOCKS.

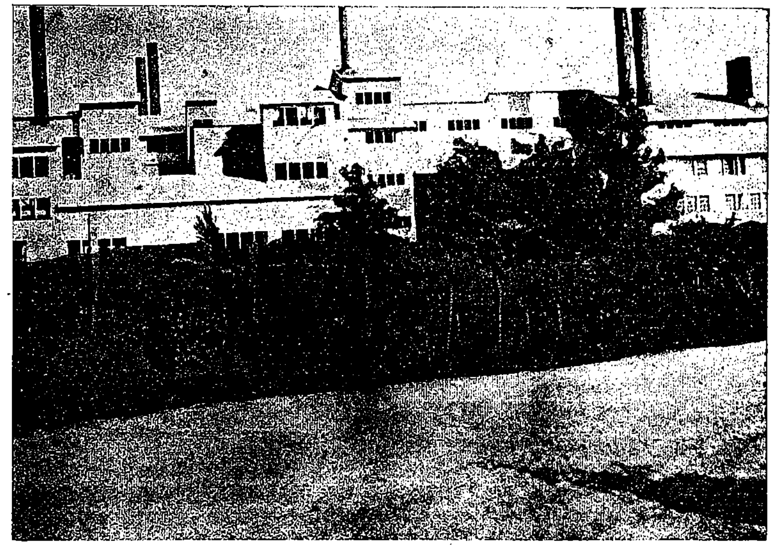
For several years, chert suitable for furnace blocks has been imported from Belgium at an average cost of $20.00 per ton.

Although tests have not been made, it is the writer's opinion that the chert contained in the chert member, bed No. 2, of the Limestone Ridge area may be used for this purpose.

The fresh chert is best exposed in the quarry at Chockie and in the railroad cut at Limestone Gap. It is thin bedded, and interstratified with beds of limestone of equal thickness. The individual layers of chert have a thickness of from 2 to 6 inches, which is the thickness of an ordinary furnace black. The rock may be quarried very easily as it splits parallel to the bedding planes. Due to the fact that it is quite brittle, it may then be readily shaped into the form of furnace blocks.

If this chert is found to be suitable for this purpose, it could be made the source of a very considerable revenue.

PLATE VIII



A. VIEW OF PLANT OF CHOCTAW CEMENT COMPANY.

B. VIEW OF QUARRY OF CHOCTAW CEMENT COMPANY.

GLASS SAND IN THE SIMPSON FORMATION.

In the small exposure of the Simpson formation that occurs in section 27 of T. 2 S., R. 8 E., the writer observed a deposit of pure white sandstone that should be suitable for glass manufacture. The rock is very friable and breaks down into a fine sand under a slight blow of the hammer. The deposit has a thickness of 300 feet of which the lower 75 feet are of marked purity. The deposit occurs in the lower part of the formation near the granite. Above the sandstone occur beds of green shale, and above the shale a massive bed of white sandstone. This upper sandstone, however, contains considerable quantities of iron-bearing minerals.

MANGANESE ORE IN THE CHIMNEYHILL LIMESTONE.

Deposits of manganese ore occur in the Chimneyhill limestone. The deposits have been prospected from time to time, but little serious mining has been done. The writer visited a prospect in section 28 of T. 1 S., R. 8 E., and noted the following in regard to the manner of occurrence of the ore:

The ore minerals are hematite, limonite, pyrolusite, and rhodochrosite. The principal manganese ore mineral is pyrolusite.

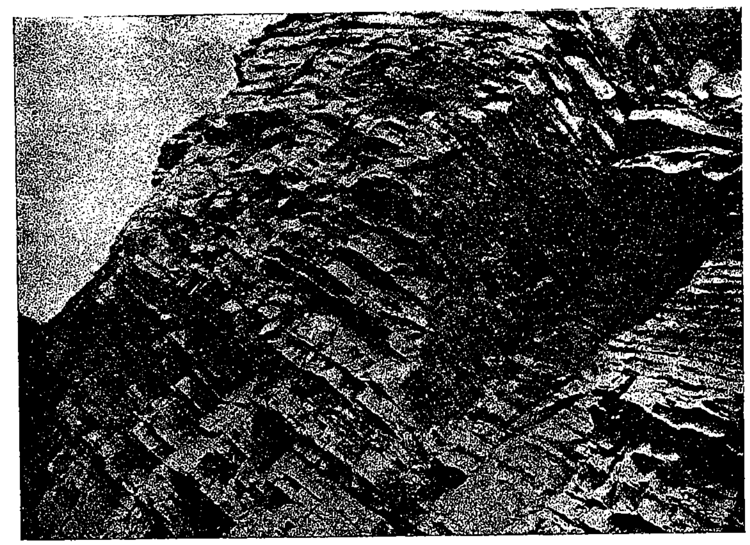
The ore occurs in pockets and is a residual and metasomatic deposit of limestone. A cross-section of a pocket would show hematite and limonite in the center, and pure, hard pyrolusite in contact with the country rock. Polished specimens of limestone taken from the adjacent country rock, show that descending manganiferous solutions have penetrated the limestone along minute cracks and fissures, and have replaced it, giving rise to manganese carbonate. This, in turn, has altered to pyrolusite. This replacement has not extended a great distance into the limestone. One may pass within a foot, from pure pyrolusite to pure limestone. It is thus seen that the limestone is the direct cause of the precipitation of the ore. The deposits have not been exploited enough to determine the size of the pockets. They occur at the same general horizon in the Chimneyhill limestone. Since the ore occurs as a residual deposit, it may be found only in the zone of weathering, and may not be expected to extend to any great depth below the surface. The fact that it occurs in pockets. makes its exploitation and development on a large scale hazardous. Considerable quantities of ore occur, however, and small scale operations could be carried on at a profit. The Bromide branch of the Missouri, Oklahoma, and Gulf Railroad runs to within 2 miles of the nearest deposit.

The manganese content is variable as the ore grades from practically pure limonite or hematite into pure pyrolusite.

In Bulletin No. 3 of the Oklahoma Geological Survey, Chester A. Reeds has given several analyses of the ore. The following analysis is of the best grade ore:

PLATE IX

A. EXPOSURE OF WAPANUCKA CHERT IN QUARRY AT CHOCKIE.



B. STEEPLY DIPPING STRATA IN WAPANUCKA AT LIMESTONE GAP, 8 MILES SOUTH OF KIOWA.

Analysis of Manganese Ore from sec. 17, T. 1 S., R. 8 E.

Mn_2O_4	84.20
SiO_2	1.28
Fe_2O_3	2.86
Al_2O_3	1.34
CaO	2.20
MgO	none
Loss on ignition (CO_2)	6.48
Moisture	.80
P_2O_5	.38
Total	99.90

FARMING CONDITIONS.

The chapter on economic geology may be closed with a statement in regard to farming conditions throughout the area.

Due to the very unusual civil conditions that have existed in Indian Territory up to within the last few years, this part of the state has developed but slowly. At the present time, however, a large part of the land is under cultivation, with large tracts of government land still available.

The best farm land is that which is composed of Caney and Atoka shales. The very heavy residual soil makes cultivation an easy matter. The rainfall is sufficient for all crops.

The land in the vicinity of Wapanucka seems to be a little more productive than that farther east in the vicinity of LeFlore. The following is a comparison of the yield per acre in the two districts:

Crop.	Yield per acre. Wapanucka.	LeFlore.
Cotton	¾ to 1 bale	½ to ¾ of a bale
Corn	40 bu.	25-30 bu.
Wheat	30-40 bu.	25-30 bu.
Ooats	60-80 bu.	40-60 bu.
Value of land	$25 to $40	$25 to $30

It is seen from the above that cotton is the most profitable crop. The yield for corn is realized only when the rainfall is plentiful during the summer months. This is usually not the case and the fact should be emphasized that this is not a corn country. Large crops of hay are raised. The average price per bale is 35 cents. Compared with farm lands in other parts of the country, those in this area may be considered of but fair grade. Compared with the price that must be paid for high grade farm land in other areas, however, that asked in this area is very reasonable, and the percentage realized on the money invested proportionately large. As the region becomes more thickly populated the value of the land will rise. Anyone buying farm land in this area may feel confident of securing a fair return on the money invested

CHAPTER VIII.

NATURE AND ORIGIN OF THE OOLITE.

As a concluding chapter of this study of the Wapanucka limestone, it may be interesting to state briefly the views that are held in regard to the mode of formation of oolites, and to describe the structure and probable origin of the Wapanucka oolite.

Some very important advances in regard to our knowledge of the mode of formation of oolites have been made within the last few years.

Two widely different views have been held. The first is that oolites are produced through the activity of algae; the second that they are formed by chemical precipitation. Very recently, conclusive evidence has been advanced to show that they are formed by chemical precipitation, but that this precipitation has been caused indirectly by the activity of denitrifying bacteria. This last method may be considered a modification or advanced form of the chemical precipitation theory. The subject will be treated chronologically.

In 1892, Rothpletz studied the oolites now forming at Great Salt Lake, Utah. He found oolites covered with bluish-green masses of living algae which he determined to be *Gloeocapsa* and *Gloeotheca*. Upon dissolving the oolites in weak hydrochloric acid, he found, in the residue, crumpled cells of dead algae. He concluded as a result of his observations that the oolites were formed through the activity of the algae and that the dead cells represented algae of a former generation that had died and been included in layers of aragonite deposited by algae of the present generation.

Combating this theory, T. C. Brown, an advocate of the chemical precipitation theory, suggests that the dead algae, while living, had merely attached themselves to the oolitic particles, just as the present-day ones have done, and were imprisoned by the further accretion of aragonite by chemical precipitation. (It will be shown later that both Rothpletz and Brown are probably wrong in so far as the supposed algae are concerned).

In Volume 25 of the Bulletin of the Geological Society of America for 1914, T. C. Brown presents a very clear discussion of the chemical precipitation theory. In this paper he calls attention to the fact that as early as 1879, Sorby stated that all recent oolites consist of calcium carbonate in the form of aragonite. He then summarizes the work of Linck who was able to obtain oolites by chemical precipitation in the laboratory. Experimenting with sea water, Linck found that the calcium of calcium sulphate in such water, when precipitated by sodium or ammonium carbonate, comes down in the form of aragonite in either warm or cold solutions, and largely in the form of spherical oolites. From a solution of calcium sulphate free from other salts (fresh water), the calcium was precipitated, by sodium or ammonium carbonate, in the form of calcite in either warm (40° C.) or cold (18° C.) solutions. Linck concludes as the result of his investigations that the aragonite oolites now forming in the sea are the result of chemical reaction between the calcium sulphate of the sea-water and the sodium and ammonium carbonate generated by the decay of animal and plant tissue.

In publication 182 of the Carnegie Institution of Washington, 1914, G. H. Drew gives the results of a series of experiments dealing with the precipitation of calcium carbonate in sea water by the action of denitrifying bacteria. In this investigation, the sea water and bottom deposits in the vicinity of Florida and the Bahama Islands were studied. Dr. Drew found that these bottom deposits, which consist of a chalky mud carrying oolites, swarmed with millions of an unknown denitrifying bacterium which yielded ammonia. He isolated the bacterium and named it *Bacterium calcis*. Experimenting further, he found that when this bacterium was allowed to develop in sea water to which small amounts of nutrients such as calcium succinate and potassium nitrate had been added, flocculent calcium carbonate was precipitated at the end of 12 hours. This material was so very finely divided that much of it would not settle. The solution reacted for ammonia which had been generated by the bacteria. He believed that ammonium carbonate, formed by the combination of ammonia with carbon dioxide from the air (or some other source) reacted with the calcium sulphate of the sea water according to the following reaction:

$$CaSO_4 + (NH_4)_2CO_3 = CaCO_3 + (NH_4)_2SO_4$$

When grains of sand or other small objects were thrown into the vessel, finely divided calcium carbonate aggregated around them in such a manner as to form concretions which looked like oolites. Upon microscopic examination, however, they were found not to be true oolites, as there was no evidence of lamination. Also the material seemed to be nearer calcite than aragonite.

This investigation proves that calcium carbonate may be precipitated in a finely divided condition by the action of denitrifying bacteria. Since the chalky mud in the bottom deposits around Florida and the Bahama swarms with these bacteria, Drew and Vaughan believe that they have caused the precipitation of this material. These bacteria flourish best in relatively shallow water (not more than 10 fathoms) that has a temperature of 30° C. If this method of limestone formation is to be regarded as an im-

portant one, a clue is given in regard to the conditions under which limestones have been deposited in the past. Drew thinks that this method of formation of calcium carbonate may have been an important factor in the formation of chalk and of very dense limestones. As it is practically in the colloidal state of division, it would also act as a cement in the formation of clastic rocks.

In a companion paper to that by Drew, T. W. Vaughan, in Publication 182 of the Carnegie Institution of Washington, discusses the origin of the Bahama and Florida oolites. He believes that the oolites are of *secondary* origin and that they have developed in the chemically precipitated mud above referred to. Some of the mud, in which small oolites were present, and which had been strained through bolting cloth in November, was found in March to contain oolites too large to pass through the cloth. This experiment proved that the oolites had grown larger during this period.

Supplementing the work of Drew and of Vaughan, Dr. Karl F. Kellerman of the Bureau of Plant Industry of the U. S. Department of Agriculture was able to produce oolites *directly* through the action of pure cultures of determined species of bacteria. The results of his investigation were given in a paper read before the American Association for the Advancement of Science during the Christmas meeting held at Philadelphia, December 1914-January 1915. Dr. Kellerman has very kindly loaned the writer the manuscript of this paper. The following is a description of three of the experiments.

In all of the experiments an Ehrlenmeyer flask was used in which water containing the bacteria was placed. A collodion tube containing calcium sulphate was then introduced into the flask. The calcium sulphate dissolved and dialysed out into the surrounding liquid as fast as the bacteria growing there precipitated enough calcium carbonate to appreciably reduce the concentration of the calcium sulphate solution in the sea water. In this way a continuous supply of soluble calcium sulphate was maintained in the culture flask.

The precipitation of calcium carbonate was found to be most rapid when mixed cultures of bacteria were used, namely those that produced ammonium and those that produced carbon dioxide. These produce ammonium carbonate, which could then react with the calcium sulphate.

Experiment one.—Apparatus as above. Water in culture flask obtained from Great Salt Lake. Bacteria used—those naturally present in Great Salt Lake water. Small quantities of sugar and peptone were introduced into the culture flask to stimulate the growth of the bacteria. Calcium sulphate in collodion tube. Result: a spherultic precipitation of calcium carbonate. This spherulitic precipitate was examined under the microscope and found to have the structure that is characteristic of oolites. Quoting Dr. Kellerman further: "The dark center contains a closely compressed bacterial mass which may be strained and examined thoroughly after the calcium carbonate is removed by washing with weak acid. The bacterial cells are distorted and perhaps partially disintegrated, and these masses or clumps closely resemble the organic centers often found in the natural oolites from the Great Salt Lake. It is probable therefore that Rothpletz confused these bacterial masses with fission algae and was in error in ascribing the oolitic formation in the Great Salt Lake to algae."

Experiment two.—Apparatus as above. Quoting Dr. Kellerman: "This (spherulitic) precipitate was produced from water from Biscayne Bay, Florida, to which had been added small quantities of nutrients including potassium nitrate and calcium acetate, and which had then been sterilized and reinoculated with a pure culture of *Pseudomonas calcis*, the denitrifying organism which Drew also found to occur in large numbers in the region of the Bahamas. Carbon dioxide was supplied by keeping the cultures in a room where this gas was plentiful."

Experiment three.—Conditions the same as in experiment two, except that the water used was from Great Salt Lake, and the organism, a variety of *Pseudomonas calcis*, was also isolated from Great Salt Lake water. Result: A spherulitic precipitate with clearly defined zonal structure.

Dr. Kellerman compared oolites formed in this way with natural oolites taken from Great Salt Lake. He says in conclusion: "Though the natural oolite may be larger and may show a greater number of zones or layers than those produced in the laboratory, the very close agreement in their form and structure suggests the similarity of the processes of their origin.

In the culture flasks, it has not always been possible to predict when calcite crystals might be produced and when spherulites would form instead. From a study of the laboratory records, it seems probable that the formation of crystals occurs when the concentrations of ammonia, carbon dioxide, and calcium are comparatively strong, thus causing a rapid formation of calcium carbonate."

Reviewing the above mentioned recent investigations it seems that Drew was able to produce a flocculent precipitate of calcium carbonate, while Kellerman, using the same bacterium, but working under better control, was able to produce oolites.

It seems to the writer that such a mode of formation is what might naturally be expected to occur. If each colony of bacteria may be considered as constituting a nucleus the ammonium carbonate generated by each would cause a *local* precipitation of calcium carbonate, and this encrusting layer would have the topographic form of the nucleus.

The structure of the Wapanucka oolite will now be described, and evidence will be advanced which, in the writer's opinion, will further the conclusions reached by Dr. Kellerman.

The Wapanucka oolite consists of well defined particles that have all of the structural characteristics of a true oolite.

The particles are either spherical in form or have an ovate cross-section.

The diameter of the spherical particles varies from one-fourth to one-half a millimeter, the longer axis of the ovate particles from one-half to one and one-half millimeters.

The particles are *very* close packed, there being a minimum of cementing material or matrix.

The matrix is composed of calcite.

Cross-sections of the oolitic particles show a well defined nucleus, which is composed of calcite, surrounded by from 2 to 15 concentric shells of aragonite.* (See Plate X).

The concentric shells simulate to a high degree the surface of the nucleus.

A study of thin sections and polished surfaces has shown that some of the oolitic particles are ideomorphic while others are hypideomorphic, indicating that the latter were formed at a later date than the former.

The statement that the shells are now composed of aragonite is not entirely true. Investigation has shown that all recent oolites are composed of aragonite while in fossil oolites the aragonite has altered to calcite, the more stable form of calcium carbonate. This is most probably what has happened in this case. The material in the shells was so extremely finely divided as to be inactive under the microscope. (Inactive in the sense that no definite optical data could be obtained). The cobalt nitrate test for aragonite was made, and showed no aragonite to be present. As the rock analysis 97% $CaCO_3$, it is evident that the shells must now be calcite. It is believed that the calcite has retained the structural form of the original aragonite needles.

When examined closely, the calcite nuclei were found to be of secondary origin. Any individual nucleus was found to be composed of a mass of minute crystalline particles, heterogeneously oriented. The orientation of the particles in the outer portion of any nucleus was that characteristic of a *geode* or *cavity filling*, the crystals pointing inward as though they had lined the walls of a cavity. The heterogenous arrangement in the centers of the nuclei would also indicate such a mode of formation.

Under the higher powers of the microscope, a haze of calcite particles was found to permeate that part of any oolitic particle lying outside of the nucleus. This was especially noticeable in the areas lying between the concentric shells.

The shells were found to be fairly complete.

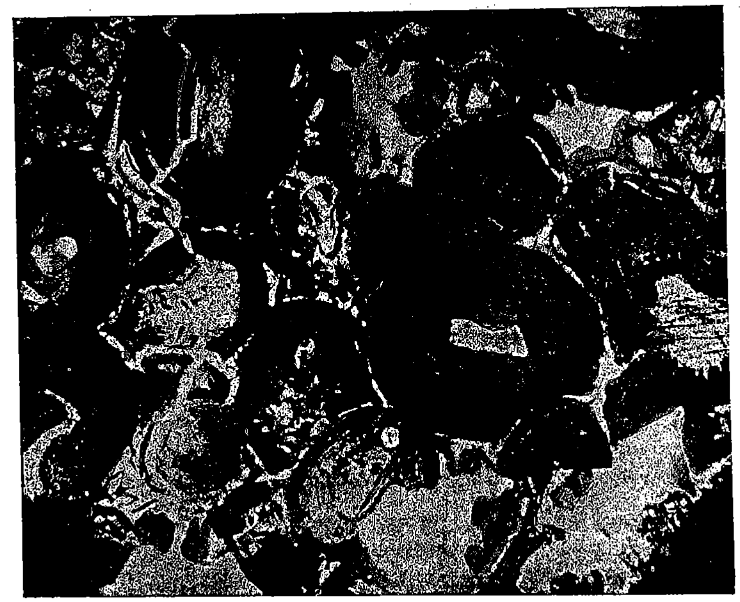
The above facts are well brought out in Plate X. The following points may be noted. The ideomorphic character of some of the grains and the hypideomorphic character of others. All of the dark material in any particle represents what was formerly aragonite while the light represents secondary calcite. A haze of calcite may be seen to permeate the whole particle. The mottled effect shown by the nuclei is due to the presence of a large number of calcite crystals heterogeneously oriented. The small amount of matrix present consists of calcite. The calcite cleavage is well shown in the matrix in the northeast quadrant.

The above description of the Wapanucka oolite is a statement of observed facts. In the following paragraphs, the writer wishes to present his personal interpretation of the facts observed.

The writer would account for all of the above observed phenomena by sketching the history of the formation of an oolitic particle as follows:

A mass or colony of bacteria generating ammonium carbonate would cause a local precipitation of calcium carbonate in the form of aragonite about them.* This aragonite would form an encrusting wall about the bacterial mass. Passage ways allowing communication with the outside would have to be kept open, otherwise the bacteria would die at once. (These passage ways may or may not have been formed). These or other bacteria could spread over the shell of aragonite already formed and cause the precipitation of a second encrusting layer. This process could proceed until a number of layers were formed. Finally the colony would die and the local precipitation of aragonite would cease. The last layer of dead bacteria would prevent any further deposition of calcium carbonate.

PLATE X



PHOTOMICROGRAPH OF WAPANUCKA OOLITE.

A second particle, nearby, that had started to grow at a later date would be interfered with by the presence of the particle already formed. It would hence develop a hypideomorphic structure. It is evident that the first particle formed *must* be protected in some way, otherwise ammonium carbonate, generated by the colony forming the second particle, would cause a precipitation of calcium carbonate on the first particle. The writer suggests that this protection could be afforded by a layer of dead bacteria.

No instances were noted in which an aragonite shell precipitated by the colony of the second particle encompassed both particles. This is very significant fact and strengthens the statement that the agents that caused the precipitation must have been very local; also that the first particle was covered with something that would prevent precipitation. It is evident to all who are familiar with the processes of crystallization that a crystal once formed would (unless protected) attract other molecules to itself as though it were a magnet.

So far as the writer has been able to learn, hypideomorphism of some of the particles has not been observed to occur in other deposits of oolite. Usually the particles are ideomorphic and separated by a fair amount of matrix. But in the Wapanucka oolite hypideomorphism seems to be the rule, more particles showing such a structure than not.

After the bacteria had died, the porous mass could be infiltered by solutions of calcite, silica, or some other material. The fact that the calcite in the nuclei simulate cavity fillings would support such an hypothesis. The cavities left by the bacteria between the concentric shells could be filled in the same way. The heterogeneous arrangement of the calcite particles between the shells would indicate that this has happened.* The material in the concentric shells is now composed of calcite, but this calcite has a different structural form (probably pseudoaragonitic) from that which is present in the nucleus and in between the concentric shells. It seems most probable, therefore, that the shells were originally composed of aragonite, and that cavities left by the bacteria have been filled with secondary calcite.

The suggestion has been made to the writer that the nuclei are too large (about one-tenth of a millimeter) to have been composed of one colony of bacteria. In reply, he can but point to the work of Dr. Kellerman, who has produced oolites in the laboratory whose nuclei were composed of masses of bacteria. It is clear in the mind of the writer that the present calcite nuclei in the Wapanucka oolite represent cavity fillings, and he has sketched the above described history of the formation of an oolitic particle to account for this phenomenon.

The statement has often been made that grains of sand, shell fragments, or other material may constitute the nuclei of oolitic particles. The writer suggests that closer examination may show these to be secondary silica, secondary calcite, etc. If they are found to be primary, however, the mode of formation need not have been very different from that sketched above. Bacteria could accumulate around a grain of sand and cause the precipitation of an aragonite shell around them. Other layers could then he formed as described above.

---

*The mineral form aragonite is probably not due to the bacteria. They merely generate ammonia. The precipitation of the calcium carbonate is inorganic and purely chemical. Other factors, especially the fact that the medium is sea water are probably the cause of the calcium carbonate being precipitated as aragonite instead of as calcite. Link, Kellerman, and others have found that when fresh water is used the precipitate is always calcite, while when sea water is used the precipitate is in large part aragonite.

SUMMARY STATEMENT.

The more important features of the present study may be summarized as follows:

In the opening chapters a brief sketch of the general geology of south-central and southeastern Oklahoma is given. This sketch includes a discussion of the latest views in regard to the correlation of the strata throughout the region.

A detailed description of the geology of the Wapanucka limestone is then presented. The net gain as a result of this work may be summarized as follows:

In the area covered by the Coalgate and Atoka folios the structural features have been described in greater detail and a detailed description of the Wapanucka limestone has been given.

Starting from these previously-described areas, and using the formational units as defined therein by J. A. Taff, the areal extent of the Wapanucka limestone throughout the McAlester and Tuskahoma quadrangles was mapped and described.

Chapters on the following special subjects have been included:

1. "Unconformities within the Wapanucka Formation." The recognition of these unconformities is of great geological significance. In this chapter the probable age of the Wapanucka formation was also discussed. The writer regards the Wapanucka as representing a transition series between the Mississippian and Pennsylvanian systems.

2. "Economic Geology of the Wapanucka Limestone." In this chapter the deposits of oolite were described and their areal extent given. Deposits of limestone suitable for burning into lime, for cement manufacture, glass manufacture, and crushed stone were also described. Paragraphs dealing with deposits of chert suitable for use as furnace blocks, with deposits of glass sand, and with deposits of manganese ore were included.

3. "Nature and Origin of the Oolite." In this chapter a short sketch of the most recent advances that have been made in regard to our knowledge of the mode of formation of oolites has been given. The structure of the Wapanucka oolite is then described, and suggestions made regarding its probable origin.

BIBLIOGRAPHY.

Coalgate folio, Indian Territory; description by J. A. Taff. Geologic Atlas U. S., folio 74, 1901.

Atoka folio, Indian Territory; description by J. A. Taff. Geologic Atlas U. S., folio 79, 1902.

Tishomingo folio, Indian Territory; description by J. A. Taff. Geologic Atlas U. S., folio 98, 1903.

Preliminary report on the geology of the Arbuckle and Wichita Mountains, by J. A. Taff. U. S. Geol. Survey, Prof. Paper 31; 1904.

Fauna of the Caney shale of Oklahoma, by G. H. Girty. U. S. Geol. Survey, Bull. 377, 1909.

A report on the geology and mineral resources of the Arbuckle Mountains of Oklahoma, by Chester A. Reeds. Oklahoma Geol. Survey, Bull. 3, 1910.

The fauna of the Moorefield shale of Arkansas, by G. H. Girty. U. S. Geol. Survey, Bull. 439, 1911.

The Hunton formation of Oklahoma, by Chester A. Reeds. Am. Jour. Sci., 4th series, vol. 32, October, 1911.